COUNTY CORK
(SOUTHERN DIVISION)

GROUNDWATER PROTECTION SCHEME

EXECUTIVE SUMMARY

Cork County Council
County Hall
Cork

Geological Survey of Ireland
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in collaboration with:

Cork County Council

1 Introduction

This Groundwater Protection Scheme is the result of co-operation between Cork County Council and the Geological Survey of Ireland (GSI).

The Scheme consists of an Executive Summary, Main Report, Source Reports and maps, and a suite of six regional maps (at a scale of 1:50,000), each map in three sheets (East, West and South):

Primary Data or Basic Maps

- bedrock geology map
- subsoils map
- outcrop and depth to bedrock map

Derived or Interpretive Maps

- aquifer and hydrogeological data map
- groundwater vulnerability map

Land-use Planning Maps

- groundwater protection zone map

The Schedule of Maps is given on page 9.

The objectives of the Scheme, which are interrelated, are as follows:

- to assist Cork County Council and other public authorities to meet their statutory responsibilities for the protection and conservation of groundwater resources;
- to provide geological and hydrogeological information for the regulatory 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, focus attention on the higher risk areas and activities, and provide a logical structure within which contamination control measures can be selected.

The Scheme provides a framework for decision-making and guidelines for the statutory authorities in carrying out their functions.

The Scheme 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.

2 The Need for a Groundwater Protection Scheme

Groundwater is an important and abundant natural resource in County Cork. About 18% of the public water supply in the South Cork area comes from groundwater from over fifty wells and springs. Also, the great majority of people who are not supplied from public sources depend on groundwater from group schemes and private wells.

The quality of this groundwater resource is generally good, although there are some problems with localised contamination. Recent years have seen increasing public concern about the risk of contamination from various sources such as intensive agriculture, industrialisation, septic tank systems and landfills. Positive measures are required by national and EU legislation to protect groundwater from contamination.

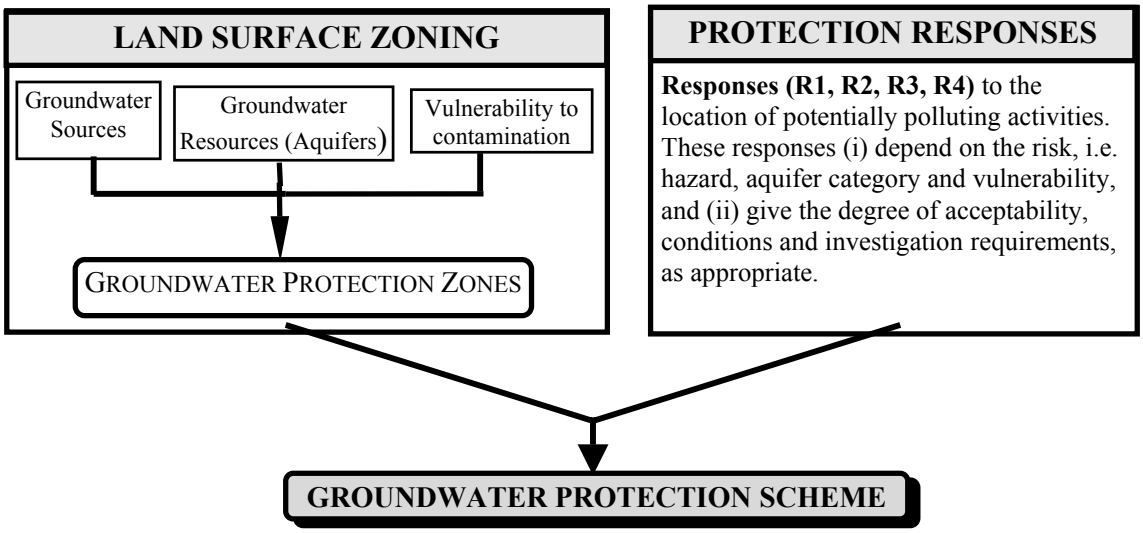
The basis of national and European environmental policy is that contamination should be prevented at source. The local authority's planning control system is therefore an important element in groundwater protection, by ensuring that developments are managed so as to prevent contaminants from entering groundwater. To assist in this, the GSI has drawn up, at the request of the County Council, a Groundwater Protection Scheme for adoption by the Council and which can be referred to in the County Development Plan. It can also be used by the EPA in considering Integrated Pollution Control Licences for prescribed activities.

3 How a Groundwater Protection Scheme Works

There are **two main components** of the groundwater protection scheme (Figure 1):

- **Land surface zoning;**
- **Groundwater Protection Responses for potentially polluting activities.**

Figure 1 Summary of Components of Groundwater Protection Scheme



Land surface zoning provides the general framework for a groundwater protection scheme. 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 a groundwater vulnerability map.
- Delineation of **areas surrounding** individual **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.

These three elements are integrated to give maps showing **groundwater protection zones**.

The location and management of potentially polluting activities in each groundwater protection zone is by means of a groundwater protection response 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 (land zoning maps and groundwater protection responses) are different, it is important in conceptualising the scheme to see them as being closely interlinked.

4 Flexibility, Limitations and Uncertainty

The Groundwater Protection Scheme 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 the 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 scale used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Where site specific data received by the County Council in the future are at variance with the maps, this does not undermine the scheme, but rather provides an opportunity to improve it. In essence a Groundwater Protection Scheme is a tool which helps Council staff to respond to development proposals and is a means of showing that the Council is undertaking its responsibility for groundwater protection in a practical and reasonable manner.

5 Data and Map Compilation

The first major task was to compile all available information on the geology of South Cork. This resulted in the production of the following basic maps:

- **Bedrock Geology**
- **Outcrop and depth to bedrock**

Data from the Teagasc 'FIPS-IFS Soil Parent Material Map' compiled by R. Meehan was used to prepare the following map:

- **Subsoils**

All available data on water wells, groundwater investigations, geotechnical investigations, mineral exploration and groundwater quality were compiled. Where necessary, we have used from similar rocks in neighbouring counties (Kerry, Limerick and Waterford) to assist in map compilation. The above maps together with an assessment of the hydrogeological data led to production of the following maps:

- **Aquifers and Hydrogeological data**
- **Groundwater vulnerability**

These maps were combined to give the **Groundwater Resource Protection Zones map**.

6 Groundwater Source Protection Reports

Detailed assessments were conducted around six public supply sources (Ballinspittle, Coachford, Crookstown, Grenagh, Minane Bridge, and Robert's Cove); reports on each well were written and **Source Protection Zones** were delineated. In addition, a source protection report for the Dower Spring (Whitegate Regional WSS) was prepared in 1996, and a new report has been prepared for the Cloyne-Aghada WSS, based on a thesis prepared in 1997.

The information needs and links in producing groundwater resource and source protection zones are illustrated in the conceptual frameworks given in Figures 2 and 3.

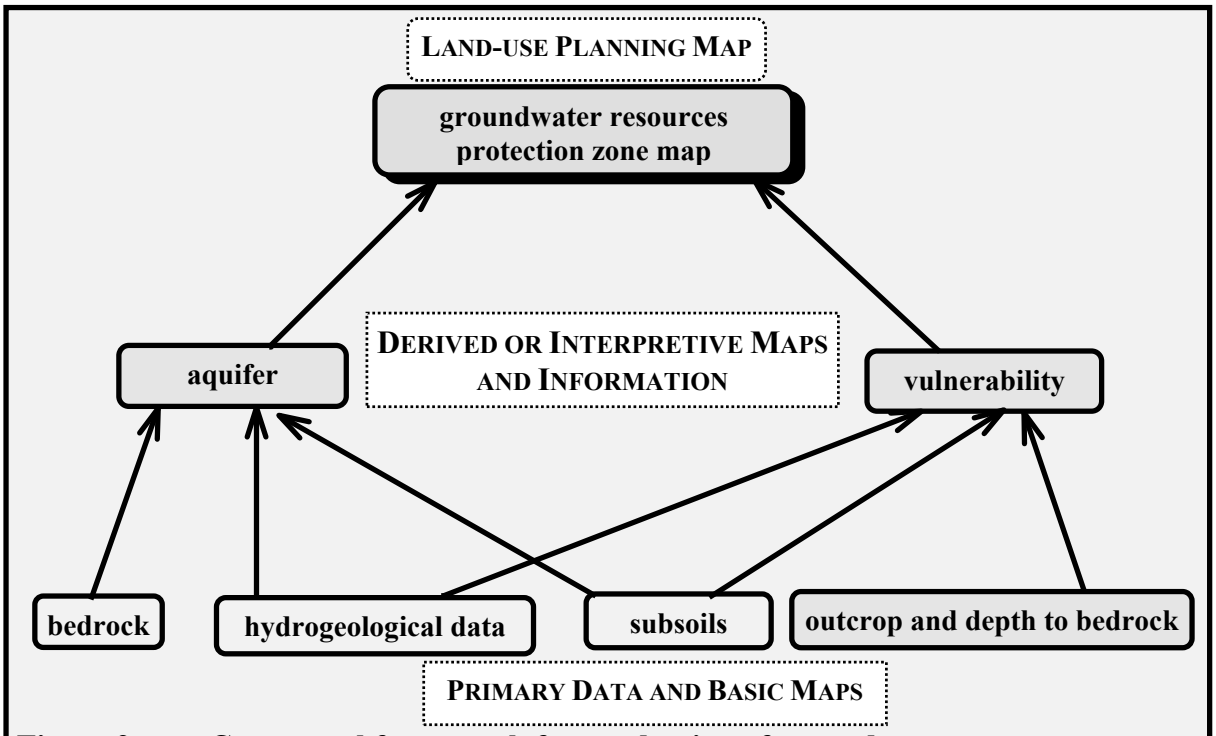


Figure 2 **Conceptual framework for production of groundwater resource protection zones, indicating information needs and links.**

