

# **County Roscommon Groundwater Protection Scheme**

## **Main Report**



Tobermore Springs, Killeglan Water Supply Scheme, County Roscommon

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## **Appendix II: Permeability Regions in County Roscommon**

# **1 Introduction**

## **1.1 Groundwater Protection – A Priority Issue for Local Authorities**

The protection of groundwater quality from the impact of human activities is a high priority for land-use planners and water resources managers. This situation has arisen because:

- groundwater is an important source of water supply;
- human activities are posing increasing risks to groundwater quality as there is widespread disposal of domestic, agricultural and industrial effluents to the ground and the volumes of waste are increasing;
- groundwater provides the baseflow to surface water systems, many of which are used for water supply and recreational purposes. In many rivers, more than 50% of the annual flow is derived from groundwater and more significantly, in low flow periods in summer, more than 90% is from groundwater. If groundwater becomes contaminated the rivers can also be affected and so the protection of groundwater resources is an important aspect of sustaining surface water quality;
- groundwater generally moves slowly through the ground and so the impact of human activities can last for a relatively long time;
- polluted drinking water is a health hazard and once contamination has occurred, drilling of new wells is expensive and in some cases not practical. Consequently ‘prevention is better than cure’;
- groundwater may be difficult to clean up, even when the source of pollution is removed;
- unlike surface water where flow is in defined channels, groundwater is present everywhere;
- EU policies and national regulations are requiring that polluting discharges to groundwater must be prevented as part of sustainable groundwater quality management.

## **1.2 Groundwater – A Resource At Risk**

Groundwater as a resource is under increasing risk from human activities for the following reasons:

- a lack of awareness of the risks of groundwater contamination, because groundwater flow and contaminant transport are generally slow and neither readily observed nor easily measured;
- contamination of wells and springs is occurring;
- there is widespread application of domestic, agricultural and industrial effluents to the ground;
- the quantities of domestic, agricultural and industrial wastes are increasing;
- a significant increase in the application of inorganic fertilisers to agricultural land, and usage of pesticides in recent years;
- there are greater volumes of road traffic and more storage of fuels/chemicals; and
- manufacture and distribution of chemicals of increasing diversity and often high toxicity, used for a wide range of purposes.

The main threats to groundwater in Ireland are posed by both point and diffuse contamination sources. There are various potential point contamination sources, such as farmyard wastes (mainly silage effluent and soiled water), septic tank effluent, sinking streams where contamination of surface water has occurred, leakages, spillages, pesticides used for non-agricultural purposes and leachate from

waste disposal sites. Diffuse sources include the spreading of fertilisers (organic and inorganic) and pesticides. While point sources have caused most of the contamination problems identified to date, there is evidence that diffuse sources are increasingly impacting on groundwater.

### 1.3 Groundwater Protection Through Land-use Planning: A Means of Preventing Contamination

There are a number of ways of preventing contamination, such as improved well siting, design and construction and better design and management of potential contamination sources. However, one of the most effective ways is by integrating hydrogeological factors into land-use policy and planning by means of groundwater protection schemes.

Land-use planning (including environmental impact assessments), integrated pollution control licensing, waste licensing, water quality management planning, water pollution legislation, etc., are the main methods used in Ireland for balancing the need to protect the environment with the need for development. However, land-use planning is a dynamic process with social, economic and environmental interests and impacts influencing to varying degrees the use of land and water. In a rural area, farming, housing, industry, tourism, conservation, waste disposal, water supply, etc., are potentially interactive and conflicting, and may compete for priority. How does groundwater and groundwater pollution prevention fit into this complex and difficult situation, particularly as it is a resource that is underground and for many people is ‘out of sight, out of mind’? Groundwater protection schemes enable planning and other regulatory authorities to take account of both geological and hydrogeological factors in locating developments. Consequently, they are an essential means of preventing groundwater pollution.

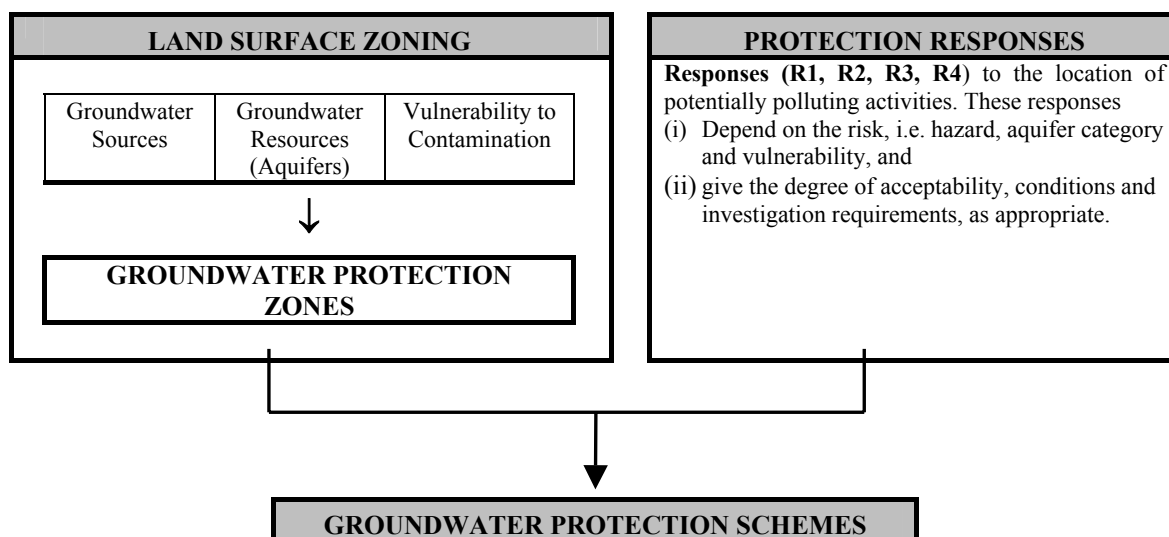
### 1.4 ‘Groundwater Protection Schemes’ – A National Methodology for Groundwater Pollution Prevention

The Geological Survey of Ireland (GSI), the Department of Environment and Local Government (DELG) and the Environmental Protection Agency (EPA) have jointly developed a methodology for the preparation of groundwater protection schemes (DELG et al., 1999). The publication **Groundwater Protection Schemes** was launched in May 1999, by Mr. Joe Jacob TD, Minister of State at the Department of Public Enterprise. Three supplementary publications were also launched, namely, **Groundwater Protection Responses for Landfills**, **Groundwater Protection Responses for Landspreading of Organic Wastes** and **Groundwater Protection Responses for On-Site Systems for Single Houses**. Similar ‘response’ publications will be prepared in the future for other potentially polluting activities and developments.

There are two main components of a groundwater protection scheme, which are shown schematically in Figure 1.1.

- **Land surface zoning;**
- **Groundwater protection responses for potentially polluting activities.**

**Land surface zoning** provides the general framework for a groundwater protection scheme. The outcome is a map, which divides any chosen area into a number of groundwater protection zones according to the degree of protection required.



**Figure 1.1 Summary of Components of Groundwater Protection Schemes**

There are three main hydrogeological elements to land surface zoning:

- Division of the entire land surface according to the **vulnerability** of the underlying groundwater to contamination. This requires production of a vulnerability map showing four vulnerability categories – extreme, high, moderate and low.
- Delineation of **areas contributing to groundwater sources** (usually public supply sources); these are termed source protection areas.
- Delineation of areas according to the value of the groundwater resources or **aquifer category**; these are termed resource protection areas.

The vulnerability maps are integrated with each of the other two to give maps showing **groundwater protection zones**. These include source protection zones and resource protection zones.

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities, which describes: (i) the degree of acceptability of each activity; (ii) the conditions to be applied; and, in some instances (iii) the investigations that may be necessary prior to decision-making.

While the two components (the protection zone maps and the groundwater protection responses) are separate, they are incorporated together and closely interlinked in a protection scheme.

Two of the main chapters in **Groundwater Protection Schemes** are reproduced in Appendix I. While these describe the two main components of the national groundwater protection scheme, it is recommended that, for a full overview of the groundwater protection methodology, the **Groundwater Protection Schemes** publication (DELG et al., 1999) should be consulted.

## 1.5 Objectives of the County Roscommon Groundwater Protection Scheme

The overall aim of the groundwater protection scheme is to preserve the quality of groundwater in County Roscommon for drinking purposes and other beneficial uses, and for the benefit of present and future generations.

The objectives, which are interrelated, are as follows:

- to assist the statutory authorities in meeting their responsibilities for the protection and conservation of groundwater resources;
- to provide geological and hydrogeological information for the planning process, so that potentially polluting developments can be located and controlled in an environmentally acceptable way;
- to integrate the factors associated with groundwater contamination risk, to focus attention on the higher risk areas and activities, and to provide a logical structure within which contamination control measures can be selected.

The scheme is not intended to have any statutory authority now or in the future; rather it will provide a framework for decision-making and guidelines for the statutory authorities in carrying out their functions. As groundwater protection decisions are often complex, sometimes requiring detailed geological and hydrogeological information, the scheme is not prescriptive and needs to be qualified by site-specific considerations.

## **1.6 Scope of County Roscommon Groundwater Protection Scheme**

The groundwater protection scheme is the result of co-operation between Roscommon County Council and the Geological Survey of Ireland.

The geological and hydrogeological data for County Roscommon are interpreted to enable:

- delineation of aquifers;
- assessment of the groundwaters' vulnerability to contamination;
- delineation of protection areas around six public supply wells and springs identified by Roscommon County Council: Rockingham Spring (Boyle-Ardcarn), Longford/Silver Island Springs (Castlerea), Ballybane Springs (Ballinlough), Ballinagard Spring (Roscommon Central), Tobermore Spring (Killeglan) and Cloonlaughnan Springs (Mount Talbot);
- production of a groundwater protection scheme which relates the data to possible land uses in the county and to codes of practice for potentially polluting developments.

By providing information on the geology and groundwater, this report should enable the balancing of interests between development and environmental protection.

This study compiles, for the first time, all readily available geological and groundwater data for the county. In addition, this information has become part of a database within the Geological Survey of Ireland (GSI) which can be accessed by the local authority and others, and which can be up-dated as new information becomes available.

Accompanying this report is a suite of environmental geology maps. These are as follows:

### **Primary Data or Basic Maps**

- Bedrock Geology Map (Map 1)
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map (Map 2)
- Outcrop and Depth to Bedrock Map (Map 3)
- Hydrogeological Data Map (Map 4)

### **Derived or Interpretative Maps**

- Aquifer Map (Map 5)
- Groundwater Vulnerability Map (Map 6)

### **Land-use Planning Map**

- Groundwater Protection Scheme Map (Map 7)



The protection scheme deliverable has recently been enhanced by the incorporation of these outputs into a digital Geographical Information System (GIS) dataset, registered to the standard Ordnance Survey map base. This GIS dataset is designed to be compatible with planning department GIS systems in the Local Authorities. As well as the interpretative maps described above, the GIS incorporates groundwater protection responses, for each protection zone, for **landfill**, EPA-licensable **landspreading** of organic wastes, and **on-site wastewater treatment systems for single houses** ('septic tanks'). It is envisaged that the protection responses will be the feature of most interest to the Local Authorities, as they have direct relevance to the planning process.

The GIS and paper maps can be used not only to assist in groundwater development and protection, but also in decision-making on major construction projects such as pipelines and roadways. However, they are not a substitute for site investigation.

Detailed regional hydrogeological investigations in County Roscommon have included extensive work by the GSI in the 70's, 80's and early 90's, as well as feasibility studies for the development of public supply sources, Environmental Impact Statements and research publications. Despite this, it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of the county, but this report provides a good basis for strategic decision-making and for site specific investigations.

## **1.7 Roscommon County Development Plan**

It is envisaged that this Groundwater Protection Scheme should be incorporated into the County Development Plan, by whatever means the Council deems suitable.

## **1.8 Structure of Report**

The structure of this report is based on the information and mapping requirements for land surface zoning. The groundwater resource protection zone map (Map 7) is a land-use planning map and is the ultimate or final map as it is obtained by combining the aquifer (Map 5) and vulnerability maps (Map 6). The aquifer map boundaries, in turn, are based on the bedrock map (Map 1) boundaries, and the aquifer categories are obtained from an assessment of the available hydrogeological data (Map 4). The vulnerability map is based on the subsoils map (Map 2), the depth to rock map (Map 3) and an assessment of specifically relevant permeability and karstification information. This is illustrated in Fig. 1.2.

Similarly, the source protection zone maps result from combining vulnerability and source protection area maps. The source protection areas are based largely on assessments of hydrogeological data. This relationship is illustrated in Fig. 1.3.

Chapters 2 and 3 provide brief summaries of the bedrock and subsoils geology, respectively. Chapter 4 summarises and assesses the hydrogeological data for the different rock units, and gives the basis behind each of the aquifer categories. Chapter 5 describes the county with respect to mapped permeability regions and gives the basis behind the vulnerability categories. Finally, Chapter 6 draws all of this information together and summarises the groundwater protection zones present in County Roscommon. The hydrochemistry and water quality in Roscommon is presented in a separate report. Similarly, the reports outlining the protection of the public supplies are provided separately.

## **1.9 Acknowledgements**

The preparation of this groundwater protection scheme involved contributions and assistance from many people:

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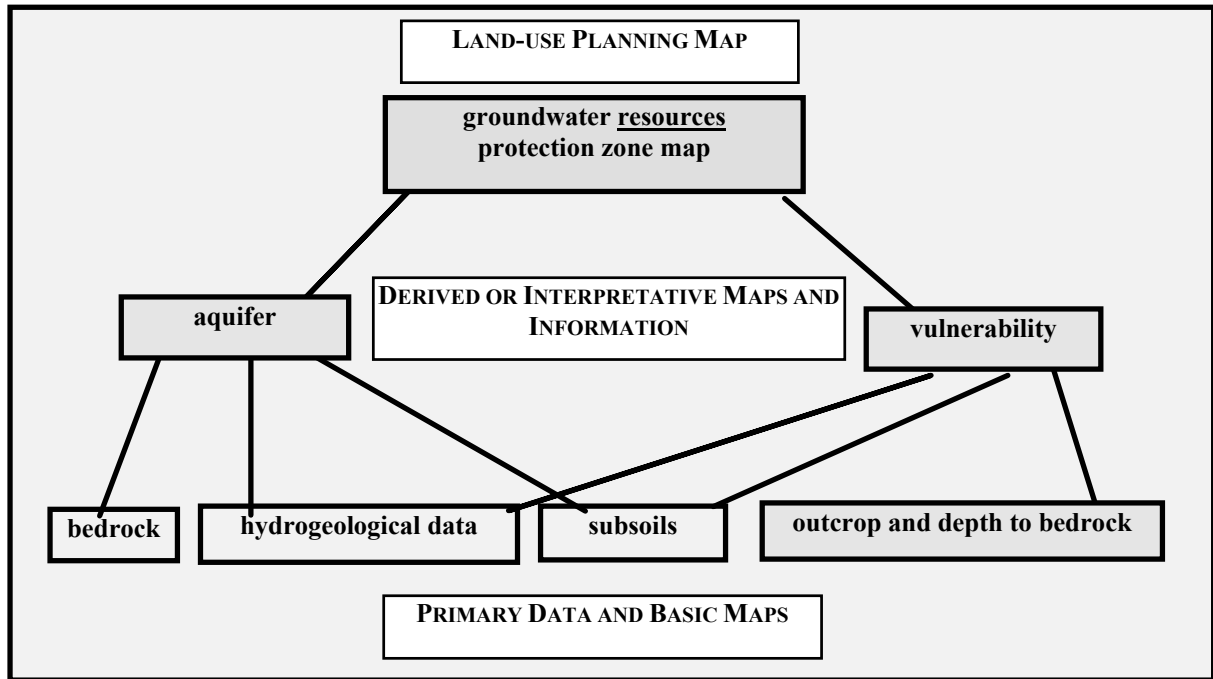


Fig. 1.2 Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

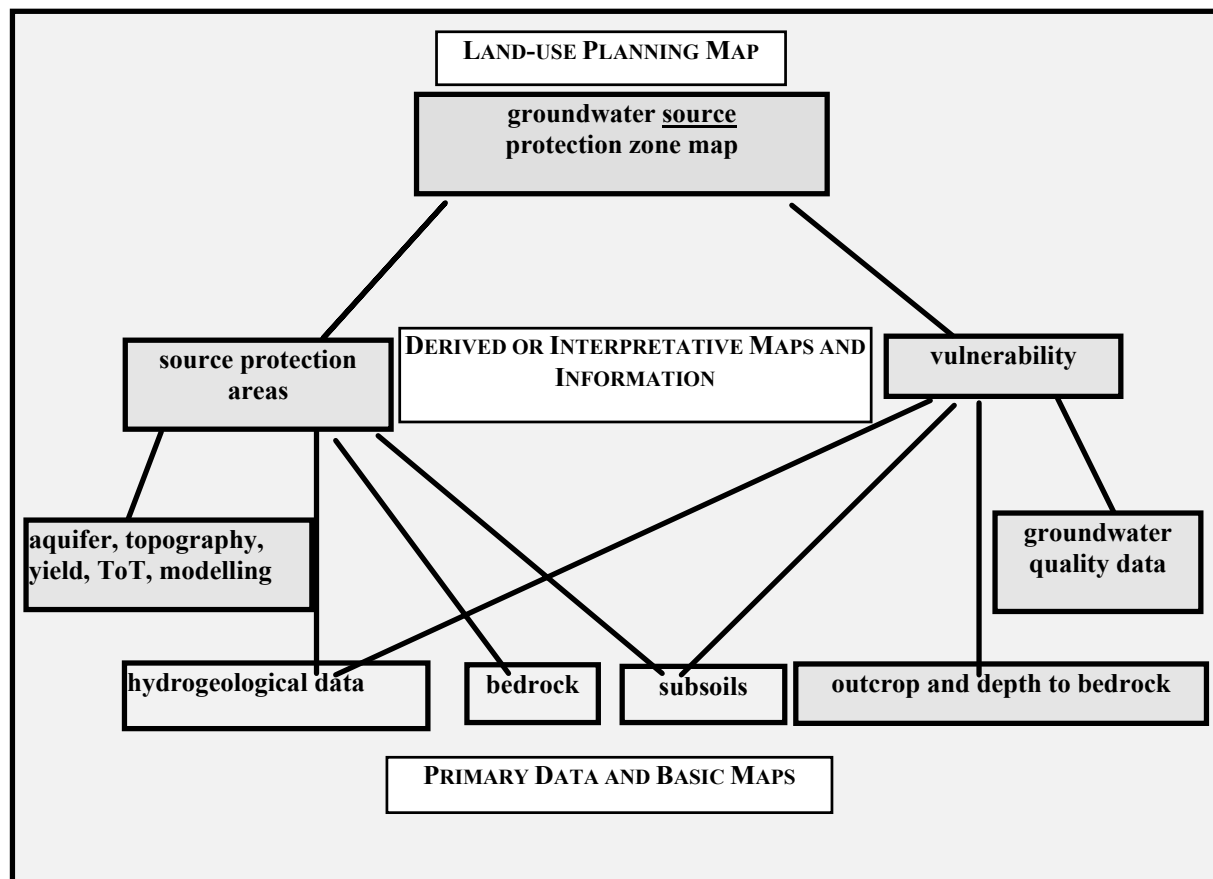


Fig. 1.3 Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

## 2 Bedrock Geology

### 2.1 Introduction

This chapter presents a brief description of the elements of the bedrock geology of Co. Roscommon that are relevant to the hydrogeology, namely the rock composition (lithology) and the rock deformation that occurred during the long geological history of the county.

The rocks range in age from Precambrian (c. 750 million years old) to the Namurian of the Upper Carboniferous (c. 300 million years old) and are mainly sedimentary in origin, consisting of limestones, sandstones and shales. There are small outcrops of volcanic rocks to the east of the county near Strokestown, and to a lesser extent, to the west of Lough Key in the Curlew Mountains.

The landscape of Co. Roscommon reflects the varied underlying geology. The flattish-topped Kilronan Mountain in the very north of the county is underlain by Namurian Shales, which are capped with hard Namurian Sandstones. The Curlew Mountains, also toward the north of the county, form a narrow ridge composed of resistant Devonian Sandstone. Similarly the ridge feature of Slieve Bawn to the east of Strokestown comprises the more resilient Ordovician Sandstones and Volcanics. The younger, softer and more soluble Carboniferous limestones and shales underlie the remainder of Co. Roscommon, stretching from Boyle to the southern tip of the county. Where these are lower lying, they are covered by a blanket of glacial deposits, or 'till'. These rocks were folded, faulted and uplifted in response to deformation events, which originated to the south of the country but which also influence the landscape in Co. Roscommon.

The geology of the county is complex with both temporal and lateral changes in rock composition. A brief description of the different rock units and their inter-relationships is given in this report; more detailed descriptions of some of the formations are given in Morris et al. (2002) and MacDermot et al. (1996). In describing the rock units the emphasis is placed on the rock lithology or composition because this is the feature of most relevance to groundwater flow. The formal rock formation name and letter code is also given to enable hydrogeologists to link the brief descriptions in this report to the more detailed descriptions in the literature. The rocks are described in groups according to their age, starting with the oldest:

- (i) Precambrian (Dalradian) Rocks,
- (ii) Ordovician Rocks<sup>\*</sup>,
- (iii) Silurian Rocks<sup>\*</sup>,
- (iv) Devonian Rocks;
- (v) Lower Carboniferous Rocks;
- (vi) Namurian (Upper Carboniferous) Rocks.

The bedrock geology of the area is shown in Maps 1N, 1S and 1W. These maps were compiled from the Bedrock Geology 1:100,000 scale GSI map series, Sheet 12 (Geraghty et al., 1996) Sheet 7 (Harney et al, 1996) and from unpublished field mapping and compilation carried out by Sarah Gatley, Conor MacDermot and Michael Philcox, Bedrock Section, GSI.

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<sup>\*</sup>The Ordovician and Silurian rocks are also collectively referred to as the Lower Palaeozoic rocks.

Table 2.1 Bedrock Succession in Co. Roscommon

Age (million years)	North/West Succession		Mid Succession		South Succession	
Upper Carboniferous: <i>Namurian</i> (290)	<b>Sandstones (LH)</b>	Sandstones, siltstones, coal				
	<b>Shales (DE, GO)</b>	Dark grey carbonate shales				
Lower Carboniferous: Visean	<b>Carraun Shale (CN)</b>	Grey/black shales with minor limestones	<b>Visean Lst (undifferentiated) (VIS)</b>  Generally poorly exposed. Likely to comprise units of clean and muddy limestones north of Tuls. Likely to comprise clean limestone south of Tuls.		<b>Lucan Fm (LU)</b> Dark limestone and Shales (Calp)	
	<b>Bellavally Shale (BE)</b>	Grey fine-grained limestones, shales, evaporites				
	<b>Meenymore (ME)</b>	Interlaminated limestones, shales, evaporites				
	<b>Bricklieve Lst (BK)</b>	Thick bedded, clean, cherty limestones				
	<b>Croghan Lst (CL)</b>	Medium bedded, fine-grained, muddy limestones				
	<b>BallymoreLst (BM)</b> Thin bedded dark limestones, mudstones, shales	<b>Lisgorman Shale (LG)</b> Thin-bedded calcareous shales, limestones				
		<b>Greyfield Fm (GF)</b> Coarse-grained clastic rocks, conglomerates, mudbank carbonates				
		<b>Oakport Lst (OK)</b>				
Courceyan  (355)	<b>Kilbryan Lst (KL)</b>	Dark nodular limestones and shales	<b>Argillaceous Lst (AL)</b> Dark, bedded limestones, shales, chert			
	<b>Boyle Sandstone (BO)</b>	Sandstones and red and green conglomerates	<b>Waulsortian Lst (WA)</b>		Massive unbedded lime-mudstones	
			<b>Ballysteen Lst (BA)</b>		Dark grey muddy limestones	
			<b>Moathill (MH)</b>	Limestones, sandstones, shales	<b>Navan Beds (NAV)</b>	Dark limestone, mudstone and sandstone
			<b>Meath (ME)</b>	Limestones, calcareous sandstones		
	<b>Fearnaght (FT)</b>	Conglomerates and red sandstones				
Devonian (410)	<b>Old Red Sandstones (KW, KWsh, KWbk MG)</b>	Sandstones and thin mudstones				
Silurian (438)	<b>Silurian (SIL)</b>	Grey to green siltstones and sandstones				
Ordovician (510)	<b>Ordovician (CX, CA, FA, LN, AE)</b>		Siltstones and sandstones, or conglomerates comprising volcanic material			
Dalradian (c.750-c.600)	<b>Cashel Schists (CI)</b>	Coarse grained schists and clastic rocks				

## 2.2 Precambrian (Dalradian) Rocks

The Dalradian Supergroup, is a group containing metamorphic rocks, and is known only in Ireland and Scotland. They are the youngest rocks in the Precambrian. They are believed to originally have been sedimentary rocks, laid down between 750 and 600 million years ago, and to have first been metamorphosed c. 475 million years ago (Grampian Orogeny). Evidence suggests that they have been subsequently affected by four other orogenies. It is believed that in the Dalradian, thinning of the crust, fragmentation of the continents and formation of an ocean basin occurred, in which sediments accumulated. The continental shelf was initially stable and deposition occurred in shallow seas. Over time the shelf became stretched and unstable, with block faulting occurring as the continent pulled apart. Volcanism was also initiated during this period. As the continent separated, the newly formed sea floor generally became wider, and sediments were deposited in a deeper off-shore environment. This resulted in the deposition of generally marine sediments. The Dalradian rocks are the oldest rocks in Roscommon, although only comprise one unit covering a very small area north west of Ballaghaderreen:

<b>Cashel Schists (CI)</b>	Metamorphic rocks of sedimentary origin. Predominantly schist rocks, as well as thick, coarse-grained clastic rocks.
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## 2.3 Lower Palaeozoic Rocks

Throughout the Ordovician period, north-west Ireland lay on the north-west side of the Ocean. An arc of volcanic islands lay off the coast, separated from the mainland by a narrow sea. Eroded material derived from the mainland and island mountains was deposited in the sea either in the shallow waters of the sea margins, or carried down into deeper waters by turbidity currents. The Ordovician rocks mainly outcrop in the upland area of Slieve Bawn. During Silurian times, the erosion of newly uplifted mountain ranges contributed to sands being deposited in the deep waters of the sea. In Roscommon, these present day rocks are only visible at the south-western end of the Curlew Mountains, north of Ballaghaderreen. A brief description of each rock unit is given below for both the Ordovician and Silurian periods, starting with the oldest rocks.

### 2.3.1 Ordovician Rocks

<b>Carracastle (CX)</b>	Volcanic rocks, including thick, coarse-grained clastic rocks.
<b>Coronea (CA)</b>	Green muddy sandstones (greywackes), red shales and minor lavas. Red shales are abundant in the lower part of the formation.
<b>Finnalaghta (FA)</b>	Bluish grey, non-calcareous sandstone, which principally contain quartz, felsic igneous and mica schist fragments. Black shaly slates, varying from less than 1 m to 15 m in thickness, are a minor component of the formation. The sandstone may include thin siltstone beds.
<b>Lacken (LN)</b>	Feldspathic sandstone with jasper.
<b>Aghamore (AE)</b>	Lava and coarse-grained clastic rock comprising clasts of volcanic origin.

