County Monaghan Groundwater Protection Scheme

Main Report

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Billy Moore, B.E., M.Sc., F.I.E.I.
County Engineer
County Offices, The Glen
Monaghan

Melissa Swartz and Donal Daly
Groundwater Section
Geological Survey of Ireland
Beggars Bush
Haddington Road, Dublin 4

Authors

Melissa Swartz, Groundwater Section, Geological Survey of Ireland

Donal Daly, Groundwater Section, Geological Survey of Ireland

with contributions by:

Vincent Fitzsimons, Groundwater Section, Geological Survey of Ireland

in collaboration with:

Monaghan County Council

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

- since groundwater flow and contaminant transport are neither readily observed nor easily measured, and both processes are generally slow, there is a lack of awareness about the risks of groundwater contamination;
- 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;
- there has been a significant increase in the application of inorganic fertilisers to agricultural land and in also the usage of pesticides in recent years;
- there are greater volumes of road traffic and more storage of fuels/chemicals; and
- chemicals of increasing diversity and often high toxicity are being manufactured, distributed and 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 (DoELG) and the Environmental Protection Agency (EPA) have jointly developed a methodology for the preparation of groundwater protection schemes (DoELG et al., 1999a). 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.

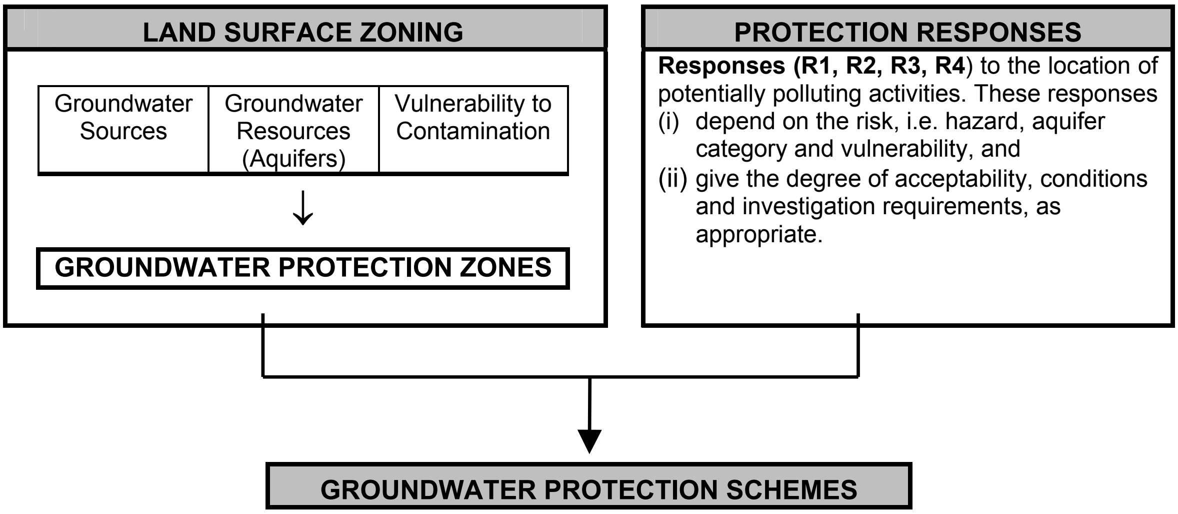

Figure 1.1 Summary of Components of Groundwater Protection Schemes

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 (DoELG et al., 1999a) should be consulted.

1.5 Objectives of the County Monaghan Groundwater Protection Scheme

The overall aim of the groundwater protection scheme is to preserve the quality of groundwater in County Monaghan 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 Monaghan Groundwater Protection Scheme

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

The geological and hydrogeological data for County Monaghan are interpreted to enable:
- delineation of aquifers;
- assessment of the groundwaters' vulnerability to contamination;
- delineation of protection areas around the wells at two public supplies (Clones and Monaghan);
- 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)
- subsoils (Quaternary) geology 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 most of 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.

It is important to recognise that detailed regional hydrogeological investigations in County Monaghan are limited to a number of public supply sources, Environmental Impact Statements and research publications. One valuable source of information is a report on the groundwater resources in the northeastern region, which was carried out in the early 1980s by An Foras Forbartha (AFF) and the GSI. This report summarises the general aquifer characteristics of the area, including water quality information, and provides a good starting point for assessing the hydrogeology of County Monaghan. Despite this information, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of County Monaghan. However, this report provides a good basis for strategic decision-making and for site specific investigations.

1.7 Link with County Development Plan and Measures Report

1.7.1 County Development Plan, 1999

The County Development Plan states that it is a policy of the Council to:
"Protect the water resources of the County: rivers, lakes and groundwater for the benefit of all present and future users".

1.7.2 Measures Report, 1999

The commencement of a groundwater protection plan was listed as an immediate term new measure in the Monaghan County Council Measures Report.

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, gives the basis behind each of the aquifer categories. It also describes the potential for future groundwater development. Chapter 5 describes the county with respect to mapped permeability regions and gives the basis behind the vulnerability categories. Finally, chapter 6 draws the whole lot together and summarises the groundwater protection zones present in County Monaghan. The hydrochemistry and water quality in

Monaghan is presented in a separate report. Similarly, the reports outlining the protection of the two 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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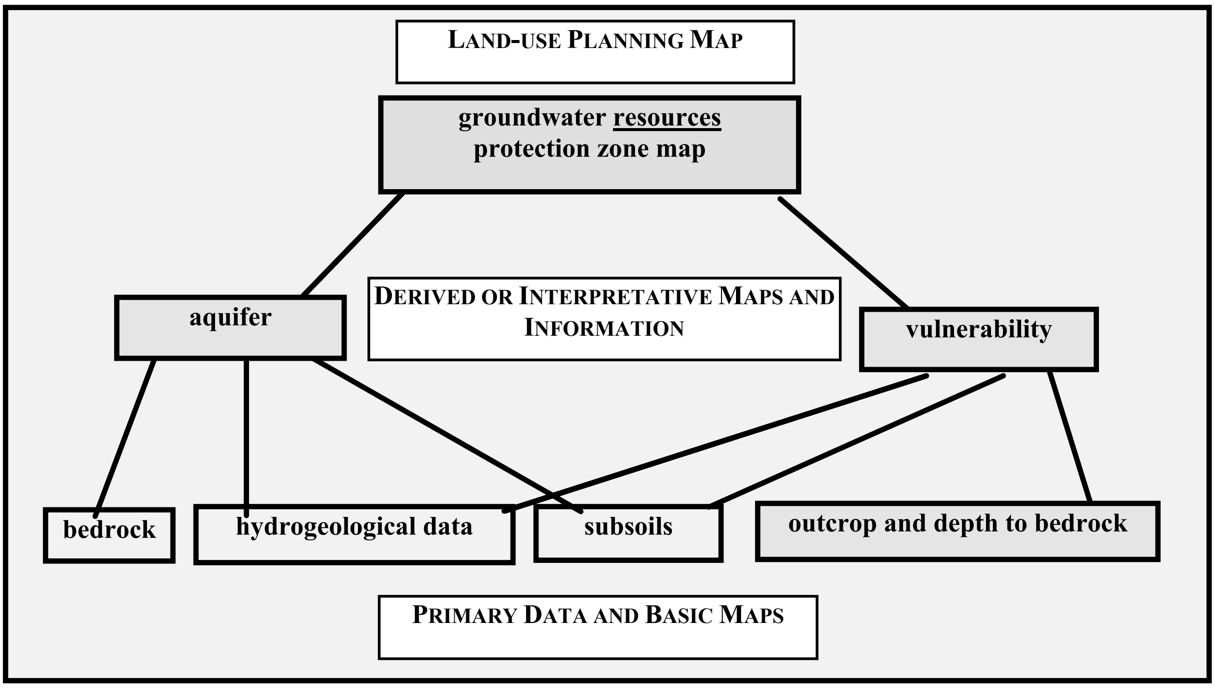

Fig. 1.2 Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

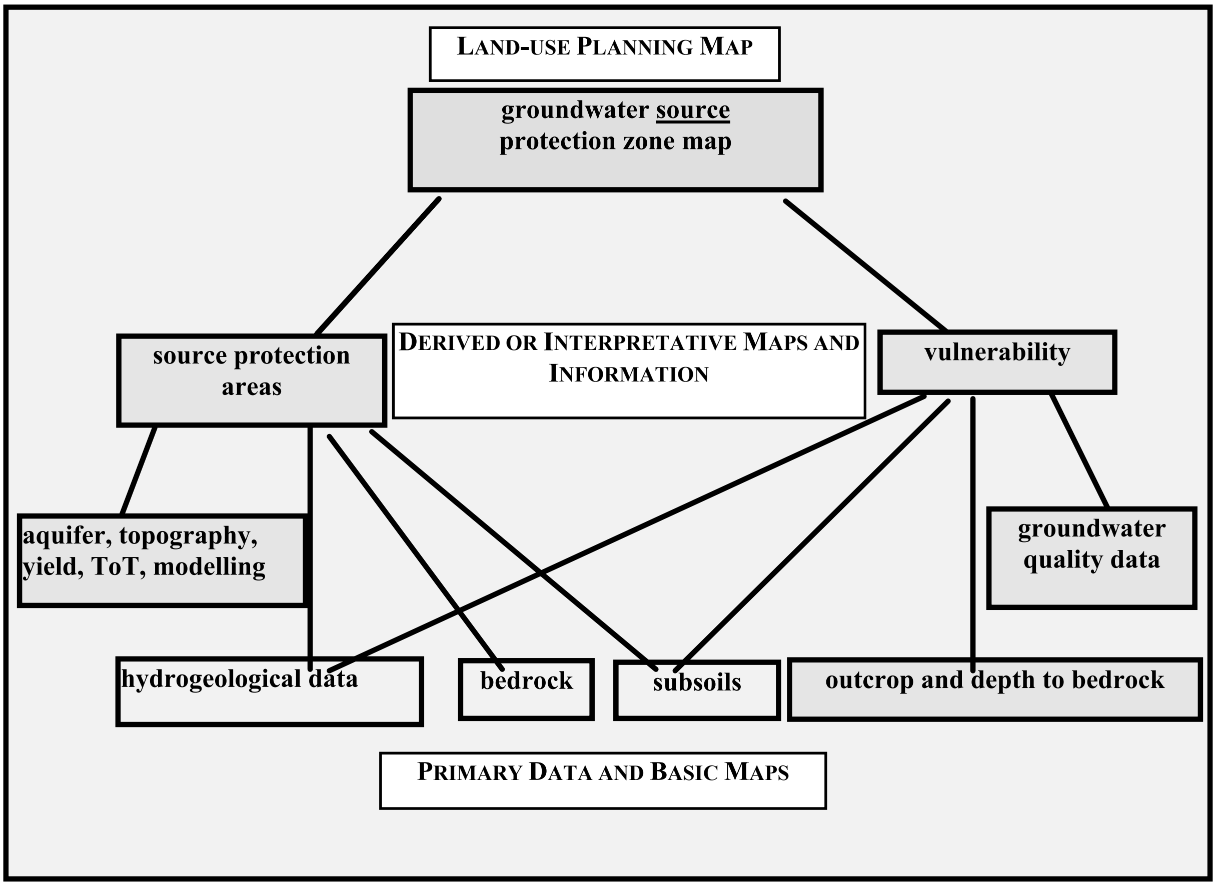

Fig. 1.3 Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

2 Bedrock Geology

2.1 Introduction

This chapter provides a brief description of the elements of the bedrock geology of County Monaghan 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 Ordovician (c. 500 million years old) to the Triassic (c. 200 million years old) and are mainly sedimentary in origin, consisting of limestones, sandstones and shales. Dykes (linear intrusions) of igneous rocks from the Tertiary (c. 60 million years old) are found near Castleblaney and Clontibret. Older intrusions are found south of Monaghan.

The landscape of County Monaghan reflects the varied underlying geology. The majority of the county is composed of resistant Ordovician and Silurian sandstones, siltstones and shales, which create a topographic high in the middle of the county. These rocks are faulted against younger, softer and more soluble Carboniferous limestones, shales and sandstones which comprise the north of the county. At the southern tip of the county lies a small pocket of Carboniferous limestone, Namurian, Permian and Triassic sandstones, all faulted against the older Ordovician and Silurian rocks.

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; a more detailed description is given in Geraghty et al. (1997). In describing the rock units, emphasis is placed on the rock lithology or composition as this feature is 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 other literature. The rocks are described in groups according to their age, starting with the oldest:

i. Lower Palaeozoic Rocks*
   a. Ordovician Rocks*
   b. Silurian Rocks*
ii. Lower Carboniferous Rocks
iii. Namurian and Wesphalian (Upper Carboniferous) Rocks
iv. Permian and Triassic Rocks
v. Tertiary intrusions

The bedrock geology of the area is shown in Map 1, which was compiled from the Bedrock Geology 1:100,000 scale GSI map series, Sheet 8/9 (Geraghty et al., 1997) and a small portion of Sheet 13 (Geraghty and McConnell, 1999).

* Ordovician and Silurian rocks are collectively referred to as the Lower Palaeozoic rocks.

Table 2.1: Bedrock Stratigraphy of County Monaghan

Age (million years)	**Geological Formation** – Main Succession		**South Monaghan Succession**	
TERTIARY (65)	**Dolerite (D)**	Intrusive igneous rock composed of basic minerals (containing little quartz).		
TRIASSIC (250)	**Kingscourt Sandstone (KS)**	Siltstone with minor sandstone overlain by 200 m of red sandstone.		
PERMIAN (290)	**Kingscourt Gypsum (KG)**	Mudstone with gypsum and anhydrite deposits.		
UPPER CARBONIFEROUS *Westphalian* (310)	**Westphalian (WES)**	Grey to black thinly bedded siltstone and fine grained sandstone with minor, thin beds of coal.		
Namurian	**Carrickleck Sandstone (CR)**	Interbedded sandstone and shale.		
	Carrickleck Sandstone Member (CRcg)	Tan coloured ferruginous sandstone.		
(325)	**Ardagh Shale (AD)**	Dark grey to black calcareous shale with occasional ironstone bands, thin sandstone and minor limestone.		
LOWER CARBONIFEROUS	**Mullaghfin Limestone (MF)**	Pale sandy and fine grained limestone.	**Milverton Limestones (MLV)**	Sandy dolomite, muddy limestone with minor shale and bioclastic limestone.
	Meenymore (ME)	Interlaminated limestone, mudstone, dolomites and occasional sandstone and evaporites.	**Fingal Limestone and Shale (FNG)**	Calcareous sandstone and fossiliferous shale, muddy limestone and shale, and cherty calcareous sandstone and shale.
	Carnmore Sandstone Member (MEce)	Pale grey to fawn, very coarse to medium grained sandstone.		
	Dartry Limestone (DA)	Fossiliferous, muddy limestone and fine calcareous sandy limestone.		
	Benbulben Shale (BB)	Laminated calcareous shale and siltstone interbedded with calcareous sandstone.		
	Mullaghmore Sandstone (MU)	Laminated cyclic units of shaly siltstone, siltstone and shale which coarsen upwards to calcareous sandstone.		
	Bundoran Shale (BN)	Bedded, calcareous, clean sandstone, thin silty shale and muddy calcareous sandstone with bands of fossiliferous shale.		
	Drumgesh Shale (DH)	Fossiliferous shale with minor limestone to poorly fossiliferous, muddy limestone with minor shale beds.		
	Ballyshannon Limestone (BS)	Limestone and silty shale at base of unit with pale grainstones at top of unit	**Cruicetown Limestone (CRT)**	Muddy limestone and calcareous sandstone.
	Ballysteen Limestone (BA)	Clean sandy or silty limestone grading into an muddy fine grained limestone		
	Ulster Canal Limestone (UC)	Clean sandy or silty limestone with some fine grained limestone	**Navan Group (NAV)**	Sandstone, siltstone, mudstone and limestone.
	Cooldaragh (CH)	Pale brown-grey siltstone and mudstone; algal, evaporitic and muddy micrites; muddy siltstone		
	Fearnaght Sandstone (FT)	Pale conglomerate and red sandstone		
	Carrickaness Sandstone (CS)	Sandstone, siltstone and mudstone.		
(355)	**Maydown Limestone (MA)**	Blue-grey fossiliferous limestone with dark grey calcareous siltstone and shale.		
SILURIAN (438)	***Various***	Muddy sandstones, shales, siltstones and mudstones.		
ORDOVICIAN (510)	***Various***	Muddy sandstones and shales with some minor volcanics.		

2.2 Lower Palaeozoic Rocks

The geologic history of County Monaghan begins in the ocean. During the Ordovician and part of the Silurian periods (410-510 million years ago, mya), the central part of Monaghan was being formed in a deep sea. By the end of the Silurian, this ocean slowly disappeared as the continents on either side gradually inched towards each other and collided. The zone of this collision, or suture, in Ireland runs from County Louth to the Shannon Estuary, and the associated rocks are referred to as the "Longford-Down Inlier". These rocks, made of deep sea sediments, were formed and deformed during the collision. Today, this mass of rocks forms a topographic high across the middle of the county. A brief description of each rock unit is given below for both the Ordovician and Silurian periods, starting with the oldest rocks.

2.2.1 Ordovician Rocks

Coronea Sandstone (CA)	Green muddy sandstones (greywackes), red shales and minor lavas. Red shales are abundant in the lower part of the formation.
Ballygreany Sandstone (BY)	Muddy sandstones and minor shales. There are many faults mapped within this unit.
Shanmullagh Mill Sandstone (SH)	Shales and muddy sandstones in equal proportions.
Red Island Sandstone (RI)	Medium to coarse grained, muddy sandstones derived from volcanic debris with local conglomerates. Minor grey to grey black shales.
Carrickateane Sandstone (CT)	Muddy sandstones with minor amounts of black shales and carbonate nodules.
Castleshane Shale (CE)	Dark grey to black, laminated shales (locally chert-rich) and muddy sandstones.

2.2.2 Ordovician/Silurian Rocks

Slieve Glah Siltstone (SG)	Grey to dark grey slaty siltstones and mudstones. This unit also contains occasional thicker bedded, fine to coarse grained (or microconglomeritic) muddy sandstones.
Carrickatee Shale (CK)	Dark grey to black shale/mudstone and occasional pale grey-green mudstone with pyrite. This formation also contains minor pillow basalts, cobble conglomerates, tuffs (rocks of air-born volcanic debris), and thin-bedded muddy sandstones.
Lough Avaghon Sandstone (LA)	Grey, fine to coarse grained massive muddy sandstones, microconglomerates and amalgamated beds, with interbedded sandstones and mudstones becoming prevalent towards the northwestern part of the unit. A volcanic horizon has been described in this bedrock unit; it also contains minor amounts of dark shales.