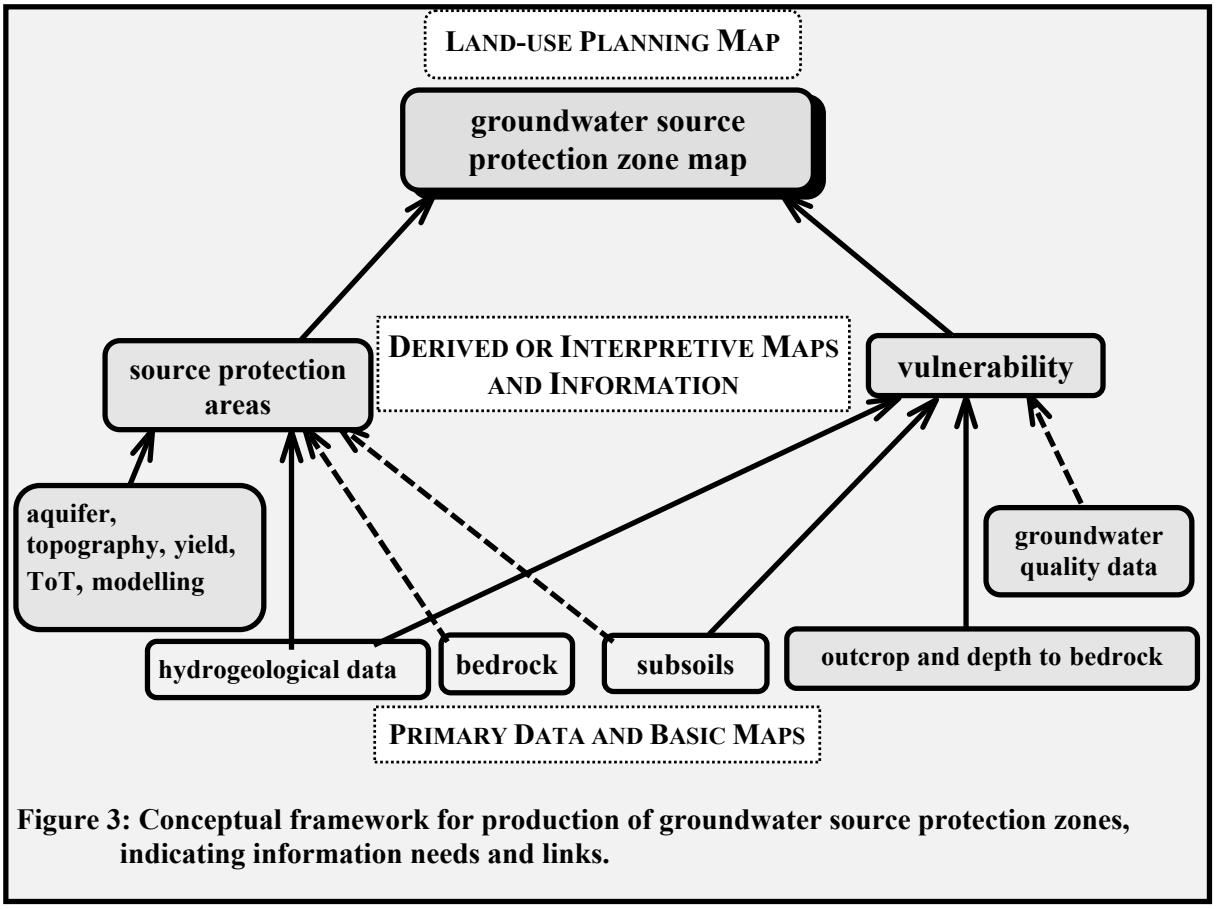


Figure 3: Conceptual framework for production of groundwater source protection zones, indicating information needs and links.

7 Maps of Bedrock, Depth to Bedrock and Hydrogeological Features

These are the basic data maps which underpin the groundwater protection scheme.

Assessment of the bedrock data in combination with the hydrogeological data provides the aquifer categories.

Assessment of the subsoils, depth to bedrock and hydrogeological features data provides the vulnerability categories.

The map numbers are as follows:

- 1E, 1W and 1S — Bedrock Geology
- 2E, 2W and 2S — Subsoils
- 3E, 2W and 3S — Outcrop and Depth to Bedrock
- 4E, 4W and 4S — Aquifers and Hydrogeological Data
- 5E, 5W and 5S — Groundwater Vulnerability

8 Aquifers

All rock units in South County Cork have been assigned to one of three basic categories:

- **Regionally Important Aquifers (R)**
- **Locally Important Aquifers (L)**
- **Poor Aquifers (P)**

These aquifers are shown on Maps 4E, 4W and 4S.

The aquifer categories reflect the resource potential of the different rock units and depend on several factors, mainly their permeability, areal extent, and storage capacity. Each category may be further subdivided into two or three sub-categories, according to the type and extent of permeability in the aquifer.

Regionally Important Aquifers (R): The term "regionally important" is used in the context of a county, part of a county or a river catchment. The most productive bedrock aquifer in County Cork is the Waulsortian Limestone. It is extensively karstified (dissolved), and it is therefore classed as a karstified aquifer(**Rk**). In the other pure limestone in South Cork – the Little Island Limestone – there is little evidence of karstification, so it is classed as a regionally important fissured aquifer (**Rf**). No regionally important sand/gravel aquifers (**Rg**) have been identified.

Locally Important Aquifers (L): The rocks in this category are subdivided into '**Lm**' (Bedrock which is Generally Moderately Productive), '**Ll**' (Bedrock which is Moderately Productive only in Local Zones) and '**Lg**' (Sand/gravel with an intergranular permeability). A large area of South Cork, including areas underlain by muddy limestones, sandstones, siltstones and shales (the Old Red Sandstone, and the rocks of the Cork Group), is classed as **Ll**. A few limited sand/gravel deposits present in South Cork are classed as locally important (**Lg**) aquifers. About % of South Cork is underlain by locally important aquifers.

Poor Aquifers (P): These are sub-divided into '**Pl**' (Bedrock which is Generally Unproductive except for Local Zones) and '**Pu**' (Bedrock which is Generally Unproductive). Only a few small areas in the western part of the division are classed as **Pu**.

9 Groundwater Vulnerability to Contamination

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. It provides a measure of the likelihood of contamination occurring.

The vulnerability of the groundwater to contamination depends mainly on the thickness and permeability of the subsoils which lie between the point where contaminants are released and the groundwater in the bedrock or sand/gravel aquifer. Where this subsoil is absent or thin, or where it is very permeable, the groundwater is most vulnerable. Where subsoil is thick and has a low permeability, the groundwater is least vulnerable. Karst features indicate high permeabilities and rapid recharge, so groundwater in the vicinity of these features is 'extremely' vulnerable. On the basis of the available information, the entire land surface has been divided into four vulnerability categories: extreme (**E**), high (**H**), moderate (**M**) and low (**L**). These are outlined in Table 1 with detailed definitions in the Main Report. These are shown on Map 5E, 5W and 5S.

Table 1. Summary of Vulnerability Classification of South Cork

Vulnerability Rating	Hydrogeological Setting
Extreme 49.8%	• Areas where rock is at the ground surface • Areas where the subsoil is known or interpreted to be <3m thick • Areas of *sand/gravel aquifer* where the water table is <3m below surface
High 46.3%	• Areas of *high* permeability subsoil known or interpreted to be >3m thick • Areas of *moderate* permeability subsoil known or interpreted to be 3-10m thick • Areas of *low* permeability subsoil known or interpreted to be 3-5m thick • Areas of *sand/gravel aquifer* and water table >3m
Moderate 3.2%	• Areas of *moderate* permeability subsoil known or interpreted to be >10m thick • Areas of *low* permeability subsoil known or interpreted to be 5-10m thick
Low 0.01%	• Areas of *low* permeability subsoil known or interpreted to be >10m thick

Note: approximately 0.7% of the county is occupied by lakes/reservoirs

10 Groundwater Source Protection Zones

Detailed groundwater protection maps have been drawn for eight individual groundwater sources, delineating appropriate protection zones around each source. Control of potentially polluting activities in these zones is considered essential to the preservation of the water quality from these important sources.

Two source protection areas were delineated for each water source:

- Inner Protection Area (**SI**), designed to give microbial protection;
- Outer Protection Area (**SO**), encompassing the remainder of the source catchment area or zone of contribution (ZOC).

These were combined with the vulnerability map to give the groundwater source protection zones. Each protection zone on the map is given a code representing both the proximity to the well and the vulnerability of the groundwater to contamination. The codes are shown in Table 2.

Table 2. Matrix of Groundwater Source Protection Zones

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

The text and maps for each source are produced as separate reports.

In order to protect groundwater, and more particularly to assess the risks to a particular water supply source, it is necessary to locate and assess all potential hazards in the zone of contribution of the source. This has not been undertaken by the GSI, but some has been carried out by Council staff.

11 Groundwater Resource Protection Zones

The **groundwater protection zone maps** (Maps 6E, 6W and 6S) were produced by combining the vulnerability maps (Maps 5E, 5W and 5S) with the aquifer maps (Maps 4E, 4W and 4S). Each protection zone on the map is given a code representing both the groundwater value and the vulnerability of the groundwater to contamination. The codes for the zones in South Cork are shown in Table 3 with the percentage of the total South Cork area that they cover. Thus, for any site for which permission or a licence is sought for a given type of development, a Groundwater Protection Zone category exists which reflects the degree of protection required for the groundwater beneath that site.

Table 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**	**Lg**	**Ll**	**Pl**	**Pu**
Extreme (E)	Rk/E 1.17%	Rf/E 0.65%	Lg/E 0.12%	Ll/E 40.8%	Pl/E 6.54%	*Pu/E* *absent*
High (H)	Rk/H 2.73%	Rf/H 1.37%	Lg/H 0.70%	Ll/H 38.74%	Pl/H 2.27%	*Pu/H* *absent*
Moderate (M)	Rk/M 1.19%	Rf/M 0.95%		Ll/M 0.59%	Pl/M 0.21%	*Pu/M* *absent*
Low (L)	Rk/L 0.004%	Rf/L 0.001%		Ll/L 0.002%	*Pl/L* *absent*	*Pu/L* *absent*

While maps showing these zones can be used on their own for purposes other than groundwater protection (such as groundwater development), when considering groundwater protection they should be applied in conjunction with **groundwater protection responses** for potentially polluting activities.

12 Groundwater Protection Responses

The **Groundwater Protection Responses** contain a series of **Response Matrices**, each setting out the recommended response to a certain type of development. 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 responses do not necessarily restrict development, but 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 recommended for the Irish situation:

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 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

At present, **groundwater protection responses** have been completed for three potentially polluting activities, landfills, landspreading of agricultural wastes and, on-site wastewater systems for single houses.

13 Status of Scheme

The scheme provides **guidelines** for the regulatory authorities in carrying out their functions.

While the scheme is aimed at decisions regarding groundwater protection, consideration will also be given to the balancing of interests in the water environment as well as in a wider context. Therefore the scheme is seen as a framework for decision-making and is not necessarily prescriptive in any individual circumstance.

The scheme is designed for general information, strategic planning and site evaluation purposes. It may be necessary in many situations to augment the information in the scheme with site specific information.

14 Conclusion

The Groundwater Protection Scheme set out in the Main Report and in the associated maps provides a realistic and flexible means of enabling the County Council to fulfil its responsibility for controlling contamination and conserving the county's groundwater resources for current and future beneficial use.

Schedule of Maps

Map 1(E) Bedrock Geology (East)
Map 1(W) Bedrock Geology (West)
Map 1(S) Bedrock Geology (South)

Map 2 (E) Subsoils Map (East)
Map 2 (W) Subsoils Map (West)
Map 2 (S) Subsoils Map (South)

Map 3(E) Outcrop & Depth to Bedrock (East)
Map 3(W) Outcrop & Depth to Bedrock (West)
Map 3(S) Outcrop & Depth to Bedrock (South)

Map 4(E) Aquifers & Hydrogeological Data (East)
Map 4(W) Aquifers & Hydrogeological Data (West)
Map 4(S) Aquifers & Hydrogeological Data (South)

Map 5(E) Groundwater Vulnerability (East)
Map 5(W) Groundwater Vulnerability (West)
Map 5(S) Groundwater Vulnerability (South)

Map 6(E) Groundwater Resource Protection (East)
Map 6(W) Groundwater Resource Protection (West)
Map 6(S) Groundwater Resource Protection (South)

South Cork
Groundwater Protection Scheme

Main Report

Cork County Council (Southern Division)
County Hall
Cork

Geological Survey of Ireland
Beggars Bush
Haddington Road
Dublin 4

May 2002

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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 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 can be 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 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 are posed by:

(a) point contamination sources – farmyard wastes (mainly silage effluent and soiled water), septic tank effluent, contaminated streams which sink underground, leakages, spillages, pesticides used for non-agricultural purposes and leachate from waste disposal sites;

(b) diffuse sources – 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 integrating hydrogeological factors into land-use policy and planning by means of groundwater protection schemes.