### 2.3.2 Silurian Rocks

**Undifferentiated Silurian (SIL)** Grey to green sandstones and siltstones, poorly exposed.

## 2.4 Igneous Activity

During the Ordovician and Silurian periods, igneous rocks were formed in the west of the county. Some were brought to the surface by violently erupting volcanoes, while others were intruded into the sedimentary rocks, deforming and heating them. The igneous rocks formed during this time are:

**Felsite (F)** Creamy-white flinty textured, extremely fine grained volcanic rock.

## 2.5 Devonian Rocks

Deposition of the Old Red Sandstone (ORS) rocks took place in a desert-like environment which was subjected to periodic, torrential rainfall giving rise to intense erosion and then deposition of gravel, sand, silt and some clay in the flood plains of meandering rivers. The sandstones and conglomerates are seen in the Curlew Mountains and in the Slieve Bawn upland area, and are typical of Old Red Sandstone. The sandstones are reddish-brown in colour, reflecting the arid sub-aerial oxidising conditions under which these rocks were formed. They exhibit layers of fine and coarse material which reflects the varying speed of river flow during their deposition. Coarser material is common, sometimes concentrated into distinct conglomerate beds. A brief description of each rock unit is given below, beginning with the oldest:

**Moygara (MG)** Clast and matrix-supported conglomerates, composed of quartzite and rounded pebbles of vein quartz and jasper, interbedded with red-purple pebbly sandstones. The upper part of the formation is dominated by red sandstones and pebbly sandstones, as conglomerates decrease in abundance and clast-size.

**Keadew (KW)** Sheets of quartz-rich sandstone. These rocks appear to be massive, though a faint parallel lamination or cross stratification can sometimes be seen. Beds generally capped by a thin veneer of mudstone and the tops are gently undulating.

**Sheegory (KWsh/bk)** Coarse-grained volcanic sediments, interbedded with thin-bedded purple sandstones and laminated mudstones. Conglomerates are composed of primary volcanic material (pumice, ash) and reworked material such as lava and consolidated tuffs.

## 2.6 Lower Carboniferous Rocks

The Lower Carboniferous was a period of marine deposition as warm tropical seas transgressed northwards from present day Co. Cork over the Devonian Old Red Sandstone continent. On land, rivers deposited sand and silt, now represented by the Boyle Sandstone. In shallow near-shore waters muddy limestones and shales were formed, and further off shore pure limestones were formed, such as the Oakport Limestone. At the same time, earth movements caused the seabed to subside or uplift; the area north of Sligo, and the Curlew Mountains were both elevated during this period. This caused eroded sand and mud to be deposited southwards; thick mud accumulating further away from the influence of fast-flowing, near-shore, currents. Deltas were built out from the coast in shallow waters.

At the maximum extent of the deltas, the Lisgorman Shale was deposited although there is some evidence of their influence in the Ballymore beds around Boyle. The successive period saw a subsiding of the sea floor, during which period ‘mudmounds’ and the Bricklieve Limestone were formed.

After this period, there were three major episodes of delta-building interrupted by the deposition of shale. The Meenymore Formation comprises the deposition of muds and finely laminated limestones in shallow seas. After the first delta building episode, the sea advanced and retreated several times, depositing the Bellavally Formation. As the sea eventually deepened, the Carraun Shales were laid down. Each rock unit is briefly outlined below, starting with the oldest rocks:

<b>Boyle Sandstone (BO)</b>	Three members: 1) A basal sequence of poorly-bedded, red-purple pebbly grit, and coarse sandstone conglomerates, capped by intervals of mudrock with carbonate nodules. Approximately 45-90 m in thickness and well displayed between Crossna and Derreenargan (east of Lough Key). 2) The Lough Key Mudstone Member described as laminated black mudstones with thin shelly layers and gypsum beds, interbedded with sandstone (60-140 m in thickness). 3) The Rockingham Sandstone Member described as pale grey sandstone overlain by calcareous sandstone with shelly fragments (5 m).
<b>Fearnaght (FT)</b>	Pale, quartz-rich conglomerate with a sandy matrix, red and purple mica-rich flaggy sandstones, and purple-brown clean sandstones.
<b>Meath (ME)</b>	Consists of 200 m of varied shallow water lithologies including fine-grained limestones, clean limestones, sandstones, muddy fossiliferous limestones, silty limestones and shales. The lower part (up to 60 m in thickness) is predominantly fine-grained limestones with interbedded thin shales and several thick, discontinuous horizons of dolomite (Braithwaite and Rizzi, 1997).
<b>Moathill (MH)</b>	Predominantly silty, coarse-grained limestones and siltstones with bands of shales. More minor lithologies include sandstone, muddy limestones and fossiliferous mudstones (approximately 110 m thick).
<b>Undifferentiated Navan Group (NAV)</b>	Equivalent to the Meath and Moathill Formations.
<b>Kilbryan Lst (KL)</b>	Limestones interbedded with calcareous, often fossiliferous shales and strongly muddy limestone. Small gypsum nodules occur over a 15m interval in the middle of the formation, which is 100m thick in the type section, although exposures are scant.
<b>Ballysteen (BA)</b>	Dark grey, muddy fine-grained limestones with interbeds of calcareous fossiliferous shale.
<b>Waulsortian (WA)</b>	Massive pale grey fine-grained clean fossiliferous limestone which formed in mound structures. Original cavities are now filled with calcite which may form a significant proportion of the total volume of the rock.
<b>Argillaceous Lst (AL)</b>	Dark, well-bedded, fine-grained limestones with shale interbeds and chert.



<b>Oakport Lst (OK)</b>	Three members: 1) A basal member (27 m thick) of clean, coarse-grained limestone containing occasional coarse fossiliferous beds and mud-supported limestones. 2) A fine-grained sedimentary rock with high silt content. 3) An upper member consisting of uniform, shale-free, medium to fine grained limestones with shelly horizons and carbonate towards to base. A palaeokarstic horizon has been recorded in a 5 m quarry exposure adjacent to the type section borehole.
<b>Ballymore Lst (BM)</b>	Subdivided into three with a basal unit of medium-bedded fossiliferous, limestone with very thin shale partings (approximately 75 m thick). The middle unit (40 m thick) consists of thin-bedded dark nodular limestones with thick interbeds of calcareous shales. The topmost division (52 m thick) is similar to the basal unit although slightly shalier.
<b>Greyfield (GF)</b>	Succession of locally derived sandstone conglomerates with limestone and sandstone clasts, shales and varied carbonates including mudbank limestones.
<b>Lisgorman Shale (LG)</b>	Dark grey calcareous shales are interbedded with very fine-grained limestone beds, which are usually 5 cm in thickness. The upper part is shale-dominated. Higher beds (intersected in the Curlew Mountain Fault) contain interbedded fossiliferous shales and fine-grained, sometimes crinoidal, carbonate rocks. Approximately 275 m thick.
<b>Croghan Lst (CL)</b>	The lowest subdivision (40 m in thickness) comprises thin-bedded brown, weathered, muddy limestone with shale partings. The middle member is a 15 m thick, massive, medium to coarse-grained limestone, which is even-bedded and is occasionally oolitic. The youngest member (52 m thick) resembles the basal unit with a reduction in mud content and appearance of nodular chert towards the top of the formation.
<b>Bricklieve Lst (BK)</b>	Medium to thick-bedded grey bioclastic limestones, generally mud-supported, clastic and devoid of internal bedding features. Shale is almost absent except from the lowest exposed beds. Chert is abundant throughout the succession, forming up to 70 % of the rock towards to top of the sequence. At intervals there are crinoidal limestones free from chert.
<b>Lucan (LU)</b>	Predominantly dark grey, well bedded, cherty limestones interbedded with calcareous shales. Limestone bed thickness, grain size and proportion of shales vary widely.
<b>Visean Lst (VIS)</b>	<p>The majority of Roscommon between Hillstreet to the north and Bellenamullia to the south is categorised as undifferentiated limestones. This is due to lack of exposures and drilling information, although they are likely to be Visean in age. Further unpublished information does highlight further subdivision of this area:</p> <p>(a) north of Tulsk the limestones are likely to be a combination of clean and muddy limestones equivalent to the Oakport, Croghan and Ballymore Limestones;</p> <p>(b) south of Tulsk the limestones are likely to be predominantly shelf limestones equivalent to Burren Limestone. In other parts of the country, this is described as a pale to medium grey, fossiliferous, clean, medium to coarse-grained limestone.</p>

<b>Meenymore (MEe)</b>	Inter-laminated limestones, mudstones, dolomites, laminates, and occasional sandstones. The inter-lamination consists of near equal proportions of dolomite, shales and evaporites. This formation was probably deposited in an inter-tidal environment.
<b>Bellavally Shale (BE)</b>	Grey, fine-grained limestone, with shale, laminate, and evaporites.
<b>Carraun Shale (CN)</b>	Grey to black fossiliferous shales and mudstones with thin subordinate limestones and dolomites (averaging 54 m in thickness). The basal four members comprise single or grouped beds of fine-grained limestone with fossiliferous shales. This is overlain by thin laminated limestone, which in turn is overlain by thin calcareous sandstone. This formation can be seen west of Lough Allen.
<b>'mudbank lst' (mk)</b>	Massive grey shelly limestones which have formed in 'reef like' structures in deep water with an influx of muds. Equivalent in age to the Ballymore Limestone.

## 2.7 Namurian (Upper Carboniferous) Rocks

The Namurian period throughout southern Ireland was predominantly characterised by the deposition of shale with some sandstone. As a result of the uplift to the north, rivers flowed into the sea depositing large amounts of mud at an earlier stage in Roscommon than to the south. The Dergvone and Gowlaun Shales were formed as thick deposits of mud in a rapidly subsiding basin. This deposition occurred before and after the second delta-building period, mentioned in the previous section. The third major advance of the deltaic system represented by the Lackagh Sandstone Formation. The sediments were deposited in a series of cycles, in each of which progressively coarser-grained sediments were laid down.

<b>Dergvone Shale (DE)</b>	Four main shales. 1) A dark, metallic-looking, sometimes calcareous, fossiliferous shale, which may contain limestone blocks. 2) Similar to the first but less fossiliferous. 3) Unfossiliferous shale containing carbonate mudstones and nodules. 4) Silty shale with thin beds of ironstone and flaggy sandstone. The whole formation is approximately 118 m in thickness in the Slieve Aneiran area.
<b>Gowlaun Shale (GO)</b>	Two marine bands composed of dark calcareous shales, each of which is overlain by metallic-looking, unfossiliferous shales with carbonate bands and nodules.
<b>Lackagh Sandstone (LH)</b>	Cyclically deposited layers of a) dark grey, non-marine mudstones passing up through b) silty mudstones into c) interbedded fine sandstones, siltstones and mudstones. These are overlain by d) thick-bedded sandstones, which form an average of 80 % of each cycle. Impure coals often rest on each sandstone layer.

## 2.8 Structural History

The regional structure of the area is influenced by three major structural events known as the Taconic, Caledonian and Variscan Orogenys.

The earliest Taconic Orogeny marked the collision firstly of the offshore volcanic arc with the margins of Laurentia, and then later of two continents, Gondwana and Laurentia, which resulted in the

closure of an ancient ocean (the Iapetus Ocean). The boundary between the continents is a suture line running between the present day Shannon Estuary to Silvermines, Navan and Drogheda. The collision affected the older rocks only (the Dalradian, Ordovician and the Silurian rocks) and the intensity of deformation increases southwards towards the line of suture.

The deeply buried Dalradian rocks were deformed in a ductile manner, and were converted into schists. The Ordovician Rocks were deformed in a brittle manner, being faulted, thrust and folded. New minerals grew under compressive forces, which also turned the finer-grained sediments into slates. The successor to the Iapetus Ocean was then closed during the Caledonian Orogeny, resulting in shearing, stretching and folding of the rocks, and regional uplift. Probably during the latter part of this Orogeny, the Curlew Mountains were uplifted and deformed into a large fold, giving rise to large areas of near-vertical bedding.

The Variscan Orogeny was a north-south compression event. As the deformation front was located south of the country, the effects of the strain seen in Co. Roscommon mainly resulted in gentle folds, uplift and block faulting, especially of the Carboniferous Rocks, although with minimal metamorphism.

## **3 Subsoil Geology**

### **3.1 Introduction**

This chapter deals primarily with the geological materials that lie above the bedrock and beneath the topsoil. The subsoils were deposited during the Quaternary period of glacial history. The Quaternary period encompasses the last 1.6 million years and is sub-divided into the Pleistocene (1,600,000-10,000 years ago) and the more recent Holocene (10,000 years ago to the present day). The Pleistocene, more commonly known as the ‘Ice Age’, was a period of intense glaciation separated by warmer interglacial periods. The Holocene, or post-glacial, saw the onset of a warmer and wetter climate approaching that which we have today.

During the Ice Age the glaciers and ice sheets laid down a wide range of deposits that differ in thickness, extent and lithology. Material for these deposits largely originated from bedrock or previously lain glacial deposits, and was subjected to different processes within, beneath and around the ice. Some were deposited randomly and so are unsorted and have varying grain sizes, while others were deposited by water in and around the ice sheets and are relatively well sorted and coarse grained. As ice moves, pieces of rock and soil over which it flows become attached to its base, and may become incorporated into the lower layers of the ice, making the base of the ice very abrasive. This allows the ice to rapidly erode the underlying material. In this way the substrate is eroded, picked up and transported by the ice. When the ice melts, the material is deposited as one of the many landforms caused by glacial ice. For example, water from melting glaciers tends to wash away the finer particles, leaving behind well sorted gravel deposits.

For Roscommon, the subsoils mapping was undertaken by Robbie Meehan, in Teagasc, Kinsealy. This was part of the Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) project and comprised initial compilation of all available Quaternary data, and then photogrammetric modelling of aerial photographs to infer Quaternary geological (subsoil) boundaries. Field mapping was undertaken to check these boundaries. The end product was the Soils Parent Material Map, which formed the foundation of subsequent subsoil permeability assessments (described in Chapter 5). Subsoil distribution is presented in the FIPS-IFS Soils Parent Material Map (Map 2), and discussed briefly in Section 3.2. An overview of evidence for ice flow directions has been provided in Section 3.4.

### **3.2 Subsoil Types**

Many of the subsoils in County Roscommon were laid down during the last glaciation affecting Ireland. The deposits remaining from this glaciation are varied in their sedimentology and their landforms. Six subsoil types are identified in Roscommon, as shown on Maps 2N, 2S and 2W:

- till
- sands and gravel
- alluvium
- peat
- lake deposits
- outcrop and shallow rock (i.e. where bedrock comes within about 1 m of the surface)

### **3.2.1 Till**

Till (often referred to as boulder clay or drift) is the most widespread subsoil in County Roscommon. It is a diverse material that is largely deposited sub-glacially and has a wide range of characteristics due to the variety of parent materials and different processes of deposition. Tills are often tightly packed, unsorted, unbedded, and have many different particle and stone sizes and types, which are often angular or subangular. Some of the tills in Roscommon have been formed into elongated hills, or drumlins, which are thought to give an indication of ice flow direction, as discussed in Section 3.4.

Boundaries based on till texture are not shown on the subsoil Maps 2N, 2S and 2W. A number of particle size analyses were carried out during the permeability mapping and these results are discussed in the context of subsoil permeability and groundwater vulnerability in Chapter 5.

### **3.2.2 Sand and Gravel**

Deposition of sands and gravel takes place mainly when the glaciers are melting, which gives rise to large volumes of meltwater with great erosive and transporting power. The subsoils deposited in this environment are primarily well rounded gravel and sand, with the finer fractions of clay and silt washed out. Outwash deposits take the form of fans of stream debris dropped at the glacier front via drainage channels. Deltaic deposits are similar but are formed where drainage channels discharge into a standing body of water. Deposits remaining in the drainage channels form eskers, similar to a river drainage system in arrangement, with tributaries converging downstream.

Roscommon does not have particularly extensive deposits of sand and gravel. The larger sand and gravel deposits are found to the west of Athlone, in the south of the county, and around Garranlahan, Ballinlough, Lough O'Flynn and Lough Errit, all in the west of the county. All of these deposits are widely quarried. Usually, the presence of sand and gravel is reflected in the topography as ridges (eskers), hummocks and hollows (kames and kettle holes) or in large fan shaped deposits (outwash, deltas). The eskers are especially apparent around Garranlahan, as their number and density form a landscape unique to this part of the country.

### **3.2.3 Alluvium**

Alluvial sediments are deposited by rivers and include unconsolidated materials of all grain sizes, from coarse gravel down to finer silts and clays, and may contain organic detritus. These deposits are usually bedded, consisting of many complex strata of waterlain material. Most of the alluvial deposits in Roscommon comprise sand, silt and clay, and occasionally gravel. The largest area of mapped alluvium is along the River Shannon in the south of the county.

### **3.2.4 Peat**

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and undecomposed plant matter that accumulated in a waterlogged environment. Peat has an extremely high water content averaging over 90% by volume. Two main types of peat bog are distinguished in Roscommon: blanket bog, which is characteristic of upland areas with excessive rainfall, and raised bogs, which are characteristic of lowland areas with impeded drainage.

In Roscommon, blanket bog is found on the upper reaches of the Corry, Kilronan and Curlew Mountains, and is likely to be between one and three metres thick. Raised bog is extremely common in low-lying areas throughout the county, although is found extensively in the western region, between Lanesborough and Roosky, between Athlone and Ballinasloe, and along the southern county boundary. Both types of bog have been worked for peat, whether on a commercial basis with machinery, or on a local scale.

### **3.2.5 Lake Deposits**

These deposits were formed in the quiet waters of lakes formed by melting glacier waters. Only a few small areas of lake deposits are mapped in Roscommon, and these typically consist of silty and clayey material, similar to the finer type of alluvium.

## **3.3 Depth to Bedrock**

The depth to bedrock (i.e. subsoil thickness) is a critical factor in determining groundwater vulnerability. Subsoil thickness varies considerably over the county, from very thin to depths of more than 20 metres.

Broad, regional-scale variations in depth to bedrock have been interpreted across the county by using information from the GSI databases, field mapping and air photo interpretation. Depth to rock data maps (Maps 3N, 3S and 3W) show areas where rock crops out at the surface and also depth-to-rock point data from borehole records. The borehole records are colour-coded according to the degree of locational accuracy (i.e. data points coloured red are plotted to within an accuracy of 50 m). In addition to these data, some general assumptions are made in order to extrapolate to areas where data are not available. Generally speaking, the thickest deposits in Roscommon are till and sand/gravel found on the lower-lying areas throughout the county.

## **3.4 Ice Flow Direction**

Specific studies of the ice flow direction have not been carried out for County Roscommon. However, in a study of glacial landforms in the Irish Midlands, Clark and Meehan (2001) suggest that there were several phases of ice flow affecting Roscommon. The existing landforms indicate that ice flow direction during the Last Glacial Maximum was approximately north-westwards across Roscommon. After this was a period of de-glaciation in Ireland. The very beginning of this period appears to have resulted in ice flowing from north west to south east across the county.

## **4 Hydrogeology and Aquifer Classification**

### **4.1 Introduction**

This chapter summarises the relevant and available hydrogeological and groundwater information for County Roscommon. A brief description of the hydrogeology of each rock unit is given, followed by the aquifer category based on the GSI aquifer classification scheme. The hydrogeological data for the county are summarised on Maps 4N, 4S and 4W and the aquifers are shown on Map 5N, 5S and 5W.

### **4.2 Data Availability**

All the groundwater data in the GSI and from County Council files, consultants and drillers (1450 wells and springs in total) were compiled and entered into a computer database in the GSI.

The assessment of the hydrogeology of County Roscommon is based on the following data and reports:

- A hydrogeological study of the Boyle River Basin, undertaken by the GSI from 1970s to 1990s.
- Abstraction data for public water schemes, group scheme sources, and for a limited number of other high yielding private wells.
- Information from the Well Improvement Grant Scheme.
- Specific capacity and discharge data for some wells in Roscommon and the surrounding counties (specific capacity is the rate of abstraction per unit drawdown; the unit used is  $\text{m}^3/\text{d}/\text{m}$ ). Specific capacity is plotted against discharge as ‘QSC Graphs’ to get a ‘productivity category’, which can be related to aquifer categories (Wright, 2000).
- Information on large springs.
- The GSI karst database.
- Specific karst mapping and tracer test work carried out by the GSI.
- The findings of four MSc theses, three of which were carried out in conjunction with the GSI (Keohane, 1983; Doak, 1995; Price, 1998; Ibbotson, 2000).
- Hydrochemical data from County Council/GSI and EPA sampling rounds of the main Public and Group Water Schemes.
- Reports by engineering and hydrogeological consultants.
- Relevant academic research papers.
- General hydrogeological experience of the GSI, including work carried out in adjacent counties (Mayo, Sligo, Leitrim, Longford, Westmeath, Offaly, Tipperary, Galway).

### **4.3 Rainfall, Evapotranspiration and Recharge**

Mean annual rainfall in Roscommon for 1961–1990 varied from 900 to 1000 mm in the lower lying southern and eastern areas of the county, and from 1000 to 1200 in the higher northern and western regions (Fitzgerald and Forrestal, 1996). Over most of the county, the average is 900–1100 mm.

There are no Met Eireann synoptic weather stations in County Roscommon, meaning that no long term mean annual potential evapotranspiration (PE) has been calculated for the county. The closest stations are Claremorris to the west, Mullingar to the east, and Birr to the south, where data for the period 1961 to 1990 has been analysed (Met Eireann data). The mean annual PE for Roscommon is estimated to vary from approximately 400 to 450 mm. Actual evapotranspiration is estimated at about 90 to 95% of the PE.

The mean annual potential recharge (rainfall minus actual evapotranspiration) values are therefore estimated to be in the range 500 to 800 mm, with the lowest levels in the low-lying areas in the south and east, and the highest in the uplands in the north and west. The actual annual recharge to the groundwater depends on the relative rates of infiltration and surface runoff. In many areas recharge is likely to be as low as 25% of the potential recharge.

#### 4.4 Groundwater Usage

A large proportion of the drinking water in County Roscommon is supplied by groundwater: 12 of the 15 public water schemes (approximately 73% of water abstracted), and 47 of the 56 group water schemes (based on County Council figures, 1999). Areas not served by public or group water schemes generally rely on individual private wells as their source of water. The 12 public water schemes supplied by groundwater are outlined in Table 4.1.

**Table 4.1. Summary of Public Water Supply Schemes**

<b>Public Water Scheme</b>	<b>Source</b>	<b>Approximate Abstraction (m3/d)</b>
Roscommon Central	Ballinagard Springs	6,000
	Rockfield Spring/stream	1,000
Knockcroghery	Toberreeogue Springs	1,000
Four Roads	Cloonlaughnan Spring	3,500
Ballyleague	Borehole	400
South Roscommon	Killeglan Spring	7,000
Castlerea Urban	Silver Island Spring	1,300
Castlerea Rural	Longford Springs	3,000
Boyle/Ardcarn	Rockingham Spring	6,000
Arigna	Derrenvogy Spring/Gubbaruda Spring	200
Ballyfarnon	Tober Maire Spring	200
Ballinlough	Ballybane Spring	4,000
Keadew	Borehole	150

#### 4.5 Aquifer Classification

The aquifer classification used by GSI (Daly, D. 1995) has three main aquifer categories, with each category sub-divided into two or three classes:

##### **Regionally Important (R) (or Major) Aquifers**

- (i) Karstified aquifers (**Rk**)
- (ii) Fissured bedrock aquifers (**Rf**)
- (iii) Extensive sand/gravel (**Rg**)



**Locally Important (L) (or Minor) Aquifers**

- (i) Sand/gravel (**Lg**)
- (ii) Bedrock which is generally moderately productive (**Lm**)
- (iii) Bedrock which is moderately productive only in local zones (**LI**)

**Poor (P) Aquifers**

- (i) Bedrock which is generally unproductive except for local zones (**PI**)
- (ii) Bedrock which is generally unproductive (**Pu**)

**4.5.1 Bedrock Aquifers**

Irish bedrock aquifers are not generally thought to have significant pore-space permeability. Consequently, flow is thought to depend on the development of a network of secondary permeability within fractures. Thus bedrock aquifer categories have been designed to take account of the following factors:

- The overall potential groundwater resources in each rock unit.
- The area of each rock unit. The minimum area for a regionally important aquifer (**R**) is 25 km<sup>2</sup>.
- The localised nature of the higher permeability zones (e.g. fractures) in many of the bedrock units.
- The highly karstic nature of some of the limestones.
- All bedrock types give enough water for domestic supplies and therefore all are called ‘aquifers’.

Karstification and dolomitisation are two processes strongly influencing the development of secondary permeability and aquifer potential in Irish bedrock units. Each are explained briefly below. The terms will occur in several of the classifications provided in Sections 4.6 to 4.10.

**4.5.2 Karstification**

Karstification is the process whereby limestones are slowly dissolved away by acidic waters moving through them. This most often occurs in the upper bedrock layers and along some of the pre-existing fissures and fractures in the rocks which become slowly enlarged. This results in the progressive development of distinctive karst landforms such as collapses, caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits. The solution is influenced by factors such as: the type and solubility of the limestone; the degree of jointing, faulting and bedding; the chemical and physical character of the groundwater; the rate of water circulation; the geomorphic history (upland/lowland, sea level changes, etc.); and the subsoil cover. One of the consequences of karstification is the development of an uneven distribution of permeability, which results from the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones.

There are gradations in the degree of karstification in Ireland from slight to intensive. In order to assist in the understanding and development of regionally important (**R**) limestone aquifers, the GSI has compartmentalised the broad range of karst regimes into three categories. Where karstification is slight, the limestones are similar to fissured rocks and are classed as **Rf**, although some karst features may occur. Aquifers in which karst features are more significant are classed as **Rk**. Within the range represented by **Rk**, two sub-types are distinguished, termed **Rk<sup>c</sup>** and **Rk<sup>d</sup>**.

**Rk<sup>c</sup>** are those aquifers in which the degree of karstification limits the potential to develop groundwater. They have a high ‘flashy’ groundwater throughput, but a large proportion of flow is concentrated in conduits, numerical modelling using conventional programs is not usually applicable, well yields are variable with a high proportion having low or minimal yields, large springs are present,

storage is low, locating areas of high permeability is difficult and therefore groundwater development using bored wells can be problematical.

**Rk<sup>d</sup>** aquifers are those in which flow is more diffuse, storage is higher, there are many high yielding wells, and development of bored wells is less difficult. These areas also have caves and large springs, but the springs have a more regular flow. In general, these aquifers can be modelled (at an appropriate scale) using conventional programs.

#### 4.5.3 Dolomitisation

Dolomitisation is a weathering process where calcium ions are replaced by magnesium ions in the crystal lattice of dolomite ( $\text{Ca Mg}(\text{CO}_3)_2$ ). Hydrogeologically, the most important consequence of dolomitisation is that it results in an increase in the porosity and permeability of the carbonate rock. Dolomitised rocks are a highly weathered, yellow/orange/brown colour and are usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery. Dolomitisation often occurs along fault zones, can cross bedrock lithology boundaries and results in unpredictable very high permeability zones. In general, the cleaner the original limestone, the greater the degree of dolomitisation.

#### 4.5.4 Sand/Gravel Aquifers

Sand/gravel deposits have a dual role in groundwater development and supply. Firstly, in some cases they can supply significant quantities of water for supply and are therefore classed as aquifers, and secondly, they provide storage for underlying bedrock aquifers.

A sand/gravel deposit is classed as an aquifer if the deposit is highly permeable, more than 10 m thick and greater than one square kilometre in areal extent. The thickness of the deposit is often used rather than the more relevant saturated zone thickness as the information on the latter is rarely available. In many instances it may be assumed that a deposit with a thickness of 10 m will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief, for example eskers or deposits in high topographic areas, as these gravels are often dry.