Aghnamullen Member (LAan)	This member of the Lough Avaghon Sandstone is dominated by thin-bedded muddy sandstones, with interspersed zones of very finely laminated to massive siltstone-mudstone.
Mullanalt Member (LAmt)	Very finely laminated grey siltstone, siltstone-mudstone and non-laminated siltstone with interspersed thicker, pale muddy sandstones.
Cootehill Member (LAcl)	There are two principal lithotypes in the Cootehill Member: (a) Thin-bedded, calcareous shales, mudstones and muddy sandstones, and (b) Very finely-laminated clayey muds with some laminated siltstones. In addition, horizons of both muddy and clean sandstones are found within this member.
Kehernaghkilly Shale (KY)	This unit is similar to the Carrickatee Shale (CK). Typically, it is a pale green to dark grey shale-mudstone with pyrite. It also contains some minor pale grey siliceous tuffs (rocks derived from airborne volcanic debris).
Oghill Sandstone (OL)	Grey to grey-green massive muddy sandstones and microconglomerates. It also contains subordinate thin to thick-bedded muddy sandstones and local pyritic shale-mudstones.
Laragh Mudstone (LH)	Green, grey and black shale-mudstone-slate containing pyrite and chert.
Shercock Sandstone (SK)	Grey to green-grey, fine to coarse grained marine deposits that range from mudstones to sandstones. This formation also contains massive sandstones.
Inniskeen Sandstone (IN)	Medium to thick bedded muddy sandstones and minor amounts of shale. This unit's characteristic feature is the high mica content of the sandstones. In addition, the fine-grained parts of the formation often contain purple/red mudstones.
Magoney Bridge Sandstone (MB)	Massive clean sandstones and thick to medium bedded muddy sandstones.
Taghart Mountain (TM)	Pale to dark grey, quartz and mica rich marine deposits that range from coarse sandstones to fine mudstones, sandstones and amalgamated beds. It is interspersed with very distinctive, laminated siltstone-dominant horizons.
Clontail Sandstone (CL)	Red mica rich muddy sandstone. These rocks are found in south Monaghan, along the border with Counties Meath and Louth.
Gabbro (G) and Diorite (D)	Intrusive igneous rocks. A small areas of gabbro and diorite are mapped in the Lower Palaeozoic rocks, south of Monaghan town. The age of these are unknown, but as they are mapped within the Lower Palaeozoic rocks, they are included in this section.

Dolerite (D)

An intrusive igneous rock composed of basic minerals (containing little quartz). The dolerites mainly occur in small sheet like igneous bodies which cut across bedding or structural planes of the host rock. They tend to occur in large swarms. The dolerites in Monaghan are of Tertiary age (c. 60 million years old), but since they are predominantly found in the Lower Palaeozoic rocks, they are included in this section.

2.3 Devonian Rocks

During the Devonian period, from 355-410 mya, Ireland lay at equatorial latitudes. The climate was hot and arid, and geologically this time is associated with the erosion of mountains and deposition of river sediments. Rocks from this period are commonly referred to as "Old Red Sandstones", and are not found in County Monaghan.

2.4 Lower Carboniferous Rocks

During the Carboniferous (355-290 mya), Ireland was transformed into a region of shallow tropical seas as the land was flooded from the south. There are two areas where Lower Carboniferous rocks are found in County Monaghan. Most are found north of the Lower Palaeozoic rocks (around and north of Monaghan town). They lie in northeast-southwest trending bands across the county, decreasing in age to the north. A smaller area of these rocks are found around Carrickmacross, where they are also juxtaposed against the Lower Palaeozoic rocks on the west, and younger sandstones to the east. At one time, Lower Carboniferous rocks most likely covered most of the county but have since been eroded to their present level.

The lower most members of the Lower Carboniferous rocks reflect the change from a subaerial to a submarine environment. Evaporite deposits were formed as the sea ingressed, when the sediments were occasionally exposed to the air. A variety of sediments was laid down depending on the depth and the turbulence of the waters, and their position in relation to the deepening sea. Clean limestones (such as the limestones around Monaghan and Carrickmacross) were laid down in shallower water. As the sea deepened, more shaley limestones (such as the limestones around Clones) were formed in the quieter environment due to the presence of silts and muds. As the sea began to retreat again, the rocks of the northern part of the county were deposited in a shallow sea and beach environment.

Navan Group (NAV)

The Navan Group comprises four formations, which are not differentiated on the geology map. The rocks in this group range from coarse sandstones and conglomerates at the base (Red Beds), through laminated siltstones, mudstones and shales and muddy limestones (Liscartan Formation), into muddy calcareous sandstones, silts and shales (Meath Formation), finally ending in bioclastic sandstones, shales and siltstones (Moathill Formation). These rocks are found in south Monaghan, along the border with Counties Meath and Louth.

Cruicetown Limestone (CRT)

The Cruicetown Limestone consists of two formations, which are not differentiated on the geology map. The Slane Castle Formation is equivalent to the Ballysteen Limestones, and is located at the bottom of the group. The overlying Kilbride Formation is made of thick bedded, coarse grained shallow water calcareous sandstones with very little shale. This unit is

	most likely equivalent to the Waulsortian Formation, which is found in many parts of Ireland. These rocks are found in south Monaghan, along the border with Counties Meath and Louth.
Maydown Limestone (MA)	Blue-grey, fossiliferous limestones that may be muddy and silty, with dark grey calcareous siltstones and shales. The limestones become less muddy towards the top of the formation.
Carrickaness Sandstone (CS)	Sandstones, siltstones and mudstones. The sandstones are fine to medium grained, quartz dominant sandstones that are usually white or pale grey, but may be heavily iron stained. The mudstones are dark grey to fawn coloured blocky mudstones. This unit is relatively thin (60 m) and is found within the mapped area of the Maydown Limestones.
Fearnaght Sandstone (FT)	Pale, quartz-rich conglomerate with a sandy matrix, red and purple mica-rich flaggy sandstones, and purple-brown clean sandstones.
Cooldaragh (CH)	Pale brown-grey siltstones, mudstones and muddy limestones. This formation contains evaporite deposits.
Ulster Canal Limestone (UC)	Pale silty and sandy limestones with some fine grained limestones.
Ballysteen Limestone (BA)	A succession of muddy limestones and fossiliferous shales. The sequence shows a general upward change from relatively clean sandy or silty limestones, through muddy fossiliferous limestones, to muddier, finer grained limestones.
Ballyshannon Limestone (BS)	Dark grey to bluish grey fossiliferous limestones and bituminous silty shales near the base of the unit, with the upper part consisting of grainstone, which is a clean limestone.
Drumgesh Shale (DH)	This formation ranges from fossiliferous shales and mudstones with very minor limestones to dark, very fine calcareous sandy limestone with local chert and shaly interbeds. It sits conformably on the Ballysteen Limestones but is mapped only in the western part of County Monaghan, near Clones. This unit is thought to grade eastward into the Ballyshannon Limestones.
Bundoran Shale (BN)	Grey shales with beds of fine to medium grained grey, bedded calcareous clean sandstone, thin silty shales and muddy calcareous sandstones with bands of grey fossiliferous shales.
Mullaghmore Sandstone (MU)	This formation consists of a series of laminated cyclic units of dark grey shaly siltstones, siltstones and shales which coarsen upwards into medium to coarse grained calcareous sandstone. This formation is dominated by the sandstones.

Benbulben Shale (BB)	Laminated dark grey calcareous shales and siltstones, interbedded with ribs of dark grey fine calcareous sandstone. Laminated grainstones also occur. The upper portion of this unit is highly fossiliferous.
Dartry Limestone (DA)	Massive to thick bedded fossiliferous, muddy limestone (biomicrite) and fine calcareous sandy limestone. Bands and nodules of irregular chert are commonly found along bedding. Bands of dolomitisation and fine silicification are common.
Meenymore (ME)	Interlaminated limestones, mudstones, dolomites, laminates and occasional sandstones. The interlamination consists of near equal proportions of dolomite, shales and evaporites. This formation was probably deposited in an intertidal environment.
Carnmore Sandstone Member (MEce)	Pale grey to fawn, very coarse to medium grained sandstone with pebbles concentrated in thin, discontinuous layers.
Fingal Limestone and Shale (FNG)	The Fingal Limestone and Shale comprises three formations, which are not differentiated on the geology map. The Tober Collen Formation consists of interbedded calcareous sandstones and fossiliferous shales, overlain by mudstone and muddy limestones. The Lucan Formation consists of muddy limestones and shales. The overlying Loughshinny Formation is made of interbedded cherty calcareous sandstones and shales overlain by thick shales. These rocks are found in south Monaghan, along the border with Counties Meath and Louth.
Milverton Limestone (MLV)	The Milverton Limestone consists of five formations, only one of which (the Mullaghfin Limestone) is differentiated on the geology map. At least three of the remaining formations are present in southern Monaghan. The McGuinness Formation is composed on thickly bedded, pale, clean, sandy dolomite and sandstone with thin shale horizons. The Lane Formation is a muddy limestone with minor shales. The Holmpatrick Formation, which is probably the dominant formation in the area, is a well bedded, bioclastic limestone. These rocks are found in south Monaghan, along the border with Counties Meath and Louth.
Mullaghfin Limestone (MF)	Pale sandy and finer grained limestones. Carbonate mudbanks have been identified in the upper portion of this unit. This limestone unit is found in and around Carrickmacross.

2.5 Namurian and Westphalian (Upper Carboniferous) Rocks

During the Namurian (310-325 mya) the sea continued to retreat across Monaghan, with rivers becoming more dominant. The majority of sediments deposited in Monaghan at this time were laid down in a delta environment, where rivers met the sea. In the Westphalian (300-310 mya), the land became dominated by densely vegetated marshes. Fluctuations of sea levels resulted in the swamping of the vegetation that rotted to form organic rich layers, which eventually became coal. These Upper Carboniferous rocks are found in a small area just west of Carrickmacross.

2.5.1 Namurian Rocks

Ardagh Shale (AD)	Dark grey to black calcareous shales with occasional ironstone bands, thin sandstones and minor limestones. This formation thins towards the north, and only a small amount of it is found in south Monaghan, along the border with County Meath.
Carrickleck Sandstone (CR)	Interbedded sandstones and shales. These units had been subdivided into three other formations of similar lithology, but have been grouped together for the purposes of this report.
Carrickleck Sandstone Member (CRcg)	This unit occurs at the base of the Carrickleck Sandstone and consists of tan coloured, feruginous sandstone.

2.5.2 Westphalian Rocks

Westphalian (WES)	Grey to black shale, thinly bedded siltstones and fine grained sandstones. Minor, thin beds (up to about 1.5 m) of coal are also found in this formation.

2.6 Permian and Triassic Rocks

Monaghan in the Permian (250-290 mya) had a severe environment - a harsh, irregular desert bounded by steep fault scarp margins. As the Permian ended and the Triassic (205-250 mya) began, the land was again flooded by a shallow sea, this time from the northeast. Permian and Triassic rocks in Monaghan are found in a small area just west of Carrickmacross.

2.6.1 Permian Rocks

Kingscourt Gypsum (KG)	The base of this formation consists of a conglomerate, which is overlain by a mud-dominant sequence that contains two major evaporite deposits. These evaporites are gypsum and anhydrite, which are currently being mined at Knocknacran.

2.6.2 Triassic Rocks

Kingscourt Sandstone (KS)	This unit lies directly on top of the Kingscourt Gypsum Formation. It is comprised of siltstones with minor sandstones at the base, with a 200 m thick red sandstone member at the top of the formation.

2.7 Structural History

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

The earlier Caledonian (late Lower Palaeozoic, c.410 mya) orogeny marked the collision of two continents, Gondwana and Laurentia which were once separated by an ancient ocean (The Iapetus

Ocean). The boundary between the continents is a suture line running between the present day Shannon Estuary, across Monaghan to Clogher Head. Many of the rocks found in Monaghan were deposited in this ocean, and with the collision of the continents, were thrust up and over one another, creating a chain of mountains. In the course of this mountain building, the rocks were faulted and folded, with the Silurian rocks now dipping up to 70° off the horizontal.

The Variscan Orogeny (late Carboniferous, c.290 mya) was a north-south compression event and as the deformation front was located in the south of the country, there are only weak effects of the strain seen in County Monaghan. Gentle east-west trending anticlines and synclines dominate, primarily around Slieve Beagh and into Counties Cavan and Fermanagh, and there are numerous north-south cross faults, which can be seen in the Lower Carboniferous Limestones from Monaghan to Clones.

There is one other feature in Monaghan that stands out - an area called the "Kingscourt Outlier". This small, faulted wedge of rocks is located in and around the area of Carrickmacross, where a block of Lower Carboniferous Limestones, Upper Carboniferous Sandstones, Permian and Triassic rocks are juxtaposed against the Lower Palaeozoic rocks. The Kingscourt Outlier is bounded on the west by the Kingscourt Fault, which though most movement on it occurred in the post-Triassic, some movement occurred during the Variscan. This fault defines a topographic high, which can been seen from west of Carrickmacross down to Nobber, in County Meath.

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.

Mapping of the Quaternary deposits in Monaghan was originally carried out by Michael O'Meara of the GSI, in the 1950s. This mapping covered approximately 85% of the county, and tended to exclude areas where rock was generally close to the surface (around Clontibret), and areas where the subsoils were fairly uniform and unchanging (around Rockcorry). These maps formed the foundation of subsequent subsoil permeability assessments, which are described in Chapter 5. Subsoil distribution is presented in Maps 2N and 2S, and discussed briefly in Section 3.2. The thickness of the subsoils is outlined in Section 3.3; an overview of evidence for possible ice flow directions is provided in Section 3.4.

3.2 Subsoil Types

Many of the subsoils in County Monaghan were laid down during the last glaciation affecting Ireland. County Monaghan was completely smothered by the ice sheet, which moved in a general southeasterly direction (Clark & Meehan, 2001). The deposits remaining from this glaciation are varied in their sedimentology and their landforms. There are seven subsoil types identified in County Monaghan and shown on Maps 2N and 2S:

- till
- sands and gravels
- till with 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 Monaghan, as can be seen from Maps 2N and 2S. 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. Many of the tills in Monaghan have been formed into elongated hills, or drumlins, which are thought to be bedforms of the glacier and 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 and 2S, but symbols indicate the texture at specific locations. Instead, the tills are categorised according to their dominant lithological component, e.g. Limestone till (TLs) or Lower Palaeozoic shale till (TLPs). A number of particle size analyses were carried out during the permeability mapping; these results are discussed in the context of subsoil permeability and groundwater vulnerability, in Chapter 5.

3.2.2 Sands and Gravels

Deposition of sands and gravels 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 gravels 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.

Monaghan does not have extensive deposits of sand and gravel. The majority of sand and gravel deposits are small and discontinuous, with only three sizeable and continuous deposits located at Smithborough, near Bragan and east of Monaghan town. Of these, the gravels at Smithborough and Bragan have been 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). While there are no mapped eskers in Monaghan, the small sand/gravel deposits are usually hummocky, in contrast with the surrounding drumlin topography.

3.2.3 Till with Gravel

This term encompasses those areas where till and gravel are intimately mixed, either vertically or horizontally, or both, so that individual areas of one sediment or the other cannot be delineated. The largest mapped deposit of Till with Gravel in Monaghan is just south of Scotshouse. Smaller pockets of these are found in the area between Monaghan and Clones.

3.2.4 Alluvium

Alluvial sediments are deposited by rivers and include unconsolidated materials of all grain sizes, from coarse gravels down to finer silts and clays, and may contain organic detritus. Alluvium is mapped only on modern river floodplains. The alluvial deposits are usually bedded, consisting of many complex strata of waterlain material left both by the flooding of rivers over their floodplains and the meandering of rivers across their valleys. Most of the alluvial deposits in Monaghan are comprised of sand, silt and clay, although one deposit mapped southwest of Carrickmacross is comprised of coarse gravel. The largest area mapped as alluvium in Monaghan is along the Finn River, west of Clones.

3.2.5 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 Monaghan: blanket bog, which is characteristic of upland areas with excessive rainfall, and raised bogs, which are characteristic of lowland areas with impeded drainage.

In Monaghan, blanket bog is only found on the upper reaches of Slieve Beagh, and is likely to be between one and three metres thick, although in limited areas it may be between 3-5 m thick. Small areas of raised bog are mapped only in the inter-drumlin valleys throughout the county. Although both types of bog have been worked for peat, it has mostly been on a local scale.

3.2.6 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 area mapped in Monaghan, on the south and east slopes of Slieve Beagh. These sediments are typically 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 and 3S) show areas where rock crops out at the surface and depth-to-rock 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. In Monaghan, the most significant assumption made is that the drumlins do not have cores of rock.

The thickest deposits in Monaghan are tills which, while found throughout the county, dominate the northern and western parts of the county. In the area from Clontibret to Latton and south to Cortobber, the subsoils are generally less than 1 m thick, with the drumlin hills being greater than 3 m. In the south, around Carrickmacross, the thickness is slightly more mixed, with the interdrumlin areas thought to be largely 3 m or less, with the drumlins greater than 3 m thick.

3.4 Ice Flow Direction

A specific study of the ice flow direction in County Monaghan has not been carried out. Drumlins can be used as directional indicators of ice flow, since the steeper side of drumlins faces up-ice, with the down-ice portion of the drumlin being longer and more sloped (Bennett and Glasser, 1996). Warren (1993) locates an ice dome northwest of Monaghan, and shows ice flow directions being to the southeast. Additionally, in a study of glacial landforms in the area, Clark and Meehan (2001) found that the overall ice flow direction in Monaghan is from northwest to southeast.

4 Hydrogeology and Aquifer Classification

4.1 Introduction

This chapter summarises the relevant and available hydrogeological and groundwater information for County Monaghan. 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 Map 4 and the aquifers are shown on Map 5.

4.2 Data Availability

Groundwater data from the GSI, County Council and EPA (ENFO, Dublin) files were compiled and all existing well records were entered into the GSI database. Relevant data were obtained from the main hydrogeological consultants and from published hydrogeological reports on County Monaghan. Information for those areas of Northern Ireland near Monaghan was supplied by the GSNI.

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

- Information from more than 1500 well records held in the GSI database.
- Well information for local authority and group schemes sources, and for a limited number of other high yielding private wells, e.g. creameries and industry.
- Well information from the GSNI for areas surrounding the Monaghan border.
- Information from the well improvement grant scheme.
- Specific capacity and discharge data for some wells, mainly local authority owned and grant scheme wells. (Specific capacity is the rate of abstraction per unit drawdown; the unit used is $m^3/d/m$.) Specific capacity is plotted against discharge as 'QSC graphs' to get a 'productivity class', which can be related to aquifer categories.
- Analysis of pumping test data from consultants reports for new public supply wells.
- Findings of an MSc theses carried out in conjunction with GSI during the course of the project on the Tydavnet Group Scheme (Kelly, 2001).
- The GSI karst database.
- Reports by engineering and hydrogeological consultants.
- Relevant academic research papers.
- General hydrogeological experience of the GSI and GSNI, including work carried out in adjacent counties and for other groundwater protection schemes.

4.3 Rainfall, Evapotranspiration and Potential Recharge

There is little variation in the mean annual rainfall in Monaghan; this is reflected in data for the period 1961–1990 recorded by Met Eireann (Fitzgerald and Forrestal, 1996). Data from 10 of the 11 stations in the county shows rainfall for this period to be between 910-968 mm/yr. The maximum rainfall was at the Castleblaney station, where an average of 1037 mm/yr was recorded over this period. Averaging these data from 1961-1990 gives a value of 952 mm/yr.

Potential evaporation (P.E.) in Monaghan is estimated to be 438 mm/yr. P.E. data are from a synoptic weather station located in Clones, and are also averaged over the years 1961-1990. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., which equals 416 mm/yr.

Based on these values, the mean annual potential recharge (rainfall minus A.E.) is estimated to be 536 mm/yr in County Monaghan. This is the total estimated amount of water available to surface water and groundwater.