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

1.4 'Groundwater Protection Schemes' – A National Methodology for Groundwater Pollution Prevention

The Geological Survey of Ireland (GSI), the Department of Environment and Local Government (DELG) and the Environmental Protection Agency (EPA) have jointly developed a methodology for the preparation of groundwater protection schemes (DELG/EPA/GSI, 1999). The publication **Groundwater Protection Schemes** was launched in May 1999, by Mr. Joe Jacob TD, Minister of State at the Department of Public Enterprise. Three supplementary publications have also been produced: **Groundwater Protection Responses for Landfills, Groundwater Protection Responses for Landspreading of Organic Wastes** and **Groundwater Protection Responses for On-site Wastewater.**

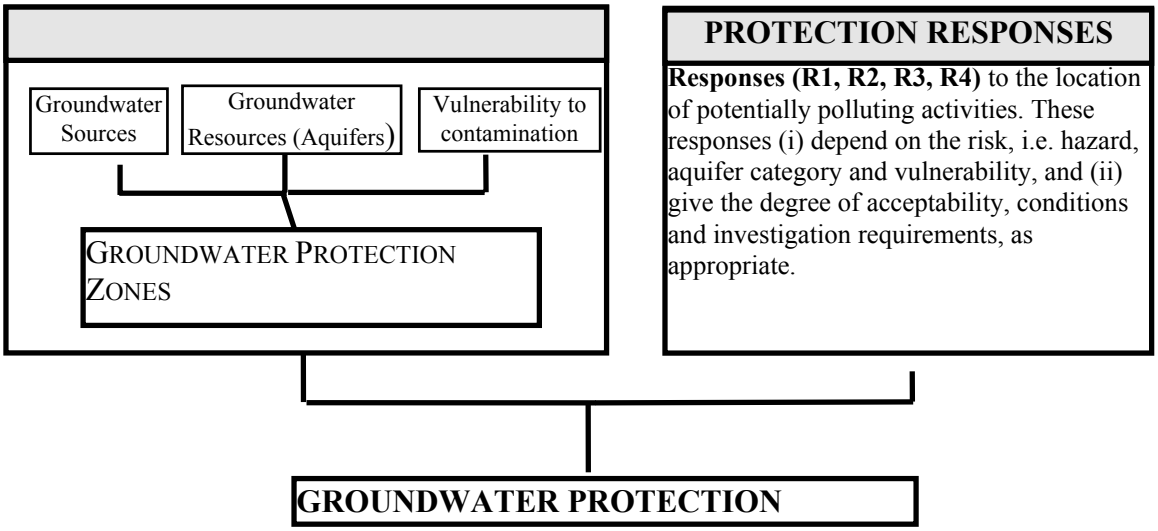

Fig. 1.1 Summary of Components of Groundwater Protection Scheme

Systems for Single Houses. Similar 'responses' publications are planned for other potentially polluting activities and developments.

A groundwater protection scheme has two main components:

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

These are shown schematically in Fig. 1.1.

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.

There are three main hydrogeological elements to land surface zoning:

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

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

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

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

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

1.5 Objectives of the South Cork Groundwater Protection Scheme

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

The groundwater protection scheme is the result of co-operation between Cork County Council (Southern Division) and the Geological Survey of Ireland. The Southern Division of County Cork covers the area shown in Fig 1.2 below. It stretches from the border with Kerry, west of Macroom (minimum Easting 106000), to Youghal (maximum Easting 211000) in the east. However further south it only extends from around Enniskean (Easting 133000) to Crosshaven (Easting 182000). Its most northerly extent is just north of Glenville (maximum Northing 095000) and it extends as far south as the coast around Kinsale (minimum Northing 039000). The Southern Division of County Cork is a separate Sanitary Authority, operating independently of the County Council in the implementation of sanitary services.

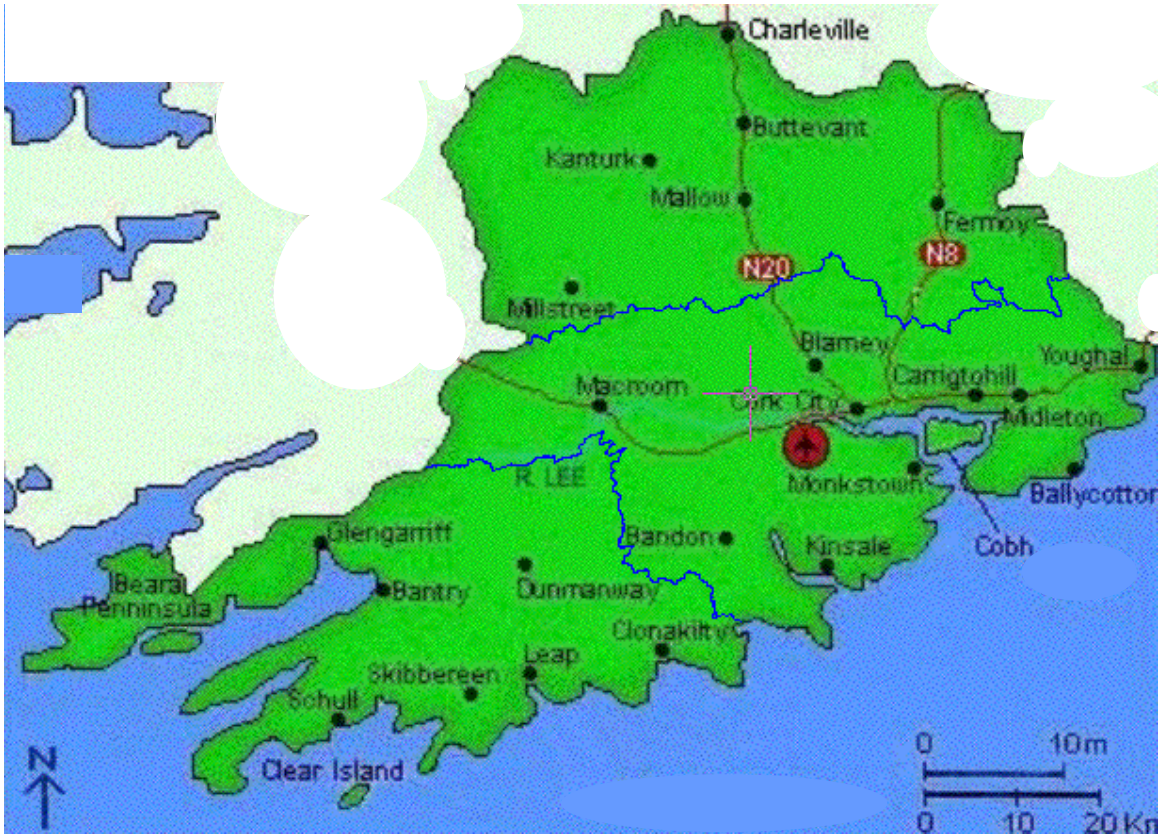

Figure 1.2 County Cork with South Cork Boundary

The geological and hydrogeological data for South Cork are interpreted to enable:

(i) delineation of aquifers;

(ii) assessment of the groundwater vulnerability to contamination;

(iii) delineation of protection areas around, and reports written for, eight public supply sources: Ballinspittle, Cloyne, Coachford, Crookstown, Dower, Grenagh, Minane Bridge and Robert's Cove.

(iv) 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 has compiled, all readily available geological and groundwater data for the county and created 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.

A suite of environmental geology maps accompanies the report. These are:

(i) Primary Data or Basic Maps:

- Bedrock geology map (Map 1)
- Subsoils map (Map 2)
- Outcrop and depth to bedrock data map (Map 3)

(ii) Derived or Interpretative Maps

- Aquifer and hydrogeological data map (Map 4)
- Groundwater vulnerability map (Map 5)

(iii) Land Use Planning Maps

- Resource protection map (Map 6)

These 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. They are not however, a substitute for site investigation.

It is important to recognise however, that detailed regional hydrogeological investigations in South Cork are limited to a number of public supply sources, some environmental impact statements and research publications. Consequently, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of South Cork. However, this report provides a good basis for strategic decision-making and for site-specific investigations.
This groundwater protection scheme was executed in two phases. In the first phase an Interim Groundwater Protection Scheme was prepared. The interim scheme assessed the bedrock units and delineated the aquifers, but only areas of Extreme (E) groundwater vulnerability were delineated. This was due to the limited amount of detailed information then available relating to subsoil thickness and permeability. Phase Two involved upgrading the interim scheme to a full Groundwater Protection Scheme in which areas of Extreme (E), High (H) Moderate (L) and Low (L) Groundwater Vulnerability were delineated. Chapter 5 of this report outlines how the Groundwater Vulnerability Categories were assigned. The Interim Groundwater Protection Scheme for South Cork is now superseded by this report.

1.7 Cork County Development Plan

This is the groundwater protection scheme referred to in Sections 1.3 and 1.4 of the Proposed Draft Aquifer Protection Policy Variation of the Cork County Council Development Plan. The county plan incorporates the whole of County Cork, although the aquifer protection scheme outlined in this document only deals with the Southern Division (as explained above in Section 1.6)

1.8 Structure of Report

The structure of this report is based on the information and mapping requirements for land surface zoning. The groundwater resources protection map (Map 6) is a land use planning map and is the ultimate or final map as it is obtained by combining the aquifer (Map 4) and groundwater vulnerability maps (Map 5). 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. The groundwater vulnerability map is based on the depth to rock map (Map 2) and an assessment of specifically relevant information on permeability and karstification. This is illustrated in Fig. 1.3.

Similarly, the source protection maps result from combining vulnerability and source protection area maps. The source protection areas are based largely on assessments of hydrogeological data. This is illustrated in Fig. 1.4.

Chapter 2 provides brief summaries of the bedrock and subsoils geology. Chapter 3 summarises and assesses the hydrogeological data for the different rock units, gives the basis behind each of the aquifer categories, and describes the potential for future groundwater

development. Chapter 4 gives a summary of a separate report on the hydrochemistry and groundwater quality in Co. Cork. Chapter 5 describes the subsoil permeability distribution and the derivation of the groundwater vulnerability categories. Chapter 6 draws the whole together and summarises the final groundwater protection zones present in South Cork.