Table 4.2 Sand/Gravel Aquifer Classification

	<b><i>Regionally important</i></b>	<b><i>Locally important</i></b>
<b>Aerial extent</b>	> 10 km <sup>2</sup>	1-10 km <sup>2</sup>
<b>Saturated thickness</b>	> 5 m	> 5 m
<b>Permeability</b>	High	High

Sand/gravel aquifers are therefore classified based on the permeability, areal extent, and the thickness of the unsaturated zone (see Table 4.2). The permeability can vary considerably depending on how they were deposited, so in practice the geological history is also considered. Poorly sorted sand/gravel deposits for example, rarely have a high enough permeability to enable sufficient throughput to be achieved due to the presence of clays and silts. In the absence of permeability test data, gravel with a fines content of less than approximately 8% are generally considered to have sufficient permeability for aquifer development (O'Suilleabhain, 2000).

A regionally important gravel aquifer should have an aerial extent of *at least* 10 km<sup>2</sup>. This is to ensure that there will be enough recharge to provide a supply of one million cubic metres per year from the whole aquifer, assuming an average annual rainfall of 400 mm. A locally important aquifer on the other hand can be expected to have enough resources to supply a group scheme or village.

#### 4.5.5 Aquifer Classification Criteria

As yield is one of the main concerns in aquifer development projects, yields from existing wells are conceptually linked with the main aquifer categories outlined in Section 4.5.1:

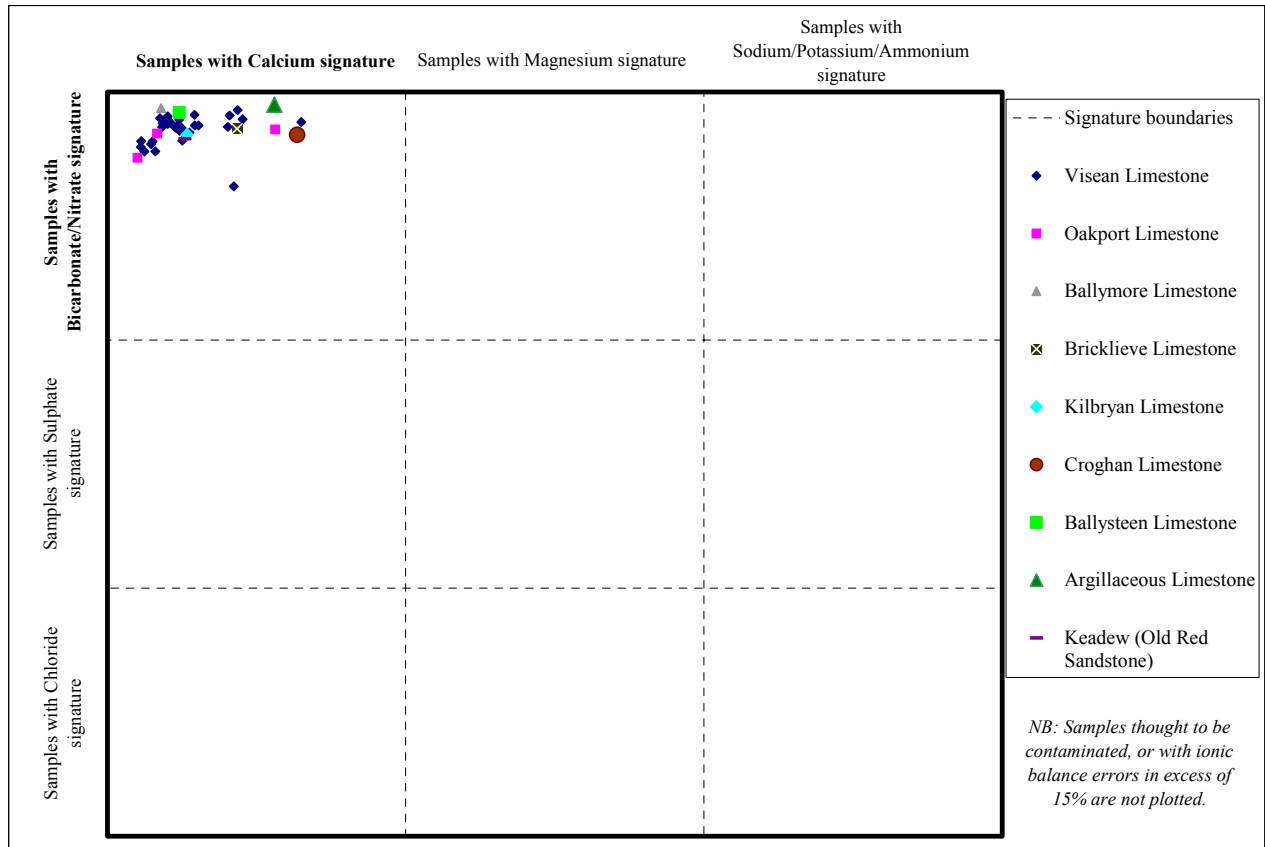
- Regionally important (**R**) aquifers should have (or be capable of having) a large number of ‘excellent’ yields: in excess of approximately 400 m<sup>3</sup>/d (4000 gph).
- Locally important (**L**) aquifers are capable of ‘good’ well yields 100-400 m<sup>3</sup>/d (1000-4000 gph).
- Poor (**P**) aquifers would generally have ‘moderate’ or ‘low’ well yields - less than 100 m<sup>3</sup>/d.

In practice, existing well yield information is often difficult to use because reliable, long term yield test data are quite rare (particularly for the less productive aquifers). In practice, then, the following criteria are used in aquifer classification:

- Permeability and transmissivity data from formal pumping tests, where discharge and water levels readings have been taken over a period of many hours or days.
- Productivity data from wells where either formal pumping tests have been undertaken or where at least one combined reading of discharge and drawdown data are available. The GSI has developed the concept of ‘productivity’ as a semi-quantitative method of utilising limited well test data (Wright, 2000). A ‘productivity index’ is assigned to a well from one of five classes: I (highest), II, III, IV, and V, using a graphical comparison of well discharge with specific capacity (discharge divided by drawdown). Generally, wells in regionally important aquifers should plot in classes I and II, locally important aquifer data will plot in classes II to IV, and those in poor aquifers typically plot in classes IV and V (Wright, 2000).
- Occurrence of springs with ‘high’ flows (greater than 2160 m<sup>3</sup>/day total flow).
- Occurrence of wells with ‘excellent’ yields (greater than 400 m<sup>3</sup>/day discharge).
- Hydrological information such as drainage density where overlying strata are thin, and baseflows or flows in rivers (better aquifers will support higher baseflows and summer flows).
- Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water. Clean limestones for example, are more permeable than muddy limestones. Clean washed and sorted sand and gravel are also more permeable than poorly sorted glacial tills. Areas where folding and faulting has produced extensive joint systems tend to have higher permeability than areas where this has not occurred.
- Aquifer assessments undertaken in neighbouring counties.

All factors are considered together; productivity and permeability data are only given ‘precedence’ over lithological and structural inferences where sufficient data are available. Because well data from County Roscommon are limited, information from neighbouring counties in similar geological environments is included. All of these data used are summarised in Table 4.3.

Additional information used includes the study of the ‘major ion’ chemistry to provide a water quality categorisation, or ‘chemical signature’, for each supply source (Figure 4.1 below). This signature can aid assessment of the overall groundwater flow regime in the aquifers with available data, as well as giving indirect indications of groundwater vulnerability.



The classification of all rock units and of sand and gravel aquifers in Roscommon is presented in Sections 4.6 to 4.11. A summary can be found in Table 4.3, and on Maps 5N, 5S and 5W.

Some bedrock units have been grouped if they are of similar geological age and have similar lithological/structural characteristics. In considering the classifications provided, it is important to note that:

- The bedrock aquifer classifications are based on the bedrock units described in Chapter 2 and depicted on Maps 1N, 1S and 1W.
- Irish hydrogeology is unusually complex and variable. Aquifer delineation is a generalisation reflecting the overall resource potential. Consequently, there will often be exceptionally low or high yields which do not conform with the aquifer category given.
- The top few metres of all bedrock types are likely to be relatively permeable, even in the poor aquifers.
- There may be localised areas where recharge is restricted. This could occur, for example, where the vulnerability is low, or where a small portion of the rock unit has been faulted away from the main body of the unit. In these situations, the development potential even of regionally important aquifers may be limited. In considering major groundwater development schemes at particular sites, it will be important to consider the long term balance between recharge and abstraction, as well as the aquifer potential.

The sections that follow examine the hydrogeological information available for each rock unit and conclude by giving the aquifer category.

**Table 4.3 Summary of Well Productivity & Yield Categories for Roscommon Aquifers**

Formations	Well Productivity Index					Well Yield (m <sup>3</sup> /d)					Spring Yield (m <sup>3</sup> /d)		Aquifer Category
	I	II	III	IV	V	E (>400)	G (400-100)	M (100-40)	P (<40)	F (<3)	H	I	
Dalradian, Lower Palaeozoic and Volcanic Rocks	No Data						1						Pl
Devonian Old Red Sandstones			1				1						Pl
Fearnaght (FT)	No Data					No Data							Lm
Meath (ME), Moathill (MH), Navan Group (NAV)	No Data						2			1			L1
Ballysteen Limestone (BA)	1			3	2		1	5	1				L1
Waulsortian Limestone (WA), mudbank limestones (mk)	2	1	1	1	4	2	1	2	5				L1
Boyle Sandstone (BO)	No Data						1						L1
Kilbryan Limestone (KL)		1	3	2	1	1	6	2	4	1			L1
Argillaceous Limestone (AL)		1	3	2	1		1	2	3	11			L1
Oakport Limestone (OK)		1	3	2	1		1	6	2	4			L1
Ballymore Limestone (BM)		1	1	1			1	1	2	3			L1
Greyfield (GF), Liscorman Shale (LG)	No Data					No Data							Pl
Croghan Limestone (CL)	No Data									1			L1
Bricklieve Limestone (BK)	No Data												L1
Lucan (LU)	No Data					No Data							L1
Visean Limestones (VIS, VISoo)	3	26	10	15		1	2	6	11	16			L1
Upper Visean Shales, Namurian Shales/Sandstones	5	2		5	7	9	13	2	9	3	7	11	Rk <sup>c</sup>
Quaternary Deposits (Sand/Gravel)		3		1		2	1	1					Pl
	No Data					No Data							Pl
	2	4	2	3	1	3	3	4	2				None

These data are drawn from Co. Roscommon (first row of each formation) and neighbouring counties: Mayo, Sligo, Leitrim,

Longford, Westmeath, Offaly, Tipperary, Galway (second row, below dashed line where data are available).

These statistics may be skewed towards higher yielding sources; mainly public and group scheme supplies.

Most well records have neither drawdown data (for specific capacities) nor maximum yields.

## 4.6 Regionally Important Karst Aquifers (Rk)

### 4.6.1 Oakport Limestone (OK) and Ballymore Limestone (BM)

These two units are combined to form one of the karstified aquifers in County Roscommon. Together, they cover 172 km<sup>2</sup>, stretching from Cootehall to Errit Lough, passing just south of Boyle and Ballaghaderreen. Smaller areas are also underlain by these rocks to the north east of Hillstreet (both limestones), and to the south of Ballinlough (Oakport Limestone). See Maps 1N and 1W.

A considerable amount of work has been undertaken in this region over the last few decades. This has provided a large amount of information and significantly improved our understanding of groundwater movement, and especially through the Oakport and Ballymore Limestones. A brief outline of the information is given in this Section.

The Oakport Limestone is a clean, medium to coarse grained, generally even bedded limestone. The Ballymore Limestone overlies the Oakport. It has medium bedded basal and upper limestone beds with thin shale partings. The muddier middle unit is thinly bedded, with interbeds of shale. It is therefore likely to be less permeable than the other Ballymore units, although no specific permeability data are available. This muddy unit is approximately a quarter of the thickness of the limestone.

Due to the lack of outcrop and exposure data in Roscommon, the three main Ballymore beds have not been differentiated. The Ballymore Limestone aquifer category is therefore based on the available hydrogeological data, which may be biased towards the cleaner units. Despite the lithological differences between the Oakport and Ballymore Limestones, they are considered to form the same aquifer for two main reasons:

1. They are in hydraulic continuity.
2. Both limestones exhibit the general characteristics of a highly karstification regime. These are outlined below.

#### ***Karstification***

***Karst Features.*** Numerous karst features have been mapped in these rocks. Their unusually high density is shown on Map 4N and 4W. The features include enclosed depressions, springs, swallow holes, turloughs, caves, dry valleys, and limestone pavement. More features are recorded in the Oakport Limestone (Figure 4.2) than in the Ballymore Limestone (Figure 4.3). However, it is understood from local knowledge that there are a large number of unrecorded karst features throughout this region.

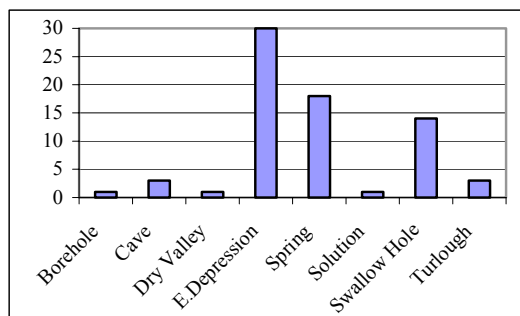


Figure 4.2. Karst Features Recorded in the Oakport Limestone.

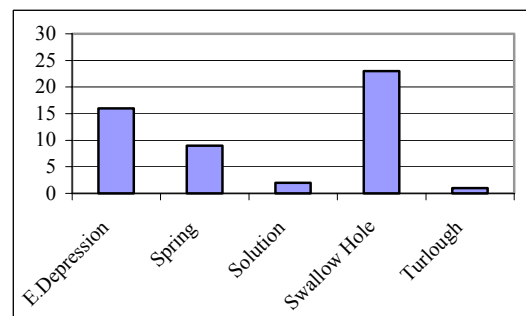


Figure 4.3. Karst Features Recorded in the Ballymore Limestone

***Interconnection between Surface Water and Groundwater.*** The high degree of interconnection between surface water and groundwater is demonstrated in three main ways:

- Higher topographical areas (e.g. Plains of Boyle, around Garranlahan) have no streams as the surface water is drained through karst features (enclosed depressions, swallow holes, caves,

limestone pavements) into the groundwater system. Therefore, groundwater recharge occurs rapidly.

- Surface streams frequently sink through karst features to flow as groundwater for some distance. They sometimes re-emerge as springs, to once again form significant surface streams. Thus these springs are essentially surface water e.g. Pollmore Springs, east of Lissydaly.
- Turloughs are found throughout the aquifer. These are seasonal lakes, which appear as the groundwater rises above ground level through springs or estevelles in lower lying areas.

*Conduit Flow.* Groundwater flow appears to be mainly localised, occurring in solutionally enlarged conduits and fissures. These are capable of rapidly transmitting large volumes of groundwater. The predominance of conduit over diffuse flow is suggested from several pieces of evidence:

- Conduits/fissures are recorded up to 40 m b.g.l. in borehole and geophysical investigations.
- Surface geophysical work suggests large conduits near the Rockingham Springs (McGrath, 2001).
- Rapid velocities of large volumes of groundwater imply relatively sizeable and straight channels. Such velocities are recorded in several tracer tests: 279 m/hr across the Ballymore – Oakport boundary, and 218 m/hr within the Oakport Limestone (Rockingham Springs tests, GSI, 2000); 32 – 50 m/hr in the Oakport Limestone (Pollmore Spring test, east of Lissydaly, GSI, 1987).

*Springs.* Springs associated with conduit flow are frequently large, often representing a single discharge point/area for a specific conduit/fissure zone. The localised conduit flow means that these rocks are likely to have a relatively low storage capacity, and the springs commonly have a rapid flow response to rainfall events. All of these features exist in these rocks:

- Very large springs are located in the Oakport Limestone e.g. Rockingham Springs (public water supply), Ballybane Springs (public water supply) and Cloonmagunnaun Springs (historically a public water supply).
- Low storage capacity is exhibited by a number of ‘seasonal’ springs, which have no flow in summer but relatively large flows in winter e.g. Pollaneigh Spring. The public water supply springs do not generally run dry due to their large catchment areas. However they can exhibit large ranges in discharge (Rockingham Springs: 6,000 m<sup>3</sup>/d – 16,000 m<sup>3</sup>/d).
- The rapid response to rainfall events is inferred by the ‘spikey’ hydrographs previously recorded at the Rockingham Springs over a longer period of time (Price, 1998).

*Water Quality.* Karst springs frequently have variable water quality as there is negligible filtering of groundwater when it flows through large conduits/fissures. Poor water quality may be further compounded if contaminated surface water enters through karst features, thus bypassing the attenuation capacity of the topsoil and subsoil. The Cloonmagunnaun Springs have not been used for over 10 years because their karstic nature has rendered them particularly vulnerable to pollution.

### ***Hydrogeological Data***

There are sparse hydrogeological data for the Ballymore Limestones hence these have been assessed with the Oakport data (solid colour in Figures 4.4 and 4.5). The data highlight that 13 of the 20 well yields are either ‘good’ or ‘excellent’ and over half of the 14 productivity values fall within categories ‘I’ or ‘II’. Two ‘poor’ yields and one ‘failed’ well are recorded in the Ballymore Limestone, although there is a range across all yield and productivity categories in both limestones. The calculated transmissivity data for both units show a general trend towards higher values and a large variability in values. For example, at Rockingham Springs the production well has a transmissivity of 3574 – 5475 m<sup>2</sup>/d (Ibbotson, 2000), and the augmentation borehole, which is approximately 300 m away, has values of 35 – 95 m<sup>2</sup>/d (K.T. Cullens, 1999).

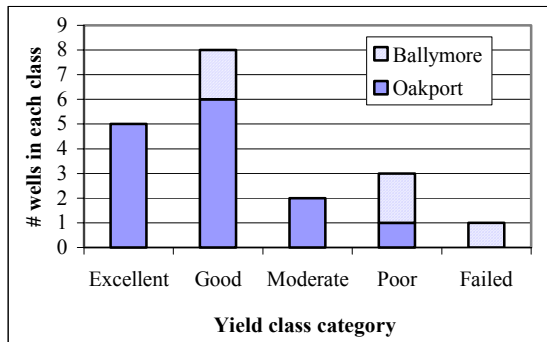


Figure 4.4. Well Yield Data for the Oakport and Ballymore Limestones.

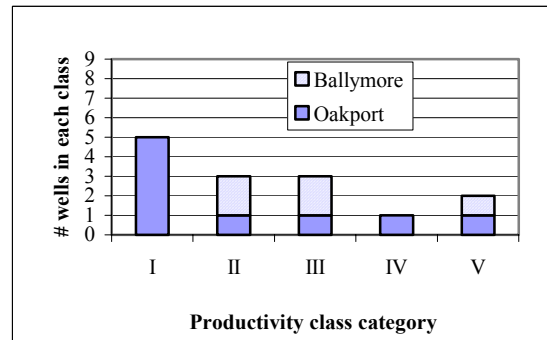


Figure 4.5. Well Productivity Data for the Oakport and Ballymore Limestones.

Hydrochemical data have been obtained from one water supply in each rock unit; Ballinlough Public Supply Scheme in the Oakport Limestone and Oldtown, Ballinameen Group Scheme in the Ballymore Limestone. The samples from these supplies highlight that bicarbonate and calcium ions are dominant (Figure 4.1) and that the waters are ‘very hard’ ( $> 350 \text{ mg/l CaCO}_3$ ). This hydrochemical signature is typical of a clean limestone aquifer and issues associated with the ‘natural’ chemistry of these waters may include lime-scale problems.

Both Oakport and Ballymore units are generally clean, highly karstified limestones, which are capable of sustaining significant yields, including three public water supply schemes. Thus, this aquifer is classified as a regionally important karstic aquifer (Rk). Given the identification of large conduits/fissures, variability in yield and productivity categories, low storage capacity and rapid response to rainfall, this karstic aquifer is considered to be dominated by a conduit flow system (Rk<sup>c</sup>).

#### 4.6.2 Bricklieve Limestone (BK)

This clean, thick-bedded limestone covers a total area of  $37 \text{ km}^2$  and is found around Cavetown Lough and Lisdaly Lough, south west of Carrick-on-Shannon, and in a thin band south of Ballyfarnon. This unit is highly karstified, in the Bricklieve Mountain region, County Sligo, to the extent of having well developed cave systems. A high degree of karstification in these rocks is also likely to be the case in north Roscommon. Intensive karst mapping has not been undertaken in these areas in Roscommon although records do exist for springs (2), caves (2), and a swallow hole.

Two wells recorded in this unit have ‘excellent’ and ‘good’ yields and fall into productivity categories II and III respectively, which suggests these supplies are reasonably sustainable. The hydrochemistry (Figure 4.1, sample taken from the Keadew Public Water Supply Scheme) has a calcium bicarbonate signature and the water is ‘hard’ ( $250 - 350 \text{ mg/l CaCO}_3$ ) with a neutral pH. The hydrochemistry is consistent with a clean limestone. The aquifer is therefore classified as regionally important (Rk). The nature of the limestone and its highly developed karst system in Sligo would suggest that the Bricklieve Limestone is dominated by conduit flow in this general region (Rk<sup>c</sup>).

#### 4.6.3 Undifferentiated Visean Limestone (VIS, VISoo)

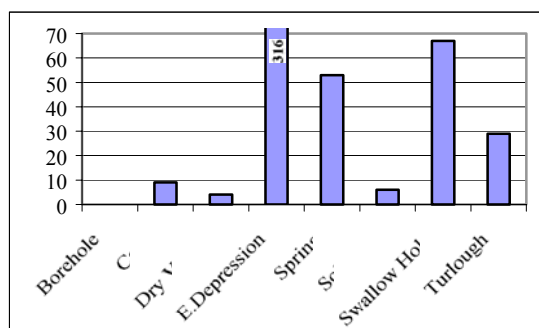
The Undifferentiated Visean Limestone is the most common division of bedrock in the county, and accounts for approximately 60% of the total area ( $1500 \text{ km}^2$ ). The area of Visean Limestone north of Tulsk is likely to consist of both clean and muddy limestones. The clean limestones would be equivalent the Oakport, Ballymore and Bricklieve units, and the muddier similar to the Croghan Limestone. South of Tulsk, the Visean Limestones generally form consistently cleaner, bedded



limestones, frequently described as ‘Burren-like’ in the original bedrock mapping, which was undertaken in the early 1900s. However, the Visean rocks cannot be subdivided due to the lack of drilling and exposure data. Therefore all available data has been used to determine the most appropriate aquifer classification for the entire unit. One division within the Visean has been made, where oolitic limestones have been mapped in the south of the county (see Map 1S). Oolitic rocks are a very clean form of limestone, and may exhibit enhanced permeability, although no specific data are available for them in Roscommon and they have been assessed along with the bulk of the Visean.

### **Karstification**

*Karst Features.* Karst features are abundant and widespread in the Visean rocks (Figure 4.6). Specific karst mapping in three study areas (around Ballaghaderreen, Castlerea, and Taghmaconnell, see Maps 4N, 4S and 4W) highlights the high density of features in some areas. Karst features are also recorded in muddier limestones (e.g. Croghan Limestone) as well as in cleaner limestones, although specific mapping has not been undertaken in these areas. A large number of additional karst features are known to exist in these rocks, but are not yet recorded and therefore not used in this assessment.



**Figure 4.6. Karst Features Recorded in the Undifferentiated Visean Limestone Rocks**

*Interconnection between Surface Water and Groundwater.* This interconnection is apparent in these rocks, and is illustrated in two main ways:

- Higher topographical areas (e.g. east of Castlerea, Tusk – Roscommon Town, Knockcroghery – Four Roads) are frequently devoid of stream, as surface water is drained through some of the karst features (enclosed depressions, swallow holes, caves, limestone pavements). Groundwater recharge occurs rapidly in such areas.
- Several seasonal lakes, or turloughs, are noted especially in the south of this unit. This results from the up-welling of groundwater through springs and estavelles as the watertable rises in winter.

*Conduit Flow.* The predominance of localised groundwater flow through solutionally enlarged conduits and fissures is shown by:

- Surface geophysical work carried out east of Castlerea, which infers the presence of at least seven large conduits (McGrath, 2001).
- Rapid velocities of large volumes of groundwater imply relatively sizeable and straight channels. Such velocities are recorded in several tracer tests: minimum velocities ranging from 68 to 107 m/hr between several connections east of Castlerea (Longford and Silver Island Springs multiple tracer test, GSI, 2001); 70 m/hr from Lough Funshinagh to Milltown Pass (Drew and Burke, 1996); 70 m/hr and 110 m/hr recorded in the Killeglan Springs tracer test (Roscommon County Council, 1991 and 1994); 24 m/hr in the Ballinagard tracer test (Roscommon County Council, 1991).

*Springs.* Large springs are frequently associated with conduit flow, often representing a single discharge point/area for a specific conduit/fissure zone. The localised conduit flow means that these rocks are likely to have a relatively low storage capacity, and the springs commonly have a rapid flow response to rainfall events. These features are recorded in the Visean Limestones:

- There are 7 ‘high’ and 11 ‘intermediate’ yielding springs located in these rocks, of which 12 are public or group scheme supplies. The public supply springs include Longford Spring, Silver Island Spring, Ballinagard Spring, Cloonlaughnan Spring, Toberreeogue/Lecarrow Springs and Killeglan Springs.
- ‘Seasonal’ springs generally flow in the winter, as they respond rapidly to rainfall. However, due to the rock’s low storage capacity, flow cannot be maintained through drier spells.

### Hydrogeological Data



Figure 4.7. Well Yield Data for the Undifferentiated Visean Limestone Rocks.

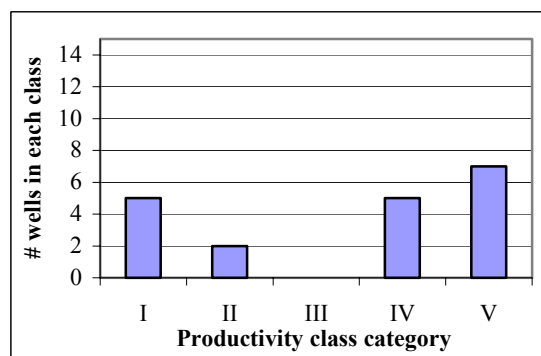


Figure 4.8. Well Productivity Data for the Undifferentiated Visean Limestone Rocks.

The majority of the wells have either ‘excellent’ or ‘good’ yields (Figure 4.7), and seven wells with ‘excellent’ yields fall into productivity categories ‘I’ or ‘II’. All of the ‘poor’ yields fall into productivity category ‘IV’ or ‘V’. Water samples from 28 Public or Group Schemes provided the data for the hydrochemical analysis (Figure 4.1). All of these samples were dominated by bicarbonate and calcium ions and the total hardness of the waters ranges from hard (250 – 350 mg/l CaCO<sub>3</sub>) to very hard (>350 mg/l CaCO<sub>3</sub>), with generally neutral pH values. These hydrochemical signatures are characteristic of clean limestone and are frequently associated with lime-scale issues.

Overall, the Undifferentiated Visean Limestone generally comprises clean, highly karstified rocks, which are capable of sustaining significant yields, including six public water supply schemes. Thus, this aquifer is classified as a regionally important karstic aquifer (Rk). The evidence for large conduits/fissures, variability in yield and productivity categories, low storage capacity and rapid response to rainfall, all indicate that this aquifer is characterised by conduit flow (Rk<sup>c</sup>).

## 4.7 Locally Important Aquifers, generally moderately productive (Lm)

### 4.7.1 Fearnaght Formation (FT)

This rock is made of quartz-rich conglomerates and sandstones, and therefore constitutes a clean sandstone aquifer. It covers a total of 42 km<sup>2</sup>, and is mainly situated on the north, east and west flanks of Slieve Bawn. Another smaller area is mapped north west of Athleague.