In addition to these general meteorological data, more complex water balances were carried out in the NERDO report for the periods 1975-1978 (AFF and GSI, 1981). These were based on four river catchments that fall within Counties Louth, Cavan and Monaghan: the Glyde, Dee, Finn and Blackwater Rivers. Overall, they found that in the Finn and Blackwater catchments (Clones-Monaghan area) the estimated infiltration to groundwater is 13-15% of total rainfall. This roughly equates to 26-30% of the potential recharge, which is between 140-160 mm/yr. In the Glyde and Dee catchments in southern Monaghan, estimated infiltration as a percentage of total rainfall was calculated to be 21-24%. This roughly equates to 42-48% of potential recharge, which is between 225-257 mm/yr. Presumably, the higher infiltration rates in the south reflect the fact that the subsoils are relatively more permeable.

4.4 Groundwater Usage

Water in County Monaghan is largely provided by surface water supplies; only 17% of the water supplies in Monaghan come from groundwater. Of the 17 public and 13 group water schemes, only seven are supplied by groundwater, including the towns of Monaghan, Clones, and Carrickmacross. A combination of surface and groundwater are used in the supplies for Carrickmacross, Clones and Monaghan. To meet increasing demands, the groundwater supplies for these towns are currently being expanded. The abstraction rates in Table 4.1 below summarise what is currently being abstracted. These values are take from County Council information and the EPA publication *The Quality of Drinking Water in Ireland, 1997-1999*. Where the planned abstraction of an expanded scheme is known, it is shown in italics.

Table 4.1: Summary of Public and Group Groundwater Supplies in County Monaghan. Planned abstraction rates for wells not yet in production are shown in italics.

Water Supply	Abstraction (m^3/d)	Source
Carrickmacross PWS	*1500*	Spring + new borehole(s) (not yet in production). This is combined with surface water.
Clones PWS	*1500*	2 Boreholes (not yet in production)
Clontibret PWS	16	1 Borehole
Monaghan PWS	*4545*	2 Boreholes + 8 new boreholes (not yet in production). This is combined with surface water.
Pullis GWS	2.25	1 Borehole
Smithborough PWS	130	2 Boreholes
Tydavnet GSW	1300	5 Boreholes
Killyneill PWS	10	1 Borehole

4.5 Aquifer Classification

The aquifer classification used by GSI (DELG et al., 1999a) 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 **(Ll)**

Poor (**P**) **Aquifers**
(i) Bedrock which is generally unproductive except for local zones **(Pl)**
(ii) Bedrock which is generally unproductive **(Pu)**

These aquifer categories take account of the following factors:
- the overall potential groundwater resources in each rock unit
- the area of each rock unit
- the localised nature of the higher permeability zones (e.g. fractures) in many of our bedrock units;
- the highly karstic nature of some of the limestones
- the fact that all bedrock types give enough water for domestic supplies (therefore all are called 'aquifers').

Aquifers are defined on the basis of:
- Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water. Pure limestones and clean sandstones are more permeable than muddy limestones and clayey sandstone, respectively. Areas where strong folding and faulting produced strong joint systems generally leads to increased permeability, as groundwater tends to flow through these fracture systems.

- Hydrological indications of groundwater storage and movement e.g. the presence of large springs (indicating a good aquifer); absence of surface drainage (suggesting high permeability) or high density of surface drainage (low permeability situation usually – the main exception is in low lying areas where there is no outlet for the water); high groundwater base flows in rivers, etc.

- Information from boreholes, such as permeabilities from pumping tests, specific capacities (rate per unit drawdown), and well yields. The use of these data for defining aquifers is explained in the following sections.

4.5.1 Use of Borehole Yields in Defining Aquifers

Well yields are just one factor used for categorising a rock unit as an aquifer. However they are often the main type of data available and they allow the three main aquifer categories to be conceptualised. Regionally important (**R**) aquifers should have (or be capable of having) a large number of wells yielding in excess of approximately 400 m^3/d (4000 gph). Locally important (**L**) aquifers are capable of moderate well yields, usually between 100-400 m^3/d (1000-4000 gph). Poor (**P**) aquifers would generally have low yielding wells - less than 100 m^3/d. However, due to the fissured and heterogeneous nature of Irish bedrock aquifers, low yielding and/or failed wells may be present in all aquifer categories.

Information from the wells throughout Monaghan and neighbouring counties show a wide variation in well yields, with 'excellent', 'good', 'moderate' and 'poor' wells all in close proximity. The details from some of these wells are limited and thus interpretation is often difficult from the available records. Because well data from County Monaghan are limited, information from the surrounding counties is included in the aquifer assessment. All data used are summarised in Table 4.3.

4.5.2 Use of Well Productivity Classes in Defining Aquifers

In order to provide a more consistent and objective measure of an aquifer's ability to yield water, the GSI has developed a 'Productivity Index' with five classes: I (highest), II, III, IV, and V (lowest) (Wright, 2000). The productivity class is read from a 'QSC Graph' which plots well discharge (Q) against specific capacity (SC). In general, wells in regionally important aquifers should plot in classes I and II, locally important aquifer data will plot within classes II to IV, while those in poor aquifers typically plot in classes IV and V (Wright, 2000).

In order to make the best use of all relevant available information, data from groundwater investigations in neighbouring counties have also been plotted on QSC graphs. These data are summarised in Table 4.3.

4.5.3 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. The result is 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. Solution of the bedrock 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 is caused by 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 $\mathbf{Rk^c}$ and $\mathbf{Rk^d}$.

$\mathbf{Rk^c}$ 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.

$\mathbf{Rk^d}$ 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 such as FLOWPATH.

4.5.4 Dolomitisation

Dolomitisation is a weathering process where calcium ions in limestone are replaced by magnesium ions to form dolomite ($Ca\,Mg\,(CO_3)_2$). Hydrogeologically, the most important feature of dolomitisation is that it results in an increase in the porosity and permeability of the carbonate rock, as magnesium ions are smaller than the original calcium ions. Dolomitised rocks are a highly weathered, yellow/pink/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.

4.5.5 Bedrock Aquifers

The bedrock aquifer categories 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 (**R**) aquifer is 25 km^2.
- 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'.

4.5.6 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 more than 10 m thick and is greater than one square kilometre in areal extent. The thickness of the deposit is 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 Guidelines for the Classification of Sand/Gravel Aquifers

	Regionally important	*Locally important*
Areal extent	> 10 km^2	1-10 km^2
Saturated thickness	> 5 m	> 5 m
Throughput	> 10 Mm^3/a	1-10 Mm^3/a

Sand/gravel aquifers are therefore classified based on the areal extent of the deposit, the thickness of the saturated zone and the estimated annual throughput (see Table 4.2). The permeability of the deposits can vary considerably depending on how they were laid down, so in practice the geological history of the deposit 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.

A regionally important gravel aquifer should have an aerial extent of *at least* 10 km^2. This is to ensure that enough recharge would be available to provide a supply of one million cubic metres per year from the whole aquifer. A locally important aquifer on the other hand can be expected to have enough resources to supply a group scheme or village.

Table 4.3 Summary of Well Productivity Index & Yield Categories for Monaghan Aquifers

Aquifers		Well Productivity Index					Well Yield (m^3/d)					Aquifer category
		I	II	III	IV	V	E (>400)	G (400-100)	M (100-40)	P (<40)	F (<2.7)	
Quaternary deposits (Sand/gravel)		1					1					**None**
Dolerite (D)		No Data					No Data					**Pl**
Kingscourt Sandstone (KS)		No Data					No Data					**Lm**
		1	*1*	*1*			*3*					
Kingscourt Gypsum (KG)							1					**Pl**
Carrickleck Sandstone (CR)		1					1					**Rf**
		1	*3*				*7*	*1*				
	Carrickleck Sandstone Member (CRcg)	1					1				1	
Westphalian Shales (WES)		No Data					No Data					**Pl**
Carnmore Sandstone (MEce)		No Data					No Data					**Lm**
Knockatallon Area:	Meenymore Formation (ME)	3					8	3				**Rf**
	Dartry Limestone (DA)	1	1				8					
			1	*1*	*2*	*1*	*1*	*3*	*2*	*1*		
Bellanode Area:	Benbulben Shale (BB)			1			2	5				**Ll**
	Mullaghmore Sandstone (MU)	No Data					No Data					
	Bundoran Shale (BN)							4				
Monaghan-Clones Area:	Drumgesh Shale (DH)		2				1	4				**Rf**
	Bundoran Shale (BN)	2					2					
	Dartry Limestone (DA)	1	1				2	1				
	Ballyshannon Limestone (BS)	4		1	1		9	4		2		
	Ballysteen Limestone (BA)	2	1	1	2		9	10	1	1	1	
		1				*1*	*1*		*1*	*1*		
	Ulster Canal (UC)	No Data					No Data					
	Cooldaragh Formation (CH)		4	1			6	6		1	1	
	Fearnaght Formation (FT)	No Data						1				
Emyvale Area:	Maydown Limestone (MA)	No Data					6	6			1	**Lm**
		No Data					*2*	*3*		*4*		
	Carrickaness Sandstone (CS)	No Data						1				
Carrickmacross Area:	Mullaghfin Limestone (MF)	2	4				6	5			1	**Rk**
	Milverton Group Limestones (MLV)	No Data					No Data					
			1	*1*			*2*	*2*				
Fingal Limestone and Shale (FNG)		No Data					No Data					**Lm**
		7	*10*	*11*	*7*	*2*	*23*	*31*	*1*	*3*		
Cruicetown Limestone (CRT)		No Data					No Data					**Pl**
Navan Group (NAV)		No Data					No Data					**Ll**
		1	*4*	*5*	*7*	*3*	*3*	*4*	*11*	*5*		
Ardagh Shale (AD)		No Data					No Data					**Pl**
Lower Palaeozoic rocks					2	7	1	8	1	8	4	**Pl**
		1		*1*	*1*		*1*	*5*	*3*	*4*		

1. The majority of these data are drawn from Co. Monaghan; data shown in italics below the dashed lines are from Counties Cavan, Meath, Louth and Northern Ireland.
2. These statistics may be skewed towards higher yielding sources, mainly Co. Co., group scheme and industrial supplies.
3. Most well records for Co. Monaghan have neither drawdown data (for specific capacities) nor maximum yields.

4.6 Aquifer Delineation

Aquifer delineation is a generalisation that reflects the overall resource potential; because of the complex and variable nature of Irish hydrogeology, there will often be exceptionally low or high yields which do not conform with the aquifer category given. It is also important to note that the top few metres of all bedrock types are likely to be relatively permeable.

The rock units in County Monaghan are listed in Table 4.3, together with a summary of the useful well data for each formation and the aquifer category.

In assessing the well data in Table 4.3, it should be noted that there will be a bias towards higher yielding wells, as these wells are used by the County Council, group schemes and industry. The remaining wells (>1100 in the GSI database) are mainly privately owned and many are shown to have 'poor' yields; however, many of these wells have not been tested properly and the yields given may not be the maximum possible. In addition, many of the well records do not have yield estimations. Therefore, these data are not used in assessing aquifer categories, but are used to give depths to rock and water levels.

The following sections examine the hydrogeological information available for each aquifer type (Rk, Rf, etc.) and include a breakdown of data for each bedrock unit. For full descriptions of the different rock types in the county, refer to Chapter 2. Bedrock aquifers are discussed in Sections 4.7 – 4.12, sand/gravel aquifer are discussed in Section 4.13. Figure 4.1 shows the general location of the regionally important aquifers (Rk and Rf), as well as the larger locally important, generally moderately productive aquifers (Lm).

4.7 Regionally Important Karst Aquifers (Rk)

4.7.1 Carrickmacross Area: Mullaghfin Limestone (MF) and Milverton Group Limestone (MLV)

These two units are combined to form the only karstified aquifer in County Monaghan. Together, they cover 73 km^2 and are located in the south, around Carrickmacross (Figure 4.1). The Mullaghfin Limestone forms the majority of the aquifer, and is one of the rock units that make up the Milverton Group Limestones (Strogen et al., 1995). A small area of southern Monaghan near Ballyhoe Lough is mapped as Milverton Group Limestone; the various limestones in this unit have not been differentiated.

These two units are combined to form one aquifer since they are clean, 'conspicuously' bedded limestones showing evidence of karstification (Jackson, 1955). The presence of the clean limestones makes them susceptible to dissolution, while the bedding provides preferential flow paths for groundwater. The Mullaghfin limestone is also reported to be dolomitised (see Section 4.5.4) (Jackson, 1955), which increases the permeability and porosity of the limestone. Dolomite often has an easily weathered sandy texture which often fills fractures caused by dissolution. Evidence of this occurring in this aquifer is given by reports of four boreholes drilled by Carrickmacross UDC being abandoned due to the ingress of silt and sand preventing development (AFF and GSI, 1981). The NERDO report also mentions this happening in wells in the Tullyvaragh Lower, Drumboagh, Lattylanigan, Tiragarvan and Leggimore townlands. Similarly, during hydrogeological investigations near Lough Fea, a well drilled into this limestone encountered very weathered, collapsing bedrock.

Karst features are found throughout this aquifer, and a range of features is present as shown in Figure 4.2 and Map 4S. The majority of visible karst features are present in the Mullaghfin formation, with

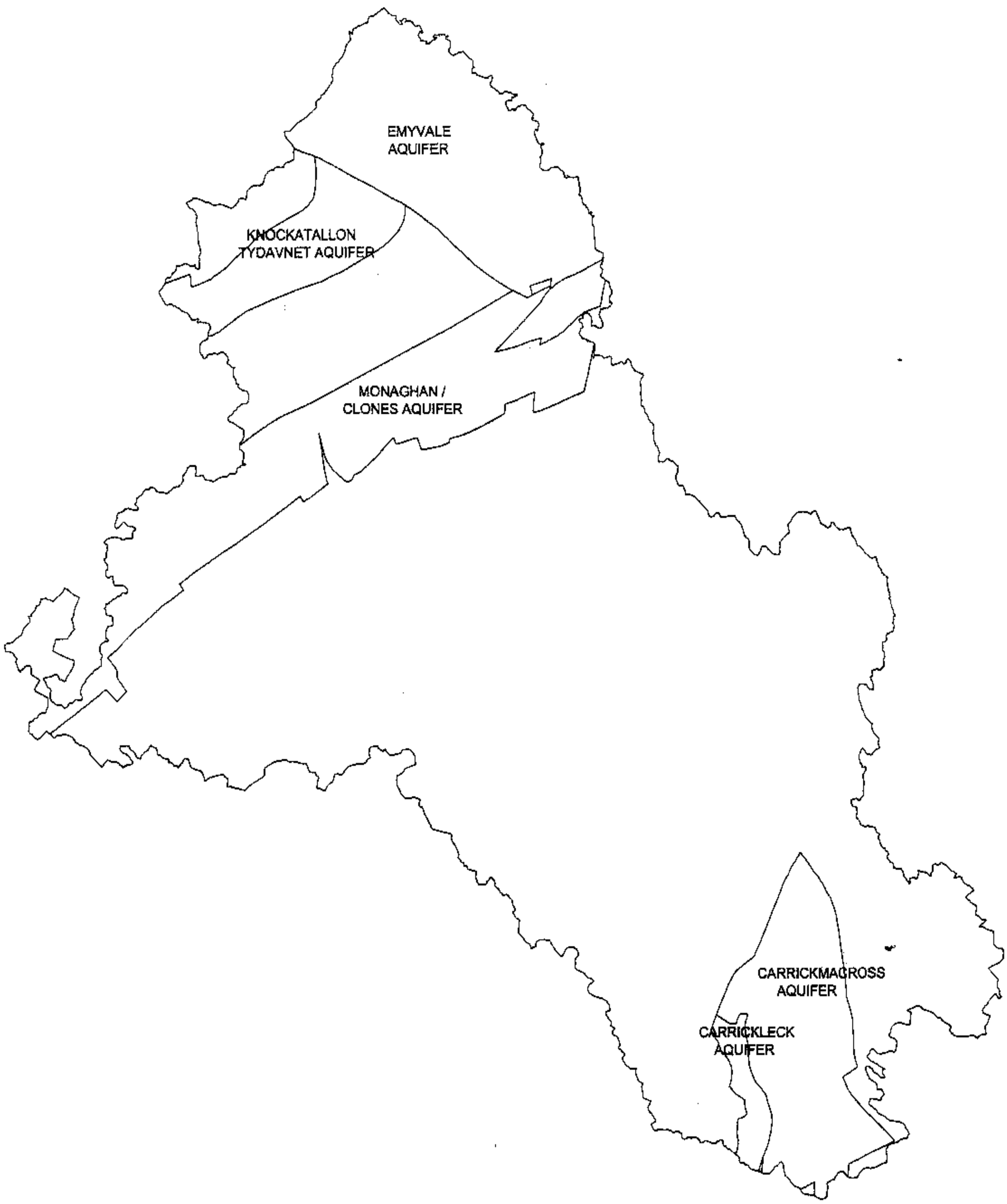

Figure 4.1 Location of the main aquifers in County Monaghan.

only two swallow holes observed in the Milverton Group Limestones (Jackson, 1955). South of the county boundary with Meath, these limestones have been extensively covered with subsoils which 'hide' the surface expression of these features. Similarly, east of Carrickmacross, the relatively thicker overburden obscures potential karst features. Extensive field mapping of the karst features in this aquifer has not been carried out, and the number of karst features on record is likely to be only a small proportion of those present. During site investigations for the N2 realignment from Aclint-Carrickmacross, a line of sinkholes near Moylan Lough is referred to in a geological pre-survey, and is shown on Map 4S (B.J. Murphy, 1993). Many of these sinkholes are included in the GSI's karst database, although information other than their location is not known. Quite a few caves are also recorded in this aquifer at Kilmactrasna, 'Finn McCool's Cave' in Cloghvally, and a ¼-mile long cave has been explored at Tiragarvan (Coleman, 1952).

Numerous springs are recorded within the Mullaghfin Limestone, although all of these may not be related to karstification. Some are likely to reflect the intersection of a high water table with the ground surface, and so do not necessarily represent the dissolution of the limestone. However, specific information is not available from every spring to allow for confirmation of their karstic nature.

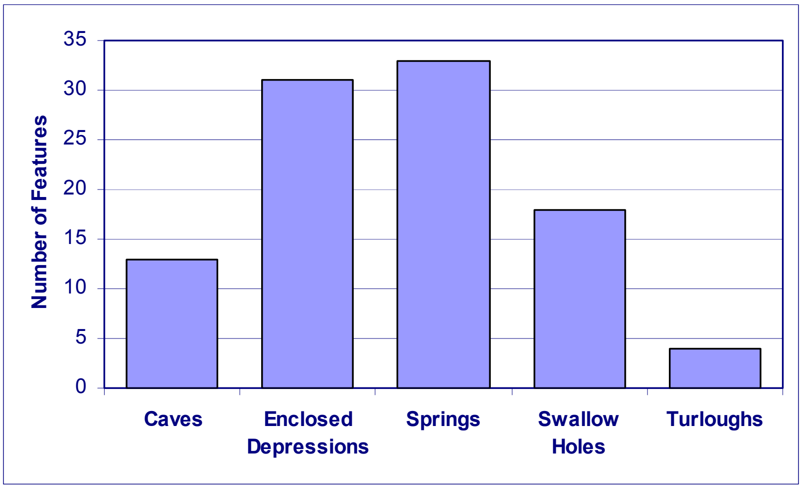

Figure 4.2 Occurrence of different karst features in the Mullaghfin Limestones in County Monaghan, as recorded in the GSI Karst Database. (It's possible that not all springs are due to the dissolution of the limestones).