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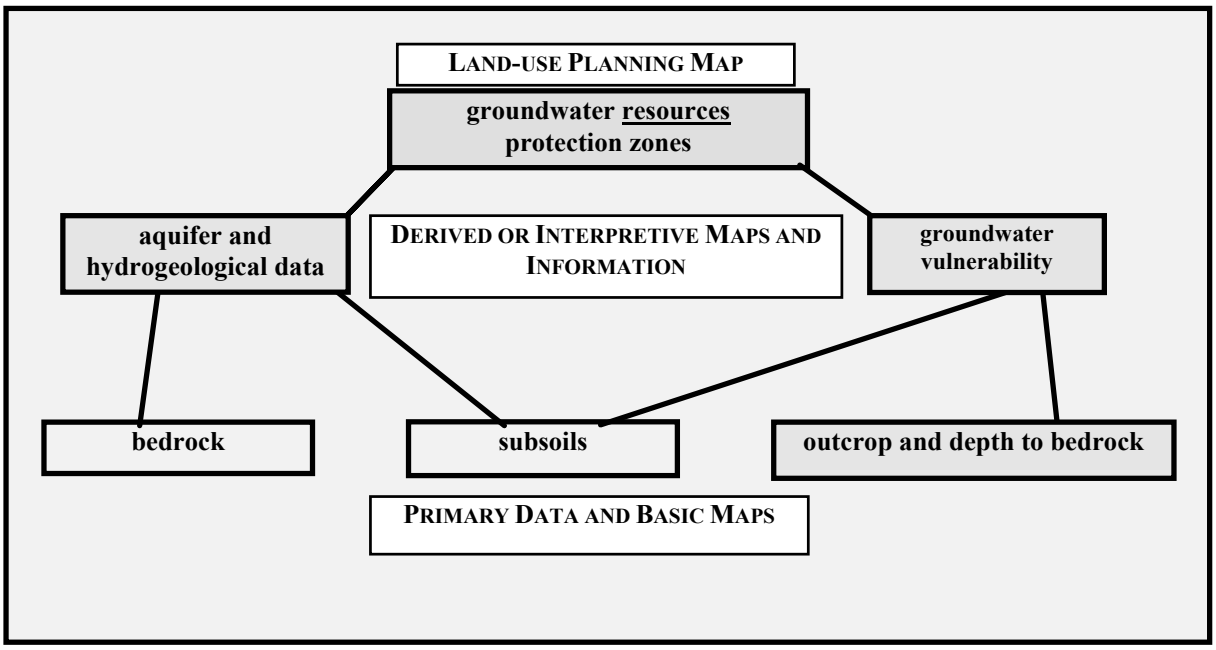


Fig. 1.3 Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

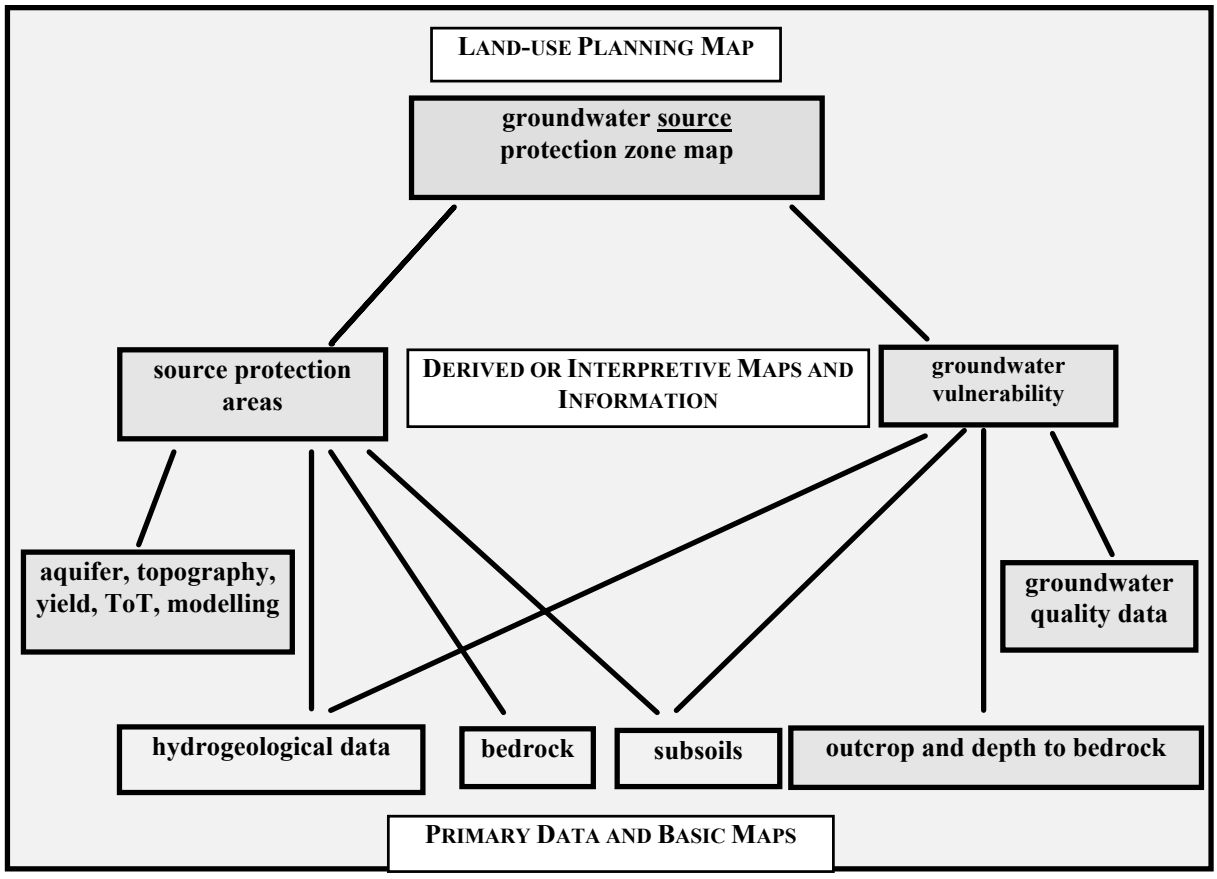


Fig. 1.4 Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

2 Geology

2.1 Introduction

This chapter presents a brief description of the elements of the geology of South County Cork that are relevant to the hydrogeology, namely the rock composition (lithology) and rock structure, as well as a brief outline of the subsoil types that occur throughout the county.

2.2 Bedrock Geology

The rocks range in age from Devonian (c. 370 million years old) to the Upper Carboniferous (c. 310 million years old) and are mainly sedimentary in origin, consisting of limestones, sandstones and some shales, with a few very small occurrences of volcanic rocks in isolated areas.

The striking variations in topography in County Cork can be related directly to the underlying bedrock geology. Large thicknesses of Old Red Sandstone rocks occur over most of the county, with limestones becoming more dominant in the eastern half of the county. The Old Red Sandstone areas form the upland areas such as the Derrynasaggart and Boggeragh Mountains. These Old Red Sandstone rocks are less readily weathered and eroded than the limestones, which are susceptible to dissolution (dissolving of the limestone by rainwater). The topography of South Cork has a pronounced 'grain' to it, with elongate east-west valleys separated by intervening ridges, reflecting the underlying geological structure. The ridges consist of Devonian Old Red Sandstone rocks while the valleys are floored by poorly exposed Carboniferous Limestones.

The bedrock geology map of South County Cork (Map 1) is derived directly from the GSI 1:100,000 scale geology maps; Sheet 21, Geology of Kerry-Cork (Pracht, M., 1997), Sheet 22, Geology of East Cork-Waterford, (Sleeman, A.G. and McConnell, B., 1995), *Sheet 24, Geology of West Cork (Pracht, M., 2000)* and Sheet 25, Geology of South Cork (Sleeman, A.G. and Pracht, M., 1994). These maps represent the most recently compiled geological information.

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 the reports mentioned above. In describing the rock units the emphasis is placed on the rock lithology or composition because this is the feature of most relevance to groundwater flow. The formal rock formation name and letter code is also given to enable hydrogeologists to link the brief descriptions in this report to the more detailed descriptions in the literature. The rocks are described in groups according to their age, starting with the oldest:

(i) Devonian Old Red Sandstones;

(ii) Uppermost Devonian and Lower Carboniferous Clastic Rocks of the Cork Group;

(iii) Carboniferous Limestones.

Table 2.1 Bedrock Succession in South County Cork

Age	(million years)	Main Succession					
		North Munster Shelf (Carboniferous Limestones)		**Suth Munster Basin (Cork Group)**			
Upper Carboniferous	Namurian (290)	Not Present		**White Strand Fmn (WS)**	Sandstone interbedded with brittle commonly pyritic grey-black mudstones		
Lower Carboniferous	Dinantian	**Clashavodig Fmn (CV)**	Skeletal, peloidal, oolitic & cherty wackestone limestones				
		Little Island Fmn (LI)	Massive calcilutite limestones (mudbank facies) & crinoidal calcilutites	**Lispatrick Fmn (LP)`**	Fissile, dark-grey to sooty black pyritic cherty mudstones		
		Cork Red Marble (CK)	Cream, pink & red fine-grained limestones & breccias in a red mudstone matrix				
		Loughbeg Fmn (LB)	Cherty & nodular calcareous mudstones with occasional crinoidal limestones				
		Waulsortian Lmst (WA)	Massive, unbedded "mudbank" facies limestone	**Courtmacsherry Fmn (CY)**	Grey calcareous & non-calcareous nodular mudstones, some subsidiary limestones		
		Ballysteen Fmn (BA)	Dark-grey bioclastic limestone becoming increasingly muddy upwards				
		Ringmoylan Fmn (RM)	Dark grey calcareous shales with thin shelly crinoidal limestones				

Age	(million years)	Main Succession					
		Mellon House Fmn (MH)	Mainly dark grey laminated siltstones & fine grained sandstones	**Kinsale Fmn (KN)**	Overall mud-dominant succession of grey mudstones & sand-lensed mudstones *Pig's Cove Mbr (KNpc)* Characterised by linsen bedded mudstones & a lack of sandstones		
		Crow's Point Fmn (CP)	Cross-stratified grey sandstones with minor mudstones		*Cuskinny Mbr (KNcu)* Flaser bedded sandstones & lenticular bedded mudstones *Narrow Cove Mbr (KNnc)* Dominated by sand lensed & streaked mudstone		
	(355)	*Castle Slate Mbr (KNcs).*			uniform dark-grey slaty mudstones		
				Central Cork Devonian Succession		**Southern Derrynasaggart Mountain Devonian Succession**	**Northern Derrynasaggart-Boggeragh Mountain Devonian Succession**
		Ardmore Mbr (GYam) *Ballyquin Mbr (GYbq)*		**Old Head Sandstone Fmn (OH)**		grey flaser bedded sandstones, fine-grained sandstones & minor mudstones	
		Ballyknock Mbr (GYbn)		**Gyleen Fmn (GY)**	Fining upwards sequences of red sandstones with thinly bedded alternations of green & red sandstones, siltstones & mudstones.	**Toe Head Fmn (TH)**	cross-bedded green & purple sandstones, rippled fine-grained grey sandstones
						Castlehaven Fmn (CE)	Purple mudstones & siltstones with fine-grained sandstones

Age	(million years)	Main Succession					
Devonian		**Ballytrasna Fmn (BS)**	Dusky red to purple mudstones & siltstones with subordinate fine-grained pale-red sandstones				
				Gun Point Formation (GP)	green-grey to purple med-coarse grained sandstones, interbedded with thick sequences of purple siltstones & fine-grained laminated red sandstones.		
				Caha Mountain Fmn (CH)	Purple siltstones & fine-grained laminated sandstones		
			Gortanimill Formation (GM)	Green medium to fine-grained sandstones, interbedded with red-purple siltstones & fine sandstones		**Glenflesk Chloritic Sst Fmn (GC)**	medium to coarse grained sandstone, pebbly sandstones, intra-formational conglomerates
				Slaheny Sandstone (SL)	cross-bedded medium-grained green sandstones, intervals of siltstone & fine-grained sandstone		
	(3??)			**Bird Hill (BH)**	Purple siltstone & fine-grained sandstones		

2.2.1 Devonian Old Red Sandstones

The Devonian Old Red Sandstone (ORS) rocks are the oldest rocks found in South Cork. Deposition of the ORS took place in a sub-equatorial arid environment, where there was intense erosion and then deposition of gravel, sand, silt and some clay in the flood plains of meandering rivers. The rocks consist primarily of red and green sandstones, siltstones and mudstones. The coarser grained sediments usually occur towards the base of the rock sequence, with greenish-grey siltstones becoming more common towards the top. These sediments accumulated in the Munster Basin, a large trough which continued to subside to form one of the thickest sequences of Old Red Sandstone in the world, up to 6 km thick.