Stratigraphically, the Fearnaght sandstone sits unconformably on the much less permeable Lower Palaeozoic (Ordovician) rocks, and beneath thin bands of the Meath and then Moathill rocks, which

are also less permeable. Therefore, this aquifer is likely to form a more permeable pathway for groundwater flow within these few strata.

There are no available hydrogeological data for this unit either in County Roscommon, or in the surrounding counties. The rock's clean sandstone lithology suggests a potentially highly permeable aquifer. However, there are no data to support this. Therefore, based on the lithology, this unit is classified as a locally important aquifer, which is generally moderately productive (Lm).

## 4.8 Locally Important Aquifers, moderately productive in local zones (Ll)

### 4.8.1 Boyle Sandstone (BO)

The 138 km<sup>2</sup> of Boyle Sandstone crops out in two bands, the first of which is south of the Curlew Mountains, passing through Lough Key, Boyle and Ballaghaderreen. The second area stretches from Ballinameen to Castlerea. The basal and upper beds comprise reasonably competent sandstones, which suggests that faults and fractures will remain relatively open and be able to transmit significant quantities of groundwater. The middle unit (Lough Key Member) comprises muddier rock interbedded with sandstone. The muddier rocks are likely to be less permeable.

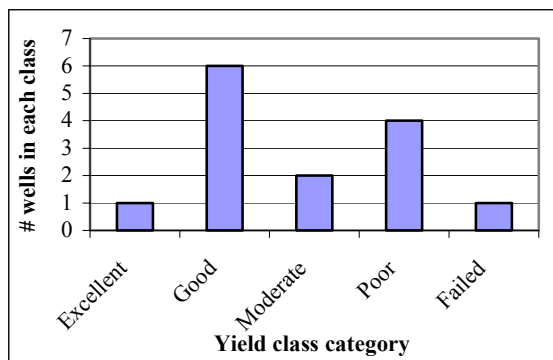


Figure 4.9. Well Yield Data for the Boyle Sandstone.

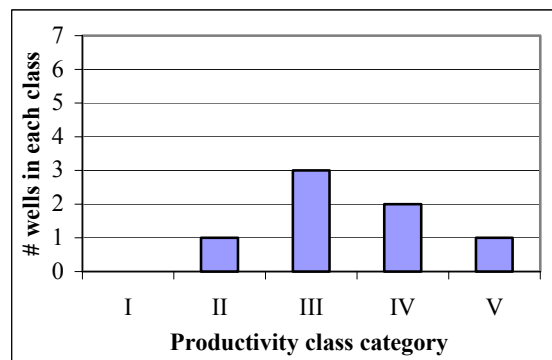


Figure 4.10. Well Productivity Data for the Boyle Sandstone.

The hydrogeological data for the Boyle Sandstone span all of the yield categories, although half of the 14 wells do have 'excellent' or 'good' yields (Figure 4.9). The productivity data trend towards the mid to lower categories (Figure 4.10). The variable permeability is also supported by the calculated transmissivity values which ranges from 4 – 356 m<sup>2</sup>/d, (Ibbotson, 2001). The range of hydrogeological data probably reflects the lithological variation in this rock. Given the variability in sustainable yields, the Boyle Sandstone is considered to be a locally important aquifer, generally moderately productive in local zones only (Ll).

### 4.8.2 Meath Formation (ME), Moathill Formation (MH) and Navan Group (NAV)

Within Roscommon, the Meath and Moathill rocks (29 km<sup>2</sup>) mainly form a narrow band between Lough Bofin and Lanesborough, east of Slieve Bawn. The younger Moathill rocks are contiguous with the Meath rocks. Both units consist of a range of lithologies including sandstones, muddy and silty limestones and shales. Their similar lithologies infer shared aquifer properties and hydraulic continuity between the two. The Meath and Moathill rocks are therefore considered to form one aquifer.

Navan Group rocks are located in the southern part of the county and cover approximately 6 km<sup>2</sup> to the south of Athlone. As this bedrock unit is equivalent to the Meath and Moathill rocks, they are all considered to have the same aquifer properties.

Groundwater movement is likely to be focused around the fault and fracture zones, especially in the cleaner sandstone or limestone beds, which are sometimes dolomitised. However, groundwater circulation is limited by the presence of high clay content in some units, which may hinder clean fracturing. Shale interbeds are also likely to reduce permeability, as these can form impermeable barriers to groundwater flow.

There are only two ‘good’ yielding wells and one ‘failed’ well recorded in the Meath and Moathill rocks (no data exist for the Navan Group in Roscommon or the surrounding counties). The ‘good’ yields infer that the aquifer is capable of producing useful quantities. The ‘failed’ well suggests that the more productive zones are possibly localised. Based largely on lithology, these rocks are classified as a locally important aquifer, which is generally moderately productive only in local zones (LI).

#### 4.8.3 Ballysteen Limestone (BA)

The Ballysteen Limestone is located to the east of Slieve Bawn, and east of Roscommon Town (30 km<sup>2</sup>) and to the south-west of Athlone (29 km<sup>2</sup>). This aquifer comprises muddy limestone with shale interbeds. Groundwater is likely to predominantly circulate through faults and fractures, as the muddy nature of these rocks and shale interbeds are likely to reduce the overall permeability.

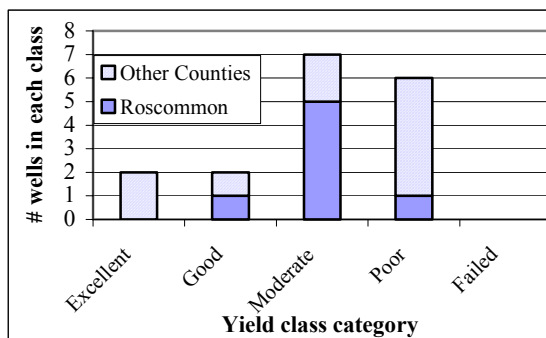


Figure 4.11. Well Yield Data for the Ballysteen Limestone in Roscommon and Surrounding Counties.

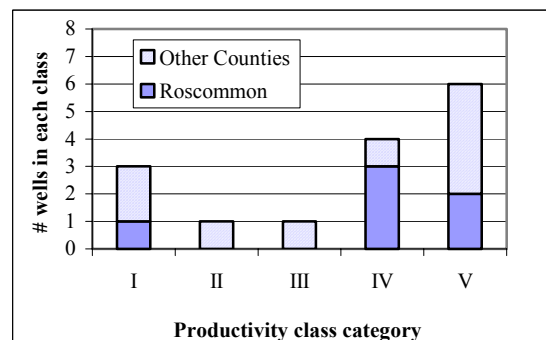


Figure 4.12. Well Productivity Data for the Ballysteen Limestone in Roscommon and Surrounding Counties.

The limited hydrogeological data available for Roscommon have been combined with the data from surrounding counties to assess these rocks (Figures 4.11 and 4.12). The Roscommon data are depicted by solid colour. These data highlight the majority of ‘moderate’ or ‘poor’ well yields, and a predominance of wells falling into productivity categories ‘IV and ‘V’. Two ‘excellent’ yielding wells, which fall into productivity category ‘I’, are also recorded. However both of these wells are located on faults in County Tipperary, suggesting that such yields are very localised.

The hydrochemistry data (Figure 4.1, one sample for the Oldtown, Clonown Group Scheme) highlight that the water has a calcium bicarbonate signature and it is categorised as ‘hard’ (250 – 350 mg/l CaCO<sub>3</sub>). This signature is frequently associated with limestone waters. In general, Daly (1982) suggest that hydrogen sulphide can present problems in shaly limestones although there is no evidence of this in the available data.

The distribution of lower yield wells and limited productivity seem to reflect the general aquifer characteristics. This suggests that the more permeable zones are constrained by the clay and shale contents. However larger faults/fractures can probably supply more significant abstractions. Therefore

this aquifer is considered to be locally important, which is generally moderately productive only in local zones (LI).

#### 4.8.4 Waulsortian Limestone (WA) and mudbank limestones (mk)

The Waulsortian Limestone covers a total of 91 km<sup>2</sup>. It is mainly located between Ballinasloe and Athlone, with minor areas around Roscommon Town. This rock unit is a massive, unbedded limestone, which is sometimes dolomitised. Although this is clean limestone, it does not appear to be karstified. Groundwater flow is therefore most likely to occur in fault zones or at the top of the rock.

The mudbank limestone (total of 4 km<sup>2</sup>) occurs in small discrete units within the Undifferentiated Viséan Limestone, to the west of Lough Ree. Both the Waulsortian and mudbank limestones were formed under similar conditions and are therefore considered to have the same aquifer properties.

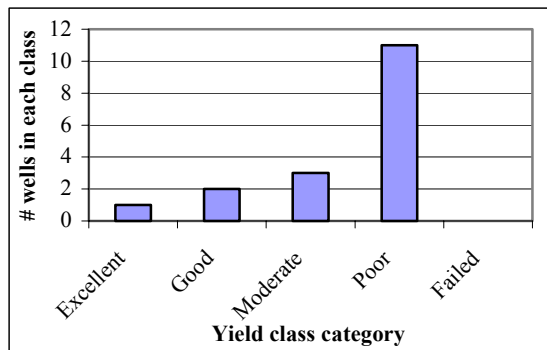


Figure 4.13. Well Yield Data for the Waulsortian Limestone.

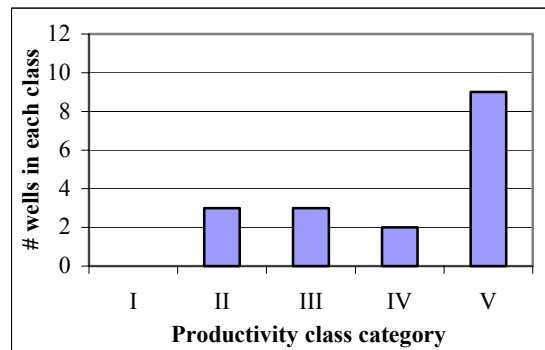


Figure 4.14. Well Productivity Data for the Waulsortian Limestone.

In Roscommon, the Waulsortian Limestone has one 'good' yielding well recorded. Data from Offaly and Westmeath show that over half of the 17 wells have 'poor' yields (Figure 4.13). The majority of these wells fall into the lowest productivity category (Figure 4.14). The wells with 'excellent' and 'good' yields fall into productivity categories 'II' and 'IV' respectively. There are no data available for the mudbank limestone.

These data suggest that permeable zones capable of supplying good yields are limited, as the massive nature of the rock restricts the development of fractures/fissures. Thus, these units are classified as locally important aquifers, which are moderately productive only in local zones (LI).

#### 4.8.5 Kilbryan Limestone (KL) and Argillaceous Limestone (AL)

The Kilbryan and Argillaceous Limestones are equivalent in age, and are both muddy, bedded limestones with interbeds of shale. They are therefore assumed to have similar aquifer properties. A band of Kilbryan Limestone stretches across the county, passing through Boyle and Ballaghaderreen. Smaller areas are located north of Lough Key, and around Castlerea. A thin band of Argillaceous Limestone stretches from Lough Bofin to Roscommon Town. There is also a small pocket east of Fuerty. The Kilbryan and Argillaceous Limestones cover a total of 54 km<sup>2</sup> and 26 km<sup>2</sup> respectively.

High clay contents (up to 50% in the Kilbryan Limestone) and shale layers are likely to restrict groundwater circulation in these rocks. However, where faults intersect these rocks they will increase permeability, especially in the cleaner limestone interbeds.

Four borehole data are available for these units. ‘Good’ yields are recorded in both the Kilbryan and Argillaceous Limestone. The Kilbryan well has an associated productivity classification of ‘II’, which suggests a reasonably sustainable supply. The remaining two boreholes record a ‘moderate’ and a ‘poor’ yield, which fall into productivity categories ‘IV’ and ‘III’ respectively.

Hydrochemical analysis have been undertaken on one water sample for each unit; north west of Ballaghaderreen in the Kilbryan Limestone and east of Slieve Bawn in the Argillaceous Limestone (Figure 4.1). The water from both units is ‘moderately hard’ (150 – 250 mg/l CaCO<sub>3</sub>) with a calcium bicarbonate signature. The signature is typical of limestone waters although these rocks are slightly ‘softer’ than waters from other limestones in Roscommon. This may be due to the muddy/shaly nature of these rocks, which is sometimes associated with hydrogen sulphide problems (Daly, 1982).

The muddier, bedded lithology and shale interbeds indicate the aquifer potential is locally rather than regionally important. The available hydrogeological data suggest that localised permeable zones can be developed to a limited extent. Therefore, this aquifer is classified as locally important, but moderate productivity only in local zones (LI).

#### 4.8.6 Croghan Limestone (CL)

In Roscommon, Croghan Limestone underlies 68 km<sup>2</sup> between Carrick-on-Shannon and Ballinameen. This is predominantly a muddy limestone with some shale partings, and a cleaner, coarse-grained middle unit (14% of the total thickness). The upper layers are noted as cleaner than the basal layers.

Groundwater flow is likely to concentrate along the more permeable faults, fractures, bedding and jointing. The presence of muddy/shaly units usually reduces the permeability. However in the cleaner middle and, to some extent, upper units, solution may occur along the existing faults and fractures. This is inferred by the presence of karst features: four enclosed depressions, two springs, two turloughs and one swallow hole (specific karst mapping has not been undertaken in this area). Hydrochemical data for the Croghan Limestone is available from the Flagford Group Scheme (Figure 4.1). These data show the water to be ‘hard’ (250 – 350 mg/l CaCO<sub>3</sub>) with a calcium bicarbonate signature, which is typical of limestone waters.

There is only one ‘failed’ well recorded in this rock which is inconclusive. However, given the lithology and presence of karst features, there is likely to be some potential to abstract groundwater in the fault/fracture zones, which are possibly solutionally enlarged. Thus, this aquifer is considered to be locally important, moderately productive only in local zones (LI).

#### 4.8.7 Lucan Formation (LU)

The Lucan Formation (calp limestone) covers approximately 40 km<sup>2</sup> in the south of the county, but is part of a more extensive unit that continues into County Galway and North Tipperary. This limestone unit is dominated by fine-grained (clayey) material, and interbedded shales.

Good quality hydrogeological data for this specific aquifer unit are only available in County Galway and North Tipperary. Figure 4.15 highlights that over half of the wells have ‘excellent’ or ‘good’ yields. Fifteen of these wells also have available productivity data, which correspond to categories II, III and IV. The remaining ‘moderate’ or ‘poor’ yield wells generally have a productivity of IV or V. Furthermore, a number of karst features (turloughs, swallow holes, enclosed depressions and springs) have been recorded in this unit even though specific karst mapping has not been undertaken in this region.

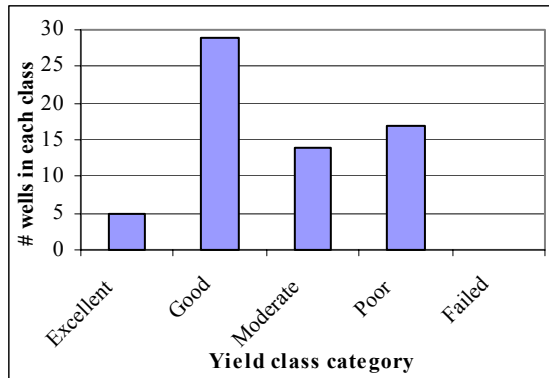


Figure 4.15. Well Yield Data for the Lucan Formation in Counties Galway and North Tipperary.

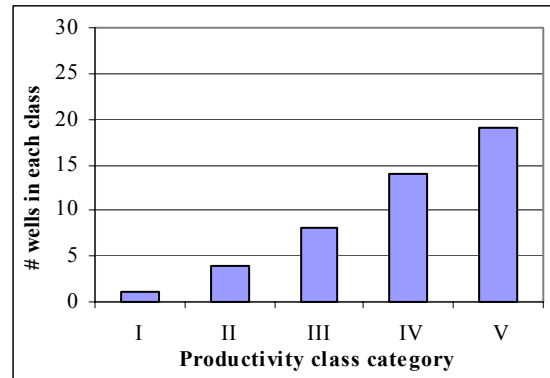


Figure 4.16. Well Productivity Data for the Lucan Formation in Counties Galway and North Tipperary.

The available productivity data generally infer a relatively poor, or possibly locally important, aquifer, which is attributed to the high percentage of clays and shales. However the high proportion of 'good' well yield highlight that this rock unit can be exploited for water abstraction, which is most likely due to fault/fracture zones providing localised pathways for groundwater movement. The potential to abstract reasonable yields from this aquifer is reinforced by the presence of karst features.

Given the karstification and recorded yields, the aquifer is considered to be an important resource at a local level. Thus, this is categorised as a locally important aquifer, which is generally moderately productive only in local zones (LI).

## 4.9 Poor Aquifers, generally unproductive except in local zones (PI)

### 4.9.1 Dalradian Rocks (CI), Lower Palaeozoic Rocks (CA, FA, LN, AE, CX, SIL) and Volcanic Rocks (F)

These rocks underlie a total of 42 km<sup>2</sup>, and are mainly located in the Slieve Bawn area. They are predominantly muddy sandstones and shales with minor volcanics and are considered as a single hydrogeological unit as the aquifer characteristics are similar in each rock type.

Groundwater flow is likely to occur in faults and fractures within this aquifer. The higher clay contents in shaly units may hinder fracturing and therefore limit the aquifer's potential to yield supplies. This lower permeability is implied on the ground surface; high stream density and the rapid response of streams to rainfall events indicate that surface water cannot easily infiltrate into the groundwater system.

The one 'good' yielding well recorded in this aquifer suggests that there is some localised potential for groundwater abstraction, which is possibly enough to sustain individual homes, or small farms. Given the low permeability of these rocks, they are considered to be a poor aquifer, which is generally unproductive except in local zones (PI).

### 4.9.2 Devonian Rocks (KW, KWsh, KWbk, MG)

This hydrogeological unit includes all Devonian (Old Red Sandstone – ORS) rocks as they are all generally described as conglomerates, sandstones and mudstones. Located in northern Roscommon, the ORS spans the county, passing through Lough Key, and forming the Curlew Mountains and upland area north west of Ballaghaderreen. They underlie a total of 91 km<sup>2</sup> of the county.



In these rocks, the groundwater circulation is probably limited to faults and fractures, which are likely to be restricted by the presence of fine-grained mudstone material. The assumed low permeability is supported by the drainage in the area, which is often poor with most of the rainfall running off to the nearest surface watercourse. Furthermore, several wells in the Curlews have static water levels within 3 m to 4 m of the surface. At such an elevation, these high water levels suggest that groundwater can only move very slowly through these rocks.

The well data for the ORS in Roscommon are sparse, therefore data from Counties Galway, Offaly, Sligo and Westmeath have also been used in this assessment (Figures 4.17 and 4.18).

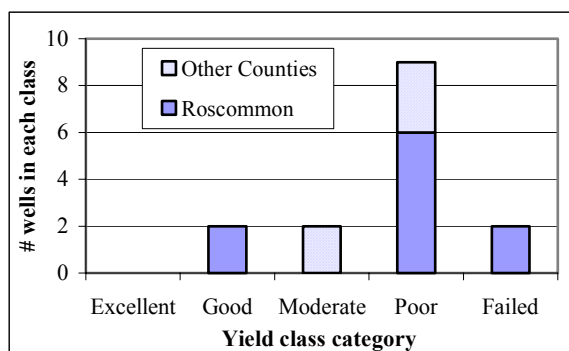


Figure 4.17. Well Yield Data for the Old Red Sandstone in Roscommon and Surrounding Counties.

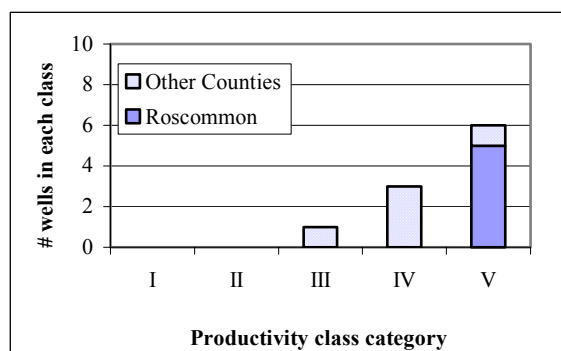


Figure 4.18. Well Productivity Data for the Old Red Sandstone in Roscommon and Surrounding Counties .

Figure 4.18 shows that most of the well yields are 'poor' and these wells mainly fall in the productivity categories 'IV' and 'V'. The low permeability in these rocks is also indicated by the two 'failed' wells, which are likely to have been drilled in less permeable zones. One water sample is available for these rocks which gives a calcium bicarbonate signature and is categorised as 'moderately hard' (150 – 250 mg/l CaCO<sub>3</sub>). This signature is not typical of a sandstone however, the subsoils are very thin in this area (< 3 m) so it is possible that the chemistry is more influenced by the composition of the rainwater, which would reflect short residence times and shallow groundwater flow in the aquifer.

The lithology, hydrogeological data and surface indicators of these rocks indicate a low permeability aquifer with limited storage capacity. Small yields are probably sustainable and therefore these rocks are classified as a poor aquifer, which is generally unproductive, except for local zones (PI).

#### 4.9.3 Lisgorman Shale (LG) and Greyfield Formation (GF)

Only a very small area in north Roscommon is underlain by these rocks (4 km<sup>2</sup>). Both units comprise muddy rocks with interbeds of shales, and are therefore considered to share aquifer properties.

Groundwater movement through these rocks is likely to occur in fault and fractures, although the overall faulting/fracturing is probably limited by the presence of fine-grained material and shaly beds. There are no well data for these rocks, but their lithology and areal extent suggests only a very localised ability to supply small yields. Therefore, these rocks are classified as a poor aquifer, which is generally unproductive, except for possibly, local zones (PI).



#### 4.9.4 Upper Visean Shales (MEe, BE, CN), Namurian Shales (DE, GO) and Sandstone (LH)

Upper Visean Shales, and Namurian Shales and Sandstones cover 54 km<sup>2</sup> to the north of Ballyfarnon and Keadew, including the upland areas of the Kilronan and Corrie Mountains. The Upper Visean Shales predominantly comprise inter-laminated limestones and shales. The Namurian Shales are dominated by shale, with minor limestone or carbonate bands. These grade up to the Lackagh Sandstone (15 km<sup>2</sup>), which comprises layers of mudstone and sandstone. These units all have a high percentage of clays and shale beds, which are considered to dictate their potential aquifer characteristics. Given their similarity, they are likely to act as one hydrogeological unit.

Any groundwater flow in these rocks will probably occur along faults and fractures. However, the very high clay contents and abundance of shaly bands is likely hinder fracturing, and also therefore, the aquifer's ability to transmit groundwater. Only one well is recorded within this aquifer which has a 'moderate' yield and falls into productivity category 'III'. On the surface, there is a high density of streams, which respond rapidly to rainfall events. This suggests that surface water cannot easily infiltrate into the groundwater system.

The lithology of these rocks strongly suggests that they would not be capable of sustaining higher yields. The inferred low permeability is also supported by the well data and surface indicators. These rocks are therefore considered to be a poor aquifer, generally unproductive except in local zones (PI).

#### 4.10 Poor Aquifers, generally unproductive (Pu)

No bedrock units have been identified as poor aquifers, generally unproductive (Pu) in County Roscommon. While some of the Dalradian/Lower Palaeozoic/Volcanic rocks, or Upper Visean Shales/Namurian Shales/Namurian Sandstones may contain units that are Pu, available data are not sufficient to distinguish these.

#### 4.11 Sand/Gravel Aquifers

A sand/gravel deposit is classed as an aquifer if it is over 1 km<sup>2</sup> in area and has a saturated thickness of at least 5 m. In the absence of detailed water table data (and hence saturated thickness), a deposit thickness of at least 10 m is taken as the criterion for inclusion. In general, a deposit over 10 m thick will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief, for example eskers or deposits in high topographic areas, as this gravel often has a thin saturated zone. Conversely, in low lying areas (e.g. flood plains), a slightly lesser thickness may be adequate.

In Roscommon sand/gravel occurs mainly in the west of the county, and west of Athlone. Some deposits are discontinuous in nature, most being on the order of 1 km<sup>2</sup> or less. Others constitute eskers. There are three more significant areas of sand/gravel which are discussed below.

##### *West of Athlone (approximately 25 km<sup>2</sup>)*

The sand/gravel in this area form a hilly and hummocky topography. There are a large number of pits, both on-going and relict, throughout these deposits which suggests that these are relatively clean. The pits highlight a depth of 5–15 m of material. Groundwater has generally not been encountered during excavation due to their higher relief.

No wells are known to be located in these deposits, and there are no data to determine the extent of any saturation. Given the higher relief and absence of existing groundwater abstractions, this unit is not considered to have a saturated thickness adequate enough to yield significant supplies. As such, these sand/gravel deposits are not classified as an aquifer.

### ***Around Errit Lough (approximately 5 km<sup>2</sup>)***

This sand/gravel unit is aligned approximately north–south and surrounds Lough Errit. These deposits can be subdivided into two main sections: the main ridge north and east of the Lough, and the deposits to the south and west of the Lough (see Maps 2W).

The north/eastern ridge rises steeply and has several smaller ridges superimposed on the main ridge. There are several historic pits, which show the material to be coarse, angular limestone gravel in a matrix of finer material. Geophysical work has suggested that the eastern ridge comprises 30–40 m of sand/gravel, of which 10–30 m may be saturated (Keohane, 1983). However, in the absence of borehole data, there is a possibility that this ridge may be till or rock-cored. One group water scheme is located within this area, on the shores of Errit Lough. It has not been confirmed whether this scheme is supplied by the sand/gravel or by the Lough.

The south/western deposits comprise three main ridges, which all have old pits. One pit shows a 5–8 m exposure of well-bedded fine to medium sized gravel. Geophysical work on this side of the Lough suggests a sand/gravel thickness of greater than 40 m, of which 10–30 m may be saturated (Keohane, 1983). A borehole located adjacent the Errit Lodge also confirmed that there is at least 39 m of sand/gravel. A short 30 minute pump test undertaken at this borehole suggested that these deposits could only support a ‘poor’ yield.

Given the depths of sand/gravel suggested by the geophysics, it is likely that the eastern and western deposits may be in hydraulic continuity beneath Lough Errit. The limited available hydrogeological data suggests that these deposits can only sustain a very small supply. Therefore these units are not classified as an aquifer.

### ***Around Garranlahan, south of Ballinlough (approximately 4.5 km<sup>2</sup>)***

Aligned approximately north–south, these sand/gravel deposits comprise two main elements. The first are eskers, which are particularly conspicuous in this region as they form long, narrow, winding ridges. Due to their higher relief, they are unlikely to have an adequate saturated thickness to be categorised as an aquifer.

The second sand/gravel unit consists of flatter, low-lying deposits, which vary in thickness from a few feet to much greater depths (Friel, 1991). The sand/gravel around the Ballybane Springs (Ballinlough Public Supply) are recorded as saturated (K.T. Cullen, 1999). A 72 hour pump test undertaken in this locality suggests that the sand/gravel unit is capable of sustaining an ‘excellent’ yield. However, the pump test was not specifically focused on the sand/gravel and the exploration was limited to one area. As such, further hydrogeological investigation would be required to confirm the aquifer potential of the sand/gravel. Given the limited available hydrogeological data, the sand/gravel deposits around Garranlahan are classified as a non-aquifer.

For all three significant areas of sand/gravel, but especially for those around Garranlahan and Errit Lough, there is a notable absence of data, which gives rise to the classification of non-aquifer. However, the areal extent, possible saturated thickness, and available hydrogeological data for these deposits suggest a potential for groundwater abstraction. Specific hydrogeological investigation would be required to determine the extent of their potential.