In well developed karst systems, most groundwater flow is expected to be along solutionally enlarged fractures and fissures, with little groundwater movement in the rock between these conduits. Also, much of the precipitation is expected to recharge rapidly to the aquifer and, where water flow does occur at the surface, the streams often have 'flashy' flow regimes. Due to the presence of conduit flow, wide fluctuations in water table levels are expected. Little data are available on water table variations in this aquifer. As part of the NERDO report, water levels were monitored within this aquifer on a monthly basis from October 1978 – September 1979. The maximum variation recorded in any well was 11.5 m at Mokeeran, although pumping of the well may have accentuated the drawdown. The mean variation of water levels in this aquifer is 5.1 m. A water table map produced from this data as part of the NERDO report shows water levels decreasing towards the south towards the River Lagan, with a groundwater ridge mapped just south of Carrickmacross. This ridge may be due to a perched water table or an impermeable zone; however, further and more recent data are needed to fully understand the cause.

The flow rates within the conduits of karstic systems are typically quite high, usually on the order of tens of metres per hour. Limited tracer tests at some of the sinkholes and springs in the Annahaia Townland were performed in 1986 to investigate the hydrogeological characteristics in the vicinity of a landfill site (Mullen, 1986). The maximum velocity measured during the test was 60 m/hr (1.4 km/d). Within the area of this aquifer a high degree of interconnection between surface water and groundwater is expected, as water flows into swallow holes and rises at springs. For example, Spring Lough is probably fed mainly by groundwater, and Mullen (1986) refers to groundwater feeding into Moylan Lough. The lack of surface water inlets or outlets for these lakes supports this conclusion.

Jackson (1955) describes the limestones in the Carrickmacross area as being well bedded. These bedding planes are likely to be the focus of groundwater movement, and the dissolution of the limestone is likely to occur preferentially along them. Little well data are available for this aquifer; only 15 wells have useable information. All of these wells have yields of more than 100 m^3/d, eight of which have yields above 400 m^3/d. These wells plot mostly in productivity classes I and II, as shown in Figure 4.3.

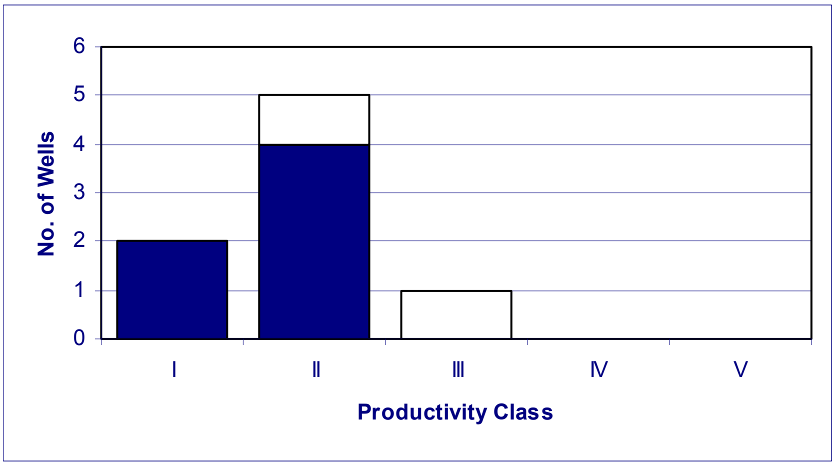

Figure 4.3 Well productivities from the Carrickmacross area aquifer. The shaded data are from the Mullaghfin Limestone in County Monaghan; unshaded data are from the Milverton Group Limestones in County Meath.

The current public water supply for Carrickmacross is located in this aquifer at Nafarty and Spring Lake. The Nafarty supply originally consisted of a spring supplying 1320 m^3/d, however, as this spring had a reduced discharge during the summer, it could not meet the water demands. Currently, the source consists of a nearby spring field that feeds a lagoon combined with a trial well that was drilled in October 2001. The spring field supplies approximately 720 m^3/d while the borehole supplies 528 m^3/d. The transmissivity calculated from a 72-hour pumping test at the Nafarty trial well is between 20-130 m^2/d (Geotechnical and Environmental Services (GES), 2000). It is expected that this trial well will be replaced by a larger production borehole in the near future. Adjacent to this supply is a production well at Rye Valley Foods, which provides 1000 m^3/d for the company. Interference between these two wells has not been reported.

The supply at Spring Lake consists of two wells supplying a total of 1400 m^3/d. Up until drilling of the wells, this amount was abstracted from Spring Lake; currently, no water is being abstracted from the lake. The maximum safe yield estimated from the 72-hour pumping test on the trial well is 895 m^3/d and the calculated transmissivity is around 210 m^2/d (GES, 2000). This well is now supplying 1128 m^3/d (47 m^3/hr), with the subsequently drilled production well supplying 272 m^3/d (11 m^3/hr). Although the wells are only 5 m apart, there is a nine metre difference in static water level between the two, suggesting that the wells intersect different fractures. In addition, the water levels in the production well appear to drop more quickly with pumping than in the original trial well. In order to increase the amount of water abstracted from this location, one more production well is expected to be drilled approximately 100 m away from the existing wells. The desired yield is 1200 m^3/d from each well.

One other exploratory public supply well was drilled in this aquifer in Tullyvaragh Lower. The maximum yield for this well was quite high at 1727 m^3/d, with a calculated transmissivity of between 115-270 m^2/d (GES, 2000).

One failed well has also been recorded in this aquifer. Usually with karst regimes, well productivities are variable and most high productivities tend to correspond to intersected karst conduits. Low productivity or failed wells can be common, reflecting the lack of flow between individual conduits. The apparent lack of variation in the well data from Monaghan for this aquifer may be influenced by the small dataset, but is most likely due the diffuse nature of flow within the karstic system.

The Carrickmacross area aquifer consists of clean limestone that has been extensively karstified. The flow regime in the area is strongly affected by the aquifer, with recharge occurring rapidly. Streams and lakes in the area are also predominantly supplied by baseflow. The well data indicate that high permeability zones exist within the aquifer. Due to the karstic nature of the aquifer, the permeabilities are likely to be variable. Thus, this aquifer is classified as a regionally important karstic aquifer (Rk). Given the number of productive wells and the apparent lack of 'failed' or 'poor' wells, this aquifer is considered to be dominated by diffuse flow within the karstic system (Rk^d).

4.8 Regionally Important Fissured Aquifers (Rf)

4.8.1 Monaghan-Clones Area: Fearnaght Sandstone (FT), Cooldaragh Formation (CH), Ulster Canal Limestone (UC), Ballysteen Limestone (BA), Ballyshannon Limestone (BS), Dartry Limestone (DA), Drumgesh Shale (DH) and Benbulben Shale (basal only) (BN)

This aquifer is comprised of eight bedrock units. While there is likely to be some variability in the hydrological parameters, they are taken to be broadly similar and to be interconnected hydraulically. The aquifer lies in a band across the county from Monaghan to Clones and covers an area of 132 km^2 (Figure 4.1). This aquifer is rarely seen in outcrop as it is covered by thick (>5 m) subsoils. Due to the subsoil cover, stream density and flow data are more likely to represent the nature of the subsoils rather than the bedrock, and so are not used to assess this aquifer.

The Monaghan-Clones area aquifer is bounded to the south by a fault that juxtaposes the Fearnaght Sandstone against Lower Palaeozoic rocks; to the north, it is bounded primarily by the Benbulben shales. However, the mapped geological boundary is not used as the aquifer boundary in this case. The bedrock compilation sheets indicate that the lower portion of the Benbulben Shale contains dolomitised limestone interbeds. As shown by one of the Monaghan public supply wells, these interbeds are capable of supplying large amounts of water. Similarly, faulting and/or associated fractures between the Dartry limestones and Benbulben shales is probably responsible for high yields for the well at Drumbenagh (PW5). Based on these well data, approximately the first 1 km (as shown on the geology map, Map 1) of the Benbulben Shale is included in the Monaghan-Clones area aquifer. This portion of the Benbulben shales included in the aquifer also matches up with the northern boundary for the Drumgesh Shales (see Map 1, Map 5 and Figure 4.1).

Only some of the bedrock units comprising the aquifer (FT, CH, UC, BA and DH) extend west to Clones and into County Cavan. In fact, the Drumgesh shale is mapped only in the western part of the aquifer; north Smithborough, the Ballyshannon Limestone grades laterally into the Drumgesh Shale. As with the Benbulben shale, the well data indicates that the Drumgesh Shale has interbeds of clean and/or dolomitised limestone, which result in highly productive wells. To the east, in County Armagh, only the basal rock units (FT, CH, and UC) are present and are faulted against the Maydown Limestone (Section 4.9.1).

Groundwater flow will occur largely along fractures and faults. Numerous north-south faults have been mapped crosscutting this aquifer, offsetting it against itself. Additionally, east-west trending faults are mapped around the Dartry Limestone. These faults are likely to increase the permeability of the aquifer, and additional fracturing may be associated with these faults. Where clean limestones are present, dissolution may occur along faults, fractures and bedding planes, widening them and enhancing the permeability.

Overall, the permeability will be influenced by the fracturing and faulting within and between the various rock units. However, the permeability will also be effected by low permeability fine grained and shaly beds within some of the limestone rock units (i.e., Ballysteen Limestone, Cooldaragh Limestone and Ulster Canal units). In general, the effect of the low permeability beds, which trend east-west, may be reduced, or even negated completely, by the fracturing and faulting which is largely north-northeast to south-southwest. The permeability in the two shale units (DH and BN) included in this aquifer will be dictated by the presence and continuity of the clean limestones and dolomite interbeds.

From 1978-1979, the water levels in 12 wells within this aquifer in Monaghan were monitored as part of the NERDO report (AFF and GSI, 1981). The maximum annual variation observed is 8.7 m, while the average annual variation is 3.3 m. Water table maps, prepared as part of the NERDO report and by the GSI for the Monaghan town source protection report, shows groundwater flow going towards the Blackwater River just west of Monaghan town. To the east of Monaghan town, groundwater is probably not discharging to the Blackwater River, but is more likely flowing eastwards to the Blackwater/Cor River system. In the vicinity of Smithborough and Clones, the groundwater flow direction is southwest, towards the Finn River.

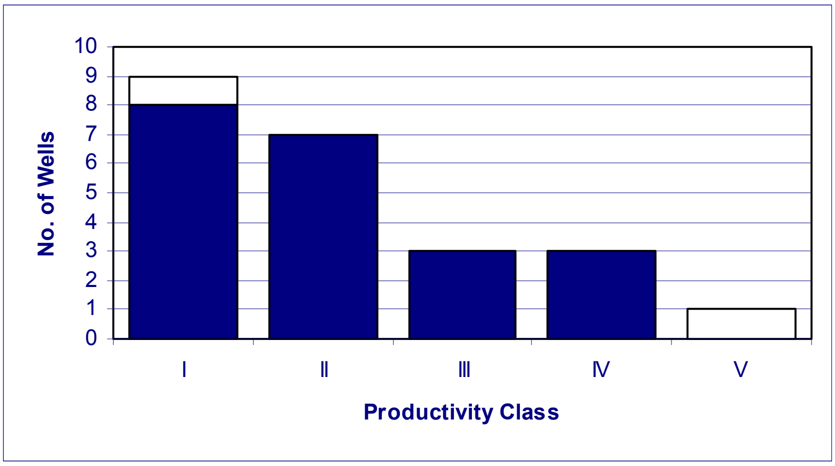

Figure 4.4 Well productivities from the Monaghan-Clones area aquifer. Shaded data are from County Monaghan; unshaded data are from surrounding counties.

Overall, there are a total of 55 wells with useable yield information in this aquifer. Of these, 84% have yields higher than 100 m^3/d and 35% are greater than 400 m^3/d. Two failed wells have been identified, suggesting that impermeable zones are present. Well productivity data are available from 19 wells; these fall largely into classes I and II, but range across all classes, as shown in Figure 4.4. The Hydrogeological Map of Northern Ireland shows that these rock units are classified as a "highly productive aquifer in which flow is dominantly in fissures or other discontinuities" (British Geological Survey (BGS), 1994). Given the nature of the rock units and the distribution of well productivities within the Monaghan-Clones area aquifer, the GSI classifies this as a regionally important, fissured aquifer (Rf), which is a similar classification to that from Northern Ireland. The following sections discuss these well data and describe the hydrogeological characteristics of each unit. Each of the rock types are described in Section 2 and are shown on Map 1.

Fearnaght Sandstone (FT)

The Fearnaght Sandstone is made of quartz-rich conglomerates and sandstones, and comprises the basal (youngest) rock unit of this aquifer. This unit is thin, and alone covers an area of less than 5 km^2. This unit abuts the Lower Palaeozoic rocks to the south, and marks the beginning of the limestones in northern Monaghan. Although the southern boundary is a fault, due to the low permeability nature of the Lower Palaeozoic rocks, little groundwater is expected to flow across this boundary. Numerous north-south trending faults also cut this rock unit. Where these faults displace the Fearnaght Sandstone against the Lower Palaeozoic rocks, little groundwater flow is expected across these faults. However, where this aquifer is displaced against other members of the Monaghan-Clones aquifer, groundwater is expected to flow across the faults as the aquifer members are hydraulically connected.

Data for the Fearnaght Sandstone are sparse, with only one well having a yield of over 100 m^3/d recorded in the county. No data are available from County Cavan or Northern Ireland.

Cooldaragh Formation (CH)

The Cooldaragh Formation covers an area of almost 30 km^2 and is comprised of interbedded siltstones, mudstones and limestones. It also contains evaporite lenses, which may affect the quality of the water (see the separate hydrochemical report for more information). Little well data are available for this rock unit from County Monaghan, nor are data available from County Cavan or Northern Ireland. Of the 14 well yields on hand, 12 have yields higher than 100 m^3/d with half of these having yields above 400 m^3/d. There is one failed well recorded, suggesting that low productivity zones are present within the unit. Five well productivities are available, four of which fall into class II and one into class III. A well drilled during the NERDO report at Templetate in Smithborough was found to have a transmissivity of 475 m^2/d, which is relatively high and indicates a good aquifer (AFF and GSI, 1981). This well is currently used as a public supply well for Smithborough.

The two new production wells in Scotshouse for the Clones public water supply are also located in this unit. Transmissivities calculated from 4-week pumping tests on wells PW1 and PW2 are 80 and 400 m^2/d, respectively. These wells are productive, although one well may be constrained since it is surrounded on three sides by fault boundaries with the low permeability Lower Palaeozoic rocks (see the separate source protection report for more information).

Ulster Canal Limestone (UC)

The Ulster Canal Limestone is likely to be fairly thin and covers an area of only 5 km^2. It is made of calcareous sandstones and clean limestones, and is expected to be fairly permeable. Data are available for only one well within County Monaghan; no data from County Cavan or Northern Ireland are available. This well is considered ‘good’ since it has a yield of >100 m^3/d; productivity data are not available for this well.

Ballysteen Limestone (BA)

The Ballysteen Limestone is a fairly thick unit that covers an area of approximately 40 km^2. These limestones are thought to be cleaner near the base of the unit, with the more muddy limestones at the top. The Ballysteen Limestone corresponds to the Argillaceous Bioclastic Limestone (ABL) mapped elsewhere and referred to in the County Meath Groundwater Protection Scheme. The well data analysed for the Ballysteen includes data from Counties Meath and Cavan.

Of the rock units that comprise this aquifer, the Ballysteen Limestone has the best information, with data from 25 wells available. Of these wells, 80% have yields higher than 100 m^3/d with half of these having yields higher than 400 m^3/d. One failed well is recorded, suggesting the presence of low permeability zones within the unit. Productivity data are available for eight of the wells and have quite a range, with four wells in Class I and II, and the remainder distributed throughout the other three classes.

The two Monaghan public supply wells at Roosky are located within the Ballysteen limestones, and are currently supplying 1110 m^3/d from this aquifer. Transmissivities calculated from the public supply well at Roosky range from 115-240 m^2/d. The Monaghan public supply well at Silver Stream (PW7) is also located within this unit. The transmissivity calculated by K.T. Cullen and Co. (KTC, 1998) from a 72-hour pumping test is 160 m^2/d. A well at Cortlovin Bridge, studied as part of the NERDO report, has an estimated transmissivity of 174 m^3/d (AFF and GSI, 1981). Together, these data show that the Ballysteen is permeable, productive aquifer.

The majority of the productive wells in this unit are located near Monaghan town; fewer productive wells are found in the Ballysteen limestones around Clones. Whether this is due to lithological or structural reasons, or just due to the number of wells drilled, is unknown. In other counties, well productivities in the Ballysteen limestones have been variable and aquifer classifications range from a poor aquifer (Pl) to locally important (Lm). In Monaghan, available well data indicates that this unit is part of the regionally important, fissured Monaghan-Clones area aquifer. The reason for the greater productivity in the Monaghan-Clones aquifer is not known.

Ballyshannon Limestone (BS)

The Ballyshannon consists of clean, well bedded limestones with infrequent shale beds and possible dolomitised zones (see Section 4.5.4) and covers an area of 27 km^2. They are found mostly to the west, north and northeast of Monaghan town and are underlain by the Ballysteen Limestone. Just north of Smithborough, the Ballyshannon limestones are truncated by a fault against the Drumgesh Shale.

Numerous north-south trending faults intersect the Ballyshannon, usually displacing it against itself or the Ballysteen Limestone. These faults and associated fractures are likely to provide conduits for groundwater flow. In addition, dissolution will probably occur along these zones due to the presence of clean limestone. The presence of dolomitisation has been recorded in geological descriptions as well as in the borehole logs for the Monaghan town public supply wells. However, it is unknown whether the dolomitisation follows fractures or bedding planes, or both. Either way, dolomitisation will increase the permeability of this unit.

The majority of the recently drilled production wells for Monaghan town are located in the Ballyshannon Limestone, as are many industrial wells, including those at Monaghan Co-Op and Monaghan Poultry Products. Overall, yield data are available for 15 wells with six having productivity data; no data from surrounding counties are obtainable. Of these wells, 13 have yields greater than 100 m^3/d and nine have yields greater than 400 m^3/d. Additionally, four of the six productivities are in class I, indicating an important aquifer. The remaining wells plot in classes III and IV, suggesting that low permeability zones are present within this unit. The public supply wells at Lambs Lough (PW1), The Wood (PW2), Ballyalbany (PW4) and Crosses (PW8) are located within the Ballyshannon limestone. Transmissivities calculated from 72-hour pumping test data at these are high and range from 65-200 m^2/d. Pumping has only started at Lambs Lough (PW1), which is abstracting at a rate of 1100 – 1350 m^3/d. Pumping at the remaining wells is expected to start in 2002.

Dartry Limestone

The portion of the Dartry Limestone in the Monaghan-Clones area aquifer covers an area of 6.5 km^2. The Dartry limestones are clean and well bedded with bands of chert. Two wells with yields above 400 m^3/d are located in this unit. Both of these are Monaghan town public supply wells, and are located at Drumbenagh (PW5) and Kilnadreen (PW6). Productivities for these wells are in class I, suggesting an important aquifer. The transmissivities calculated from 72-hour pumping tests at the related trial wells are 200-290 m^2/d for PW5, and 50 m^2/d for PW6. The borehole log for PW5 describes “cavernous and collapsing limestone”, and the geologic map indicates that this well may lie on or near a fault. The high transmissivity from this well are most likely due to the fault zone, or fractures associated with the fault zone.

Well data from the Darty Limestone outside this aquifer show similar well yields and productivities, and are discussed as part of the Knockatallon/Tydavnet Aquifer, in Section 4.7.3.