The ORS rocks of most of South Cork fall into 2 different successions (Sleeman & Pracht, 1994). The western succession is found along the western edge of the Munster Basin. It includes formations such as the Gortanimill, Caha Mountain, Gun Point, Castlehaven and Toe Head formations. The Gortanimill Formation is the only formation common to both the western and the eastern (and central) successions. The eastern succession also encompasses the Ballytrasna and Gyleen formations.

Further west towards the Cork-Kerry border, there are two other rock successions associated with the Derrynasaggart-Boggeragh Mountains (Pracht, 1997). The Southern Derrynasaggart Mountains Succession is almost equivalent to the Western Succession, apart from some older formations (such as the Bird Hill Formation) not found in more central areas of Cork. The Northern Derrynasaggart-Boggeragh Mountains Succession is somewhat different and one of its main formations, the Glenflesk Chloritic Sandstone Formation, occurs within the boundaries of South Cork.

2.2.1.1 Northern Derrynasaggart-Boggeragh Mountains Succession

Glenflesk Chloritic Sandstone Formation (GC) This formation occurs only in the very northwest of South Cork, along the Kerry border, but is very widespread in Co. Kerry. It consists of green-coloured, mostly medium-grained sandstone, conglomerate and pebbly sandstone, together with green and purple siltstone. The green highly chloritic sandstones are very characteristic. The formation is conformably overlain by the Gun Point Formation and is the lateral equivalent of the Bird Hill, Gortanimill and Caha Mountain Formations seen further east.

2.2.1.2 Southern Derrynasaggart Mountains Succession

Bird Hill Formation (BH) This formation outcrops to the south of the Kenmare Syncline, between Macroom and the Kerry border to the west, and in the area around Ballyvourney. Its estimated minimum thickness is 920 m. It mainly comprises fine-grained strata, predominantly purple-grey to grey-green fine-grained sandstones with beds usually less than 1 m thick. Cross laminations occur in some of the beds.

Slaheny Sandstone Formation (SL) This unit occurs near the border with Kerry. It is a 670 m thick formation of alternating purple siltstone-rich sequences and medium to coarse-grained green-grey micaceous sandstones with occasional intraformational conglomerates at their base.

2.2.1.3 Western Succession

Gortanimill Formation (GM) This formation is described as varied medium-grained sandstone bodies and thick sequences of green fine-grained sandstone and siltstone. The siltstones can be cross-laminated. It occurs in a very large area of South Cork from around Ballyvourney in the west to northeast of Watergrasshill in the east. In the Derrynasaggart Mountains the formation is thought to be the eastern equivalent of the Slaheny Sandstone Formation (both of which pass into the Caha Mountain Formation).

Caha Mountain Formation (CH) This formation is dominated by purple siltstones and sandstones, and has an estimated maximum thickness of 2400 m. Some of the purple sandstones have cross-laminations. It is the lateral equivalent of the Ballytrasna Formation, which lies further east.

Gun Point Formation (GP) This formation consists of purple and green medium and coarse-grained sandstones, locally pebbly, with some thin interbedded purple siltstones. The sandstones are purple, grey or green, medium-grained and cross-stratified. The purple siltstones are usually found in the Derrynasaggart Mountains towards West Cork and also in the Northern Derrynasaggart-Boggeragh Mountain Succession.

Castlehaven Formation (CE) Characterised by intensely purple coloured mudstones and siltstones, with interbedded sandstone dominant units. Local calcareous material can be found as well as mud clast breccias. Deposition of these sediments was probably under strongly oxidising conditions as channel flood plain deposits. The formation is restricted to the Galley and Seven Heads areas in the south but is also found in the Macroom area around the lakes, and from Dunmanway to Enniskean.

Toe Head Formation (TH) This formation occurs in the core of the Bandon Anticline and the most western area of the Cork Syncline, west of Crookstown, as well as a small occurrence south of the Macroom Syncline on and between Toe Head and Sandy Cove. It is dominated by sandstones with minor amounts of mudstones. In southwest Cork the formation ranges from 290 to 424 m thick, although much thinner in places. The mudstone units can reach thicknesses of 11 m and are usually purple, green or grey in colour. The sandstones are distinguished by not having the obvious purple colour and

can have large-scale cross-bedding or ripples. Further east, this formation passes into the Gyleen Formation.

2.2.1.4 Central and Eastern Succession

In general, only the higher parts of the Old Red Sandstone facies are mapped in the central and eastern parts of the Munster Basin. However, the Gortanimill Formation occurs as far eastwards as Ballynoe.

Ballytrasna Formation (BS) This very widespread formation ranges in thickness from 360 m to 1500 m. Up to 90% of the formation comprises dusky-red mudstones while the rest is composed of pale-red fine-medium grained sandstone. The sandstones can have large-scale cross-laminations. It occurs from East Cork, around Youghal, across South Cork on either side of the Cork Syncline, and as far west as the Awboy River Fault, which runs from Millstreet to Macroom and down as far as Enniskean. This formation can be broadly correlated with the Caha Mountain, Gun Point and Castlehaven Formations in the west of the Munster Basin.

Gyleen Formation (GY) This formation consists of alternating mudstones and sandstones. At the type section, (Cotter's Point, near Gyleen), the formation comprises about 20% medium grained sandstone with large and small-scale cross-laminations and 80% mudstones. Colour varies from green through grey to purple. This formation occurs along the edges of the synclines (e.g. the Cork Syncline) from Knockadoon Head and Youghal in the east to Coachford and southwest of Crookstown, and also in the centre of the Blarney Syncline.

Ballyknock Member (GYbn) This member, up to 365 m thick, comprises alternating green siltstone and sandstone with red mudstones. Thick fining-upwards sequences (found in the rest of the Gyleen Formation) are rare. Thin pale green and grey mudstones occur towards the top of the unit. This unit can be found in the area around Crosshaven and east as far as Ballycotton.

Ballyquin Member (GYbq) The base of this member passes up from the Ballytrasna Formation, and the top passes up to the Ardmore Member described below. It consists of alternating thick grey and red medium-grained sandstones with thick red mudstones.

Ardmore Member (GYam) This member is distinguished by regular alternations of grey and pale red sandstones with grey-yellow siltstones. Red beds are isolated and discontinuous.

2.2.2 The Cork Group

The Carboniferous rocks are divided into two distinct facies in South Cork, delimited by a line running from Cork to Kenmare. North of this line are the Lower Limestone Shales and Carboniferous Limestones which will be discussed in the next Section. South of this line lie

the rocks from the first marine sandstones of the uppermost Devonian (the Old Head Sandstone Formation) up into the Namurian (Upper Carboniferous) sandstones and mudstones. This succession is known as the Cork Group and lies in what was the South Munster Basin. The marine clastic rocks of the Cork Group are widely found in South Cork, mainly around Kinsale extending northwards as far as Halfway, with other exposures in the synclines west and east of Cork city and down around Cloyne and Gyleen. They are represented by the Old Head Sandstone, Kinsale, Courtmacsherry, Lispatrick and White Strand Formations.

The Upper Devonian marked the start of the inundation of the Old Red Sandstone facies by the shallow tropical seas of the Carboniferous. The start of the Lower Carboniferous was therefore a period of marine deposition in a deepening sea. The Kinsale Formation however represents a water depth within the influence of waves and consists of mudstones. This was followed by a change in sediment type as calcareous sediments (the Courtmacsherry Formation) started to be deposited over the mudstones. At a later time, as subsidence continued, the sea of the South Munster Basin deepened and slowed down the rate of sedimentation, shown in the upper part of the Courtmacsherry Formation and the Lispatrick Formation. Deep water conditions remained during the deposition of the White Strand Formation. Some uplift also occurred at this time and this is discussed later.

Old Head Sandstone Formation (OH) This formation comprises a thick succession of grey sandstones and minor mudstones. It has been divided into two members, the Bream Rock Member and the Holeopen Bay Member, (not distinguished on the bedrock map). It is found around Ballinspittle, the type section at the Old Head of Kinsale, east of Nohaval, around Kilbrittain and in the Bandon Syncline. Thinner exposures follow a line from Carrigaline and Crosshaven, across Cork Harbour and over to Whitegate and Ringabella, as well as from Enniskean to Ballinhassig and a small occurrence on the southern limb of the Macroom Syncline.

Kinsale Formation (KN) This formation, up to 760 m thick at the Old Head of Kinsale, is a mud-dominant succession of grey mudstones and sand-lensed mudstones with some sandstones. It is divided into four members (described below, but not differentiated on the bedrock map).

Castle Slate Member (KNcs) This member consists of uniform dark-grey slaty mudstones, with common phosphatic quartz nodules. It is marked on the map by a single line as it is not very thick, and is associated with the Old Head Sandstone Formation which it immediately succeeds.

Narrow Cove Member (KNnc) This member has a fairly limited exposure around the Old Head of Kinsale and just north of Innishannon, along the Cork-Bandon road. It is 303 m thick at its type section at Narrow Cove. The dominant lithology is a sand-lensed mudstone, with subsidiary flaser-bedded sandstones. The top few metres are sand-dominant and the proportion of

sandstone also increases north and east away from the Old Head.

Cuskinny Member (KNcu) This member is the lateral equivalent of the Narrow Cove Member and is found north and east of the Carrigada Fault, which runs from Innishannon, east to Ballymartle and then turns south to Belgooly. It is 243 m thick at its maximum at South Ringabella. It is distinguished from the Narrow Cove Member by its more dominant sandstone facies, and is composed of conglomeratic sandstone units alternating with thin sandstone laminated mudstones and some claystones.