## 4.12 Summary of the Potential for Future Groundwater Development in County Roscommon

The rock units in County Roscommon are classified into the different aquifer categories, as summarised in Table 4.5.

**Table 4.5 Summary of Aquifer Classifications for County Roscommon**

<b>Aquifer Category</b>	<b>Subdivision</b>	<b>Bedrock Unit <sup>3</sup></b>
<b>Regionally important (R)</b> (67%) <sup>1</sup>	Karst – conduit flow dominant ( <b>Rk</b> ) <sup>2</sup>	<ul style="list-style-type: none"> <li>• Oakport Limestone, Ballymore Limestone</li> <li>• Bricklieve Limestone</li> <li>• Undifferentiated Visean Limestone</li> </ul>
	Fissure flow dominant ( <b>Rf</b> ) <sup>2</sup>	None identified
<b>Locally important (L)</b> (22%) <sup>1</sup>	Bedrock which is generally moderately productive ( <b>Lm</b> ) <sup>2</sup>	<ul style="list-style-type: none"> <li>• Fearnaght Formation</li> </ul>
	Bedrock which is moderately productive only in local zones ( <b>LI</b> )	<ul style="list-style-type: none"> <li>• Boyle Sandstone</li> <li>• Meath Formation, Moathill Formation, Navan Group</li> <li>• Ballysteen Limestone</li> <li>• Waulsortion Limestone, mudbank limestones</li> <li>• Kilbryan Limestone, Argillaceous Limestone</li> <li>• Croghan Limestone</li> <li>• Lucan Formation</li> </ul>
<b>Poor (P)</b> (8%) <sup>1</sup>	Bedrock which is generally unproductive except for local zones ( <b>PI</b> )	<ul style="list-style-type: none"> <li>• Dalradian, Lower Palaeozoic and Volcanic Rocks</li> <li>• Devonian Old Red Sandstones</li> <li>• Greyfield Formation, Lisgorman Shales Formation</li> <li>• Upper Visean Shales, Namurian Shales/Sandstones</li> </ul>
	Bedrock which is generally Unproductive ( <b>Pu</b> )	None identified <sup>4</sup>

1. Percentages refer to the proportional areal extent of each aquifer category in Co. Roscommon (4% of the area is covered by lakes)
2. The locations of the main aquifers are shown on Maps 5N, 5S and 5W.
3. The locations of the rock unit names listed here are shown on Map 1N, 1S and 1W.
4. No sand/gravel aquifers are delineated in County Roscommon.

## 5 Groundwater Vulnerability

### 5.1 Introduction

The term ‘Vulnerability’ is used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (DELG et al., 1999). The vulnerability of groundwater depends on:

- the time of travel of infiltrating water (and contaminants)
- the relative quantity of contaminants that can reach the groundwater
- the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- the type and permeability of the subsoils that overlie the groundwater
- the thickness of the unsaturated zone through which the contaminant moves
- the recharge type – whether point or diffuse

In other words, vulnerability is based on evaluating the relevant hydrogeological characteristics of the protecting geological layers along the pathway, and the possibility of bypassing these layers. In summary, the entire land surface is divided into four vulnerability categories: **Extreme**, **High**, **Moderate** and **Low** based on the geological and hydrogeological characteristics. Further details of the hydrogeological basis for vulnerability assessment can be found in the DELG/EPA/GSI publication ‘Groundwater Protection Schemes’ (DELG et al., 1999).

The Vulnerability Maps (6N, 6S and 6W) show the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1–2 m below the ground surface. For bedrock aquifers, the target needing protection is the water table where the water table is below the top of the bedrock. However, where the aquifer is fully saturated, the top of the bedrock is the target. The vulnerability maps are intended to be a guide to the likelihood of groundwater contamination were a pollution event to occur. It does not replace the need for site investigation. Additionally, the characteristics of individual contaminants are not considered.

With the exception of areas where point recharge occurs (e.g. swallow holes), the vulnerability depends on the type, permeability and thickness of the subsoils. For the purpose of identifying permeability regions, the subsoils described in Chapter 3 are not necessarily treated as individual units. Instead, permeability boundaries may cross mapped subsoil units in order to show areas of similar permeability. Thus, the subsoils described in Chapter 3 are incorporated into permeability regions described in this chapter.

The vulnerability map is derived from combining the permeability and depth to rock maps using GIS functions in AutoCAD. There are three subsoil permeability categories: high, moderate and low; and five depth to rock categories: shallow rock (<1m), <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown in Table 5.1.

**Table 5.1. Vulnerability Mapping Guidelines (adapted from DELG et al., 1999).**

SUBSOIL THICKNESS	HYDROGEOLOGICAL CONDITIONS				
	DIFFUSE RECHARGE: SUBSOIL PERMEABILITY AND TYPE			POINT RECHARGE	UNSATURATED ZONE
	High Permeability (sand/gravel)	Moderate Permeability (e.g. sandy subsoil)	Low permeability (e.g. Clayey subsoil, clay, peat)	(e.g. within 30 m radius of swallow holes)	(Sand/gravel aquifers only)
0 - 3.0 m	Extreme	Extreme	Extreme	Extreme	Extreme
3.0 - 5.0 m	High	High	High	N/A	High
5.0 - 10.0 m	High	High	Moderate	N/A	High
> 10.0 m	High	Moderate	Low	N/A	High
Notes:					
(i) N/A = not applicable.					
(ii) Permeability classifications relate to the engineering behaviour as described by BS5930.					
(iii) Release point of contaminants is assumed to be 1 - 2 m below ground surface.					
(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability.					

## 5.2 Sources of Data

Specific vulnerability field mapping and assessment of data collected during the subsoils mapping programme were carried out as part of this project. Fieldwork focused on assessing the permeability of the different subsoil deposit types (Maps 2N, 2S and 2W), so that they could be subdivided into the three permeability categories. This involved:

- describing selected exposures/sections according to the British Standard Institute *Code of Practice for Site Investigations* (BS5930:1999).
- collecting samples for particle size analysis, sometimes including the silt+clay breakdowns (hydrometer analysis). Hydrometer analyses were typically used to establish general particle size distributions for an area. Additional samples were collected for particle size and hydrometer analysis in complex permeability boundary areas.
- assessing the recharge characteristics of selected sites using natural and artificial drainage, vegetation and other recharge indicators.

The following additional sources of data were used to assess the vulnerability and produce the map:

- the FIPS-IFP Soil Parent Materials Maps (see Chapter 3, Maps 2N, 2S and 2W)
- the FIPS-IFP Landcover Maps (see Chapter 3)
- the bedrock geology map (see Chapter 2, Map 1N, 1S and 1W)
- the GSI karst database
- the GSI well database
- the General Soils Map of Ireland (Gardiner *et al.*, 1980)

## 5.3 Permeability of the Subsoils

### 5.3.1 Methodology

The permeability categories, and resulting vulnerability categories depicted on the vulnerability map (Maps 6N, 6S and 6W), are qualitative regional assessments of the subsoils based on how much potential recharge is infiltrating and how quickly potential contaminants can reach groundwater. The permeability of subsoils is largely a function of (a) the grain size distribution; (b) the amount (and sometimes type) of clay size particles present; and (c) how the grains are sorted and packed together. It can also be influenced by other factors such as discontinuities (fissures/cracks, plant roots, pores formed by soil fauna, isolated higher permeability beds or lenses, voids created by weathering of limestone clasts) and density/compactness of the deposit. In poorly sorted sediments such as glacial tills, which are the most common subsoils in County Roscommon, these characteristics describe the

engineering behaviour of the materials as detailed in the subsoil description and classification method derived from BS5930:1999 (Swartz, 1999). This method is therefore used to assess the permeability of the subsoils at each exposure, and is combined with recharge and drainage observations in the surrounding area for a regional, three-dimensional classification. Each of the approaches used in assessing the permeability are discussed briefly here. Some of these are described in more detail in the research theses of Lee (1999) and Swartz (1999):

*Subsoil Description and Classification Method (derived from BS5930:1999).* Using this method, subsoils described as sandy CLAY or CLAY have been shown to behave as low permeability materials. Subsoils classed as silty SAND and sandy SILT, on the other hand, are found to have a moderate permeability (Swartz, 1999). In general, sand and gravel that are sorted are considered to have a high permeability. Permeability mapping focuses on where soils and subsoils are thicker than 3m, since those thinner than this are automatically considered 'Extremely Vulnerable'.

*Particle Size Analyses.* The particle size distribution of sediments describes the relationships between the different grain sizes present. Well-sorted sediments such as water-lain gravel (high permeability) or lacustrine clays (low permeability) will, on analysis, show a predominance of grain sizes at just one end of the scale. Glacial tills, on the other hand, are more variable and tend to have similar proportions of all grain sizes. Despite their complexity, evaluation of the grain size analyses for a range of tills in Ireland, including Roscommon, have established the following relationships (Swartz, 1999; Fitzsimons, pers. comm.):

- i. Samples described as moderate permeability based on observation of recharge indicators (vegetation, drainage density) typically have less than 35% silt and clay.
- ii. These 'moderate permeability' samples also tend to have less than 12% clay.
- iii. Samples similarly described as low permeability have more than 50% silt and clay.
- iv. These 'low permeability' samples also tend to have more than 14% clay.
- v. High permeability sand/gravel deposits tend to be sorted and have less than 7.5% silt and clay (O'Suilleabhain, 2000).

Once the general characteristics and variations have been identified, these can be extrapolated to other similar areas where permeability observations may be lacking.

*Subsoils Parent Material.* The subsoils parent material, in this case the bedrock, plays a critical role in providing the particles that have created different subsoil permeability. Sandstones, for example, give rise to a high proportion of sand size grains in the deposit matrix, clean limestones provide a relatively high proportion of silt, while shales, shaly limestones and mudstones break down to the finer clay size particles. A good knowledge of the nature of the bedrock geology is therefore critical. It is also useful to know the direction of movement of the glaciers and the modes of deposition of the sediments as these will dictate where the particles have moved to, how finely they have been broken down, and what the relative grain size make up and packing are. Understanding the processes at work enable predictions to be made where observations are lacking.

*Recharge Characteristics.* Examining the drainage and recharge characteristics in an area gives an overall representative assessment of the permeability. Poor drainage and certain vegetation species can indicate low permeability subsoil once iron pans, underlying low permeability bedrock, high water tables, and excessively high rainfall are ruled out. Well-drained land suggests a moderate or high permeability once artificial drainage is taken into consideration (Lee, 1999). Rigorous analysis of drainage density was not undertaken in this project, but general abundance or absence of drainage ditches was recorded.

*Soils Map.* No specific soils map exists for County Roscommon. The General Soil Map of Ireland can be used to indicate broad drainage characteristics, especially where specific site recharge observations are not available. Poorly drained soils such as surface water gley are usually related

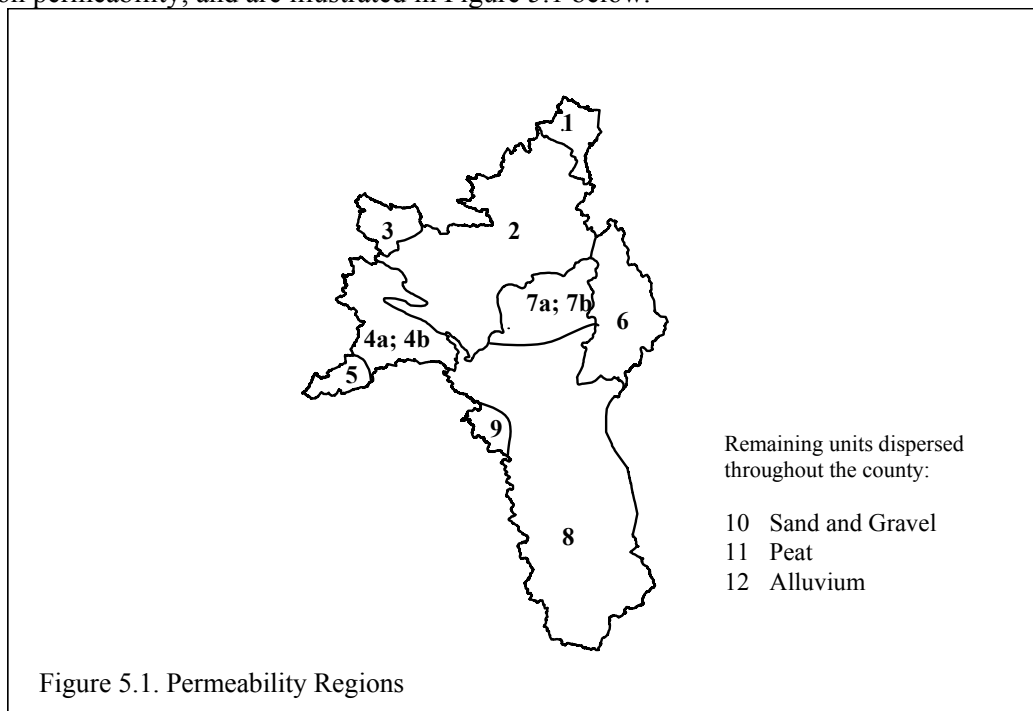
to underlying low permeability subsoils; the more free draining soils such as grey brown podzolics are more typical of the sandy and silty moderate permeability subsoils. The availability of a county specific soils map would have increased the confidence of some permeability boundaries, especially in areas where permeability varies.

*Quantitative Analysis.* The boundary between moderate and low permeability is estimated from limited field permeability measurements over the country to be in the region of  $10^{-8}$  m/s –  $10^{-9}$  m/s. While the moderate to high boundary has not yet been looked at in detail, one study suggests that this boundary may be in the region of  $10^{-4}$  m/s (O’Suilleabhain, 2000). However, permeability measurements are highly scale dependent: laboratory values, for example, are often up to two orders of magnitude smaller than field measurements which in turn are smaller than regional assessments measured from large scale pumping tests. Thus, for regional permeability mapping, qualitative assessments incorporating the engineering behaviour of the subsoils and recharge characteristics are more appropriate than specific permeability measurements.

None of these methods can be used in isolation; a holistic approach is necessary to gain an overall assessment of each site and thereby build up a three dimensional picture of the regional hydrogeology and permeability. In any one area, as many factors as possible are considered together in order to try to obtain a balanced, defensible permeability decision. In order to extrapolate from point data to areal assessments, the county is divided into permeability regions, usually on the basis of similar subsoil and/or bedrock characteristics. It is intended that the assessments will allow a broad overview of relative permeability across the county, in order to help focus field investigations for future development projects on areas of interest. In mapping an area the size of County Roscommon, the process cannot hope to be comprehensive at a site-specific level. Consequently, it is stressed that these permeability assessments are not a substitute for site investigations for specific projects. Brief descriptions of the permeability assessments are presented in section 5.4. Vulnerability maps, which are partly based on the permeability mapping, are presented on Maps 6N, 6S and 6W. Details of the supporting data for each permeability decision can be found in Appendix II.

## 5.4 Permeability Regions

There are twelve broad permeability regions within County Roscommon. These are outlined below based on permeability, and are illustrated in Figure 5.1 below.



### 5.4.1 Low Permeability Areas

In Roscommon, the deposits that have a low permeability are clayey glacial tills, lacustrine clays and peat. Clayey tills are the most common of these low permeability deposits, dominating the north and west part of the county. Only very small areas of lacustrine clay are mapped in the county, which are usually quite thin (1–2 m maximum). They do not generally influence the vulnerability classifications as these are based on the thicker underlying subsoil. There are extensive areas of peat deposits, which are principally located in the north and west of the county, east of Slieve Bawn and in the south.

#### ***Permeability Region 1: The Northern Tip***

This region stretches from the northern uplands (Corry and Kilronan Mountains) to the lower lying area east of Knockvicar, which is characterised by drumlin topography. The bedrock mainly comprises shales and sandstone, from which the clayey matrix of the till is derived. The extensive peat deposits are included in this region because of their low permeability where thicker, and because the low permeability of the underlying subsoil is likely to control the permeability where they are thinner. Alluvium pockets have also been mapped but are considered separately as part of Permeability Region 12.

Overall, this area is poorly drained, as indicated by the abundant rushes and field drainage ditch boundaries. Seven of the nine subsoil samples are described as ‘CLAY’, and grain size analyses show that all samples consistently have more than 50% fines and 14% clay, indicating low permeability. In addition, the soils are poorly drained surface water gley, which supports the low permeability classification.

#### ***Permeability Region 2: The Central-Northern Area***

This large permeability region is in the central northern part of the county. Topography is varied, frequently reflecting the underlying bedrock, which comprise karstified and muddy limestones, and muddy sandstones. The subsoil are mainly till, which have been strongly influenced by the muddy sandstones, and shales to the north, thus suggesting a generally southerly ice flow direction in this region (R. Meehan, *pers. comm*). Peat deposits are included in this region because of their general low permeability, and because the low permeability of the underlying subsoil is likely to control the permeability where they are thinner. Alluvium pockets mapped in this region are considered separately as part of Permeability Region 12.

Subsoil descriptions in this region are predominantly ‘CLAY’, and the majority of the grain size data have more than 14% clay, indicating low permeability. Rushes and field drainage ditches are common, and the main soil is a heavy textured gley, which all supports the low permeability classification.

#### ***Permeability Region 3: Northwest of Ballaghaderreen***

A relatively small upland permeability unit, which is mainly underlain by muddy sandstone, siltstone and some limestone bedrock. Subsoil is subdivided into a muddy sandy matrix till, and peat. Peat is generally low permeability, and where thinner, the low permeability of the underlying subsoil is likely to control the permeability.

Descriptions and grain size data from three subsoil samples suggest a low permeability although these are not conclusive as there are likely to be small pockets of till with a cleaner sandstone matrix. The cleaner pockets have not been delineated due to the scale of mapping in this project. However, the frequent occurrence of field drainage and widespread rushes strongly indicate an overall poor drainage, thus further supporting a low permeability.

#### ***Permeability Region 4a: The Western Area***

Located to the west of Ballaghaderreen and Castlerea, this region is generally low-lying and flat to undulating, with a number of till ridges. Karstified limestone is the dominant bedrock, and the subsoil comprises large proportions of peat and till on the lower lying areas. The till matrix appears to be strongly influenced by the sandstone rock to the north and west of this region. Peat deposits are



included in this region because of their general low permeability, and because the low permeability of the underlying subsoil is likely to control the permeability where they are thinner. Alluvium pockets mapped in this region are considered separately as part of Permeability Region 12.

‘CLAY’ subsoils descriptions are predominant and these are supported by over half of the grain size data having more than 14% clay. The overall poor drainage is indicated by the frequency of rushes and drainage ditches seen. Further the soils maps records mainly heavy textured gley and peat in this region, which also indicate low permeability.

#### ***Permeability Region 6: Slieve Bawn Area***

This region includes Slieve Bawn and the low-lying flat, peaty area east of Slieve Bawn. Sandstones, siltstones and conglomerates essentially form the upland area and these rocks appear to influence the shaly/sandy matrix of the till subsoil over this entire region. Karstified and muddy limestones underlying the eastern flatter area, although this portion of the permeability region is dominated by peat subsoil. Peat generally has a low permeability, and where thinner, the low permeability of the underlying subsoil is likely to control the permeability. Alluvium pockets mapped in this region are considered separately as part of Permeability Region 12.

Rushes and field drainage ditch boundaries are common, and management is required to maintain reasonable grazing land. Subsoil is described as ‘CLAY’ in 14 of the 16 samples, and the grain size data highlight greater than 14% clay in the three samples tested, indicating low permeability. Further, the soils are poorly drained gley, and peat, which both support the low permeability classification.

#### ***Permeability Region 7b: Elphin to Tulsk; Low Permeability Units***

This small permeability unit comprises a single till ridge, which is underlain by karstified limestone bedrock. The till has a clayey matrix, not normally associated with clean limestone. However, this unit is in close proximity to Region 2 and exhibits similar low permeability till characteristics. It is likely that the various ice movements across mid Roscommon deposited random units of reworked till material beyond the general extent of Region 2 (R. Meehan, *pers.comm.*). This would indicate that there are possibly other discrete units of low permeability till within the general area of Region 7a, which appears to be a relatively transitional permeability zone. Further investigation would be required to identify such units, which is not appropriate to the scale of this project.

This particular ridge is distinguished from Region 7a by the appearance of rushes and increased artificial drainage. Also, two samples in this unit were described as ‘CLAY’ and have greater than 14% clay, which also supports the low permeability classification.

#### ***Permeability Region 9: West of Donamon***

Located to the west of Donamon, this small region comprises a number of hills, which are underlain by karstified limestones. The subsoil are mainly glacial till with a sandy clayey matrix, which is likely to be sourced from the muddy sandstone bedrock to the west, or possibly to the north. The low-lying areas between the hills have peat subsoil. Peat deposits are included in this region because of their low permeability, and because the low permeability of the underlying subsoil is likely to control the permeability where they are thinner.

Both of the two available subsoil samples in this region are described as ‘CLAY’ and have 14% clay or more. The abundance of rushes and field drainage ditches also supports the overall poor drainage capacity and therefore low permeability.

#### ***Permeability Region 12: Peat***

Peat deposits are extremely common throughout County Roscommon although they are predominantly found in the western region, along the eastern county boundary between Lanesborough and Roosky, between Athlone and Ballinasloe, and along the southern county boundary. Although they are underlain by a wide variety of bedrock types and occur in most of the other permeability regions, peat deposits all consist of partially decomposed vegetation.

Peat subsoil (‘blanket’ or ‘cutover’) is mapped on Maps 2N, 2S and 2E, where it is greater than 1 m thick (R. Meehan, *pers. comm.*). However, where the peat is thinner than 2.5-3 m, the underlying subsoil is likely to control the permeability. Thinner areas of peat, which have often been reclaimed,

are able to sustain other vegetation. Such areas have been delineated from processed satellite imagery and are generally mapped as ‘wet grassland’ or ‘dry grassland’<sup>1</sup>. These areas have also been delineated on Maps 2N, 2S and 2W.

The remaining areas of peat areas are mapped as peat subsoil and have either intact peat-associated vegetation, or have been mechanically cut<sup>1</sup>. Surveys of cutover peat on study areas in County Roscommon have shown that significant thickness of peat inappropriate for commercial use remain after cutting, and this is underlain by low permeability till (Barry *et al.*, 1973). This is likely to be the case for ‘cut’ peat throughout the county. Thus the remaining areas of peat and cut peat are assumed to be greater than 3 m thick and have a low permeability.

#### 5.4.2 Moderate Permeability Areas

In Roscommon, moderately permeable deposits are typically silty or sandy subsoil, alluvium and poorly sorted sand/gravel deposits. Till described as ‘SILT’ or ‘SAND’ is most commonly found south of Tulsk. The region between Elphin and Tulsk also has much of this subsoil, although it shows a higher degree of mixed sediments. Sandy till is found to the south west of Garranlahan and discrete units of poorly sorted, fines-rich sand and/or gravel occur in the west of the county. Some areas mapped as alluvium are also described in this section.

##### ***Permeability Region 4b: The Western Area; Moderately Permeable Units***

This region is made up of discontinuous moderate permeability units mapped within a generally low permeability region (4a; Section 1.4.1). The delineated units are ridges of till, comprising poorly sorted, stony, gravelly material, which are underlain primarily by karstified limestone. They are neither clean enough nor large enough to contain pits. These small hills are ‘morainic’ accumulations of material, which collected sporadically at the ice margin as ice retreated back north-westwards across County Roscommon. They are often oriented perpendicular to and along the flanks of drumlins. (R. Meehan, *pers.comm.*). It is possible that there are other deposits of moderately permeable material in this general area, however identification would require further mapping which is not appropriate to the scale of this project.

These units are distinguished from the surrounding low permeability area (Region 4a) by their more free-draining appearance and lack of drainage ditches. All of the subsoil samples in these units are described as ‘SILT’, ‘SAND’ or ‘GRAVEL’ and three of the four grain size data have <12% clay. Some of the soils generally located in the west of the county are recorded as gravelly/sandy loam, which also suggest relatively permeable sediments in this area.

##### ***Permeability Region 5: Southwest of Garranlahan***

Covering the south-western tip of the county around Cloonfad, this region is mainly underlain by karstified limestones. The subsoil largely comprises till, with pockets of peat and alluvium. The sandy matrix till subsoil on the higher areas is possibly derived from the cleaner sandstone rocks to the west. The peat areas are considered separately as part of Region 11 and the alluvial deposits are discussed in Region 12.

The two subsoil descriptions from this area are described as ‘SILT’ and ‘SAND’, the latter of which has <30% fines and 42% sand. The vegetation and lack of field drainage ditches suggests that drainage is relatively good, and the soils in this region are predominantly mapped as gravelly/sandy loam. These indicators therefore correspond with the moderate permeability inferred by the subsoil sample descriptions and grain size data.

##### ***Permeability Region 7a: Elphin to Tulsk***

The Elphin to Tulsk permeability region is relatively small and is underlain by clean limestones. The subsoils are dominated by till, with very minor pockets of peat and alluvium. The peat areas are considered separately as part of Region 11 and the alluvial deposits are discussed in Region 12. The

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<sup>1</sup> FIPS-IFS Landcover Map

till in this area appears to represent a transitional zone from the northern low permeability material in Region 2 to the moderate permeability identified to the south in Region 8. It is likely that the various ice movements across mid Roscommon deposited reworked material from the shaly/clayey rocks in the north as well as the cleaner southern limestones (R. Meehan, *pers.comm*), giving rise to a range of permeability.

Accordingly, the subsoil samples cover the spectrum of descriptions however, over half are either 'SAND' or 'SILT', and only one of 13 is 'CLAY'. Similarly the majority of the grain size data show 'inconclusive' amounts of clay (12-14%) and fines (35-50%). However only one of these 9 samples possibly suggests a low permeability, having 46% fines. The soils mapped in this area suggest both heavy textures and gravely/sandy loam, which further support the mixed nature of the sediments. The vegetation, low occurrence of field drainage ditches, and natural drainage density suggest that the over-riding drainage capacity of these deposits is good. On balance, the available information indicates an overall moderate permeability in this region.

#### ***Permeability Region 8: The Southern Area***

This is the largest permeability region in Roscommon, covering the majority of the county south of Tulsk. The underlying bedrock is dominated by karstified limestone, although there are small areas of muddier limestones around Roscommon Town and between Athlone and Ballinasloe. The subsoil mainly comprise till, although there are large expanses of peat (east of Roscommon Town, along the southern county boundary, discussed as part of Region 11) and sand/gravel (west of Athlone, part of Region 10). There are also alluvial deposits, mainly associated with the Rivers Shannon and Suck (Region 12). This permeability region deals more specifically with the glacial till, the matrix of which suggests that the till is derived from the underlying clean limestone.

The general vegetation on this till is extremely free draining and the large fields are characterised by their stone wall boundaries. Streams are also lacking throughout this region, being limited to the low-lying valleys. This overall impression of good drainage is supported by the subsoil samples; 61 of the 79 samples are described as 'SILT', 'SAND' or 'GRAVEL'. The grain size data show that 60% of the samples tested have <12% clay and a third have <35% fines. Although 24 of the samples have 'inconclusive' fines, half of these have 40% fines or less which frequently correlate to moderately permeable material. The soils across this area are predominantly described as either well drained or excessively well drained, where the parent material is sandy or gravely. The majority of the information indicate that this region has an overall moderately permeability till.

#### ***Permeability Region 12: Alluvium***

Alluvial deposits are found in narrow strips along streams and rivers throughout the county. They are underlain by a wide range of rock types, occur within most permeability regions, and are largely composed of water-sorted silt and sand, with occasional thin clay lenses.