Drumgesh Shale

The Drumgesh Shale ranges from fossiliferous shales and mudstones with minor limestones to calcareous sandy limestone with local chert and shaly interbeds. It overlies the Ballysteen Limestone, and is only mapped in the western part of County Monaghan, near Clones. This unit is thought to grade eastward into the Ballyshannon Limestones, reflecting a deepening of the basin it was deposited in (MacDermot, pers. comm.). Due to this lateral transition, interbedding of the clean Ballyshannon limestones with the Drumgesh shales is expected in the base of the formation, near the contact with the Ballysteen. Overall, the Drumgesh Shale covers an area of 22 km^2 and is between 400 and 1200 m thick.

Boreholes drilled during water supply exploration in the Roranna and Clonagore townlands have encountered weathered, dolomitised limestones and cavities at depth. The weathered zone in the Roranna townland well appears to be similar to descriptions of the dolomitised Ballyshannon Limestone. These are most likely dolomitised limestone interbeds within the shales. In Clonagore, a two metre cavity was encountered at 15 m below ground level. This cavity is probably due to the dissolution of clean limestone interbeds in the shale. Since the Drumgesh shales are thought to grade eastward into the Ballyshannon limestones, these zones most likely represent some ‘interfingering’ of the two units, and will dominate the permeability of this unit.

Little well data are available for the Drumgesh shales. Of the five available well yields, all are above 100 m^3/d and one has a yield of over 400 m^3/d. The two available well productivities plot in category II, suggesting a good aquifer. Borehole logs for these zones indicate that the productive zones correspond to the weathered, clean dolomitised portions of the well. It is unknown how pervasive the dolomitised and weathered zones are within this aquifer.

According to the Hydrogeological Map of Northern Ireland, the Drumgesh Shale is considered part of the ‘lower limestones’, and so is classed as a ‘highly productive aquifer in which flow is dominantly in fissures and other discontinuities’ (BGS, 1994). While the overall nature of this unit may be shaly, groundwater flow will probably occur along the non-shale, high permeability zones. Given the potential for productive wells in this unit, the Drumgesh Shales are considered as part of the regionally important Monaghan-Clones area aquifer.

Bundoran Shale

This rock unit consists of shales with interbeds of clean limestone and dolomite near the base of the unit, where it overlies the Ballyshannon limestones. Productive wells are associated with these dolomitised zones, as shown by the Monaghan public supply wells at Drumreask (PW3) and Drumbenagh (PW5).

The well at Drumreask has a planned abstraction rate of 1250 m^3/d. Analysis of the results of a 72-hour pumping test at the associated trial well give a transmissivity of 200 m^2/d. The borehole log for this well shows that water inflows correspond to zones of dolomitised limestone, which probably represents interbedded zones of Ballyshannon-type limestone within the Bundoran shale.

The public supply well at Drumbenagh (PW5) is located on a fault boundary between the Bundoran Shale and Dartry Limestone. This well is also very productive, with a planned abstraction of 1250 m^3/d. Analyses of a 72-hour pumping test at the associated trial well give a transmissivity of 250 m^2/d. The borehole log for this well indicates ‘cavernous and collapsing limestone’, which may reflect the presence of, or fractures associated with, the fault.

While the overall nature of this unit may be shaly, the interbeds of clean and/or dolomitised limestone are expected to influence the permeablity of the lower portion of the Benbulben Shale. Given the presence of these non-shale, high permeability zones, and the potential for productive wells in this unit, a portion of the Benbulben Shale is considered as part of the regionally important Monaghan-Clones area aquifer. The boundary of this is based on information from the 1:10,560 bedrock data sheets, and marks the approximate area where the dolomite interbeds become less frequent.

4.8.2 The Knockatallon/Tydavnet Area: Dartry Limestone (DA) and Meenymore (ME)

The Knockatallon area aquifer consists of two rock units, the Dartry Limestone and the Meenymore, which are expected to be hydraulically connected. Within Monaghan, these rocks occur in a band along the south flank of Slieve Beagh, from the Mountain Water River in the east to the border with Fermanagh in the west. It is bounded by the Benbulben Shale to the south, the Carnmore Sandstone to the north, and by faults on the east and west. The Meenymore is present again in County Tyrone on the north side of Slieve Beagh, where it is quite thick. Overall, the aquifer covers an area of 80 km^2 and is rarely seen in outcrop as it is covered by thick (>20 m) subsoil deposits. Because of this, stream density and flow data are more likely to represent the nature of the subsoils rather than the bedrock, and so are not used to assess this aquifer.

Small areas of the Meenymore and Dartry units are mapped along the northern county boundary, just west of Aughnacloy. While this is not laterally contiguous with the Knockatallon area aquifer, it is adjacent to a large area of the Meenymore in County Tyrone, is a similar succession of rocks, and is expected to have similar hydrogeological characteristics. This area is therefore included in the discussion of the Knockatallon area aquifer.

The Meenymore is comprised of laminated limestones, mudstones, shales, sandstones and dolomites. This unit also contains evaporite deposits which influence the hydrochemistry of this aquifer (see the separate hydrochemistry report for more information). The Dartry Limestone is a clean, well-bedded unit with occasional chert bands. Groundwater flow will occur largely along fractures and faults within this aquifer. Little faulting is mapped within these rock units, although this is probably due to the thick cover of subsoils. Where (unmapped) faults do cut the aquifer, they are likely to increase the permeability somewhat, although within the shaly units the high clay content will hinder clean fracturing. Faulting in the non-shale interbeds may result in more open fractures, and in areas of clean limestone, dissolution may further enhance the permeability.

Extensive exploration for water supply wells has been carried out in this aquifer. In the early 1980s, and again in 1996, Monaghan UDC investigated using this aquifer to supply water for Monaghan town. Three trial wells were drilled in the early 1980s, one of which was subsequently used as a production well by the Tydavnet group water scheme. In July 1996, eight trial wells were drilled in the area, however the estimated yields were not high enough to meet the demands of Monaghan town. These eight wells are currently being used as observation wells by the Tydavnet group water scheme.

The Tydavnet group water scheme currently has five production wells in this aquifer, and many trial wells have been drilled in the area since the beginning of the scheme in 1981. These comprise the majority of the well data available for this aquifer assessment. Since its beginning in 1981, the group water scheme has had difficulty with dropping water levels in the wells. Between 1983-1988, pumping at the initial supply well abstracted an estimated 250 million gallons, resulting in a 30 m drop in water level. Since then, pumping in the five current supply wells has resulted in similar amounts of drawdown in those wells. Analysis by Kelly (2001) shows that the thick subsoil deposits act as a confining layer over the aquifer, greatly reducing the amount of recharge available to the aquifer. The wells used for the Tydavnet water scheme straddle the mapped boundary of the Dartry/Meenymore. Examination of borehole logs suggests that the Dartry Limestones may not be as thick as expected in this area, however the data are insufficient to re-map the potential boundaries more accurately.

Overall, yield data are available from 26 wells in this aquifer, and productivity data are available from 10 wells, the ranges of which are shown in Figure 4.5. Yields of over 400 m^3/d are found in 17 of the wells. Just over half of the wells have productivities in Class I, although well productivity data for the Dartry Limestone in County Cavan suggest a wider range of productivities (Figure 4.5). Transmissivities calculated from pumping tests carried out at three of the Tydavnet production wells range from 25-70 m^3/d. No apparent difference in transmissivities is observed between wells mapped as being in the Dartry and in the Meenymore, suggesting that they are similar hydrogeologically.

According to the Hydrogeological Map of Northern Ireland, the Meenymore and Dartry Limestone are considered different aquifers, with the Meenymore classified as a "locally important sandstone aquifer in which flow is dominantly in fissures or other discontinuities". The Dartry Limestone is considered a "highly productive aquifer in which flow is dominantly in fissures or other discontinuities" (BGS, 1994). Given the high productivities and the amount of water that has been available for abstraction for the Tydavnet group water scheme, the Knockatallon area aquifer is classified as a regionally important fissured aquifer (Rf).

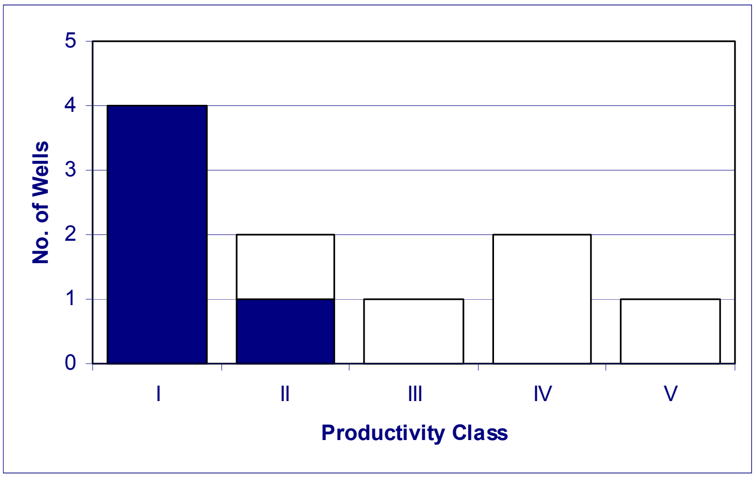

Figure 4.5 Well productivities for the Knockatallon/Tydavnet area aquifer. Shaded data are from County Monaghan; unshaded data are from County Cavan.

4.8.3 Carrickleck Sandstones (CR and CRcg)

The Carrickleck Sandstones are composed of thick alternating sequences of sandstones with shales, with the Carrickleck Sandstone Member being cleaner and less shaley. They are found in southern Monaghan, east to southeast of Carrickmacross, as shown on Figure 4.1 and Map 1. Within Monaghan they cover an area of roughly 10 km^2 and extend south into Counties Meath and Cavan, where they cover almost 8 km^2. The aquifer is bounded on the east and north by the Mullaghfin Limestone, and to the west by a fault, putting it in contact with the low permeability Kingscourt Gypsum unit. These sandstones also have a gradational contact with the Westphalian shale rocks in the northwest. While the eastern boundary may be hydraulically connected with the Carrickmacross Aquifer, little groundwater is expected to flow across the western boundary due to the contact with low permeability rocks.

These rock units are rarely seen in outcrop due to the thick (>5 m) cover of subsoils. Because of this thick overburden, stream density and flow data are more likely to represent the nature of the subsoils rather than the bedrock, and so are not used to assess this aquifer.

Groundwater flow in these sandstones is expected to be largely along faults and fractures. No faults are mapped within these sandstones. However, fractures developed in the sandstone portions of these units are likely to be open, while fractures within the shaley or mudstone beds are likely to be closed due to the high clay content in the shales. The shales within the Carrickleck Sandstone are sufficiently high in clay that in the Drumgoostat townland, weathered shales are being mined for use in pottery. Where the shales are near the ground surface, the land is often rushy and poorly drained.

Not only will the permeability of this unit be influenced by fractures and faulting, but also by the low permeability shale beds, which trend north-south.

A water table map prepared as part of the NERDO report focuses on the Mullaghfin Limestone, but suggests that groundwater in the Carrickleck Sandstones flows south-southeast towards the River Lagan. Three wells in these sandstones were monitored for water levels over a year, and an annual variation of 0.6-3.3 m was measured (AFF and GSI, 1981).

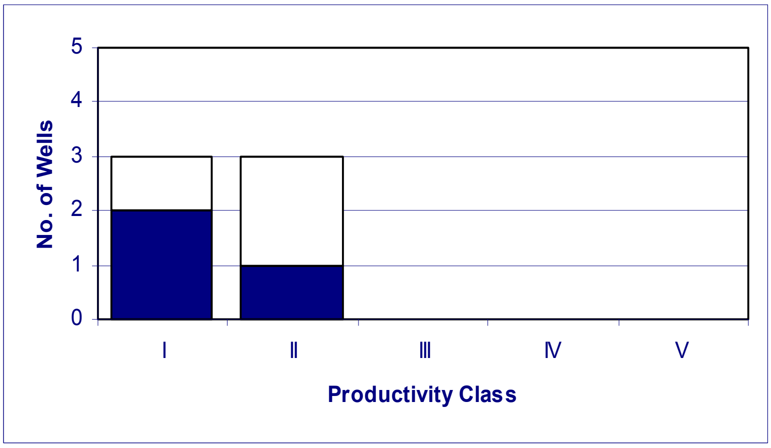

Figure 4.6 Well productivities for the Carrickleck sandstones. Shaded data are from County Monaghan; unshaded data are from Counties Cavan and Meath.

Yield information from eleven wells is available, including data from Counties Cavan and Meath. Nine of the wells have yields over 400 m^3/d, suggesting a good aquifer. Well productivities are available from six wells and are in classes I and II, as shown in Figure 4.6. One failed well is recorded in the Carrickleck Sandstone Member (CRcg), suggesting that unproductive zones are present. Eight wells drilled in the Carrickleck sandstones in Cavan and Meath, as part of investigations for the Kingscourt rural water supply, have yields ranging from 200-1200 m^3/d. Another potential water supply well for the Kingscourt RWSS was located in the Descart townland in Monaghan. Artesian conditions were observed in this borehole, with an overflow of 1090 m^3/d. During the pumping tests for these wells, steady state conditions were not obtained (Woods and Wright, 1998). Recent investigations for a new public supply well for Carrickmacross included a well drilled in the Lossets townland. This well yielded 1767 m^3/d during a 72-hour pumping test, and has an estimated transmissivity of around 100 m^2/d. Current investigations are still being carried out in this area, including a long-term pumping test on a recently installed production well.

Overall, well yields, productivities and transmissivities from these units suggest that these rocks are capable of supplying significant quantities of water, although the permeability is likely to be variable given the presence of shale beds. While this aquifer does not cover the minimum area of 25 km^2 for regional aquifer, it is classified as a regionally important fissured aquifer (Rf) due to its highly permeable nature.

4.9 Locally Important Aquifers, generally moderately productive (Lm)

4.9.1 Emyvale Area: Maydown Limestone (MA) and Carrickaness Sandstone (CS)

The Maydown Limestone and Carrickaness Sandstone underlie approximately 105 km^2 of northeast County Monaghan, including the Emyvale and Glaslough areas, as shown on Figure 4.1. The

Maydown limestones are described by Geraghty (1997) as being comprised primarily of muddy limestones, siltstones and shales. They are referred to in the NERDO report as the 'Calp Sandstones', and are described as consisting of weathered silty sandstones interbedded with muddy limestones and shales (AFF and GSI, 1981). Additionally, boreholes drilled in Emyvale show a succession of sandstones interbedded with limestones and shales. The Carrickaness Sandstone forms a band of clean quartz sandstone and mudstones within the Maydown Limestone. This aquifer seldom crops out as the area is extensively covered with thick (>10m) subsoils.

Groundwater flow will occur largely along fractures and faults within this aquifer. Due to the thickness of overburden, few faults are mapped in this unit. Those that are mapped tend to break the Carrickaness Sandstone into smaller segments, juxtaposing it against the Maydown Limestone. Additionally, a fold axis is mapped along the length of the Carrickaness sandstones, and may be associated with significant fracturing within the sandstones. The clean nature of the sandstone suggests that any fractures/faults may remain relatively open, giving rise to productive wells. Given the likely presence of some clean limestone, dissolution may occur along any fractures present within these layers. Dissolution may also occur along bedding planes within the limestones. The NERDO report mentions that wells drilled within this aquifer encountered friable sandstones, suggesting that the rocks may be weathered in places and that fractured zones are present (AFF and GSI, 1981).

As part of the 1981 NERDO study, water levels were measured in six wells within the Maydown Limestone, from 1978-1979. The maximum variation measured was 12 m at the Silverhill Duckling farm in Emyvale; however, this measurement was most likely affected by pumping at that well. The mean fluctuation over this period was 3.8 m. A water table contour map for the area shows that groundwater within this aquifer generally flows east towards the Blackwater River (AFF and GSI, 1981).

Little well data are available for this aquifer, so data from Northern Ireland have been incorporated into this assessment. Of the 23 useable well yields, over 18 have yields above 100 m^3/d and eight have yields above 400 m^3/d. Of the remaining wells, four are 'poor', and one failed. Productivity class information is available only for the four 'poor' wells, which all fall into class V. Data regarding these four shallow wells come from a landfill study in County Tyrone, Northern Ireland. Transmissivities calculated for these wells range from 0.3 – 2 m^2/d, and permeabilities range from $1.1x10^{-6}$ – $5.3x10^{-7}$ m/s (Glover Site Investigations, no date given). These values are lower than expected for this aquifer and suggest that there are unproductive zones within these limestones.

Six of the eight of the 'excellent' wells are located around Emyvale, with four belonging to Silverhill Duckling. Unfortunately, additional data are not available regarding these wells. The two remaining 'excellent' wells are located in Northern Ireland. According to the hydrogeological map of Northern Ireland, the Maydown Limestone and Carrickaness Sandstone are considered 'locally important [limestone/sandstone] aquifer in which flow is dominantly in fissures or other discontinuities' (BGS, 1994).

The presence of some high yielding wells in this aquifer suggests that these rocks can sustain productive wells. However, the interbedded nature of the limestones and sandstones also suggests that potential development may be restricted to local, high permeability zones. Thus, the Emyvale area aquifer is considered locally important, generally moderately productive (Lm).

4.9.2 Fingal Limestone and Shale (FNG)

The Fingal Limestone and Shale consist of muddy limestones and shale with some sandstone, and are a northern extension of the Calp Limestones found in County Meath (Strogen *et al.*, 1995). They underlie only 0.3 km^2 in County Monaghan; the majority of the deposit is in County Meath around Nobber. There are no well data available for this rock unit in County Monaghan.

Given the small area underlain by the Fingal Limestone and Shales, the classification for this aquifer is taken from the Meath Groundwater Protection Scheme (Woods and Wright, 1998). Thus, these rocks are classified as a locally important aquifer, generally moderately productive (Lm).

4.9.3 Carnmore Sandstone (MEce)

The Carnmore Sandstone is sub-unit of the Meenymore formation that consists of massive, clean, coarse-grained sandstone with thin, discontinuous layers of pebbles. It is found at the top of Slieve Beagh in northwest Monaghan, covering an approximate area of 19 km^2 and is thought to be about 75 m thick. Being on top of the mountain, this area is mostly covered by blanket peat deposits that are expected to be 3 m thick, on average. Since this area forms the headwaters of most streams and rivers that come off Slieve Beagh, river flow data are not available for consideration as part of the aquifer assessment.

No well data are available for the Carnmore Sandstone as there is little development in the area. Groundwater flow will occur largely along faults and fractures. The lack of shaley bands within the sandstones suggests that any faulting may result in open fractures, increasing the unit's permeability. Additionally, this aquifer potentially lies near the core of the Slieve Beagh syncline, and so may have a significant fracture system. According to the Hydrogeological Map of Northern Ireland, the Carnmore Sandstone is not differentiated from the Meenymore (Section 4.8.2), and is classified as a "locally important sandstone aquifer in which flow is dominantly in fissures or other discontinuities" (BGS, 1994).

The peat cover on these sandstones suggests that they are not sufficiently permeable to allow excess water to drain away underground. The potential proximity of this aquifer to this axis of the Slieve Beagh syncline means that there may be fractures; the clean nature of the sandstone suggests that any fractures would remain open to allow groundwater through-flow. Thus, this aquifer is considered a locally important aquifer that is generally moderately productive (Lm).

4.9.4 Kingscourt Sandstone

Within Monaghan, the Kingscourt Sandstone unit is composed of approximately 80 m of siltstone overlain by 200 m of sandstone and covers an area of 2 km^2. These sandstones are mapped as small band to the southwest of Carrickmacross that extends into Counties Cavan and Meath. They are faulted on all sides, and surrounded to the east and west by the Kingscourt Gypsum unit, which is composed of mudstones with thick (10-20 m) gypsum deposits (see Section 4.11.7).