Pig's Cove Member (KNpc) This is distinguished from the underlying Narrow Cove Member by a lack of sandstones. The lower beds comprise silt and fine sand lenses. The next beds are highly cleaved massive mudstones. The next beds again are similar to the lower beds, whilst the uppermost beds are sandier than the underlying beds. It occurs mainly around Kinsale Harbour, between Belgooly and Ringabella and at Power Head near Gyleen, reaching a maximum thickness of 709 m in the Kinsale-Ringabella area.

Courtmacsherry Formation (CY) This formation is described as grey to very dark-grey calcareous and non-calcareous nodular mudstones, which may have subsidiary limestones. The mudstones are found around the Old Head area, whereas the more limestone-rich facies is found towards Innishannon and between Belgooly and Ringabella. Further east the formation thins around the Cloyne Syncline and passes laterally into the Ringmoylan Formation discussed below.

Lispatrick Formation (LP) This formation comprises fissile and blocky dark-grey to black mudstones with interbedded bands of iron-rich dolomite. The mudstones can be extremely pyritic and often weather to a pale ash-grey colour. There is a subtle distinction between the upper part of the Courtmacsherry Formation and the lower part of the Lispatrick Formation. The formation is fairly poorly exposed and occurs in small exposures around the Old Head of Kinsale and Minane Bridge, and the western part of the Cloyne Syncline.

White Strand Formation (WS) This Namurian aged formation is the youngest found in the area and is exposed mainly in the western part of the Cloyne Syncline, as well as a small isolated exposure around the Old Head of Kinsale. It reaches thicknesses of 346 m at Ballinglanna and similar thicknesses within the Cloyne Syncline. It is described as being mainly sandstones interbedded with brittle, commonly pyritic, grey-black mudstones. In the Cloyne Syncline it comprises grey silty mudstones and dark-grey to greeny-grey medium to coarse grained sandstones.

2.2.3 Lower Carboniferous Limestones

The Carboniferous rocks of South Cork mainly consist of the Lower Limestone Shales and the Carboniferous Limestones. The Lower Limestone Shales were deposited around the same time as the mudstones and sandstones of the Cork Group, north of the Cork -Kenmare line, on the North Munster Shelf, and are represented mainly by the Crow's Point and Ringmoylan Formations. The Carboniferous Limestones occur quite widely around the east Cork area and in the Cork and Cloyne Synclines (the Cork syncline extending as far west as Crookstown), as well as in some smaller synclines around Blarney and Riverstown. They are represented by such formations as the Ballysteen, Waulsortian, Loughbeg and Little Island Formations.

2.2.3.1 Lower Limestone Shales

The Lower Limestone Shale succession in South Cork was deposited north of the Cork-Kenmare line, on the North Munster Shelf and comprises the Mellon House, Ringmoylan and Ballyvergin Shale Formations.

Crows Point Formation (CP) The exposure of this formation in South Cork is restricted to the area around Youghal. It is the lateral equivalent of the Cuskinny and Pig's Cove Members of the Kinsale Formation further south. It differs from the Kinsale Formation by being much more sandstone dominated (92% in places). It is described as a massive cross-stratified grey sandstone with minor mudstones.

Mellon House Formation (MH) *(Whiting Bay Member)* This formation is so restricted in its occurrence in South Cork that it is represented on the map by a line which also represents the Ringmoylan and Ballyvergin Shale Formations. It is found only in the syncline north of Youghal. It is a sequence of thin-bedded skeletal limestones and alternating calcareous and non-calcareous silty mudstones.

Ringmoylan Formation (RM) *(Mallow Member)* The Whiting Bay Member of the Mellon House Formation passes up into the Ringmoylan Formation which again has a very restricted exposure. It consists of fossiliferous, calcareous mudstone with subsidiary limestone. The Mallow Member which is found around Youghal, actually has a higher proportion of limestone than the Ringmoylan Formation at its type are in Co. Limerick. The Ringmoylan is also found in the Riverstown Syncline, north of Cork City and the Blarney Syncline where a few metres of very dark grey mudstone with crinoidal bioclastic limestones are seen.

Ballyvergin Shale Formation (BV) This formation, although very restricted in exposure in South Cork, is a very distinctive marker horizon across much of the North Munster Shelf. It is characterised by greenish grey non-calcareous mudstone with thin interlaminated siltstone bands.

2.2.3.1 The Carboniferous Limestones

Ballysteen Limestone (BA) This formation is quite poorly exposed in South Cork, but can be seen at a few places such as around Cork Harbour, from Carrigtohill to Killeagh, and near Youghal and Youghal Bay. It is a dark muddy fossiliferous limestone and can be up to 125 m thick in places, becoming muddier in the upper beds.

Waulsortian Limestone (WA) These rocks are largely calcareous massive pale grey fine-grained clean fossiliferous limestones which formed in mound structures. Original cavities are now filled with calcite which may form a significant proportion of the total volume of the rock. In the South Cork area there are zones of intense fracture cleavage with a lot of recrystallisation in the cavities. It is found in the centre of the main Dinantian-filled synclines, namely Cork, Cloyne, Blarney and just north of Youghal. It is 420 m thick in the Cloyne Syncline and more than 600 m thick in the Cork Syncline.

Loughbeg Formation (LB) One small exposure of this formation occurs at Loughbeg, near Ringaskiddy. It comprises cherty and nodular calcareous mudstone with occasional beds of silicified crinoidal limestone. It is up to 43 m thick , and overlies the Waulsortian Limestones.

Cork Red Marble Formation (CK) This formation is found only in the Cork Syncline and in the Cloyne Syncline east of the harbour separating the Waulsortian Limestones from the Little Island Formation, and comprising grey cherty calcisiltites, red crinoidal breccias and cherts in a red mudstone matrix. It has been extensively quarried and used in buildings, as a polished decorative stone.

Little Island Formation (LI) This formation extends from just south of Youghal and westwards all the way along the Cork Syncline as far as Crookstown. It is quarried at a few locations, e.g. Crookstown, Carrigtohill and Midleton in the Cork Syncline and can be up to 500 m thick at its type section on Little Island. It is also found in the Cloyne Syncline northwest of Carrigaline, where it is less thick, up to 250 m. It is a uniform thick succession of mainly mudbank limestones, with massive crinoidal wackestones at the top of the formation. It is gradational to the overlying Clashavodig Formation.

Clashavodig Formation (CV) This formation, seen from Little Island eastwards as far as Midleton, overlies the Little Island Formation. It is generally a poorly-bedded to well-bedded sequence of fine-grained limestones (wackestones), oolitic grainstones and cherty calcilutites (limestone consisting of dominantly clay sized particles). The base of the formation is marked by a change from poorly-bedded to well-bedded limestones and an

increase in crinoid content. The upper part is characterised by peloidal and oolitic beds and palaeokarstic top surfaces, overlain by a thin layer of shale (clay wayboard).

2.2.4 Igneous Rocks

A few volcanic rocks are found in South Cork but are not mapped as individual formations. A few tuff layers are found at a number of localities near the Devonian/Carboniferous boundary. One can be seen on the west side of the Old Head of Kinsale within the Castle Slate Member, and another in the Old Head Sandstone Formation on the western side of Clonakilty Bay.

There are also a number of occurrences of intrusive rocks in South Cork. Two alkali metagabbro sills found near Myshells House just north of Bandon have a total thickness of 140 m and extend along strike for 3 km.

2.2.5 Structural History

The regional structure of the area is dominated by the major structural event known as the Variscan Orogeny.

The Variscan Orogeny was a north-south compression event and as the deformation front was located on a line running approximately from Dingle Bay to Dungarvan. East-west trending anticlines and synclines dominate and there are numerous north-south cross faults. The degree of deformation can be correlated with the lithology of the rocks; the least competent shales and thin muddy units are characterised by brittle folding and faulting while the more competent clean limestones deform with more open, gentle, simple folding.

According to Sleeman & Pracht (1994), the overall form of the Variscan fold belt is arcuate, with the an east-west strike east of Cork harbour, but west of Cork Harbour the trend swings around to east-northeast to west-southwest. The outcrop pattern as seen in Map 1 (Bedrock Geology), is controlled largely by the number of large-scale synclines and anticlines with many second and third order folds on their flanks. Major folds include the Ardmore Syncline, the Cork Syncline, the Great Island Anticline, the Cloyne Syncline, the Church Bay Anticline, the Ringabella Syncline and the Bandon Anticline. Smaller folds to the north of Cork City include the Blarney and Riverstown Synclines. The north-northwest to south-southeast trending faults cross-cut these fold belts. Strike parallel faults have been identified in a number of areas in Cork Harbour.

Further west in South Cork, towards Co. Kerry, the structural history of the rocks becomes more complicated, with many more folds, faults and thrusts in evidence. The folds within South Cork include the Ballyvoge Anticline, the Macroom-Blarney Syncline and part of the Cork Syncline. There are many thrust and faults which cross-cut these folds, including the Sullane River Thrust, the Reananerree Thrust and the Poulnabro Bridge Fault.

2.3 Subsoil Geology

This section deals primarily with the geological materials which lie above the bedrock and beneath the topsoil, referred to here as subsoils. The subsoils were deposited during the Quaternary period of geological history which encompasses the last 1.6 million years and is sub-divided into: the Pleistocene (1.6M–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 Pleistocene, the glaciers and ice sheets laid down a wide range of deposits which differ in thickness, extent and lithology. Material for the deposits originated from fresh and weathered bedrock and previously deposited materials. They were subjected to different processes within (englacial), beneath (subglacial) and around (ice-marginal) the ice. Some were deposited randomly and so are unsorted and have variable grain sizes, while others were deposited by water in and around the ice sheets and are relatively well sorted and often coarse grained. During the Holocene, rivers have deposited alluvial and estuarine deposits which vary from fine grained to coarse grained materials depending on the energy of the system. Peats have also formed in low-lying poorly drained hollows, in former lakes and on high ground where precipitation is high.

Very little subsoil (Quaternary) mapping had been carried out in the South Cork area until recently and the availability of previous compiled data on subsoils was relatively sparse. Subsoils mapping has been recently undertaken by Dr R. Meehan, Teagasc, Kinsealy as part of a larger FIPS-IFS project. This involved initial compilation of all available Quaternary data, followed by photogrammetric modelling of aerial photographs to infer Quaternary geological (subsoil) boundaries. Field mapping was undertaken to check these boundaries. The end product was the "FIPS – IFS Soil Parent Material Map" which forms the basis of the Subsoils Maps (Maps 2E, 2W and 2S). This formed the foundation of subsequent subsoil permeability assessments (described in Chapter 5).

2.3.2 Subsoil Types

The main subsoil types in South Cork are:

- till (of varying lithologies and textures)
- sands and gravels
- alluvium
- peat
- lake sediments
- marine deposits
- estuarine deposits

2.3.2.1 Till

Till (often referred to as boulder clay or drift) is the most widespread subsoil in Cork. It is a diverse material,l which is deposited subglacially 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. Tills found close to bedrock and where the deposits are relatively thin, comprise a coarse matrix with angular clasts and can be described as broken up bedrock or immature till.