In County Roscommon, these deposits are usually quite narrow and thin (1-2 m maximum, R. Meehan, *pers.comm*), and do not generally influenced vulnerability classifications, which are based on the thicker underlying subsoil. However, along the larger rivers, which are principally the Rivers Shannon and Suck, the alluvial deposits are more likely to be thicker than 3 m and therefore determine the vulnerability. As the dominant grain size is usually silt, alluvium tends to be of moderate permeability. Limited data are available for these deposits which show a range of subsoils descriptions from 'SILT/CLAY' to 'SAND' or 'GRAVEL'. The single available grain size has 13% clay and 35% fines, which generally corresponds to moderate permeability.

### **5.4.3 High Permeability Areas**

In County Roscommon, the high permeability deposits are well-sorted sand and gravel sediments. These deposits are limited within the county, frequently occurring as discontinuous units. The sand and gravel were most likely deposited by glacial melt-water, which washed away the smaller particles

(silt and clay). The well-sorted sand and gravel are generally located in the south and in the west of the county. The sediments are discussed together because they have similar permeability characteristics.

#### ***Permeability Region 10: Sand and Gravel Deposit***

Sand and gravel are located to the west of Athlone in the south of the county, and around Garranlahan, Ballinlough, Lough O'Flynn and Lough Errit, in the west of the county. Both areas are underlain by karstified limestone.

In the south, the sand/gravel are generally concentrated in one main unit forming the largest coverage of these deposits. They form a hummocky hilly landscape, with several eskers (long, narrow, sinuous ridges) generally radiating out to the north and west from the main sand/gravel unit. The direction of the eskers frequently corresponds to the direction of ice flow (Meehan, 1998).

In the west of the county, the sand/gravel are more dispersed forming 3–4 smaller, discrete units. They are generally aligned north-south. Eskers are very evident in the Garranlahan deposits as a large number of them are interlaced with each other, and the general sand/gravel deposits. These form a very distinctive landscape unique to this part of the country.

All of the samples located in these deposits have been described as 'SAND'/'GRAVEL'. There are no grain size data for these samples, however there are a large number of sand/gravel pits in all of the main units, which suggests that these deposits have enough of a uniform grade to be extracted. The vegetation, lack of field drainage ditches and stream also infer very good drainage capacity. The soil is described as a gravelly/sandy loam in the west and as having a gravel/sand parent material in the south. Thus all of the available information indicate that these deposits have a high permeability.

#### **5.4.4 'Rock Close' Areas and Areas Less than 3 m**

'Rock close' describes areas where the depth to bedrock is generally less than 1 m from the surface, and consequently where the subsoil deposits are too thin to be effective for groundwater protection. They most commonly occur in upland areas throughout the county, and occasionally in lowland areas, mainly east of Ballinasloe. A permeability classification is not attached to these regions, as the depth to bedrock results in an automatic 'Extreme Vulnerability' rating.

Similarly, areas where the depth to bedrock is less than 3 m from the surface are automatically rated 'Extreme Vulnerability', which means that permeability classifications are not applied. The permeability of these areas may be higher than those where sediments are deeper, due to a greater amount of weathering and glacial abrasion of the material over its bedrock parent material.

### **5.5 Depth to Bedrock**

Along with permeability, the subsoil thickness (depth to bedrock) is a critical factor in determining groundwater vulnerability to contamination. A brief description of subsoil thickness throughout the county is given in Section 3. The source data are shown in Maps 3N, 3S and 3W.

### **5.6 Recharge at Karst Features**

Bypassing of the protecting layers of subsoil can occur where water flows rapidly underground, with minimal attenuation, at karst features such as swallow holes and dolines. Therefore, groundwater is classed as 'extremely' vulnerable within 30 m of karstic features, including along the area of loss of losing or sinking streams, and within 10 m on either side of losing streams upflow of the area of loss.

The distances can be varied depending on the circumstances, for instance, they can be increased where overland surface runoff is likely.

## **5.7 Groundwater Vulnerability Distribution**

The vulnerability maps (Maps 6N, 6S and 6W) are derived by combining the contoured depth to bedrock data with the subsoil permeability. Areas are assigned vulnerability classes of low, moderate, high or extreme.

It is emphasised that the boundaries on the vulnerability map are based on the available data and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments, and will frequently demand site investigations in order to assess the site-specific risk to groundwater. Detailed subsurface investigations and permeability measurements may reduce the area of high vulnerability and may also reduce the area of extreme vulnerability. However, the vulnerability maps 6N, 6S and 6W are considered to provide a good basis for decision-making in the short and medium term.

A large proportion of the county is classed as having either extreme or high vulnerability while areas of moderate and low vulnerability are much less common. The 3 m contour, which influences the extreme and high vulnerability categories, is based on outcrop information, subsoil mapping and borehole data. The presence or absence of 5 m and 10 m contours, which influence the moderate and low categories, is reliant solely on borehole data and uses the shallower contours as a guide for their interpretation. These contours cannot be drawn without data from boreholes. Consequently, there are probably more areas of moderate and low vulnerability than are currently depicted on Maps 6N, 6S and 6E. As more information becomes available, the maps should be up-dated.

Large areas of extreme vulnerability where rock is generally at or close to surface include upland areas, predominantly in the north of the county, which have limited development potential. Similarly, many small pockets of deeper subsoil are likely to exist even within areas where rock outcrop is common. This is particularly likely to be the case in central Roscommon over karst limestone areas.

Areas of low vulnerability have been mapped where the subsoil has a low permeability and the depth to bedrock information indicates a subsoil thickness of greater than 10 metres. This appears to be case in generally lower lying area, such as east of Slieve Bawn and south-east of Ballaghaderreen.

Areas of extreme vulnerability delineated around karst features mainly occur in the clean limestone aquifers e.g. Oakport, Ballymore and Visean Limestones. Extremely vulnerable zones are also located along sinking streams, not only on the aquifer into which it is sinking, but also along lengths of streams which flow onto the aquifer from adjacent lower permeability rocks. This delineation highlights the risks posed by developments in the vicinity of these streams.

It is noted that a large number of karst features were identified during specific karst mapping programmes, which generally focused on the source areas. It is therefore likely that there are karst features which have not yet been identified. As this information becomes available, the maps should be up-dated.

## 6 Groundwater Protection Zones

### 6.1 Introduction

The general groundwater protection scheme guidelines were outlined in Chapter 1, and in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice for potentially polluting activities – was described (see also Appendix I). Subsequent chapters described the different geological and hydrogeological land surface zoning elements as applied to County Roscommon. This chapter draws these together to give the ultimate elements of land surface zoning – the groundwater protection scheme map and the source protection maps. While these maps can be used as ‘stand alone’ elements, when considering sites for septic tanks, landfills or the landspreading of organic waste they must be considered and used in conjunction with the relevant groundwater protection responses, listed below. Two further responses are in preparation.

- **Groundwater Protection Responses for On-site Wastewater Treatment Systems for Single Houses** (DELG et al., 2001)
- **Groundwater Protection Responses for Landfills** (DELG et al., 1999)
- **Groundwater Protection Responses for Landspreading of Organic Wastes** (DELG et al., 1999)

### 6.2 Groundwater Protection Maps

The groundwater resource protection map (Maps 7N, 7S and 7W) is produced by combining the vulnerability map (Maps 6N, 6S and 6W) with the aquifer map (Maps 5N, 5S and 5W). Each protection zone on the map is defined by a code, which represents both the vulnerability of the groundwater to contamination and the value of the groundwater resource (aquifer category). Not all of the possible hydrogeological settings are present in County Roscommon. Those present, and the percentage of the area they cover, are shown in Table 6.1.

**Table 6.2 Percentage of area covered by each zone in County Roscommon**

VULNERABILITY RATING	RESOURCE PROTECTION ZONES (%)					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf	Lm	Ll	Pl	Pu
<b>Extreme (E)</b>	21	0	1	5	5	0
<b>High (H)</b>	23	0	0.5	6	1	0
<b>Moderate (M)</b>	13	0	0	5	1	0
<b>Low (L)</b>	5	0	0	4	0.5	0

1. No sand/gravel aquifers are delineated in County Roscommon.
2. 4% of the area is covered by lakes and is therefore excluded.
3. 5% of the area is covered by the Source Protection Zones.

### 6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around six public supply sources in County Roscommon:

1. Boyle-Ardcarn Water Supply Scheme (Rockingham Spring)
2. Castlerea Urban and Rural Water Supply Schemes (Longford and Silver Island Springs)
3. Ballinlough Water Supply Scheme (Ballybane Springs)
4. Roscommon Central Water Supply Scheme (Ballinagard Spring)
5. Mount Talbot Water Supply Scheme (Mount Talbot Springs)
6. Killeglan Water Supply Scheme (Tobermore Springs)

These have been produced as separate source reports.

### 6.4 Integration of Groundwater Protection Zones and Response

The integration of the groundwater protection zones and the protection responses is the final stage in the production of a groundwater protection scheme. The level of response depends on the different elements of risk: the vulnerability, the value of the groundwater and the contaminant loading. With respect to the value of the groundwater, sources are considered more valuable than resources and regionally important aquifers more valuable than locally important and so on. By consulting a **Response Matrix**, it can be seen:

- whether such a development is likely to be acceptable on that site
- what kind of further investigations may be necessary to reach a final decision
- what planning or licensing conditions may be necessary for that development.

Thus, the groundwater protection responses are a means of ensuring that good environmental practices are followed. More information on the use of these responses is presented in Appendix I.

As the appropriate level of response takes aquifer category, proximity to public supply sources and vulnerability into account, concentration on the vulnerability map alone may result in the false impression that the acceptability of certain activities is quite limited. Table 6.2 provides a broad indication of the acceptability of certain activities in Roscommon with respect to groundwater contamination.

**Table 6.2 Acceptability of Certain Potentially Polluting Activities in Roscommon**

Activity* (more will be identified in the future)	Percentage of Roscommon Occurring within Each Response Level			
	Not acceptable (R4)	Not generally acceptable subject to certain exceptions (R3)	Acceptable subject to certain conditions (R2)	Acceptable (R1)
Landfill	61	7	23	5
Landspreading (IPC licensable) **	4	32	–	60
On-site Treatment Systems	–	2	57	37

\* Details on the precise response requirement for each activity can be found in (DELG/EPA/GSI, 1999). Response levels for additional activities will be devised in the near future.

\*\* Intensive farming, sewage sludges, poultry litter, industrial wastewater treatment plant sludges.

## **6.5 Conclusions**

This groundwater protection scheme will be a valuable tool for Roscommon County Council in helping to achieve sustainable water quality management as required by national and EU policies. It will enable the County Council to take account of (i) the potential risks to groundwater resources and sources; and (ii) geological and hydrogeological factors when considering the location of potentially polluting developments. Consequently, it is an important means of preventing groundwater contamination.

The Roscommon Groundwater Protection Scheme provides guidelines that will assist the County Council with decision-making regarding the location and nature of developments and activities, with a view to ensuring the protection of groundwater. Groundwater protection schemes and the delineation of the groundwater protection zones are dependent on the available data. Thus, Roscommon County Council can apply the scheme in decision-making on the basis that the best available data are being used. The maps have limitations because they generalise (according to availability of data) variable and complex geological and hydrogeological conditions. The scheme is therefore not prescriptive and needs to be qualified by site-specific considerations and investigations in certain instances. The requirements for site specific investigations depend mainly on the degree of hazard provided by the contaminant loading and, to a lesser extent, on the availability of hydrogeological data. If the available data for an area are insufficient to provide the correct groundwater protection zone, the onus rests with the developer to provide new information enabling the protection zones to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

The scheme has the following uses for Roscommon County Council:

- it provides a hierarchy of levels of risk and, in the process, assists in setting priorities for technical resources and investigations
- it contributes to the search for a balance of interests between groundwater protection issues and other special and economic factors
- it acts as a guide and provides a ‘first-off’ warning system before site visits and investigations are made
- it shows generally suitable and unsuitable areas for potentially hazardous developments such as landfill sites and piggeries
- it can be adapted to include risk to surface water
- it will assist in the control of developments and enable the location of certain potentially hazardous activities in lower risk areas
- it helps ensure that the pollution acts are not contravened.



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# APPENDIX I

## **Appendix I**

The following text is taken from **Groundwater Protection Schemes**, which was jointly published in 1999 by the Department of Environment and Local Government (DELG), Environmental Protection Agency (EPA) and Geological Survey of Ireland (GSI). This Appendix gives details on the two main components of groundwater protection schemes – land surface zoning and groundwater protection responses. It is included here so that this can be a stand alone report for the reader. However, it is recommended that for a full overview of the groundwater protection methodology, the publications **Groundwater Protection Responses for On-Site Systems for Single Houses ('septic tanks')**, **Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses for Landspreading of Organic Wastes** should be consulted. These publications are available from the GSI, EPA and Government Publications Office.

## Land Surface Zoning

### Vulnerability Categories

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The vulnerability of groundwater depends on: (i) the time of travel of infiltrating water (and contaminants); (ii) the relative quantity of contaminants that can reach the groundwater; and (iii) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- (i) the subsoils that overlie the groundwater;
- (ii) the type of recharge - whether point or diffuse; and
- (iii) the thickness of the unsaturated zone through which the contaminant moves.

In general, little attenuation of contaminants occurs in the bedrock in Ireland because flow is almost wholly via fissures. Consequently, the subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays), are the single most important natural feature influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin and, in areas of karstic limestone, where surface streams sink underground at swallow holes.

The geological and hydrogeological characteristics can be examined and mapped, thereby providing a groundwater vulnerability assessment for any area or site. Four groundwater vulnerability categories are used in the scheme – **extreme (E)**, **high (H)**, **moderate (M)** and **low (L)**. The hydrogeological basis for these categories is summarised in Table A.1 and further details can be obtained from the GSI. The ratings are based on pragmatic judgements, experience and available technical and scientific information. However, provided the limitations are appreciated, vulnerability assessments are essential when considering the location of potentially polluting activities. As groundwater is considered to be present everywhere in Ireland, the vulnerability concept is applied to the entire land surface. The ranking of vulnerability does not take into consideration the biologically-active soil zone, as contaminants from point sources are usually discharged below this zone, often at depths of at least 1 m. However, the groundwater protection responses take account of the point of discharge for each activity.

Vulnerability maps are an important part of groundwater protection schemes and are an essential element in the decision-making on the location of potentially polluting activities. Firstly, the vulnerability rating for an area indicates, and is a measure of, the likelihood of contamination. Secondly, the vulnerability map helps to ensure that a groundwater protection scheme is not unnecessarily restrictive on human economic activity. Thirdly, the vulnerability map helps in the choice of preventative measures and enables developments, which have a significant potential to contaminate, to be located in areas of lower vulnerability.

Table A.1 Vulnerability Mapping Guidelines

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	high permeability (sand/gravel)	moderate permeability (e.g. sandy subsoil)	low permeability (e.g. clayey subsoil, clay, peat)	(sand/gravel aquifers only)	(<30 m radius)
<b>Extreme (E)</b>	0–3.0 m	0–3.0 m	0–3.0 m	0–3.0 m	–
<b>High (H)</b>	>3.0 m	3.0–10.0 m	3.0–5.0 m	>3.0 m	N/A
<b>Moderate (M)</b>	N/A	>10.0 m	5.0–10.0	N/A	N/A
<b>Low (L)</b>	N/A	N/A	>10.0 m	N/A	N/A
Notes: i) N/A = not applicable. ii) Precise permeability values cannot be given at present. iii) Release point of contaminants is assumed to be 1-2 m below ground surface.					

In summary, the entire land surface is divided into four vulnerability categories – extreme (E), high (H), moderate (M) and low (L) – based on the geological and hydrogeological factors described above. This subdivision is shown on a groundwater vulnerability map. The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1–2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants are not taken into account.

## Source Protection Zones

Groundwater sources, particularly public, group scheme and industrial supplies, are of critical importance in many regions. Consequently, the objective of source protection zones is to provide protection by placing tighter controls on activities within all or part of the zone of contribution (ZOC) of the source.

There are two main elements to source protection land surface zoning:

Areas surrounding individual groundwater sources; these are termed source protection areas (SPAs).

Division of the SPAs on the basis of the vulnerability of the underlying groundwater to contamination.

These elements are integrated to give the source protection zones.

## Delineation of Source Protection Areas

Two source protection areas are recommended for delineation:

Inner Protection Area (SI);

Outer Protection Area (SO), encompassing the remainder of the source catchment area or ZOC.

In delineating the inner (SI) and outer (SO) protection areas, there are two broad approaches: first, using arbitrary fixed radii, which do not incorporate hydrogeological considerations; and secondly, a scientific approach using hydrogeological information and analysis, in particular the hydrogeological characteristics of the aquifer, the direction of groundwater flow, the pumping rate and the recharge.

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires

little technical expertise. However, it can both over- and under-protect. It usually over-protects on the downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

There are several hydrogeological methods for delineating SPAs. They vary in complexity, cost and the level of data and hydrogeological analysis required. Four methods, in order of increasing technical sophistication, are used by the GSI:

- (i) calculated fixed radius;
- (ii) analytical methods;
- (iii) hydrogeological mapping; and
- (iv) numerical modelling.

Each method has limitations. Even with relatively good hydrogeological data, the heterogeneity of Irish aquifers will generally prevent the delineation of definitive SPA boundaries. Consequently, the boundaries must be seen as a guide for decision-making, which can be reappraised in the light of new knowledge or changed circumstances.

#### Inner Protection Area (SI)

This area is designed to protect against the effects of human activities that might have an immediate effect on the source and, in particular, against microbial pollution. The area is defined by a 100-day time of travel (ToT) from any point below the water table to the source. (The ToT varies significantly between regulatory agencies in different countries. The 100-day limit is chosen for Ireland as a relatively conservative limit to allow for the heterogeneous nature of Irish aquifers and to reduce the risk of pollution from bacteria and viruses, which in some circumstances can live longer than 50 days in groundwater.) In karst areas, it will not usually be feasible to delineate 100-day ToT boundaries, as there are large variations in permeability, high flow velocities and a low level of predictability. In these areas, the total catchment area of the source will frequently be classed as SI.

If it is necessary to use the arbitrary fixed radius method, a distance of 300 m is normally used. A semi-circular area is used for springs. The distance may be increased for sources in karst aquifers and reduced in granular aquifers and around low yielding sources.

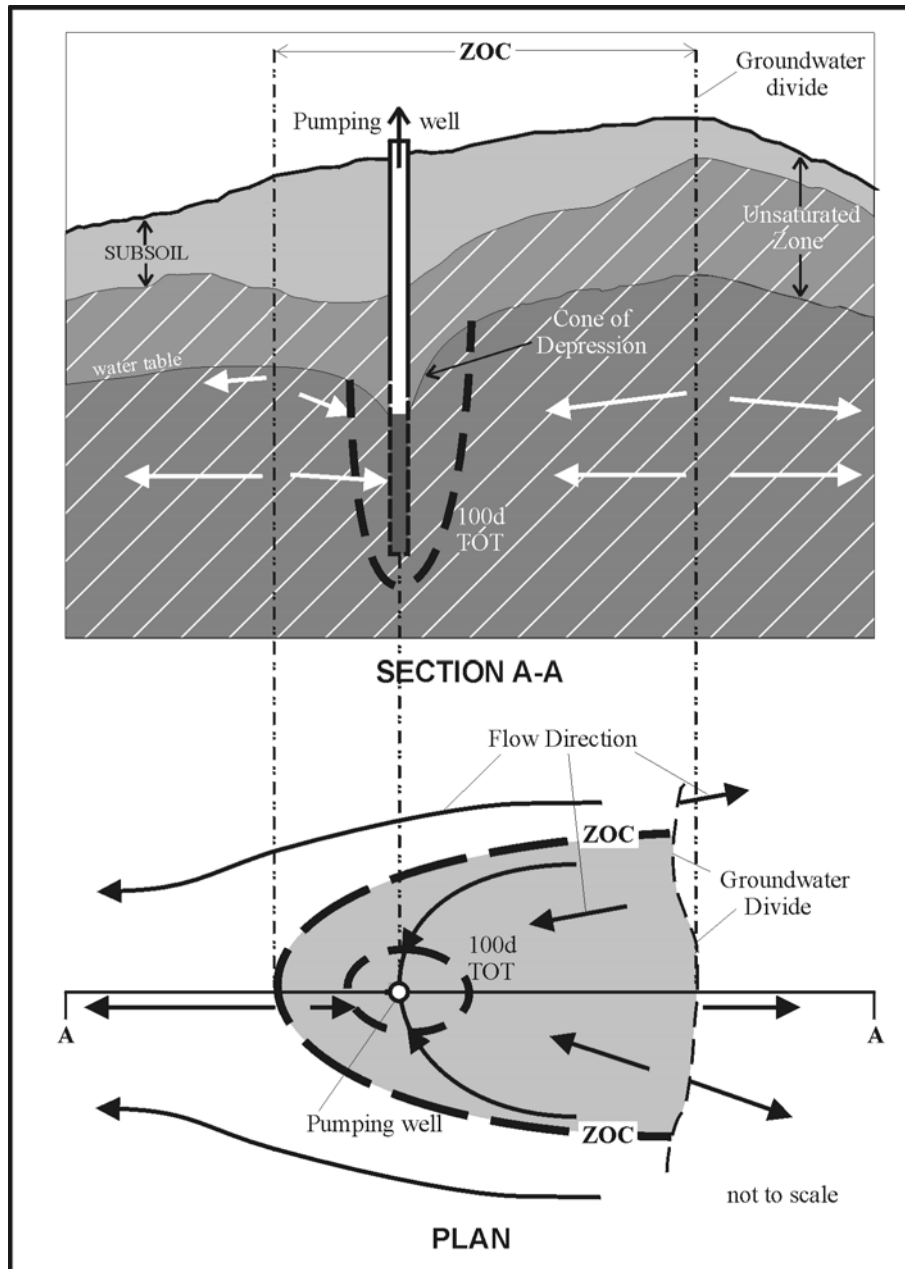
#### Outer Protection Area (SO)

This area covers the remainder of the ZOC (or complete catchment area) of the groundwater source. It is defined as the area needed to support an abstraction from long-term groundwater recharge i.e. the proportion of effective rainfall that infiltrates to the water table. The abstraction rate used in delineating the zone will depend on the views and recommendations of the source owner. A factor of safety can be taken into account whereby the maximum daily abstraction rate is increased (typically by 50%) to allow for possible future increases in abstraction and for expansion of the ZOC in dry periods. In order to take account of the heterogeneity of many Irish aquifers and possible errors in estimating the groundwater flow direction, a variation in the flow direction (typically  $\pm 10-20^\circ$ ) is frequently included as a safety margin in delineating the ZOC.

A conceptual model of the ZOC and the 100-day ToT boundary is given in Fig. A.1.

If the arbitrary fixed radius method is used, a distance of 1000 m is recommended with, in some instances, variations in karst aquifers and around springs and low-yielding wells.

The boundaries of the SPAs are based on the horizontal flow of water to the source and, in the case particularly of the Inner Protection Area, on the time of travel in the aquifer. Consequently, the vertical movement of a water particle or contaminant from the land surface to the water table is not taken into account. This vertical movement is a critical factor in contaminant attenuation, contaminant



**Fig. A.1 Conceptual model of the zone of contribution (ZOC) at a pumping well (adapted from US EPA, 1987)**

flow velocities and in dictating the likelihood of contamination. It can be taken into account by mapping the groundwater vulnerability to contamination.

### **Delineation of Source Protection Zones**

The matrix in Table A.2 gives the result of integrating the two elements of land surface zoning (SPAs and vulnerability categories) – a possible total of eight source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. SO/H, which represents an Outer Source Protection area where the groundwater is highly vulnerable to contamination. The recommended map scale is 1:10,560 (or 1:10,000 if available), though a smaller scale may be appropriate for large springs.



**Table A.2 Matrix of Source Protection Zones**

VULNERABILITY RATING	SOURCE PROTECTION	
	<i>Inner (SI)</i>	<i>Outer (SO)</i>
<i>Extreme (E)</i>	SI/E	SO/E
<i>High (H)</i>	SI/H	SO/H
<i>Moderate (M)</i>	SI/M	SO/M
<i>Low (L)</i>	SI/L	SO/L

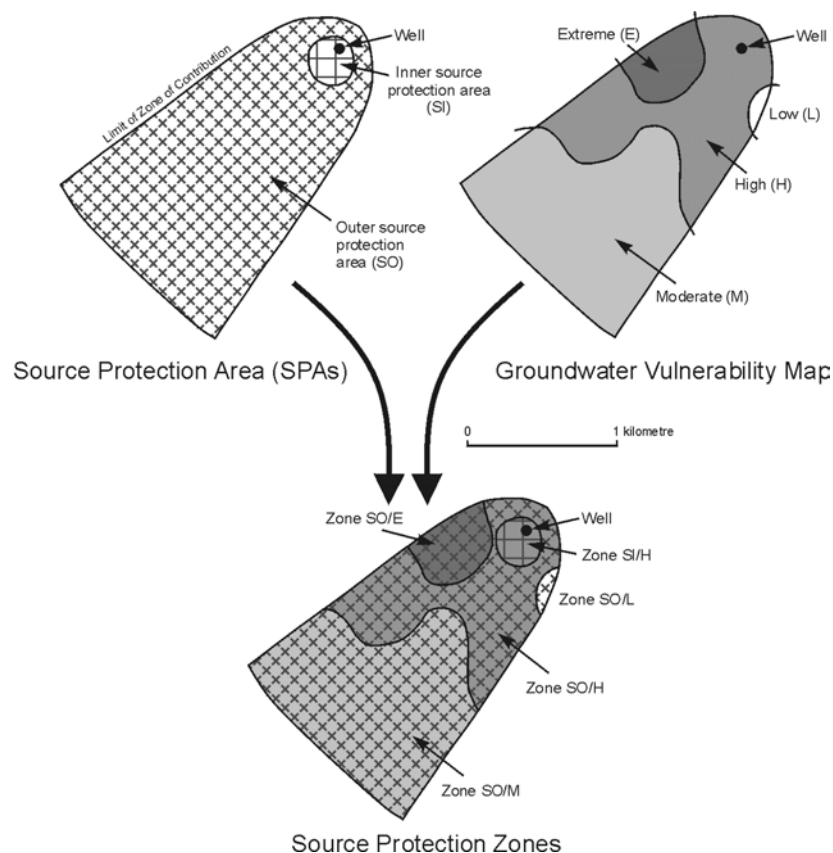
All of the hydrogeological settings represented by the zones may not be present around each groundwater source. The integration of the SPAs and the vulnerability ratings is illustrated in Fig. A.2.

### Resource Protection Zones

For any region, the area outside the SPAs can be subdivided, based on the value of the resource and the hydrogeological characteristics, into eight aquifer categories:

#### Regionally Important (R) Aquifers

- (i) Karstified aquifers (Rk)



**Fig. A.2 Delineation of Source Protection Zones Around a Public Supply Well from the Integration of the Source Protection Area Map and the Vulnerability Map**

- (ii) Fissured bedrock aquifers (**Rf**)
- (iii) Extensive sand/gravel aquifers (**Rg**)

#### Locally Important (L) Aquifers

- (i) Sand/gravel (**Lg**)
- (ii) Bedrock which is Generally Moderately Productive (**Lm**)
- (iii) Bedrock which is Moderately Productive only in Local Zones (**LI**)

#### Poor (P) Aquifers

- (i) Bedrock which is Generally Unproductive except for Local Zones (**PI**)
- (ii) Bedrock which is Generally Unproductive (**Pu**)

These aquifer categories are shown on an aquifer map, which can be used not only as an element of a groundwater protection scheme but also for groundwater development purposes.