Groundwater flow in this aquifer is expected to be largely along faults and fractures within the sandstones. Although no faults are mapped within the unit, fractures developed in the sandstone portions of these units are likely to be open. Additionally, this sandstone unit is poorly cemented and often very weathered which will further increase their permeability.

A water table map prepared as part of the NERDO report focuses on the Mullaghfin Limestone, but suggests that groundwater in these rocks flows south-southeast towards the River Lagan (AFF and GSI, 1981).

There is little hydrogeological information available for these rocks in County Monaghan. Sandstones of similar age and depositional environment to the Kingscourt Sandstone are found in Northern Ireland. These sandstones are reported to have significant primary porosity, meaning that the permeability is not dependent wholly upon fractures and fissures. The hydrogeological map of Northern Ireland shows these materials as a "highly productive aquifer in which intergranular flow is significant", and having a transmissivity of 100 m^2/d (BGS, 1994). It is assumed this is also the case in the Kingscourt Sandstones, although little research has been done on this topic. The fact that the sandstones are weathered and not very well cemented suggests that primary porosity is likely.

Additionally, being highly weathered, they are probably capable of transmitting significant volumes of groundwater.

Three excellent wells are recorded in the Kingscourt Sandstone, with well productivities ranging from Class I-III. As part of the NERDO report, a well was drilled at Mullantra, Kingscourt in 1981 to investigate the water supply potential of these sandstones. The sandstone encountered in the well was very friable and liable to collapse. The well yielded 915 m^3/d with a specific capacity of 23 m^3/d/m (productivity class II) and a transmissivity of 48 m^2/d. Additionally, the aquifer was found to be locally confined by over 40 m of till (boulder clay) at this location (AFF and GSI, 1981). Drilling of two wells east of Kingscourt in Counties Cavan and Meath for the Kingscourt water supply indicated estimated yields of 500 and 1030 m^3/d, respectively. Specific capacities for these wells are 15 and 105 m^3/d/m (productivity classes I and III).

Overall, well yields, productivities and transmissivities from these units suggest that these rocks are capable of supplying significant quantities of water. However, since it is not aerially extensive, the Kingscourt Sandstone is classified as a locally important, generally moderately productive aquifer (Lm).

4.10 Locally Important Aquifers, Moderately Productive in Local Zones (Ll)

4.10.1 Navan Group (NAV)

The Navan Group consist of a range of lithologies including basal conglomerates, sandstones, siltstones, shales, muddy limestones and cleaner limestones. Only a very small area (0.25 km^2) of the Navan Group is mapped in south County Monaghan; most of the aquifer is in County Meath.

Given the small area underlain by the Navan Group, the classification for this aquifer is taken from the Meath Groundwater Protection Scheme (Woods and Wright, 1998). These rocks are classified as a locally important aquifer, generally moderately productive only in local zones (Ll).

4.10.2 Bellanode Area: Bundoran Shale (BN), Mullaghmore Sandstone (MU) and Benbulben Shale (BB)

This aquifer covers an area of 94 km^2 and is found primarily on the southern slopes of Slieve Beagh; a small area of this aquifer also lies to the northeast of Monaghan town, just south of Glaslough. The Bundoran and Benbulben units both consist of shales with minor sandstone interbeds. These interbeds are possibly slightly more common and thicker in the Benbulben shale. The Mullaghmore Sandstone is a thin, distinct interbed that occurs between these two shale deposits. These units are considered as a unit because together they create a package with similar hydrogeologic characteristics. These units rarely crop out, due to the thick covering (>10 m) of subsoil deposits.

The high degree of bedded, fine grained material is likely to restrict groundwater circulation in this aquifer. Where faults cut the aquifer, they are likely to somewhat increase permeability, although the high clay content will hinder clean fracturing. Faulting in the non-shale interbeds may result in more open fractures. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are probably most intense.

Well data for these units are few and indicate a locally important aquifer. Eleven well yields are available, all of which have yields greater than 100 m^3/d and two of which have yields over 400 m^3/d. Only one well productivity value is available, which falls into categories III.

The limestone and sandstone interbeds in this unit, coupled with the available well yield data, indicate that this is not a poor aquifer. The lithology suggests that development will be possible in local zones (i.e. along faults, fractures and zones of clean limestone). Given this information, the Bellanode area aquifer is considered a locally important, generally productive only in local zones (Ll)

4.11 Poor Aquifers, Generally Unproductive Except for Local Zones (Pl)

4.11.1 Lower Palaeozoic Rocks (various bedrock units)

Many different rock units have been identified as Lower Palaeozoic rock, and are described in Chapter 2 and shown on Map 1. They are predominantly dirty sandstones and shales with minor volcanics and cover an area of 817 km^2 across the middle of the county. For aquifer classification purposes, they are considered together as a single hydrogeological unit as the groundwater characteristics are similar in each formation.

Groundwater flow will occur largely along fractures and faults within this aquifer. Where faults are present, they are likely to increase the permeability, although within the shaly units the high clay contact will hinder clean fracturing. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are probably most intense. The Silurian rocks, while heavily fractured, dip quite steeply making borehole intersection with these fractures unlikely (AFF and GSI, 1981). Additionally, dolerite dykes (intrusions) are common in the Ordovician rocks, and will act as barriers to groundwater flow since they crosscut faults and fractures.

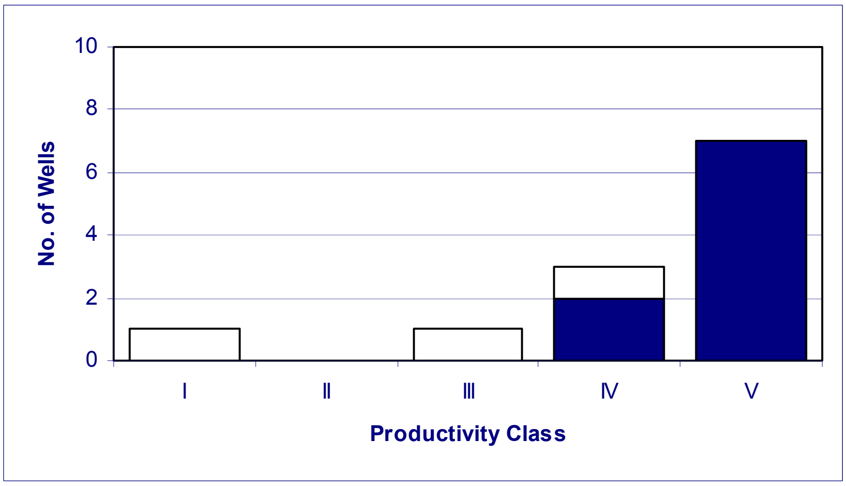

Figure 4.8 Well productivities for the Lower Palaeozoic rocks. Shaded data are from County Monaghan; unshaded data are from the surrounding counties.

Little data are available for these units, with well yields available for 37 wells including data from surrounding counties. No data are available for many of the individual rock units that make up this aquifer. Of the 37 wells, 13 have yields higher than 100 m^3/d, and only two have yields above 400 m^3/d. Four failed wells are also located within this aquifer. Well productivity data for the Lower Palaeozoic rocks in Monaghan, shown in Figure 4.8, generally fall into classes IV and V, indicating a poor aquifer.

Further evidence of the relatively low permeability is provided by the high drainage density, flashy runoff response of streams to rainfall, and a lack of large industrial wells or group water supplies located in these rocks. The public supply well for Clontibret is located in these rocks, however this well is only abstracting 12 m^3/d. No drawdown information is available from this well. According to the Hydrogeological Map of Northern Ireland, the Lower Palaeozoic rocks are classified as "aquifers of limited potential" and "a region underlain by impermeable rocks; generally without groundwater except at shallow depth" (BGS, 1994).

While the Lower Palaeozoic rocks are capable of supplying individual homes, and maybe even farms, it is unlikely that a large group or public water supply scheme could be sustainably developed in these rocks. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are probably most intense. Given the available well data and the low permeability nature of these rocks, they are considered poor aquifer, generally unproductive except for local zones (Pl).

4.11.2 Gabbro (G), Diorite (Di) and Dolerite (D)

Three small, separate intrusions of Gabbro and Diorite are located in the Ordovician rocks, covering a combined area of 2 km^2. No well data are available for these units. Dolerite dykes (linear intrusions) are also common in the Ordovician rocks. While these are unlikely to be large enough to provide significant amounts of groundwater, they may act as barriers to groundwater flow within the Lower Palaeozoic rocks since they crosscut faults and fracture systems.

The resistant nature of these rocks is likely to restrict groundwater circulation in these aquifers. Where faults cut these units they are likely to somewhat increase the permeability, however their areal extent is small and no faults are mapped within them. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are most intense. Similar intrusive rocks are considered "aquifers of limited potential" and "regions underlain by impermeable rocks; generally without groundwater except at shallow depth" (BGS, 1994).

Given these rock types and their limited areal extent, the gabbro, diorite and dolerite intrusions are classified as poor aquifers, generally unproductive except for local zones (Pl).

4.11.3 Cruicetown Limestone (CRT)

Only a very small area (0.4 km^2) in south Monaghan is underlain by these rocks, which extend south into County Meath. They are comprised of muddy limestone overlain by coarse grained, calcareous sandstone with little shale. It corresponds to the Argillaceous Bioclastic Limestone (ABL) referred to on earlier maps and in the County Meath Groundwater Protection Scheme.

Given the small area in Monaghan underlain by the Cruicetown Limestone, the classification for this aquifer is taken from the Meath Groundwater Protection Scheme (Woods and Wright, 1998). These rocks are classified as a poor aquifer, generally unproductive except for local zones (Pl).

4.11.4 Ardagh Shale (AD)

Only a very small area (0.07 km^2) in south Monaghan is underlain by the Ardagh Shales, which are predominantly composed of siltstones, mudstones and shales. These shales extend south into County Meath, where they are more extensive.

Given the small area in Monaghan underlain by the Ardagh Shale, the classification for this unit is taken from the Meath Groundwater Protection Scheme (Woods and Wright, 1998). These rocks are classified as a poor aquifer, generally unproductive except for local zones (Pl).

4.11.5 Westphalian Shale (WES)

The Westphalian shales in Monaghan are located south east of Carrickmacross and cover an approximate area of just 1.3 km^2. These rocks consist of black shales with thin-bedded siltstones, sandstones and thin seams of coal; overall the unit is thought to be about 80 m thick. The Westphalian shales are not generally seen in outcrop due to the thick (>5m) cover of subsoil generally found in this area.

The high degree of bedded, fine grained material is likely to restrict groundwater circulation in this aquifer. Where faults cut the aquifer, they are likely to somewhat increase permeability, although the high clay content will hinder clean fracturing. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are probably most intense.

No well data are available for this aquifer, even when considering data from similar rocks in surrounding counties. Given the shale-rich nature of this unit, widespread secondary permeability is unlikely to occur. Thus, this unit is classified as a poor aquifer, which is generally unproductive except for local zones (Pl).

4.11.6 Kingscourt Gypsum

The Kingscourt Gypsum unit covers an area of 6.4 km^2 in County Monaghan. It is composed of fine grained mudstones with thick (10-20 m) gypsum deposits, and is found to the southwest of Carrickmacross. To the east, it is faulted against the Carrickleck sandstones; on the west, it is faulted against the low permeability Lower Palaeozoic rocks. To the northeast, it is in fault-contact with the Westphalian Shales. Finally, in the middle of the unit, the Kingscourt Sandstone is mapped as a thin, faulted strip.

The high degree of bedded, fine grained material is likely to restrict groundwater circulation in this aquifer. Where faults cut the aquifer, they are likely to somewhat increase permeability, although the high clay content of the mudstones will hinder clean fracturing. Groundwater flow through the aquifer is likely to be restricted to the upper few metres, where weathering and fracturing are probably most intense.

A water table map prepared as part of the NERDO report (1981) focuses on the Mullaghfin Limestone, but suggests that groundwater in these rocks flows south-southeast towards the River Lagan. Water levels in one well in the Kingscourt Gypsum were monitored for over a year, showing an annual variation of 6.9 m.

There is little hydrogeological information available for these rocks in County Monaghan, with only one well with a yield of over 400 m^3/d recorded in this unit. Mining has revealed karst features within the gypsum units that may transmit groundwater. However, the quality of water from the gypsum units may be unacceptable for drinking as a result of expected high sulphate concentrations. Furthermore, groundwater is thought to contribute little to the water in the mine, and the majority of water pumped out of the mine is thought to be surface water (Dave Kent, pers. com.).

Given the fine grained nature of this unit, widespread secondary permeability is unlikely to occur. This suggests that it is a poor aquifer, which is generally unproductive except for local zones (Pl).

4.12 Poor Aquifers, Generally Unproductive (Pu)

No bedrock units have been identified as generally unproductive, poor aquifers (Pu) aquifers in County Monaghan. While some of the Lower Palaeozoic rocks (see Section 4.10.1) may contain units that are Pu, available data are not sufficient to distinguish these.

4.13 Sand/Gravel Aquifers

A sand/gravel deposit is classed as an aquifer if it is over one km^2 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 these gravels often have a thin saturated zone. Conversely, in low lying areas (e.g. flood plains) a slightly lesser thickness may be adequate.

Sand/gravel deposits in Monaghan occur primarily in the northwest, at the southern base of Slieve Beigh. The majority of these deposits are discontinuous in nature, most being on the order of 1 km^2 or less. Where the deposits are more extensive, they have since been mined to the edges of the mapped deposits. Many of the smaller deposits, while probably capable of supplying a single family dwelling, are not large enough (areally or in thickness) to be capable of supplying a group scheme or village. Thus, no sand/gravel aquifers are identified within County Monaghan.

4.14 Summary of the Potential for Future Groundwater Development in County Monaghan

The rock units in County Monaghan are classified into the different aquifer categories, as summarised in Table 4.4.

Table 4.4 Summary of Aquifer Classifications for County Monaghan

Aquifer Category	Subdivision	Aquifer[3]/Bedrock Unit
Regionally important (R) (20%)[1]	Karst – diffuse flow dominant (**Rk**$_d$)[2]	Carrickmacross Aquifer
	Fissure flow dominant (**Rf**)[2]	Monaghan-Clones Aquifer Knockatallon/Tydavnet Aquifer Carrickleck Sandstone Aquifer
Locally important (L) (16%)[1]	Bedrock which is generally moderately productive (**Lm**)[2]	Emyvale Aquifer Carnmore Sandstone Finglas Limestone and Shale Kingscourt Sandstone
	Bedrock which is moderately productive only in local zones (**Ll**)	Navan Group Bellanode Aquifer
Poor (P) (64%)[1]	Bedrock which is generally unproductive except for local zones (**Pl**)	Lower Palaeozoic Rocks Dolerite, Diorite and Gabbro intrusions Cruicetown Limestone and Sandstone Ardagh Shale Westphalian Shale Kingscourt Gypsum
	Bedrock which is generally unproductive (**Pu**)	None identified

Notes:

1. *The percentages refer to the proportional areal extent of each aquifer category in Co. Monaghan.*
2. *The locations of the main aquifers are shown on Figure 4.1.*
3. *The locations of the rock unit names listed here are shown on Map 1.*
4. *No sand/gravel aquifers are delineated in County Monaghan.*

4.14.1 Bedrock Aquifers

The regionally important aquifers (**Rk** and **Rf**), summarised in Table 4.4, are capable of yielding substantial quantities of water for regional or local supplies, especially the limestones comprising the Monaghan-Clones and Carrickmacross aquifers. As with all such limestones, and especially with the karstified Mullaghfin and Milverton Group, permeability can be variable, and there may be failures as well as successful wells. In many of the aquifers, especially those that are comprised of several rock units, the permeability may be influenced by the presence of fine grained and shaley beds. However, in many situations, the effect of the low permeability zones is likely to be counteracted by fracturing and faulting.

Some of the bedrock units in County Monaghan are given a 'higher' aquifer classification compared with the classification of the same unit in other counties, based on the available well information. The reasons for the higher permeabilities in Monaghan are uncertain, but may be due to factors such as the presence of dolomite and a greater degree of fracturing. In addition, some of the bedrock units may be different, lithologically.

The amount of water available for abstraction in an aquifer depends on the amount of water that can infiltrate through the overlying sediments to recharge the aquifer. In County Monaghan, the subsoils are dominated by moderate and low permeability glacial tills. Moderate permeability subsoils may transmit anywhere from 30 – 60% of effective rainfall (rainfall – actual evapotranspiration), whereas low permeability subsoils may only transmit between 2 – 20% of effective rainfall. Additionally, the amount of recharge infiltrating to the aquifer is dependent upon the thickness of the subsoils. Therefore, where there are extensive, thick deposits of low permeability subsoils, the overall amount of groundwater available for future development may be limited. The northern half of Monaghan has a covering of thick, low permeability tills. Water balance and recharge estimations should be carried out prior to the drilling of any new large abstraction wells located here. Water levels should also be monitored during pumping to provide insight to the aquifer characteristics.

One example of an area with restricted recharge is the Knockatallon/Tydavnet Aquifer (Figure 4.1). This aquifer has historically supplied significant quantities of water for the Tydavnet group water scheme. However, water levels in these wells have been steadily dropping during pumping. This is most likely due to the thick (>15 m), clayey subsoil deposits, which restrict recharge from entering the groundwater system. The development potential of this aquifer is therefore likely to be limited, and careful planning is needed to ensure further dewatering of the aquifer does not occur.

Failed or poor yielding wells are a possibility in every bedrock type, given the fractured nature of Irish bedrock aquifers. However, the chances of a successful well will be improved by careful attention to the geological environment, the topographic location, and often by employing a geophysical survey to identify a fracture zone.

4.14.2 Sand/gravel

Due to the lack of extensive sand/gravel deposits in Monaghan, it is unlikely that any of the mapped deposits have the potential to provide sufficient yields to satisfy the needs of the County Council or group water schemes.

4.14.3 Remaining Rock Units

None of the remaining rock units (see Table 4.4) has the potential to provide sufficient yields to satisfy the likely needs of the County Council. While an occasional high yielding well is always possible in view of the folded and faulted nature of bedrock in Ireland, yields are generally low and may reduce further in dry weather.

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., 1999a). 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: **E**xtreme, **H**igh, **M**oderate and **L**ow 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., 1999a).

The vulnerability maps (6N, 6S) 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 of 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 by 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., 1999a).

	HYDROGEOLOGICAL CONDITIONS				
	DIFFUSE RECHARGE: SUBSOIL PERMEABILITY AND TYPE			**UNSATURATED ZONE**	**POINT RECHARGE**
SUBSOIL THICKNESS	**High Permeability** *(sand/gravel)*	**Moderate Permeability** *(e.g. sandy subsoil)*	**Low permeability** *(e.g. Clayey subsoil, clay, peat)*	*(Sand/gravel aquifers only)*	*(e.g. within 30m radius of swallow holes)*
0 - 3.0 m	Extreme	Extreme	Extreme	Extreme	Extreme
3.0 - 5.0 m	High	High	High	High	N/A
5.0 - 10.0 m	High	High	Moderate	High	N/A
> 10.0 m	High	Moderate	Low	High	N/A

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, as depicted on Maps 2N and 2S, 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 subsoils maps produced in the 1950s by Mike O'Meara (see Chapter 3, Map 2)
- the bedrock geology map (see Chapter 2, Map 1)
- the GSI karst database
- the GSI well database
- information from meetings with Cyril Carthy and Ronan McAteer of the Monaghan Teagasc office regarding land use, drainage and general soil information
- Soils information along county boundary areas from the Ordnance Survey of Northern Ireland Soils Maps (OSNI, 1995a-d)

5.3 Permeability of the Subsoils

5.3.1 Methodology

The permeability categories, and resulting vulnerability categories depicted on the vulnerability map (Map 6), 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 Monaghan, 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, sands and gravels 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 gravels (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 Monaghan, have established the following relationships (Swartz, 1999; Fitzsimons, 2001):

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 that 7.5% silt and clay (O'Suilleabhan, 2000).