Till can be classified on the basis of the dominant clast lithology (i.e. stone type) and the matrix composition (texture). The subdivision of tills based on matrix composition depends on the proportions of fine gravel, sand, silt and clay particles present in the matrix. The method of determining the categories is by visual and manual assessment on-site and using laboratory particle size analysis where appropriate. A clayey till, for example, has a high percentage of clay particles; a silty till has a high percentage of silt in its matrix.

Warren (1991) described two types of till which occur in this region - the Ballycroneen Till and the Garryvoe Till. The Ballycroneen Till, described as a massive grey-brown diamicton, rich in clay and silt with shell fragments, was formed by ice that moved south from southwestern Scotland and the Irish Sea. It has very few phenoclasts although it does contain stony facies in places. It seems to mostly occur in the limestone synclines. Overlying this till (in places) is the Garryvoe Till, which was formed by ice that originated in the Kerry/Cork Mountains. It extends as far as Youghal in the east of the county. It is described as having a red-brown matrix and is characterised by phenoclasts of Devonian sandstone and shale along with some phenoclasts of Carboniferous Limestone, shale and chert.

The tills are not subdivided on the subsoil maps 2E, 2W, and 2S. On-site visual and manual assessments of till matrix were carried out during permeability mapping, whereby subsoil samples were described using a method derived from BS5930:1999. Particle size analyses were subsequently carried out on a number of samples (Appendix III). These results are discussed in the context of subsoil permeability and groundwater vulnerability in Chapter 5.

2.3.2.2 Sand and gravel

Deposition of sand and gravel takes place mainly when glaciers are melting. This gives rise to large volumes of meltwaters with great erosive and transporting power. The sands and gravels deposited in this high-energy environment are primarily well rounded, sorted gravels with 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.
Sand and gravel deposits identified in the Teagasc FIPS-IFS Parent Material Mapping are shown on Maps 2E, 2W and 2S. Sands and gravels occur around the Enniskean / Bandon / Innishannon area as well as near Ovens and Carrigadrohid. Some sand and gravel deposits are covered by layers of till or alluvium and are therefore not represented on the subsoils map eg, deposits around Carrigtohill and Minane Bridge, and in the Lee Valley. A County Council borehole in Cloyne found gravel deposits, which may be up to 30 m thick in places. Smaller sand and gravel deposits can be found in isolated areas along the Sullane River in western areas of South Cork at Ballyvourney and Carrigaphooca as well as at Dunisky on the River Lee. Detailed analysis of the sand and gravel deposits of South Cork regarding permeabilities and particle size analysis has not been carried out to date.

2.3.2.3 Alluvial Deposits

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. Alluvial sediments in flood plains, where flow velocities are relatively low, are expected to be primarily silty deposits with some clay. Close to the hills and mountains they are likely to be more sandy or gravelly as flow velocities are faster. The largest areas of mapped alluvium in the South Cork Region occur along the Rivers Lee, Bride and Bandon.

2.3.2.4 Peat

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and undecomposed plant matter, which has accumulated in a waterlogged environment. It has an extremely high natural water content averaging over 90% by volume,

but many have now been drained. Of the two main types of peat bog in Ireland, ('Blanket' and 'Raised') only blanket bog, characteristic of upland areas with excessive rainfall and generally 3-5m thick, occurs in South Cork.

The main areas of peat in South Cork are the relatively small deposits on the higher ground in the west of the county towards the Boggeragh and Derrynasaggart Mountains. There are also some in evidence just south of Inchigeelagh, north of Enniskean (An Foras Talúntais, 1978).

2.3.2.5 Lake Sediments

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

2.3.2.6 Marine Deposits

Beach sands and gravels are the most common marine deposits and are found along the coast. Estuarine silts and clays are also included. These have settled from suspension in salt or brackish water bodies in a tidal environment.

2.3.3 Subsoil Thicknesses

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 40 metres (from borehole log data, both wells and geotechnical). Depth to rock data maps (Maps 3E, 3W and 3S) show areas where rock crops out at the surface, areas of shallow rock and depth-to-rock data from borehole records.

As part of the preparation of this Groundwater Protection Scheme the GSI undertook a depth to rock drilling programme. Subsoil depth and type were investigated at a total of 298 sites throughout the South Cork area using a continuous-flight solid-stem earth auger (up to a maximum of 11m depth). Subsoil samples were described according to BS 5930:1999 and some samples were sent for Particle Size Analysis.

In general subsoils in South Cork are relatively shallow with just under 50% of the total area estimated to have less than 3m of subsoil cover. The thinnest subsoils and areas of 'rock close to surface' occur in the smaller valleys where there are rock outcrops along the stream beds; along the east - west trending ridges, particularly in centre and east of the region; and in the mountains in West Cork (Derrynasaggart, Boggeragh). Depth to bedrock is also seen to be very shallow in a lot of coastal areas around the cliffs of South Cork. The thickest deposits are generally encountered in the major river valleys of the Lee, Bride and Bandon and in some parts of the limestone valleys of East Cork.

The most frequent occurrences of outcrop and shallow rock are found in the west of the region near Macroom and the Derrynasaggart and Boggeragh Mountains. Moving east towards Youghal along the sandstone ridge to the north of Cork city, subsoils are generally less than 10m deep with the thinest subsoils (<3m) generally occurring in stream and river valleys. Subsoil depths of 10-15m are occasionally recorded in this region. Shallow subsoils (<3m) are frequently encountered on the ridge running east-west from Great Island to Knockadoon Head and in the area between Whitegate and Ballycotton. In the south of the region there are also frequent occurrences of outcrop and shallow rock particularly in coastal areas and along river valleys. Outside areas of outcrop and shallow rock subsoils are generally <10m deep, although depths of >10m are occasionally recorded.

In the Cork Syncline east of Midleton subsoil depths of 5-10m are frequently recorded with depths of over 20m recorded in a number of boreholes at the northern side of the valley

between Killeagh and Youghal. Towards the centre of the valley, near Castlemartyr and around Midleton, there are frequent occurrences of rock close to the surface. Similar variations in subsoil depths are observed in the Cloyne Syncline. The underlying Waulsortian limestone in these synclinal valleys is highly karstified and likely to have a very irregular surface due to the presence of swallow holes, cavities, and caves. Subsoil depths in these areas can therefore be highly variable within short distances.

In general sand and gravel deposits are usually more than 10 m thick, in particular where they have been laid down with tills as morainic deposits. Thicknesses of lake, alluvial and estuarine deposits are usually unknown but it is unlikely that they are more than 10 m thick. Peat on higher ground is typically 3 m thick or less.

Some inherent difficulties in assessing areas of shallow and deeper subsoils must be taken into account. Areas of thin subsoils are easier to assess because the outcrops and areas of rock close to surface (<3 m) have been mapped by Teagasc in conjunction with GSI. Areas of deeper subsoil can only be identified from isolated boreholes. Areas of deeper subsoils mapped in the Cork City and harbour area may be slightly biased by the deeper drilling carried out for geotechnical investigations.

3 Hydrogeology and Aquifer Classification

3.1 Introduction

This chapter summarises the relevant available hydrogeological and groundwater information for South County Cork. 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 and the aquifers are shown on Map 3.

3.2 Data Availability

Groundwater data from the GSI and County Council 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 Co. Cork. Local well drillers were also consulted to record some of their experience and knowledge.

The assessment of the hydrogeology of South Cork is based on the following data and reports:

- Information from more than 2800 well records now 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.
- Information from the well improvement grant scheme.
- Specific capacity 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 $m^3/d/m$.).
- Pumping tests carried out on wells at 3 of the public supplies during this project.
- Two MSc. theses carried out in junction with GSI: (a) a source protection scheme for the Dower Spring (Gately, 1996); (b) a groundwater flow model for the limestone aquifer around the Cloyne area (Conroy, 1997).
- The GSI karst database.
- Reports by engineering and hydrogeological consultants.
- Relevant academic research papers.
- Local drillers' experience.
- General hydrogeological experience of the GSI, including work carried out in adjacent counties and for other groundwater protection schemes.

3.3 Rainfall and Evapotranspiration

Mean annual rainfall in South Cork for 1961–1990 ranged from 933 to 2447 mm/yr over the whole of South Cork (Met Eireann data). However, East Cork is drier, ranging from 933 to 1408 mm/yr, compared with more westerly parts of South Cork which range from 1086 to 2447 mm/yr.

The closest Met Eireann evapotranspiration station at Roche's Point calculates the long term mean annual potential evapotranspiration to be 570 mm (Met Eireann). Since Roche's Point is a coastal station where evaporation is enhanced by exposure to winds, the average value over South Cork is likely to be about 525 mm. Actual evapotranspiration is taken to be about 95% of the potential evapotranspiration, i.e about 500 mm, and the mean annual potential recharge (rainfall minus actual evapotranspiration) is therefore estimated to be of the order of 400 to 1900 mm, with the lowest levels in the low-lying areas and the highest in the upland areas of west Cork.

3.4 Groundwater Usage

Some 55 public water schemes in South Cork are supplied by groundwater. In total these groundwater schemes abstract some 16,100 m^3/d (subject to revision - sources summarised in Table 3.1), or approximately 18% of the total public water supply in South Cork, slightly below the national average. Areas not served by the County Council and the Inniscarra Reservoir generally rely on individual private wells as the main source of water supply and therefore the actual proportion of the population in South Cork served by groundwater may be significantly higher.

3.5 Aquifer Classification

3.5.1 Aquifer Categories

According to the aquifer classification used by the GSI (DELG/EPA/GSI, 1999), there are three main aquifer categories, with each category sub-divided into two or three classes:

Regionally Important (R) Aquifers

(i) Karstified bedrock 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

(i) Bedrock which is Generally Unproductive except for Local Zones **(Pl)**

(ii) Bedrock which is Generally Unproductive **(Pu)**

Aquifers are defined on the basis of the following:

- Lithological and structural characteristics of geological formations which indicate an ability to store and transmit water. Clean, well sorted sands and gravels for example, are more permeable than poorly sorted glacial tills. Clean limestones and sandstones are also more permeable than muddy limestones, and sandstones interbedded with shales, respectively. Areas where folding and faulting has produced extensive joint systems tend to have higher permeabilities than less deformed areas.

- Hydrological indications of groundwater storage and movement. For example, the presence of large springs can indicate a good aquifer; the absence of surface drainage can suggest high permeability; and high groundwater base flows in rivers indicates good aquifer potential.
- Information from boreholes, such as high permeabilities from pumping tests, specific capacities (pumping rate per unit drawdown), and well yields.