The matrix in Table A.3 gives the result of integrating the two regional elements of land surface zoning (vulnerability categories and resource protection areas) – a possible total of 24 resource protection zones. In practice this is achieved by superimposing the vulnerability map on the aquifer map. Each zone is represented by a code e.g. **Rf/M**, which represents areas of regionally important fissured aquifers where the groundwater is moderately vulnerable to contamination. In land surface zoning for groundwater protection purposes, regionally important sand/gravel (**Rg**) and fissured aquifers (**Rf**) are zoned together, as are locally important sand/gravel (**Lg**) and bedrock which is moderately productive (**Lm**). All of the hydrogeological settings represented by the zones may not be present in each local authority area.

### Flexibility, Limitations and Uncertainty

The land surface zoning is only as good as the information which is used in its compilation (geological mapping, hydrogeological assessment, etc.) and these are subject to revision as new information is produced. Therefore a scheme must be flexible and allow for regular revision.

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Also, where site specific data received by a regulatory body in the future are at variance with the maps, this does not undermine a scheme, but rather provides an opportunity to improve it.

## Groundwater Protection Responses

**Table A.3 Matrix of Groundwater Resource Protection Zones**

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg	Lm/Lg	Ll	Pl	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	Ll/H	Pl/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	Pu/L

## Introduction

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities. The level of response depends on the different elements of risk: the vulnerability, the value of the groundwater (with sources being more valuable than resources and regionally important aquifers more valuable than locally important and so on) and the contaminant loading. By consulting a **Response Matrix**, it can be seen: (a) whether such a development is likely to be acceptable on that site; (b) what kind of further investigations may be necessary to reach a final decision; and (c) what planning or licensing conditions may be necessary for that development. The groundwater protection responses are a means of ensuring that good environmental practices are followed.

Four levels of response (**R**) to the risk of a potentially polluting activity are proposed:

**R1** Acceptable subject to normal good practice.

**R2<sup>a,b,c,...</sup>** Acceptable in principle, subject to conditions in note a,b,c, etc. (The number and content of the notes may vary depending on the zone and the activity).

**R3<sup>m,n,o,...</sup>** Not acceptable in principle; some exceptions may be allowed subject to the conditions in note m,n,o, etc.

**R4** Not acceptable.

## Integration of Groundwater Protection Zones and Response

The integration of the groundwater protection zones and the groundwater protection responses is the final stage in the production of a groundwater protection scheme. The approach is illustrated for a hypothetical potentially polluting activity in the matrix in Table A.4.

The matrix encompasses both the geological/hydrogeological and the contaminant loading aspects of risk assessment. In general, the arrows (→↓) indicate directions of decreasing risk, with ↓ showing the decreasing likelihood of contamination and → showing the direction of decreasing consequence. The contaminant loading aspect of risk is indicated by the activity type in the table title.

The response to the risk of groundwater contamination is given by the response category allocated to each zone and by the site investigations and/or controls and/or protective measures described in notes a, b, c, d, m, n and o.

It is advisable to map existing hazards in the higher risk areas, particularly in zones of contribution of significant water supply sources. This would involve conducting a survey of the area and preparing an

**Table A.4 Groundwater Protection Response Matrix for a Hypothetical Activity**

VULNERABILITY  RATING	SOURCE PROTECTION		RESOURCE PROTECTION						
			Regionally Imp.		Locally Imp.		Poor Aquifers		
	<i>Inner</i>	<i>Outer</i>	<i>Rk</i>	<i>Rf/Rg</i>	<i>Lm/Lg</i>	<i>Ll</i>	<i>Pl</i>	<i>Pu</i>	
<i>Extreme (E)</i>	R4	R4	R4	R4	R3 <sup>m</sup>	R2 <sup>d</sup>	R2 <sup>c</sup>	R2 <sup>b</sup>	↓
<i>High (H)</i>	R4	R4	R4	R3 <sup>m</sup>	R3 <sup>n</sup>	R2 <sup>c</sup>	R2 <sup>b</sup>	R2 <sup>a</sup>	↓
<i>Moderate (M)</i>	R4	R3 <sup>m</sup>	R3 <sup>m</sup>	R2 <sup>d</sup>	R2 <sup>c</sup>	R2 <sup>b</sup>	R2 <sup>a</sup>	R1	↓
<i>Low (L)</i>	R3 <sup>m</sup>	R3 <sup>o</sup>	R2 <sup>d</sup>	R2 <sup>c</sup>	R2 <sup>b</sup>	R2 <sup>a</sup>	R1	R1	↓
→   →   →   →   →   →   →   →   →									

(Arrows (→ ↓) indicate directions of decreasing risk)

inventory of hazards. This may be followed by further site inspections, monitoring and a requirement for operational modifications, mitigation measures and perhaps even closure, as deemed necessary. New potential sources of contamination can be controlled at the planning or licensing stage, with monitoring required in some instances. In all cases the control measures and response category depend on the potential contaminant loading, the groundwater vulnerability and the groundwater value.

In considering a scheme, it is essential to remember that: (a) a scheme is intended to provide guidelines to assist decision-making on the location and nature of developments and activities with a view to ensuring the protection of groundwater; and (b) delineation of the groundwater protection zones is dependent on the data available and site specific data may be required to clarify requirements in some instances. It is intended that the statutory authorities should apply a scheme in decision-making on the basis that the best available data are being used. The onus is then on a developer to provide new information which would enable the zonation to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

## **Use of a Scheme**

The use of a scheme is dependent on the availability of the groundwater protection responses for different activities. Currently draft responses have been developed for three potentially polluting activities: landspreading of organic wastes, single house systems and landfills. Additional responses for other potentially polluting activities will be developed in the future.

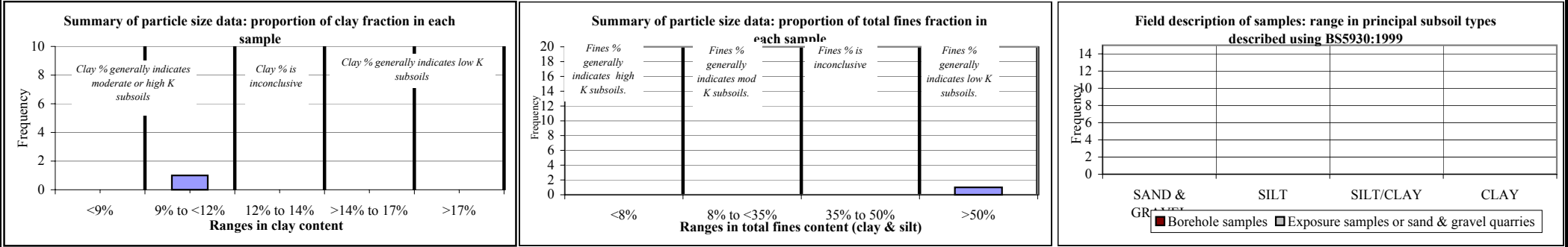
## APPENDIX II

Summary of Permeability Data and Analyses for Permeability Unit Template .

Description of unit location:	
Why is this a single K unit?	
1. General Permeability Indicators and Region Characteristics	
Rock type	
Depth to bedrock	
Subsoil type	
Soil type	
Vegetation and land use	
Artificial drainage density	
Natural drainage density	
Topography and altitude	
Ave. effective rainfall (mm)	

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results	Range Values	Typical value	Lab tests # Results	Range Values	Typical value
min/25mm							(m/sec):			(m/sec):		

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin		>>>
Particle size data		>>>
Field description data		>>>
Soil type		>>>
Artificial drainage density		>>>
Natural drainage density		>>>
Permeability test data		>>>
Rock type		>>>
Land use		>>>
		Overall conclusion >>>

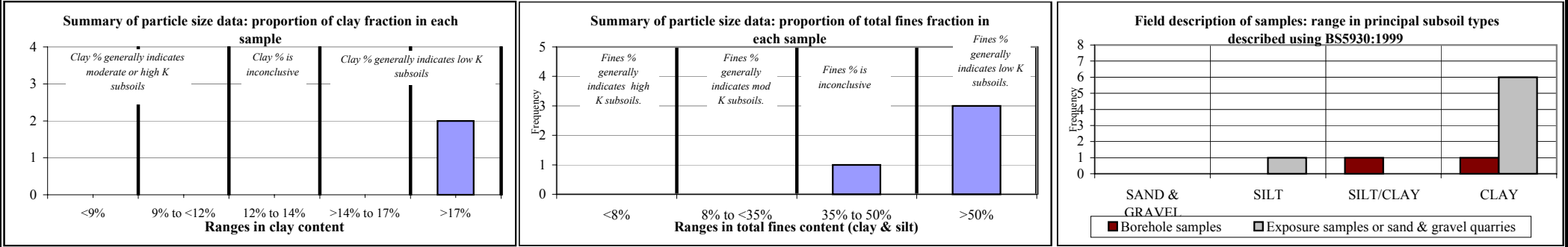
5. COMMENTS:

# Summary of Permeability Data and Analyses for Permeability Region 1: Northern Tip.

Description of unit location:	Northern Tip.
Why is this a single K unit?	Uniform till, topsoils and landuse. Relatively uniform topography. Similar bedrock types.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by shales (DE, GO, MEe, BE, CN) and sandstone (LH), with a band of karstified limestone (BK). Shales and sandstones are poor aquifers, limestone is regionally important.
Depth to bedrock	Generally shallow (0-3m). Increases to >10m along the low-lying eastern boundary.
Subsoil type	Mainly glacial tills with blanket peat over the mountain areas, where rock is shallow. Some basin peat in the lower lying areas.
Soil type	Dominated by gley (derived from carboniferous limestone and shale). Occasional pockets of peat.
Vegetation and land use	Predominantly rough grazing. Rushes extremely common.
Artificial drainage density	High
Natural drainage density	High
Topography and altitude	Upland areas to the north, rising to 400m. Lower lying drumlin area to the south-east falling to 40m.
Ave. effective rainfall (mm)	1100

## 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



## 3. Data from Permeability Tests.

<b>T' tests:</b> # Results min/25mm	# Tests T<1	# Tests T>50	<b>Variable head</b> # Results tests (m/sec):	Range Values	Typical value	<b>Pump tests</b> # Results (m/sec):	Range Values	Typical value	<b>Lab tests</b> # Results (m/sec):	Range Values	Typical value
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## 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Generally till with a shaly matrix strongly influenced by the underlying shaly bedrock.	>>>	low
Particle size data	>17% clay in all samples (low K). >50% fines in 75% of samples (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Gley and Peat	>>>	low
Artificial drainage density	Drainage ditches common	>>>	low
Natural drainage density	High density	>>>	low
Permeability test data	No data	>>>	-
Rock type	Predominantly shales which provides source for clay subsoils	>>>	low
Land use	Mainly rough grazing. Abundant rushes throughout area	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

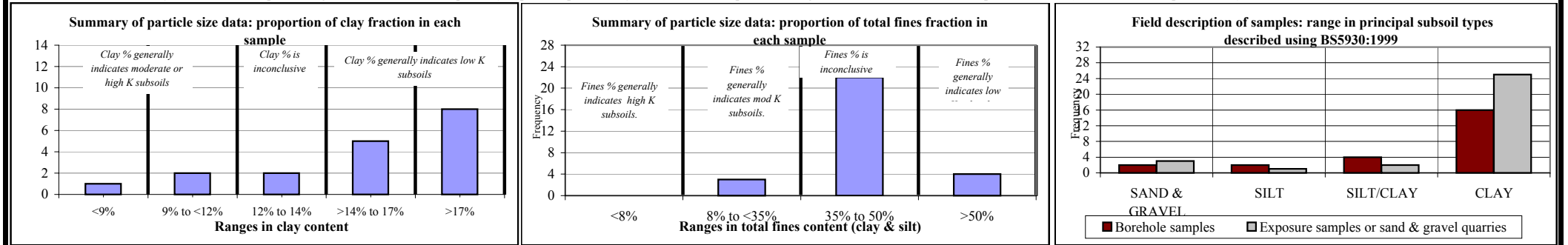
**5. COMMENTS:** Majority of available data suggest a low permeability subsoil. Source of clay subsoil is most probably from the underlying shale bedrock.

## Summary of Permeability Data and Analyses for Permeability Region 2: Central-Northern Area.

Description of unit location:	Central-Northern Area.
Why is this a single K unit?	Relatively uniform till, topsoils and landuse.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Sandstones (KW, KWsh, KWbk, MG, BO) and limestones (KL, OK, BM, CL, BK, VIS, WA). Rocks cover the full range of aquifers from poor to regionally important.
Depth to bedrock	Variable. Frequently shallow 0-3m in the higher plateau areas, and >10m in the lower lying flat areas. Drumlins in the east are often create >5m or >10m pods.
Subsoil type	Dominated by glacial till. A larger proportion of basin peat to the west.
Soil type	Dominated by gley (derived from limestone till, or Silurian shale). An area of grey brown podzolic east of Elphin and Tulsk. Large areas of basin peat to the west.
Vegetation and land use	Mainly rough grazing with frequent to abundant rushes throughout.
Artificial drainage density	Generally quite high
Natural drainage density	High in the lower-lying areas. Devoid on the higher plateaux due to the shallow, permeable bedrock.
Topography and altitude	Upland plateaux ranging from 135-180m, falling to 50m adjacent the River Shannon. Drumlin topography dominates north east of Elphin, and evident in the west.
Ave. effective rainfall (mm)	1000

### 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



### 3. Data from Permeability Tests.

T' tests: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results (m/sec):	# Results	Range Values	Typical value	Lab tests # Results (m/sec):	# Results	Range Values	Typical value
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### 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Tills generally have a shaly or shaly sandy matrix, derived from the shaly and sandstone bedrock to the north.	>>>	low
Particle size data	>14% clay in 75% of samples (low K). >50 fines in 4 samples (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Mainly gley and peat	>>>	low
Artificial drainage density	Drainage ditches common	>>>	low
Natural drainage density	High density in intermediate and lower lying areas.	>>>	low
Permeability test data	No data	>>>	-
Rock type	The sandstones are frequently dirty, providing low permeability material. The limestones are frequently clean.	>>>	low-moderate
Land use	Mainly rough grazing. Frequent to abundant rushes throughout.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

**5. COMMENTS:** Majority of data suggests low permeability subsoil. The source of the clayey matrix is probably from the shale bedrock to the north. The source of the muddy sandy matrix is likely to be derived from the sandstone bedrock, also to the north. These sandstones have also given rise to small pockets of clean sandy till, which have not been delineated due to the scale of the project.

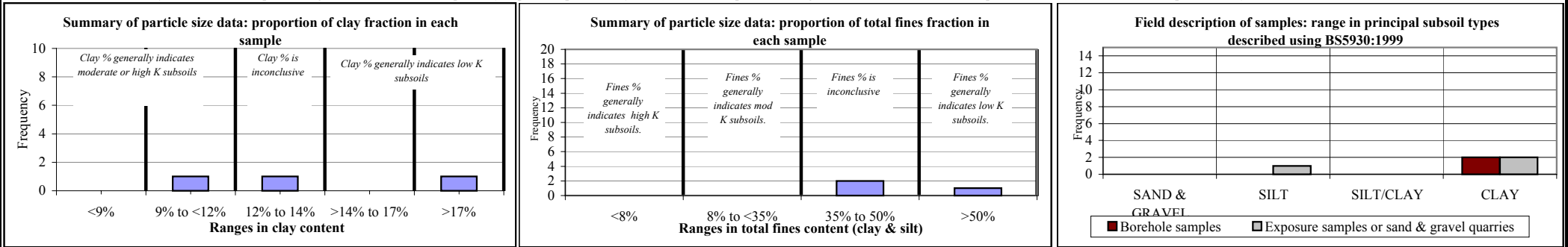


# Summary of Permeability Data and Analyses for Permeability Region 3: Northwest of Ballaghaderreen.

Description of unit location:	Northwest of Ballaghaderreen.
Why is this a single K unit?	Relatively uniform subsoils, topsoils, land use, topography.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Sandstones (KW, KWsh, KWbk, MG, BO), limestones (KL, OK) and siltstones (SIL). Rocks cover the full range of aquifers from poor to regionally important.
Depth to bedrock	Mainly shallow 0-3m.
Subsoil type	Glacial till with a larger proportion of basin peat.
Soil type	Mainly peaty podzols (derived from sandstone) and basin peat, with a small area of blanket peat.
Vegetation and land use	Rough grazing the predominant land use, with abundant rushes . Large areas of intact peat vegetation.
Artificial drainage density	Generally high.
Natural drainage density	High.
Topography and altitude	Upland area ranging from 230m, falling to 90m around Ballaghaderreen.
Ave. effective rainfall (mm)	1080

## 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



## 3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1	# Tests T>50	Variable head # Results	Range Values	Typical value	Pump tests # Results	Range Values	Typical value	Lab tests # Results	Range Values	Typical value
min/25mm			tests (m/sec):			(m/sec):			(m/sec):		

## 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Till are generally thin but have a muddy sandy matrix, derived from the underlying sandstones and siltstones.	>>>	low
Particle size data	>17% clay in one sample (low K). >50% fines in the same sample (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Peaty podzols and peat.	>>>	low
Artificial drainage density	Rough grazing requires drainage ditches over most of the area	>>>	low
Natural drainage density	High density.	>>>	low
Permeability test data	No data.	>>>	-
Rock type	Muddy sandstones, siltstones and muddy limestones provide low permeability material.	>>>	low
Land use	Rough grazing with abundant rushes although intact peat vegetation over a large area.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

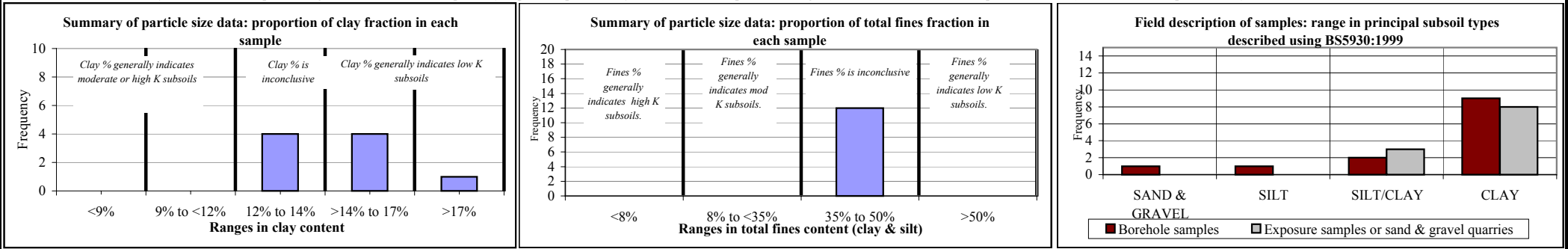
**5. COMMENTS:** This area is predominantly less than 3m to bedrock. The deeper subsoil mainly has a muddy sandy matrix, which is most likely derived from the underlying sandstone bedrock. These sandstones have also given rise to small pockets of clean sandy till, which have not been delineated due to the scale of the project.

Summary of Permeability Data and Analyses for Permeability Region 4a: Western Area.

Description of unit location:	Western Area.
Why is this a single K unit?	Similar till, topsoils, bedrock and topography.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by clean limestones (VIS, OK, WA), with some sandstones (BO) and smaller areas of muddier limestones (KL). Aquifer categories vary from regionally to locally important.
Depth to bedrock	Mainly 5-10m, with some spots >10m.
Subsoil type	A high proportion of basin peat, with pods of intervening glacial till, and areas of sand and gravel around Lough Errit and Lough O'Flynn.
Soil type	Basin Peat with some degraded grey brown podzolic (mainly derived from limestone glacial till).
Vegetation and land use	Rough grazing with frequent rushes.
Artificial drainage density	Generally high, both on higher and lower ground.
Natural drainage density	Generally high.
Topography and altitude	Ranges from 140m in the higher plateau of Slieve O'Flynn, dropping to 80m on the valley floor. Topography includes medium ridges and large expanses of flat, lower lying areas.
Ave. effective rainfall (mm)	1080

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1	# Tests T>50	Variable head # Results	Range Values	Typical value	Pump tests # Results	Range Values	Typical value	Lab tests # Results	Range Values	Typical value
min/25mm			tests (m/sec):			(m/sec):			(m/sec):		

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Till has a muddy sandy/ sandy matrix, derived from the sandstone bedrock to the north and south west.	>>>	low
Particle size data	>14% clay in over 50% of the samples (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Predominantly peat	>>>	low
Artificial drainage density	Generally high	>>>	low
Natural drainage density	Generally high	>>>	low
Permeability test data	No data.	>>>	-
Rock type	Predominantly clean limestones. Not source of overlying tills.	>>>	moderate
Land use	Rough grazing with frequent rushes.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

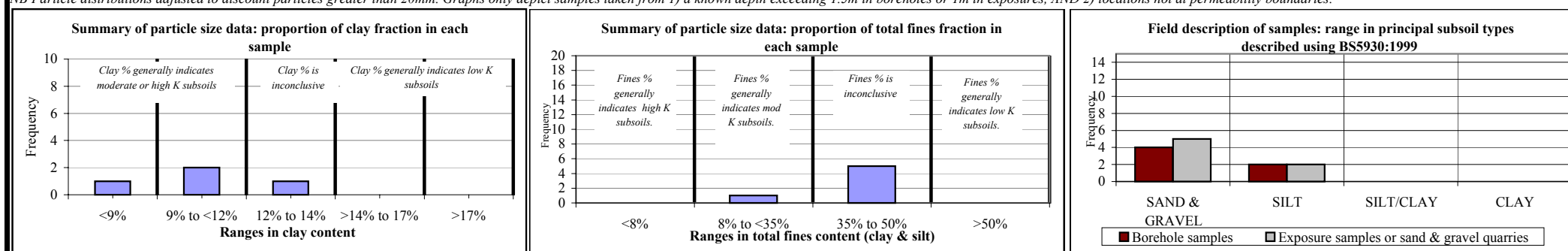
**5. COMMENTS:** Majority of data suggests low permeability subsoil. The source of the muddy sandy matrix is probably from the sandstone found to the west and to the north. These sandstones have also given rise to small pockets of clean sandy till, which have not been delineated due to the scale of the project.

## Summary of Permeability Data and Analyses for Permeability Region 4b: Western Area; Moderate Permeability Units.

Description of unit location:	Western Area - Moderate Permeability Units.
Why is this a single K unit?	Relatively unifrom till type.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by clean limestones (VIS, OK, WA), with some sandstones (BO). Aquifers fall into either regionally or locally important categories.
Depth to bedrock	Mainly 5-10m, with some spots >10m.
Subsoil type	A high proportion of basin peat, with pods of intervening glacial till, and areas of sand and gravel around Lough Errit and Lough O'Flynn.
Soil type	Basin Peat and degraded grey brown podzolic (mainly derived from limestone till).
Vegetation and land use	Rough grazing land which is generally quite free draining. Some tillage.
Artificial drainage density	Generally low.
Natural drainage density	Generally low.
Topography and altitude	Each area comprises a hill or ridge. The general elevation is between 90m and 100m.
Ave. effective rainfall (mm)	1080

## 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



## 3. Data from Permeability Tests.

T' tests: # Results # Tests T<1 # Tests T>50 min/25mm	Variable head # Results Range Values Typical value tests (m/sec):	Pump tests # Results Range Values Typical value (m/sec):	Lab tests # Results Range Values Typical value (m/sec):
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## 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Subsoils have a high proportion of sand and/or gravel, thought to be strongly influenced by the glacial melt-waters.	>>>	<u>moderate</u>
Particle size data	<12% clay in 3 of the four samples (mod K). <35% fine in one of six samples (mod K).	>>>	<u>moderate</u>
Field description data	Borehole samples	>>>	<u>moderate</u>
	Exposure samples	>>>	<u>moderate</u>
Soil type	Basin Peat indicates low K, but degraded grey brown podzolic indicate mod K.	>>>	<u>-</u>
Artificial drainage density	Low	>>>	<u>moderate</u>
Natural drainage density	Low	>>>	<u>moderate</u>
Permeability test data	No data.	>>>	<u>-</u>
Rock type	Clean limestones	>>>	<u>moderate</u>
Land use	Rough grazing land which is free draining. Some tillage.	>>>	<u>moderate</u>
<b>Overall conclusion</b>		>>>	<b>MODERATE</b>

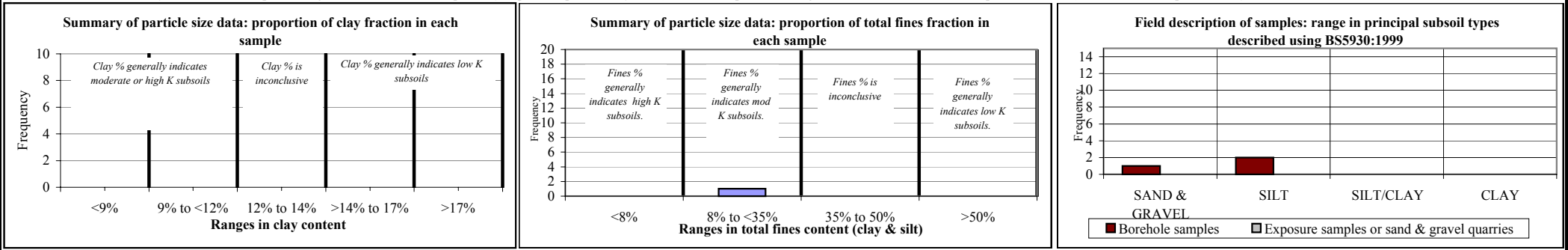
**5. COMMENTS:** These deposits are small, poorly sorted, waterlain deposits. They are mainly identified in the west of the county, where clean sand and gravel are also common. It is likely that they were deposited by melt-water from ice sheets which stagnated between the surrounding upland areas. The BS borehole and exposures data, coupled with the PSD analysis suggest a moderate permeability. This is supported by the vegetation, land use and drainage, and general soils data, which are distinguished from the surrounding low permeability area.

Summary of Permeability Data and Analyses for Permeability Region 5: Southwest of Garranlahan.

Description of unit location:	Southwest of Garranlahan.
Why is this a single K unit?	Relatively uniform bedrock, till matrix and topsoils.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by clean limestones (VIS, OK, WA), with some sandstones (BO). Aquifers fall into either regionally or locally important categories.
Depth to bedrock	Variable. Large upland area of shallow rock (0-3m) grading into another large area of >10m.
Subsoil type	Glacial till with an increasing proportion of basin peat towards the west.
Soil type	Dominated by degraded grey brown podzolics.
Vegetation and land use	Rough grazing land which is generally quite free draining, except where lower lying.
Artificial drainage density	Generally low.
Natural drainage density	Devoid in the upper areas. Intermediate in the lower, flatter areas.
Topography and altitude	The higher plateau to the east rises to 160m with the lower lying area to the west at an elevation of 60m.
Ave. effective rainfall (mm)	850

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

<b>T' tests:</b> # Results # Tests T<1 # Tests T>50	<b>Variable head</b> # Results Range Values Typical value	<b>Pump tests</b> # Results Range Values Typical value	<b>Lab tests</b> # Results Range Values Typical value
min/25mm	tests (m/sec):	(m/sec):	(m/sec):

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Till has a relatively clean sandy matrix.	>>>	moderate
Particle size data	Only one sample. This has <35% fines (mod K).	>>>	moderate
Field description data	Borehole samples	>>>	moderate
	Exposure samples	>>>	-
Soil type	Mainly degraded grey brown podzolics.	>>>	moderate
Artificial drainage density	Mainly low.	>>>	moderate
Natural drainage density	Low to intermediate.	>>>	moderate - low
Permeability test data	No data.	>>>	-
Rock type	Clean limestones mainly.	>>>	moderate
Land use	Grazing. High proportion of free draining fields . Rushes in lower lying areas.	>>>	moderate
<b>Overall conclusion</b>		>>>	<b>MODERATE</b>

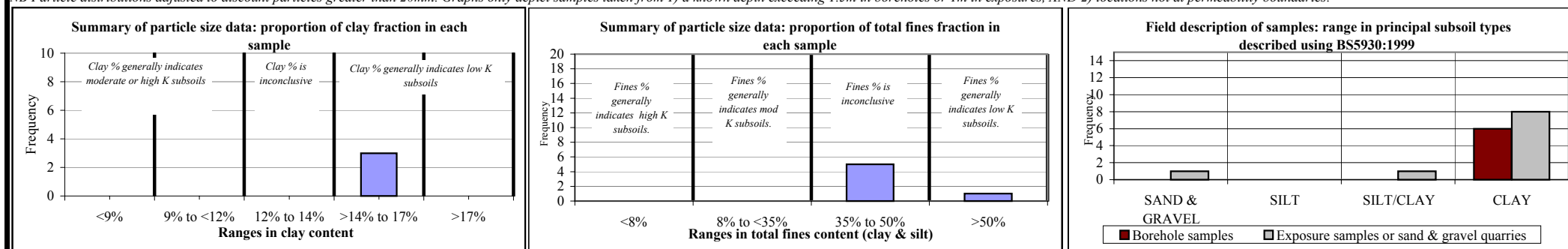
**5. COMMENTS:** The subsoil mainly has a clean sandy matrix, which is suggested by the limited number of BS descriptions, PSD and surface indicators. The till is probably derived from the cleaner units of sandstone bedrock to the west.