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

Parent material. The parent material, in this case the bedrock, plays a critical role in providing the particles that have created the different subsoil permeabilities. 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 specific vegetation species can indicate low permeability subsoils 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). No rigorous analysis of drainage density was undertaken as part of this project, but the general abundance or absence of drainage ditches was recorded.

Soils map. No soils map exists for County Monaghan. In order to gain some knowledge of soils in Monaghan, the GSI met with representatives (Mr. Cyril Carthy and Mr. Ronan McAteer) from the Monaghan Teagasc office. In addition, soils maps of Northern Ireland were used around the borders of the county to give an indication of the expected soil type. Where detailed soil data are present, they can be used to assess drainage characteristics where specific site recharge observations are not available. Poorly drained soils such as surface water gleys are usually related to underlying low permeability subsoils; the more free draining soils such as brown earths and grey brown podzolics are more typical of the sandy and silty moderate permeability subsoils. The availability of a soils map for County Monaghan would have increased the confidence of some permeability boundaries, especially in areas where permeabilities are variable.

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'Suilleabhan, 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 bedrock and/or subsoil characteristics. It is intended that the assessments will allow a broad overview of relative permeabilities 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 Monaghan, 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 sections 5.4.1 to 5.4.5. Vulnerability maps, which are partly based on the permeability mapping, are presented on Maps 6N and 6S. Details of the supporting data for each permeability decision can be found in Appendix II.

5.4 Permeability Regions

There are nine broad permeability regions within County Monaghan. These are outlined below based on permeability categories.

5.4.1 Low Permeability Areas

In Monaghan, the deposits that have low permeabilities are clayey glacial tills, lacustrine clays and peat. Clayey tills are the most common of these low permeability deposits, dominating most of the county. Only very small areas of lacustrine clay are mapped around the base of Slieve Beagh. Similarly, there are not many extensive peat deposits in Monaghan, the largest one being on the upper reaches of Slieve Beagh.

Permeability Region 1: The northern tip of County Monaghan

This area stretches across the northern portion of the county from Glaslough in the east to include the southern slopes of Slieve Beagh in the west. It is underlain by clean and muddy limestones, sandstones and shales. Subsoils in the region are largely tills, although small areas of peat, alluvium and sand/gravel are mapped. The peat deposits are included in this permeability region, partly because of their low permeability, but also because they are thin and the underlying subsoils are likely to control the permeability. Some of the alluvium and sand/gravel deposits are considered separate permeability regions (6, 8 and 9), and are discussed in Sections 5.4.2 and 5.4.3.

Overall, this area is poorly drained, as evidenced by the abundance of rushes, field boundary drains and underground drains. Of the 30 subsoil samples described, all but two are described as 'CLAY', and grain size analyses show that samples consistently have more than 35% fines and 14% clay, indicating low permeability. In addition, soils information from Northern Ireland of surrounding areas show surface water gleys with impeded drainage, which supports the low permeability classification (OSNI, 1995a,b).

Permeability Region 4: Areas of low permeability between Monaghan and Clones
This region is made of discontinuous low permeability areas mapped within the moderate Permeability Region 3 (Section 5.4.2), as shown in Figure 5.1. The delineated units are mapable areas of low permeability subsoils within the larger moderate area, and are underlain primarily by the clean limestones of the Monaghan-Clones Aquifer. They are generally clusters of drumlins sharing similar subsoil, vegetation and drainage characteristics, which are different from the surrounding moderately permeable areas. Where small pockets of peat are mapped within these areas, they are considered as part of this permeability unit since they are thin and the underlying subsoils are likely to control the permeability.

Subsoil descriptions from these units are predominantly 'CLAY', and grain size analyses show that samples consistently have more than 35% fines and 14% clay, indicating low permeability. Additionally, within these units, the occurrence of rushes and field drains is higher than in the surrounding areas, which supports the low permeability classification. Soils information would be helpful in confirming these boundaries, as the presence of surface water gley soils can provide additional evidence for low permeability areas. The permeability boundaries for this region should be re-evaluated once the soils map for County Monaghan is completed.

Permeability Region 5: Newbliss – Castleblaney – Latton – Ballybay
This permeability region begins to the south of Permeability Region 3 (Section 5.4.2) and covers the middle of the county. This is primarily an upland area underlain by the Lower Palaeozoic rocks, which are mostly dirty sandstones with some shales and minor volcanics. Subsoils in this area are predominantly tills, with pockets of peat mapped mostly in lowlands and interdrumlin valleys. The peat deposits are included in this permeability region, partly because of their low permeability, but also because they are thin and the underlying subsoils are likely to control the permeability. Minor pockets of sand/gravel deposits and alluvium are also mapped within this permeability area, and are considered separately as part of Permeability Regions 6, 8 and 9 (Sections 5.4.2 and 5.4.3).

Subsoil descriptions are consistently 'CLAY', and abundant rushes and field drains were observed throughout the area, indicating low permeability. The grain size analyses are less straightforward. Of 21 samples that have grain size and clay information, 38% of the samples suggest low permeability by having more than 14% clay. Almost half (48%) of the samples fall just under the conclusive thresholds by having between 35-50% fines and between 12-14% clay. This is most likely due to the resistant nature of the dirty sandstones, which are not as broken down by glaciation as other rock types in Monaghan. Soils maps from Northern Ireland along the county boundary show surface water gley with poor drainage, further indicating low permeability subsoils. (OSNI, 1995c).

Overall, the predominance of 'CLAY' subsoil descriptions, abundant rushes and field drains, gley soils in neighbouring areas, and even the grain size analyses indicate the area is low permeability. Although most of these have clay percentages of 13 and 14%, these data are not conclusive in their own right. However, using the borderline grain sizes analyses in combination with the recharge observations, support a low permeability classification. Again, soils information would be helpful in confirming these boundaries. When the soils map for Monaghan becomes available, it may be useful for assessing whether small pockets of moderate permeability subsoils can be delineated in this region.

Permeability Region 7: Kingscourt
This permeability region is a small area (approx. 8 km^2) southwest of Carrickmacross, and is underlain by the Carrickleck sandstone and shale and the Kingscourt Gypsum mudstone. Subsoils are largely tills, with a few small pockets of peat. The peat deposits are included in this permeability region, partly because of their low permeability, but also because they are thin and the underlying subsoils are likely to control the vertical permeability.

Subsoil exposures in this area are few, with only three exposures described. These are classified as 'SILT', 'SILT/CLAY' and 'CLAY', indicating a mix of moderate and low permeability. Grain size data are equally variable, with all three samples having between 35-50% fines and clay percentages of 10, 14 and 17%. Rushes are commonly seen in this region, as are field drains. In addition, the soil in the corresponding area in County Meath is a gley, suggesting low permeability.

The permeability in this area is likely to be influenced by the underlying bedrock. The Carrickleck Sandstone is made of interbedded clean sandstones and black, weathered shales. Where the shales are the first bedrock encountered, they are likely to give rise to clayey, low permeability subsoils. However, the clean sandstones will probably result in more sandy, moderately permeable subsoils. Similarly, the fine grained mudstones are likely to result in clayey subsoils. Since the bedrock mapping does not distinguish which rock-type is the first encountered, some variability should be expected. Although small areas of moderately permeable subsoils derived from the clean sandstone may be present, the subsoils are generally low permeability. The delineation of this permeability region is based on field observations of subsoil type, vegetation and land use, combined with borehole information of first encountered rock type. Soils information would be useful to help confirm these boundaries, and this permeability region should be re-evaluated once the Monaghan soils map is completed.

5.4.2 Moderate Permeability Areas

In Monaghan, areas that are moderately permeable are typically sandy or silty subsoils, alluvium and poorly sorted sand/gravel deposits. Tills described as 'SAND' or 'SILT' are most commonly found in the Carrickmacross area. The region between Monaghan and Clones also has many of these subsoils, although it shows a high degree of mixed sediments. Some areas mapped as alluvium and the poorly sorted sand/gravel deposits are also described in this section. These deposits, while found county-wide, are concentrated at the base of Slieve Beagh's southern slopes. Clean, well sorted sands/gravels are considered high permeability, and are discussed as Permeability Region 9, in Section 5.4.3.

Permeability Region 3: Monaghan – Clones
The area between Monaghan and Clones is underlain largely by the clean limestones of the Monaghan-Clones Aquifer, with some overlap onto the Lower Palaeozoic dirty sandstones. This area contains small and discontinuous sand/gravel deposits, many of which are too small to be shown at the 1:50,000 scale, and in some cases are too small to be mapped at larger scales. Because of this, the subsoils in the area appear to be mixed, with subsoil descriptions of 'CLAY' adjacent to those of 'SAND' or 'SILT'. Where possible, areas with consistent low permeability indicators were delineated and discussed as Permeability Region 4 (Section 5.3.2). Areas of peat, alluvium and sand/gravel deposits are mapped within this permeability area. Areas mapped as peat are considered as part of this permeability unit, since the thin nature of most peat deposits means the underlying subsoils will control the permeability. Alluvial and poorly sorted sand/gravel deposits are considered to have a moderate permeability, and are discussed separately as Permeability Regions 6 and 8. Other, more well-sorted sand/gravel deposits are considered to have a high permeability and are discussed in Section 3.4.3.

Subsoil exposures from this area – not including those from Permeability Region 4 – show a mix of materials with 60% being described as either 'SILT' or 'SAND' and 37% described as 'CLAY'. In a few cases, individual subsoil exposures were found to have interbedded layers of 'SAND' and 'CLAY'. Grain size analyses further suggest mixed sediments. A majority (57%) of the samples have less than 35% fines, indicating moderate permeability. Only 7% of the samples have greater than 50% fines, and 36% are inconclusive, having a range between 35-50% fines. Only eight clay percentages are available, with 25% of the samples having less than 12% clay, indicating moderate permeability. 38% of the samples fall between the thresholds of 12-14%, making the data inconclusive on their own. Finally, the remaining 37% of samples have more than 17% clay, which suggests low permeability. The fact that many samples fall between 12-14% clay probably represents the fact that clay percentages were rarely measured for 'SAND' samples. Therefore, the distribution of the clay percentages may not be completely representative.

While some rushes and field drains were observed, there was a marked difference in their abundance between this region and that to the north (Permeability Region 1). Within this area, the soils maps from Northern Ireland show a mix of surface water gleys with impeded drainage and freely drained brown earths, often times on the same drumlin, reflecting the mixed nature of the subsoils.

Overall, given the variety of the subsoils and the difficulty in isolating them, this area is classified as having a moderate permeability. While in some areas clayey subsoils may impede recharge to groundwater, the presence of mixed sands and clays suggests that bypassing of the clayier layers will occur, increasing the infiltration to groundwater. When the soils map for Monaghan becomes available, it may be useful for assessing whether other small pockets of low permeability subsoils can be delineated in this region.

Permeability Region 2: Carrickmacross

This permeability region covers the area around Carrickmacross, and extends to the southern and eastern borders of the county. In the west, it ends in the area around Corduff and just south of Tullyvaragh Lower in the north. The area is largely underlain by karstified limestones, but includes some areas of Namurian sandstones and Lower Palaeozoic dirty sandstones. Subsoils in the area are largely comprised of tills, with minor pockets of peat, alluvium and sand/gravel. Areas mapped as peat are considered as part of this permeability unit, since the thin nature of most peat deposits mean that the underlying subsoils will control the permeability. Alluvial deposits are generally considered moderately permeable, and are discussed separately as Permeability Region 6. Some of the sand/gravel deposits are poorly sorted and so have a moderate permeability; these are discussed as Permeability Region 8. Other sand/gravel deposits have a high permeability, and are discussed in Section 3.4.5.

Of the 69 subsoils described from exposures and boreholes, 70% are classified as 'sandy SILT' or 'silty SAND', indicating moderate permeability. Of the remaining samples, 14% are classified as 'SILT/CLAY' and are considered borderline, and 17% were described as 'CLAY'. Grain size analyses were performed on 17 samples and show that there is an almost equal amount of samples with less than 35% fines as those with between 35-50% fines. The fines content alone is inconclusive when it is between 35-50%. Analysis of clay percentages shows that 63% of the samples have less than 12% clay, indicating moderate permeability. 25% of samples fall into the borderline area, having between 12 – 14% clay, and 12% of samples have more than 17% clay.

The vegetation in this permeability region further supports the moderate permeability classification of this region. Rushes are seldom seen, and field drains are infrequently observed. While many fields are used for grazing, some are also used for growing cereals, particularly south of Carrickmacross and Inniskeen. Soil information from the Meath soils map shows a small pocket of greybrown podzolics derived from Limestone till along the county boundary, which also supports moderate permeability. The remaining county boundary areas are gleys derived from river alluvium and peat, and so are not representative.

In the western part of this region, around Inniskeen, exposures indicate SILT on top of CLAY subsoils. This may indicate a transition zone between moderate and low permeability subsoils; however, sufficient evidence is unavailable for delineating a low permeability region. The Monaghan soils map, when available, would be useful in assessing whether a low permeability region can be delineated.

Permeability Region 6: 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 consist of fine-grained water sorted sands, silts and clays. With the exception of one alluvial deposit mapped in the south, the alluvial deposits in Monaghan do not tend to be gravelly.

In general, alluvial deposits are 1-2 m thick, and are largely composed of silt and sand, with occasional thin clay lenses. The areas of alluvium mapped along the smaller streams in the county are typically deposited when the gradient of a stream drops; these deposits are then reworked as the channel meanders back and forth across the low lying area (Robbie Meehan, pers. comm.). As the dominant grain size is usually silt, alluvial deposits on their own tend to be of moderate permeability unless they are associated with high energy rivers, in which case they may have a high permeability. They are quite recent deposits that are likely to be underlain by the subsoil type abutting them. Only along the largest rivers are they likely to be thicker than two or three metres. Unfortunately, the inaccessibility of riverbanks to drilling means that the actual depths of the alluvium in Monaghan have not been widely established. One borehole along the Blackwater River near Aughnacloy (BH61) has a thickness of 2.5 m overlying rock, while a second borehole (BH60) has 7 m of sand overlying 2 m of clay.

Since thicker subsoil deposits usually underlie alluvial deposits, the composite permeability of the pathway must be taken into account for vulnerability assessments. As little data on alluvial thickness are available, it is assumed that when alluvium is mapped in areas with subsoils that are greater than 10 m, the alluvium will not influence the permeability of the pathway, and the underlying subsoils determine the permeability. Where alluvium is mapped in areas with subsoils between 5-10 m thick, the underlying subsoil still largely dominates the permeability; however, near the 5 m contour the alluvium may have an influence. In these situations, alluvial deposits are assessed individually to take account of the depositional environment.

The largest alluvial deposit in Monaghan is near the Finn River, southwest of Clones. Moderate permeability alluvial deposits are also mapped along the Blackwater River, at the border with Northern Ireland. A borehole (BH100) drilled in an alluvial deposit southwest of Carrickmacross encountered more than 10 m of coarse gravel, which resulted in this particular deposit being mapped as high permeability.

Permeability Region 8: Poorly sorted sand/gravel deposits
These deposits are found primarily in the north and northwest of the county, and consist of small pockets of poorly sorted sands and gravels. They are neither clean enough nor large enough to contain quarries. Within Monaghan, they are found mostly along the base of Slieve Beagh and probably developed from melting glaciers that stagnated against the upland area formed by the Lower Palaeozoic rocks (Permeability Region 5) (Robbie Meehan, pers. com.). When surrounded by low permeability deposits, as in Permeability Region 1, they are distinguished by their well drained appearance.

Since many of these deposits are small, exposures for describing the subsoils are not generally available. Therefore, identification of poorly sorted sands/gravels was based on assessment of subsoil descriptions and notes from the original Quaternary geology maps (i.e., where descriptions indicated 'poorly sorted', 'unbedded' or 'clayey' gravel). Given this information, these deposits are expected to be moderately permeable. However, in large areas of northern Monaghan, these gravels are thin, not widespread and are underlain by thick till deposits, and the composite permeability of the pathway must be taken into account. As little data on the thickness of these small deposits are available, where the gravels are mapped in areas with subsoils greater than 10 m, it is unlikely that the gravel will influence the overall permeability, and the underlying subsoils determine the permeability. Where gravels are mapped in areas with subsoils between 5-10 m thick, the gravels are more likely to influence the permeability of the deposit, and so these areas are considered moderately permeable.

5.4.3 High Permeability Areas

With the exception of one alluvial deposit, the only deposits in Monaghan that have high permeabilities are well-sorted sand and gravel deposits. These deposits are limited within the county and tend to be found largely in discontinuous pockets north of a line drawn from Monaghan to Clones. Small deposits are also mapped around Carrickmacross. These sands and gravels were most likely laid down by running water coming from melting glaciers in the area, which washed away the smaller particles (silt and clay).

There are four sizeable sand/gravel deposits in County Monaghan: Smithborough; near Bragan (Watterson's Quarry); and east of Monaghan town, around Silver Stream. While sizeable for County Monaghan (~15 km^2), they are small compared to the extensive sand/gravel deposits found in the midlands (i.e., Kilkenny, where gravels cover about 90 km^2). In addition to these, there are many small and discontinuous sand/gravel deposits in the county. The three larger deposits are described below as Permeability Region 9a, b, and c, respectively; the discontinuous gravel pockets are described as Permeability Region 9d.

Permeability Region 9a: Smithborough sand/gravel deposit
Since the original subsoils mapping, the deposit delineated around Smithborough has been completely mined and the ground has since been regraded for farmland, leaving behind a gravel layer of unknown thickness. The NERDO report (AFF and GSI, 1981) discusses a well in these gravels that could be pumped at a high rate without significant drawdown, indicating highly permeable materials. However, permeability or transmissivity values are not available. Vegetation and drainage in the area reflects well drained conditions, with no rushes or field drains observed. Although land reclamation is unlikely to have significantly altered the boundaries of the deposit, the present-day extent of gravels is unclear, therefore only the area originally mapped as gravel is delineated as high permeability.

Permeability Region 9b: Bragan sand/gravel deposit
The gravels in the Bragan area are currently being mined at Watterson's Quarry, and are almost completely excavated to the mapped extent of the deposit. The mapped gravel deposit comprises bedded clean sands and gravels, and a sample collected from here for particle size analysis has 6% fines and 2% clay, indicating high permeability materials. Where the ground is undisturbed by mining practices, the ground appears hummocky and no rushes or field drains were observed. Considering that this area is surrounded by low permeability tills, the contrast in vegetation and drainage can be quite striking. Given the low percentage of fines and the use of this deposit for quarrying, these sands/gravels are considered highly permeable.

Permeability Region 9c: Silver Stream sand/gravel deposit
This deposit is mapped east of Monaghan town, near Silver Stream. One borehole (BH54) drilled through this deposit showed layers of 'GRAVEL' mixed with 'sandy SILT', however this borehole is located near the edge of the deposit where more mixing is likely to have occurred during deposition. Observations recorded during the original Quaternary geology mapping from other parts of this deposit indicate that the majority is clean sand and gravel. There are no particle size analyses from this deposit, and exposures in it are rare. No rushes or field drains were observed in this area, indicating that recharge is infiltrating the subsoils. The original field descriptions of the deposit combined with the low density of artificial drainage suggest that these subsoils have a high permeability.

Permeability Region 9d: Discontinuous sand/gravel deposits
There are many small, discontinuous sand and gravel deposits mapped within Permeability Regions 1 and 3, which are mostly underlain by the clean limestones of the Monaghan-Clones Aquifer. Other sand and gravel deposits are mapped on the karstified limestone around Carrickmacross. Many of

these smaller sand/gravel deposits appear hummocky and well drained, often times in contrast with the surrounding subsoils. Because of the discontinuous nature of these deposits, few recent field descriptions are available; however, those made during the original subsoils mapping in the 1950's were used to help identify the nature of these deposits. Where the deposits were described as 'bedded' or 'clean', it was assumed that they were water-lain and have similar characteristics to the gravels described in Regions 9a-c. Where the materials were described as 'clayey gravels' they are considered moderately permeable, and so are discussed as Permeability Region 8. No information was available for some of the smaller gravel deposits. In these cases, it was assumed that these were deposited by running water and would have a low percentage of fines; therefore, they are classified as high permeability.

5.4.4 Areas where rock is close to the surface and less than 3 m deep

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

Similarly, permeability classifications are not applied to the areas where the depth to bedrock is less than 3 m. This is primarily due to the automatic 'Extreme Vulnerability' rating based on the depth to rock, which means that permeability mapping focuses on the thicker deposits. In addition, the permeability of the <3 m areas may be different from the surrounding area due to a lesser amount of weathering and glacial abrasion. For example, over the Lower Palaeozoic rocks where the subsoils are generally thin, the subsoils are not very weathered and tend to consist of angular rock pieces, as opposed to fine and medium grained till deposits. In these cases, the permeability may in fact be higher than that of the deeper deposits. While this does not effect the groundwater protection scheme maps, permeability of these areas will need to be taken into account for surface water protection.

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 3.3.

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 and 6S) 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 and 6S are considered to provide a good basis for decision-making.

County Monaghan has an almost equal proportion of extreme/high and low vulnerability areas, with the north and western half dominated by low vulnerability materials and the southern half dominated by extreme and high vulnerability areas. The 3 m contour, which influences the extreme and high vulnerability categories, is based on outcrop information, Quaternary mapping and borehole data. Areas of rock outcrop and shallow rock (i.e. where the soil and subsoil are generally <1 m) are also shown on the vulnerability maps. Knowledge of these areas can help the local authority with planning decisions, as some provision is made in the protection responses for the landspreading of organic wastes for areas where rock is particularly close to the surface. The presence or absence of 5 m and 10 m contours, which influence the moderate and low categories, is reliant on borehole data, topographic gradients and the use of the shallower contours to guide their interpretation. These contours cannot be drawn without data from boreholes. Consequently, there may be more areas of moderate and low vulnerability than are currently depicted on Maps 6S and 6N. As more information becomes available, the maps should be updated.

Most of the extreme vulnerability areas are located above poor aquifers that have little groundwater development potential. In these areas, the drumlins tend to have a deeper depth to rock, and consequently a lower vulnerability. Since the drawing of depth to rock contours is somewhat dependent upon topographic contour lines, there may be areas of low and moderate vulnerability that were missed due to the map scale. Similarly, small pockets of deeper subsoil are likely to exist even within areas where rock outcrop is common. This is particularly likely over the karst limestone area around Carrickmacross.

Moderate vulnerability areas are found in the middle of the county from Clones to Monaghan, and in the south around Carrickmacross. In both cases, the subsoils have a moderate permeability, with the till thickness ranging from three to over 10 m.

Most of the north and western half of the county is considered low vulnerability since the subsoils (tills) have a low permeability and the depth to bedrock is greater than 10 m. This rating is confirmed by the evidence for low recharge to the underlying aquifers.

Areas of extreme vulnerability are delineated around karst features in the Carrickmacross aquifer and along sinking streams, not only on the aquifer itself but also along streams flowing onto the aquifer from the surrounding lower permeability rocks, to highlight the risks posed by developments in the vicinity of these streams.

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 Monaghan. 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 waster 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** (DoELG et al., 2001)
- **Groundwater Protection Responses for Landfills** (DoELG et al., 1999b)
- **Groundwater Protection Responses for Landspreading of Organic Wastes** (DoELG et al., 1999c)

6.2 Groundwater Protection Maps

The groundwater resource protection map (Map 7) is produced by combining the vulnerability map (Map 6) with the aquifer map (Map 5). 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 Monaghan; those present are shown in Table 6.1. The percentage of area covered by each category is shown in Table 6.2.

Table 6.1 Matrix of Groundwater Resource Protection Zones in County Monaghan

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg[1]	Lm/Lg[1]	Ll	Pl	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	
High (H)	Rk/H	Rf/ H	Lm/H	Ll/H	Pl/H	
Moderate (M)	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	
Low (L)	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	

1. No sand/gravel aquifers are delineated in County Monaghan.

Table 6.2 Percentage of area covered by each zone in County Monaghan

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf	Lm	Ll	Pl	Pu
Extreme (E)	2.1%	0.56%	0.9%	0.1%	26%	-
High (H)	1.6%	3%	1.4%	0.5%	10.5%	-
Moderate (M)	1.6%	4.6%	1.7%	1.2%	9.4%	-
Low (L)	0.23%	3.3%	9.1%	4%	16.7%	-

6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around wells at two public water supply sources in County Monaghan: Clones/Scotshouse and Monaghan town. These have been produced as separate source reports.

Preliminary source protection zones have also been delineated around the Tydavnet Group Water Scheme wells. Research on the hydrogeology of this area was carried out as part of a MSc. thesis, which comprises a separate report (Kelly, 2001). Due to the semi-confined nature of the aquifer in this area, an arbitrary zone of contribution has been applied to these wells, with a 300 m buffer around each well representing the inner protection zones. Delineation of the source protection zones was not a component of this groundwater protection scheme. However, given the importance of these wells, arbitrary source protection zones were delineated, which shown on Map 7. The Inner Source Protection zone is based on an arbitrary buffer of 300 m. The northern and southern boundaries of the Outer Source Protection zone are based on geological and aquifer boundaries. A 1 km arbitrary buffer assigned to the eastern and western most wells defines the eastern and western boundaries. Numerical modelling would be necessary to produce more definitive Inner and Outer Protection Areas; it is planned that numerical modelling will be carried out in the future by the GSI.

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 groundwater protection 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 6.3 provides a broad indication of the acceptability of certain activities in Monaghan with respect to groundwater contamination.

Table 6.3 Acceptability of Certain Potentially Polluting Activities in Monaghan

Activity (more will be identified in the future)	Percentage of Monaghan Occurring within Each Response Level			
	Not acceptable	Not acceptable in principle; some exceptions may be allowed subject to conditions	Acceptable in principle, subject to certain conditions	Acceptable
Landfill	10.9%	13.8%	47.4%	26.2%
Landspreading (IPC licensable) *	0.09%	29.7%	3.5%	64.9%
On-site Treatment Systems	-	0.07%	33.1%	65.0%

* *Some provision is made in the protection responses for landspreading of organic wastes for areas where rock is particularly close to the surface. Consequently, the proportions included in this table consider areas of 'outcrop and shallow rock' separately from other areas of extreme vulnerability.*

6.5 Conclusions

This groundwater protection scheme will be a valuable tool for Monaghan 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 Monaghan 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 data available. Thus, Monaghan 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 data available 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 Monaghan 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

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 Schemes, Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses to the 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.

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)
Extreme (E)	0–3.0 m	0–3.0 m	0–3.0 m	0–3.0 m	–
High (H)	>3.0 m	3.0–10.0 m	3.0–5.0 m	>3.0 m	N/A
Moderate (M)	N/A	>10.0 m	5.0–10.0	N/A	N/A
Low (L)	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.

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.

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 ±10–20°) 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 flow velocities and in dictating the likelihood of contamination. It can be taken into account by mapping the groundwater vulnerability to contamination.

Table A.2 Matrix of Source Protection Zones

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

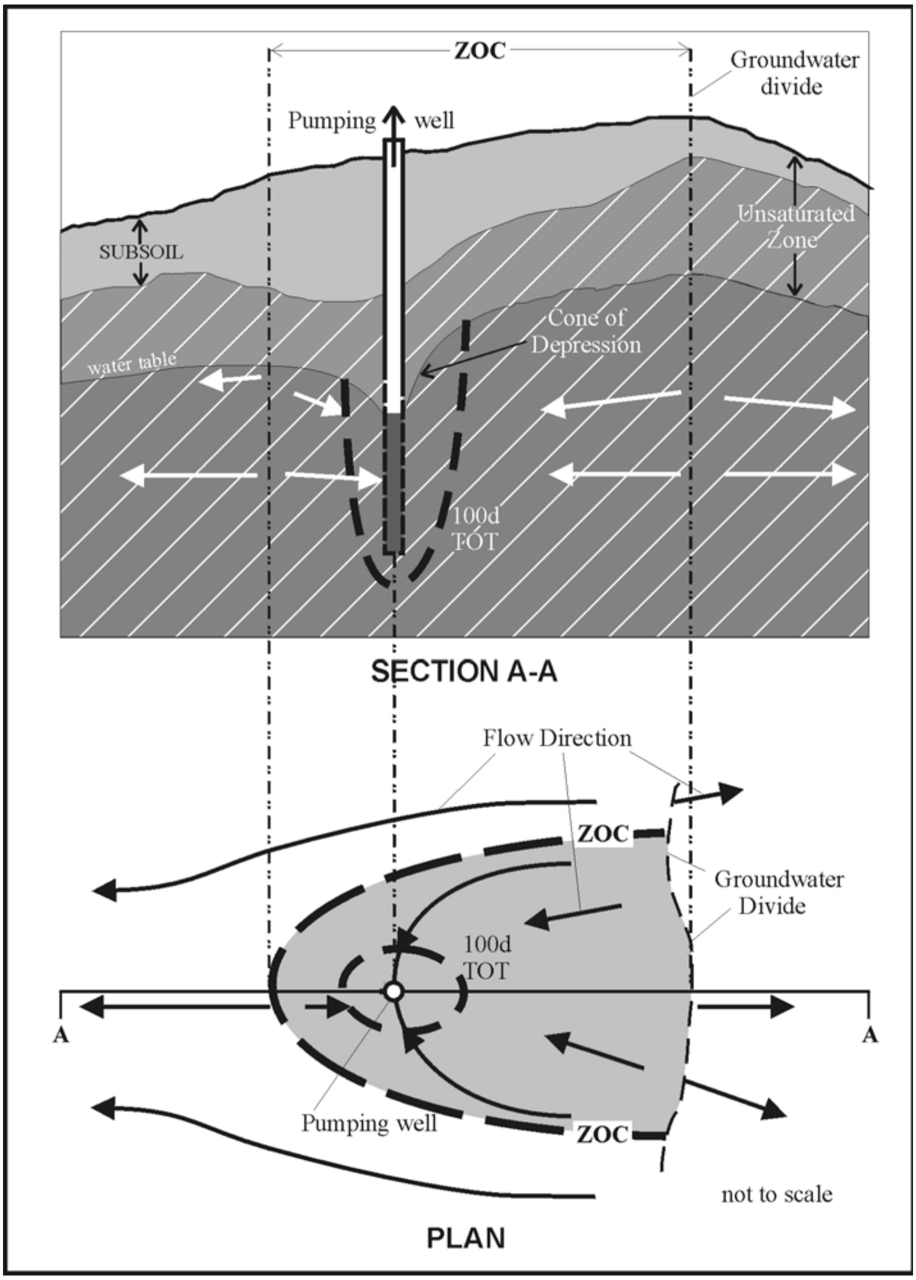


Fig. A.1 Conceptual model of the zone of contribution (ZOC) at a pumping well (adapted from US EPA, 1987)

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.

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**)
(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 (**Ll**)

Poor (P) Aquifers

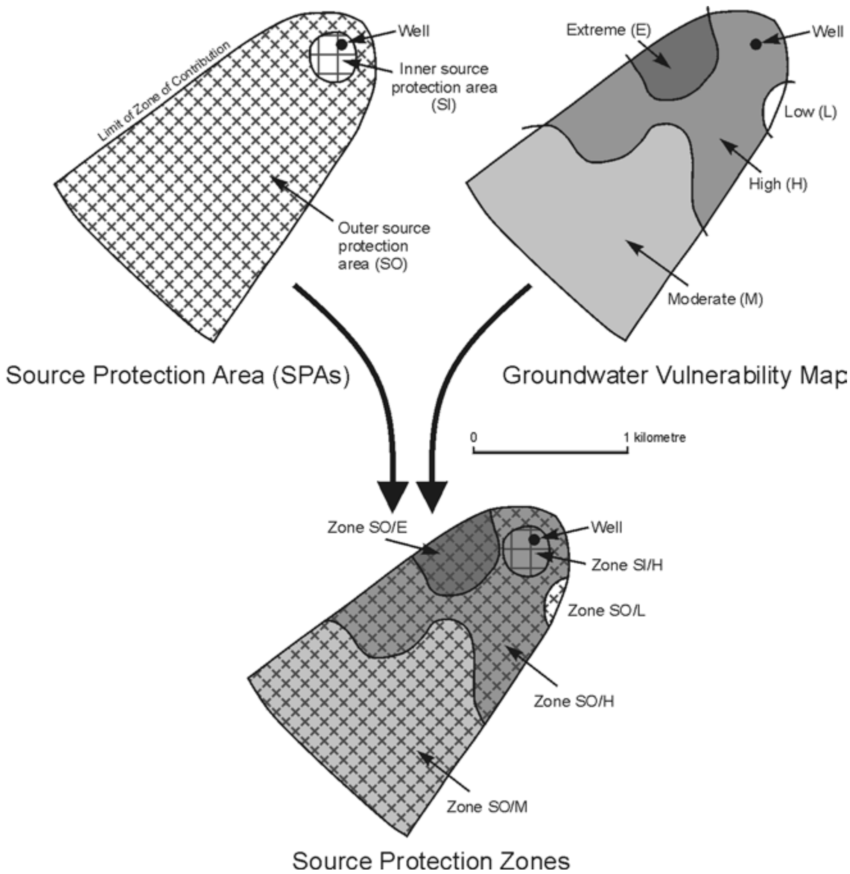


Fig. A.2 Delineation of Source Protection Zones Around a Public Supply Well from the Integration of the Source Protection Area Map and the Vulnerability Map

(i) Bedrock which is Generally Unproductive except for Local Zones (**Pl**)
(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[a,b,c,...] 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[m,n,o,...] 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.

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

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

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

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 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
Permeability Regions in County Monaghan

Summary of Permeability Data and Analyses for Permeability Unit Kingscourt Area (7) .

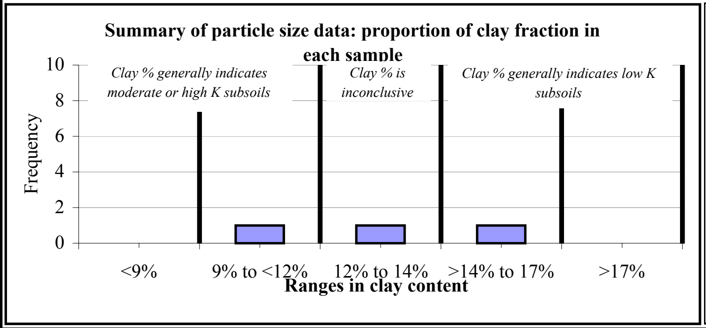
Description of unit location:	Area southwest of Lough Fea (Lossets townland), south to county boundary.
Why is this a single K unit?	General characteristics of subsoils and land use are the same in this area.

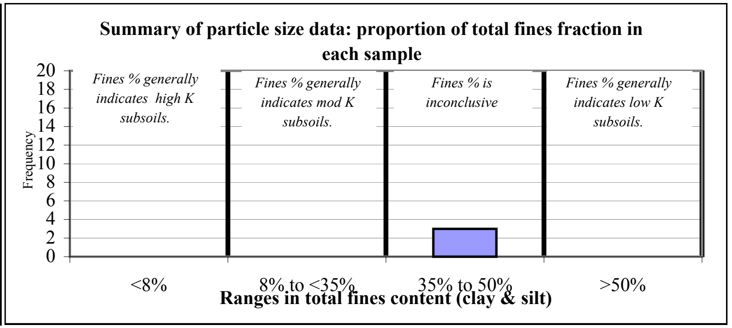
1. General Permeability Indicators and Region Characteristics

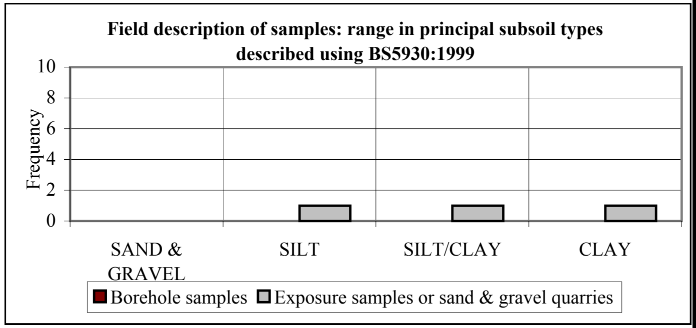
Rock type	Area mostly underlain by the Carrickleck sandstone and shale, and the Kingscourt Gypsum mudstone. In this area, the shales and mudstones are probably the first unit intersected.
Depth to bedrock	Mostly 5-10, some small areas of 3
Subsoil type	Mapped as TLPs mostly, some peat polygons
Soil type	Not mapped. Soils in Meath for corresponding area is the Street surface water gley
Vegetation and land use	Rushes mapped in this area. Land used for grazing.
Artificial drainage density	Drains mapped in some areas
Natural drainage density	Difficult to tell due to drumlins and small aerial extent.
Topography and altitude	Drumlins, generally between 25-65 mOD.
Ave. effective rainfall (mm)	536 mm/yr

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: min/25mm	# Results	# 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

4. Summary and Analysis

Criteria	**Comments**		**Implications of each criterion for assessment of subsoil permeability**
Rock type	Interbedded clean sandstone and weathered shales, and mudstone. In this area, first rock encountered is shale or mudstone	>>>	Low
Quaternary / subsoil origin	TLPs - if coming from shales, will be clayey but may be partly derived from sandstone, too	>>>	Low-Moderate
Soil type	Not mapped in Monaghan. In Meath, associated soils are the Street surface water gleys	>>>	Low
Land use	Grazing primarily, high occurrence of rushes.	>>>	-
Artificial drainage density	Boundary drains in some areas	>>>	Low
Natural drainage density		>>>	
Particle size data	Only 3 samples which are mixed. Clay percentages are 10, 14 and 17%	>>>	Low-Moderate
Field description data	Only 3 samples, ranging from SILT to CLAY.	>>>	Low-Moderate
		>>>	
Permeability test data		>>>	
	Overall conclusion	>>>	**Low**

5. COMMENTS: Overall, this area is considered low based on the abundance of rushes and drains. Where rushes were observed, the land was abundantly rushy. Overall it's likely that the permeability of the subsoil is dependent upon the first bedrock encountered in the area. Here, it is likely to be black, weathered shale or fine grained mudstones, which probably give rise to clayey, low permeability subsoils. North of here, clean sandstones are the first bedrock encountered and so result in sandier subsoils. Since the bedrock mapping does not distinguish which is the first encountered, some variability should be expected. Soils information would be useful to help confirm these boundaries. This permeability region should be reevaluated once the soils map of County Monaghan is available.