## Summary of Permeability Data and Analyses for Permeability Region 6: Slieve Bawn Area.

Description of unit location:	Slieve Bawn Area.
Why is this a single K unit?	Relatively uniform till and topsoils.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Siltstones, sandstones and conglomerates (AE, CA, CX, FA, LN) and clean and muddy limestones (ME, MH, BA, AL, VIS). The majority of the area comprises poor or locally important aquifers.
Depth to bedrock	Shallow around the upland area of Slieve Bawn (0-3m). Increasing in depth to >10m in the flat, lower lying area east of Slieve Bawn.
Subsoil type	Glacial till on the higher area. Basin peat dominant on the lower lying flatter area to the east.
Soil type	Mainly gley (derived from sandstone till) to the west and basin peat to the east.
Vegetation and land use	Generally rough grazing. Rushes are frequent. Rare tillage. Intact peat vegetation is common to the east.
Artificial drainage density	Moderate to high.
Natural drainage density	Generally high.
Topography and altitude	Upland area ranging from 260m, falling to 40m adjacent the River Shannon.
Ave. effective rainfall (mm)	890

### 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



### 3. Data from Permeability Tests.

T' tests: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests (m/sec):	# Results	Range Values	Typical value	Lab tests (m/sec):	# Results	Range Values	Typical value
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### 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Tills have shale/shaly sandy/sandy matrix, mainly derived from Lower Palaeozoic Rocks (Strokestown Inlier).	>>>	low
Particle size data	>14% clay in all 3 samples (low K). > 50% fines in one sample (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Mainly gley or basin peat to the east.	>>>	low
Artificial drainage density	Frequent ditches in fields.	>>>	low
Natural drainage density	Generally high	>>>	low
Permeability test data	No data.	>>>	-
Rock type	Siltstones, muddy sandstones and limestones provides low permeability material for subsoils.	>>>	low
Land use	Much rough grazing with frequent rushes in need of management.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

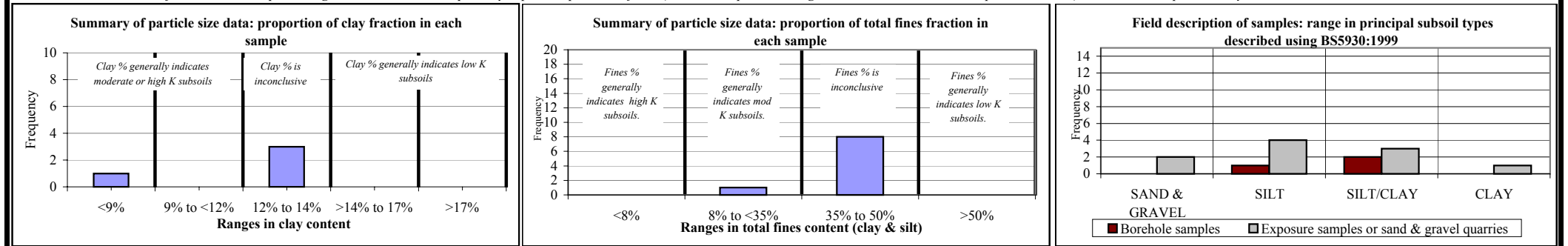
**5. COMMENTS:** Majority of data suggest a low permeability subsoil. The subsoil is likely to be mainly derived from the underlying Lower Palaeozoic and muddy limestone bedrock.

## Summary of Permeability Data and Analyses for Permeability Region 7a: Elphin to Tusk.

Description of unit location:	Elphin to Tusk.
Why is this a single K unit?	Relatively uniform bedrock and topography.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by clean limestones (VIS), which is classified as a regionally important aquifer.
Depth to bedrock	Variable. Upland areas are generally shallow (0-3m). Lowland areas are generally >5m with hills (drumlins) frequently >10m.
Subsoil type	Predominantly glacial till. Occasional basin peat in low lying areas.
Soil type	Half the area to the east is grey brown podzolic (derived from limestone till), and the western half is gley (derived from limestone till and Silurian shale).
Vegetation and land use	Grazing. Mainly free draining, although occasional rushy areas.
Artificial drainage density	Intermediate to low. A mixture of fields with stones wall boundaries and some drainage ditches, although these are less frequent on the ridges.
Natural drainage density	Intermediate. Streams and lakes in lower lying areas, flowing between drumlins, towards the Shannon.
Topography and altitude	Predominantly lower lying region (60-70m) with drumlins becoming more common to the Northeast. Higher ground rises to 140m, north of Strokestown and west of Tusk.
Ave. effective rainfall (mm)	970

### 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



### 3. Data from Permeability Tests.

T' tests: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results (m/sec):	# Results	Range Values	Typical value	Lab tests # Results (m/sec):	# Results	Range Values	Typical value
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### 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Till with mainly silty matrix but bordering on higher percentages of clay	>>> moderate
Particle size data	<12% clay in 1/3 samples (mod K). <35% fines in 1/7 samples (mod K). No samples specifically indicating low K.	>>> moderate
Field description data	Borehole samples	>>> moderate - low
	Exposure samples	>>> moderate
Soil type	Grey brown podzolics and gley	>>> moderate - low
Artificial drainage density	Intermediate to low.	>>> moderate
Natural drainage density	Intermediate.	>>> moderate - low
Permeability test data	No data	>>> -
Rock type	Clean limestones mainly	>>> moderate
Land use	Grazing which is frequently free draining on the ridges, occasionally rushy.	>>> moderate
<b>Overall conclusion</b>		>>> <b>MODERATE</b>

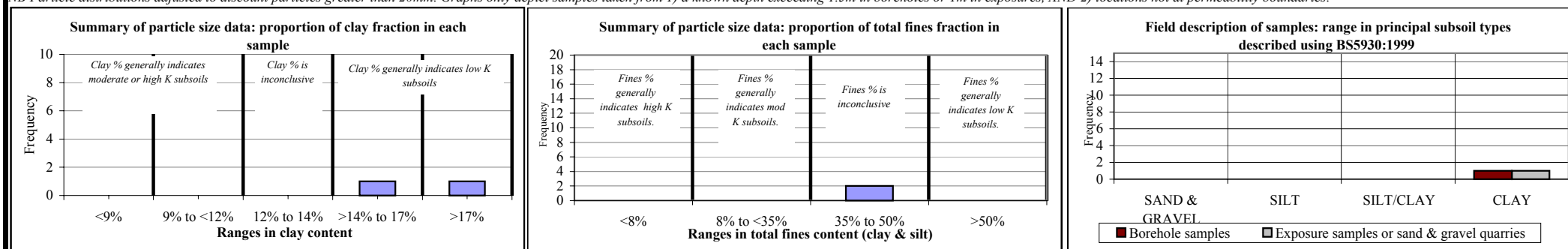
**5. COMMENTS:** An area of transitional permeability, where shaly/muddy sandy matrix, probably from the north, appears to have been incorporated into the silty matrix from the underlying clean limestones. The majority of the data suggests moderate K, although this is not as clear-cut an area as those to the north and south.

## Summary of Permeability Data and Analyses for Permeability Region 7b: Elphin to Tusk; Low Permeability Units.

Description of unit location:	Elphin to Tusk Area - Low Permeability Units.
Why is this a single K unit?	Uniform bedrock, subsoils, topsoils, topography, land use.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Clean limestones (VIS), which is classified as a regionally important aquifer.
Depth to bedrock	Mainly >10m.
Subsoil type	Glacial till.
Soil type	Grey brown podzolic (derived from limestone till).
Vegetation and land use	Grazing. Occasional to frequent rushes fields. Management required.
Artificial drainage density	Intermediate. Some fields have drainage ditches.
Natural drainage density	Too small an areas to determine.
Topography and altitude	Constitutes a single hill area (50-70m) within a lower lying region.
Ave. effective rainfall (mm)	970

## 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



## 3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results	Range Values	Typical value	Lab tests # Results	Range Values	Typical value
min/25mm							(m/sec):			(m/sec):		

## 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Till with a higher percentage of clay derived from the north, but within a general area of mainly silty matrix till	>>>	low
Particle size data	>14% clay in both samples (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Grey brown podzolics	>>>	moderate
Artificial drainage density	Intermediate.	>>>	low - moderate
Natural drainage density	-	>>>	-
Permeability test data	No data	>>>	-
Rock type	Clean limestones	>>>	moderate
Land use	Grazing land which has frequent to occasional rushes.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

**5. COMMENTS:** Within the transitional permeability area of 7a, small pockets of till with shaly/muddy sandy matrix have been located. These units have been distinguished from the surrounding moderate K area by their vegetation, land use and drainage, which is supported by the limited number of BS descriptions and PSD analysis. The deposits have similar characteristics to those in Region 2, therefore it is likely that the matrix is derived from the shales/muddy sandstones to the north of the county. There are likely to be other low permeability pockets which have not been identified due to the scale of the project.

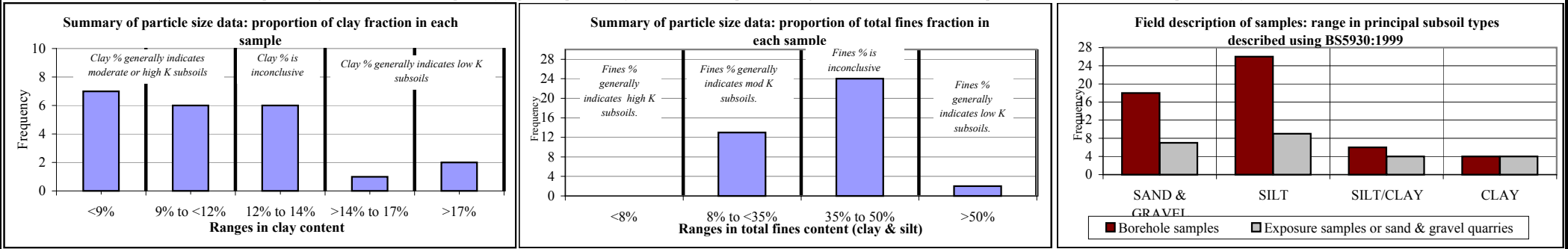


Summary of Permeability Data and Analyses for Permeability Region 8: Southern Area.

Description of unit location:	Southern Area.
Why is this a single K unit?	Relatively uniform tills and mainly clean limestones, relatively uniform topography.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Dominated by clean limestone (VIS, SHL, AW, WA), areas muddy limestones (CPU, ABL, BA, AL, MH, ME). Mainly regionally important aquifer, with smaller units of locally important.
Depth to bedrock	Large proportion has shallow bedrock (0-3m), especially in the higher areas. This grades to >10m in the lower lying flatter areas.
Subsoil type	Dominated by glacial till, with basin peat also common to the east and south of Athlone. Extensive sand/gravel immediately to the east of Athlone.
Soil type	Dominated by minimal grey brown podzolics (derived from limestone till) with small pockets of gley and peat. Southern portion is grey brown podzolics with large areas of basin peat.
Vegetation and land use	Grazing. Mainly free draining on ridges and higher areas in northern section, very free draining to the south.
Artificial drainage density	Low to very low in the south. Large fields with stones wall boundaries.
Natural drainage density	Low. Some streams in lower lying areas, especially in northern section.
Topography and altitude	Predominantly reasonably flat plains of intermediate to lower elevations (dropping to 40m). Ridges in northern section. Occasional higher ground rising to a maximum of 160m.
Ave. effective rainfall (mm)	890

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1	# Tests T>50	Variable head # Results	Range Values	Typical value	Pump tests # Results	Range Values	Typical value	Lab tests # Results	Range Values	Typical value
min/25mm			tests (m/sec):			(m/sec):			(m/sec):		

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Till derived from the clean limestone which are dominated by silt, sometimes sandy, occasionally clayey.	>>> moderate
Particle size data	<12% clay in 60% samples (mod K). <35% fines in 1/3 samples (mod K).	>>> moderate
Field description data	Borehole samples	>>> moderate
	Exposure samples	>>> moderate - low
Soil type	Mainly minimal grey brown podzolics/grey brown podzolics.	>>> moderate
Artificial drainage density	Low.	>>> moderate
Natural drainage density	Low	>>> moderate
Permeability test data	No data	>>> -
Rock type	Clean limestones mainly	>>> moderate
Land use	Grazing which is mainly free draining to very free draining.	>>> moderate - high
<b>Overall conclusion</b>		>>> <b>MODERATE</b>

5. COMMENTS: Majority of data suggests moderate permeability subsoil. The source of the predominantly silty matrix is most probably from the underlying clean limestones.

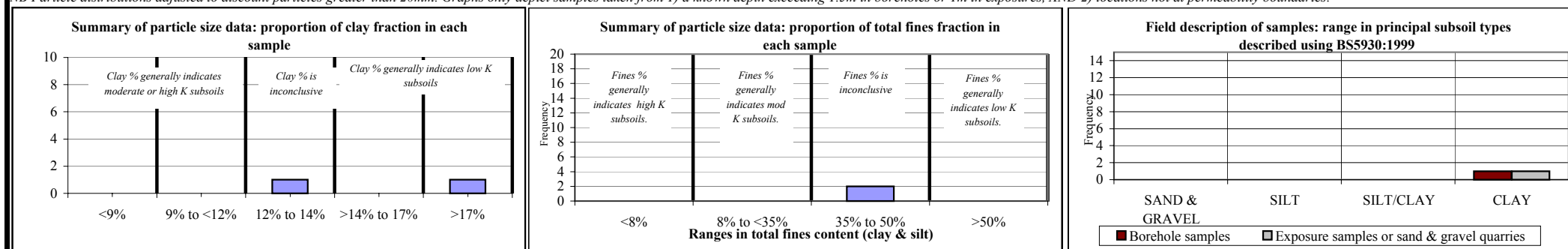


## Summary of Permeability Data and Analyses for Permeability Region 9: West of Donamon.

Description of unit location:	West of Donamon.
Why is this a single K unit?	Uniform bedrock and till type.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Clean limestone (VIS) which is categorised as regionally important aquifer.
Depth to bedrock	Mainly >10m to bedrock, although becomes shallow (0-3m) moving east.
Subsoil type	Mainly glacial till with some basin peat to the north.
Soil type	Basin peat along the north and minimal grey brown podzolic to the south.
Vegetation and land use	Mainly rough grazing with frequent to abundant rushes throughout.
Artificial drainage density	Generally quite high density of ditches as field boundaries.
Natural drainage density	High in the lower-lying areas. Devoid on the higher plateaux due to the shallow, permeable bedrock.
Topography and altitude	No streams although only a very small area
Ave. effective rainfall (mm)	930

### 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



### 3. Data from Permeability Tests.

T' tests: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results (m/sec):	Range Values	Typical value	Lab tests # Results (m/sec):	Range Values	Typical value
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### 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Till has a clayey matrix and is layered.	>>>	low
Particle size data	>14% clay in one of two samples (low K).	>>>	low
Field description data	Borehole samples	>>>	low
	Exposure samples	>>>	low
Soil type	Peat and minimal grey brown podzolic	>>>	low - moderate
Artificial drainage density	Generally quite high	>>>	low
Natural drainage density	Too small an area to determine	>>>	-
Permeability test data	No data	>>>	-
Rock type	Clean limestones	>>>	moderate
Land use	Grazing with frequent to abundant rushes, management required.	>>>	low
<b>Overall conclusion</b>		>>>	<b>LOW</b>

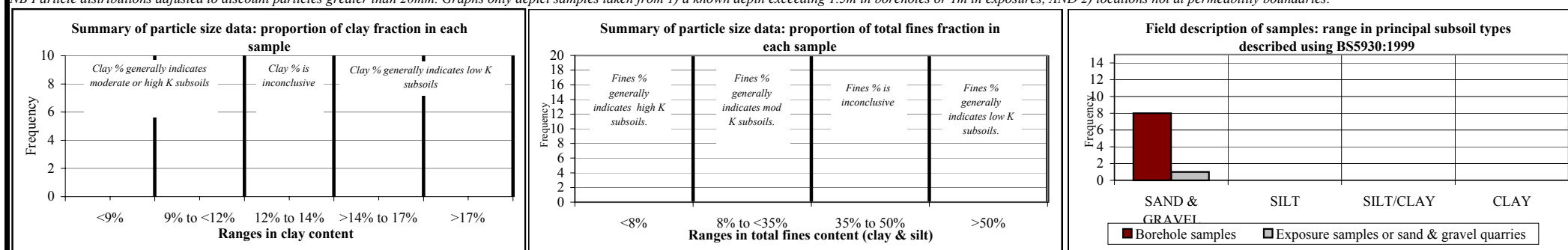
**5. COMMENTS:** A small area of till with clayey matrix adjacent the moderately permeable Region 8, in Roscommon. This area is distinguished from the surrounding Region 8 by its vegetation, land use and drainage, which is supported by the limited number of BS descriptions and PSD analysis. The deposits have similar characteristics to the those in Region 4a, therefore it is likely that the matrix is influenced by the muddy sandstones to the west of the county.

## Summary of Permeability Data and Analyses for Permeability Region 10: Sand and Gravel.

Description of unit location:	Sand and Gravel.
Why is this a single K unit?	Sand and Gravel throughout the county - three main units: west of Athlone (southern unit); around Garrahlahan (western); around Lough Errit (western).
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Mainly clean limestones (VIS, OK, WA) which are regionally and locally important aquifers
Depth to bedrock	Generally >5m and sometimes >10m.
Subsoil type	Delineated as sand and gravel.
Soil type	Grey brown podzolic (derived from limestone morainic gravel and sands); degraded grey brown podzolics (derived from limestone till) in the west.
Vegetation and land use	Grazing. Very free draining land. Often small quarries located in these areas.
Artificial drainage density	Very low.
Natural drainage density	Low, although areas are quite small.
Topography and altitude	Sand and gravel frequently forms hummocky hills, with elevations ranging between 50-80m in the south and 80-115m in the west.
Ave. effective rainfall (mm)	840 in the west to 960 in the south.

### 2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



### 3. Data from Permeability Tests.

T' tests: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results (m/sec):	Range Values	Typical value	Lab tests # Results (m/sec):	Range Values	Typical value
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### 4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Sands and gravel thought to be from glacial melt-water deposition.	>>> high
Particle size data	No data.	>>> -
Field description data	Borehole samples	>>> high
	Exposure samples	>>> high
Soil type	Grey brown podzolic/degraded grey brown podzolic.	>>> high - moderate
Artificial drainage density	Very low - negligible	>>> high - moderate
Natural drainage density	Low, small areas.	>>> -
Permeability test data	No data.	>>> -
Rock type	Clean limestones.	>>> moderate
Land use	Grazing, very free draining, small quarries.	>>> high - moderate
<b>Overall conclusion</b>		>>> <b>HIGH</b>

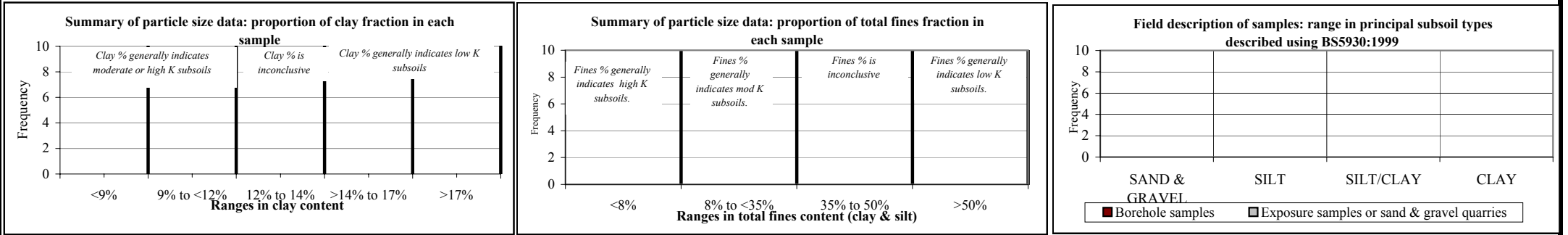
**5. COMMENTS:** Well sorted sand and gravel associated with melt-waters from glaciers. These deposits contain numerous sand/gravel pits, some quite large. The areas have the characteristic hummocky topography, and eskers (long, narrow, sinuous ridges) which were formed sub-glacially. Although no PSD analyses are available, the BS descriptions, vegetation, land use, artificial and natural drainage, soil, and the abundance of gravel pits all support a decision of high permeability.

Summary of Permeability Data and Analyses for Permeability Region 11: Peat.

Description of unit location:	Peat
Why is this a single K unit?	Uniform subsoils and land use.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Variable. Mainly clean and muddy limestones.
Depth to bedrock	Generally 3m to 10m. Thins down to 1-3m at edges.
Subsoil type	Cutover Peat'. Likely to be sitting on top of lake clays and silts.
Soil type	Frequently recorded as Basin Peat (raised bog).
Vegetation and land use	Heather, moss and rushes. Where peat is thick enough, Bord na Mona industrial harvesting is carried out.
Artificial drainage density	High. On worked areas of peat, drainage is extensive to allow entry for machinery.
Natural drainage density	Moderate. The bog can store a great deal of the recharge.
Topography and altitude	Flat plain of intermediate elevation. Altitude variable.
Ave. effective rainfall (mm)	Ranges from 110-880

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

<b>T' tests:</b> # Results # Tests T<1 # Tests T>50	<b>Variable head</b> # Results Range Values Typical value	<b>Pump tests</b> # Results Range Values Typical value	<b>Lab tests</b> # Results Range Values Typical value
min/25mm	tests (m/sec):	(m/sec):	(m/sec):

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Peat	>>>>	low
Particle size data	-	>>>>	-
Field description data	-	>>>>	-
	-	>>>>	-
Soil type	Basin Peat (raised bog)	>>>>	low
Artificial drainage density	High	>>>>	low
Natural drainage density	Intermediate	>>>>	moderate to low
Permeability test data	-	>>>>	-
Rock type	Variable	>>>>	moderate
Land use	Turf-cutting, if any	>>>>	low
<b>Overall conclusion</b>		>>>>	<b>LOW</b>

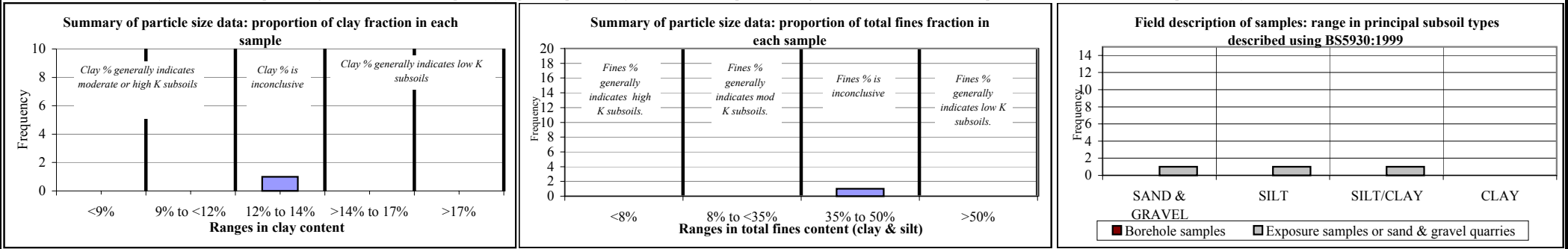
**5. COMMENTS:** Raised bogs consist of a build-up of organic matter in water-logged conditions. They developed in the warmer and wetter post glacial period and are infilled lakes. Because of their lake origin, they are lined by lacustrine clays and silts which isolate them from the rock below. This means that they are generally fed by surface water alone. Apart from the less compacted upper layers, peat has a relatively low permeability. Peat may be lying directly on glacial deposits or even bedrock. Data is sparse but it seems likely that the overall depth to bedrock is 5-10m. Where extensively cut and drained this has an effect on the depth and the permeability.

Summary of Permeability Data and Analyses for Permeability Region 12: Alluvium.

Description of unit location:	Alluvium strips mainly along Rivers Shannon and Suck.
Why is this a single K unit?	They are primarily fine-grained water-lain deposits found on the banks and flood-plains of rivers.
<b>1. General Permeability Indicators and Region Characteristics</b>	
Rock type	Variable. Mainly clean and muddy limestones.
Depth to bedrock	Typically greater than 3m. The alluvium generally overlies till or gravel deposits.
Subsoil type	Interbedded, predominantly fine-grained, sandy, silty and clayey water-lain alluvial deposits.
Soil type	Various. Not differentiated from surrounding till. Groundwater gleys expected due to high water table.
Vegetation and land use	Immediately next to the rivers, the land is commonly water-logged and rushy. Where the alluvium is extensive, it may be grazed.
Artificial drainage density	High, reflecting the proximity of the watertable to the surface.
Natural drainage density	High.
Topography and altitude	Typically in valley flats throughout the county.
Ave. effective rainfall (mm)	890

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

NB Particle distributions adjusted to discount particles greater than 20mm. Graphs only depict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND 2) locations not at permeability boundaries.



3. Data from Permeability Tests.

<b>T' tests:</b> # Results # Tests T<1 # Tests T>50	<b>Variable head</b> # Results Range Values Typical value	<b>Pump tests</b> # Results Range Values Typical value	<b>Lab tests</b> # Results Range Values Typical value
min/25mm	tests (m/sec):	(m/sec):	(m/sec):

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Water-lain, bedded, sands, silts and clays.	>>> high - low
Particle size data	One sample with 13% clay and 35% fines (borderline inconclusive to moderate K)	>>> moderate
Field description data	Borehole samples	>>> -
	Exposure samples	>>> moderate
Soil type	Varied.	>>> -
Artificial drainage density	High	>>> low
Natural drainage density	High	>>> low
Permeability test data	No data.	>>> -
Rock type	Predominantly clean and muddy limestones	>>> moderate - low
Land use	Some grazing where land is not water-logged.	>>> moderate - low
<b>Overall conclusion</b>		>>> <b>MODERATE</b>

**5. COMMENTS:** The alluvial deposits all share a common origin and the BS exposure descriptions show that they all consist of a mix of sands, silts and clays. This makes it most likely that they will have a moderate permeability (supported by the one PSD value). They are quite recent deposits that are likely to be underlain by the subsoil type surrounding them. Only along the largest rivers are they likely to be thicker than 2-3m. Despite this, along all but the smallest of streams they are likely to have an influence on the overall permeability. Inaccessibility of river banks to drilling means that the actual alluvium depths have not been established.