Table 3.1 Public Supply Groundwater Abstractions in South Co. Cork

Supply	Source	Approx. current abstraction (or available yield)
		m^3/d
Aghabullogue	Bore near village close to houses	88
Aghavrin	Bore near crossroads	no info
Ardkilly Ridge	2 bores near Sandycove	no info
Ballinadee	Spring	63.6
Ballincurrig/Lisgoold	Ballincurrig bore at the creamery Lisgoold bore (Leadington Bridge)	154 235
Ballinhassig		no info
Ballinspittle/Garrettstown	Spring north of village Garrettstown b/hole near GAA pitch Garrettstown b/hole in village	78.5 65.4 300
Ballymacoda	Springs	218.2
Ballymakeera	Springs/Infiltration Gallery	218
Ballinagree	Borehole on roadside	109
Ballyphilip	Bore near Ballyphilip House	27.3
Belgooly	Bore near bridge	218
Berrings/Ballyshoneen	Ballyshoneen borehole Berrings borehole	70 no info
Bilberry	Bore	no info
Brown's Mill	Infiltration gallery	no info
Carrigadrohid	Infiltration Gallery	369
Carrignavar	Bore	86.3
Clash East	Bore	32
Clondrohid	Infiltration Gallery	82
Cloyne/Aghada	Lissanly borehole Town Parks borehole Commons East borehole Farrannamanagh borehole	1309 1618 1772 1860
Coachford	Bore 1 at Fr. Sheahan Place Bore 2 (Old Railway Bore)	158 80
Coole East	Ballinvriskig bore Coole East bore	81.8 98
Coolyhane	Bore on road NE of Macroom	no info
Crookstown	Bore in garden of house	145
Donoughmore/Stuake	Bore 1 (Stuake) Bore 2 (Knockyrourke)	164 261
Dungourney	Well east of Dungourney Village	no info
Garranes	Bore near cross roads Bore near church	no info 54.5
Garrylucas	Borehole at Lispatrick Lower	240
Glenville	Borehole in village	65.5
Grenagh	Grenagh Village (new well) (not in use all the time) Grenagh Village (old well) Quarryhall borehole	98 130 57
Inchigeelagh	Bore east of village Bore in village (?possibly infiltration gallery) Old Bore	no info no info 49
Kilbrittain	Old borehole New borehole	no info 100
Kilcraheen		no info
Killeagh	Bore W of N25, near old railway Bore E of N25, near village	no info no info
Kilmurry	Springs east of village	no info
Kilnamartyra	Bore in village by GAA pitch	91
Knockadoon	Ballyskibbole bore Glenawilling bore	no info no info

Supply	Source	Approx. current abstraction
Knockburden	Bore near crossroads	22.7
Knocknaphreaghane	Bore	no info
Minane Bridge	Infiltration Gallery	98
New Inn	Bore near the school	54.5
Newcestown	Bore	no info
Nohoval	Bore	no info
Old Chapel	Bore	no info
Riverstick	Spring by the bridge	96
Robert's Cove	Bore 1 (Doonavanig) Bore 2 (Britfieldstown)	51 36
Rylane	Bore in the village Bore outside village	90 no info
Shanagraigue	Bore (??)	18.2
Stoneview/Blarney	Bore NE of Curraghnalaght x-rds	68
Tower/Blarney	Bore	no info
Vicarstown	Bore	no info
Walshtownbeg	Bore	no info
Whitegate Regional	Dower Spring (abstraction rate given)	4545
White's Cross	Bore near crossroads	210
Whitechurch/Ryefield	Bore in Ryefield Bore near Whitechurch village	no info no info

3.5.2 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 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'.

3.5.3 Sand/Gravel Aquifers

A sand/gravel deposit is normally 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 taken 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 3.2 Sand/Gravel Aquifer Classification

	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 3.2). The permeability of the deposits can vary considerably depending on how they were laid down, so the geological history of the deposit is also considered if this is known. Morainic sand/gravel, for example, is often too 'dirty' (too much silt and clay) to have a high enough permeability to enable sufficient groundwater throughput. Water-lain gravels are usually better sorted and as a result have a higher permeability.

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.

3.5.4 Karstification

Karstification is the process whereby limestones are slowly dissolved by slightly acidic waters moving through them. This most often occurs in the upper bedrock layers and along some of the pre-existing fissures and fractures in the rocks which become slowly enlarged. This eventually results in the 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 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 water; the rate of water circulation; the geomorphic history (upland/lowland, sea level changes, etc.); and the subsoil cover. One consequence of karstification is the development of an uneven distribution of permeability resulting from the enlargement of some fissures at the expense of others and the concentration of water flow into these high permeability zones.

There are gradations in karstification in Ireland from slight to intensive. 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**.

3.5.5 Dolomitisation

Dolomitisation is a chemical process whereby calcium ions are replaced by magnesium ions in the crystal lattice of dolomite ($Ca\,Mg\,(CO_3)_2$). There can be two different grades of dolomitisation, which have significantly different effects on permeability. The first is the typical, highly weathered, yellow/orange/brown dolomitisation which is usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery occurring. This type often occurs along fault zones, can cross bedrock lithology boundaries and results in unpredictable very high permeability zones. The other is a less highly weathered, stratigraphically controlled type of dolomitisation, which is often a black colour on the surface. This type is considered to be a barrier to groundwater flow. Dolomitisation is uncommon in South Cork, but more common in North Cork.

3.5.6 Use of Well Yields and Productivities in Defining Aquifers

Although the main type of information available for aquifer classification in South Cork is from well yields and productivities, several other sources of information have been used (e.g. bedrock lithology, structural deformation, pumping tests, surface drainage and the degree of karstification). It is emphasised that the aquifer delineation is a generalisation which reflects the overall resource potential; because of the complex and variable nature of Irish hydrogeology, and there will often be exceptionally low or high yields obtained which do not

detract from the overall category given to any particular rock unit. It is also important to remember that the top few metres of any bedrock type are likely to be relatively permeable.

Well yields should never be used on their own as the basis for assigning a rock unit to a particular aquifer category. 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 would have (or be capable of having) a large number of wells yielding in excess of 400 m^3/d (approx. 3700 gph); locally important (**L**) aquifers are capable of moderate well yields 100–400 m^3/d (900–3700 gph); and poor (**P**) aquifers would generally have low yielding wells, i.e. less than 100 m^3/d.

Where specific capacity data are available, a method has been developed (Wright, 2000) whereby the well yield (Q, in m^3/d) is plotted against the specific capacity (SC, in m^3/d/m) for that borehole. The graphs (termed "QSC Graphs") allow a 'borehole productivity class' (I, II, III, IV, or V) to be derived. The relative frequency of these classes for a given rock unit help in its classification as an aquifer.

Well data are considered to be useful if they indicate high yields, i.e. 'excellent' or 'good', if they are failed wells or if they have a specific capacity, as these enable an assessment of the productivity of the aquifer. It should be noted that in compiling the useful well data there may be factors which bias the data in various directions:

- Many of the most reliable data points are obtained from the County Council for public supplies and these tend to be higher yielding than most wells.
- Many wells in the database are privately owned wells drilled in the 1960s and 1970s. The abstractions are usually small, the wells were not yield-tested and it is unclear whether the yield given is the maximum available or just the amount required by the owner. These data were therefore not used in assessing aquifer categories but were used mainly to give depth-to-rock and water levels.
- In recent years, data has been obtained from well grant applications, which are for small private wells, often in areas of poor or locally important aquifers. While the tests on these wells have not been subject to rigorous technical supervision, nevertheless the collective data set is considered to be useful and relevant in evaluating aquifer potential.

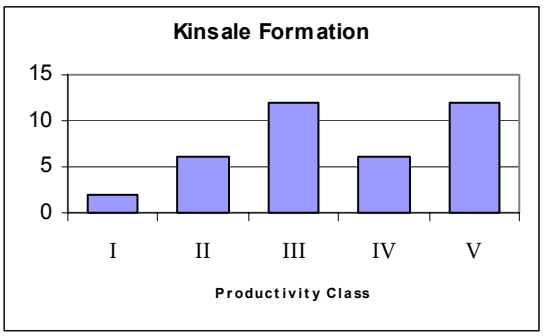
The rock units in South Cork are listed in Table 3.3, together with a summary of the useful well data from South Cork and relevant neighbouring areas, the karst features present in each unit, productivity data and the aquifer category.

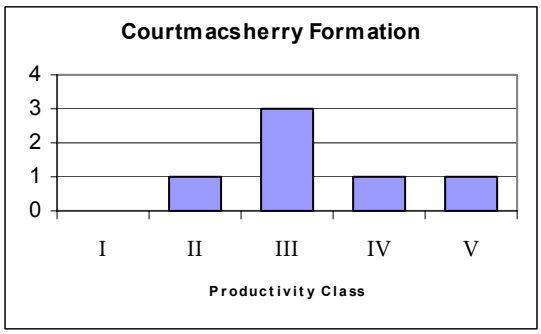
Below the table a series of charts illustrates the relative frequency of well productivity values for the main rock units. Other units have too few data to be graphed.

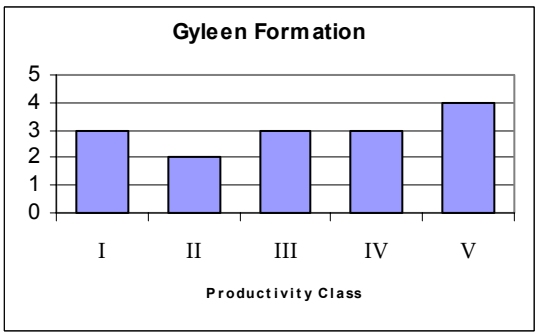
Table 3.3 Data supporting Aquifer Categories

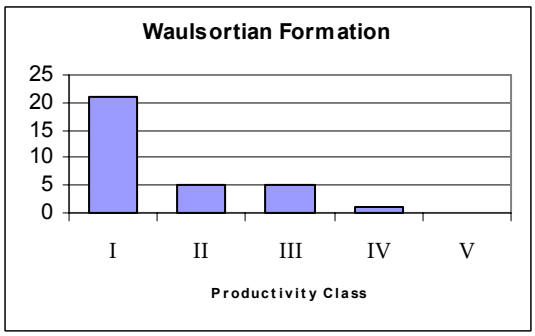
Group	Formation	Code	Thickness m	Dolomite	Karst	Excellent or Good Yields	Productivity I/II/III/IV/V	Aquifer Category
	Volcanics	V		n/a	n/a	insufficient data		**Ll**
	Clashavodig Fm	CV			?			**Rf**
clean	Little Island Formation	LI	200+		uncommon	common	11/4/9/8/6	**Rf**
limestones	Cork Red Marble Fm	CK	120		?	common	1/4/0/2/1	**Rf**
	Loughbeg Fm	LB			?			**Rf**
Waulsortian	Waulsortian Limestone	WA	up to 400	No	abundant	some/common	21/5/5/1/0	**Rk**
Ballysteen Fm	Ballysteen Fm	BA	300	No	uncommon	some/common	1/9/7/7/7	**Ll**
	Crow's Point Fm	CP		No	n/a			**Ll**
Lower Limestone Shale	Mellon House Fm Ringmoylan Shale Fm	MH/ RS/	20 - 35	n/a	n/a	?rare/some	0/0/1/4/3	**Pl**
	White Strand Fm	WS			n/a			**Pl**
Cork	Lispatrick Fm	LP			n/a		0/1/2/0/0	**Ll**
Group	Courtmacsherry Fm	CY			n/a		0/1/3/1/1	**Ll**
	Kinsale Fm	KN			n/a		2/6/12/6/12	**Ll**
	Old Head Sandstone Fm	OH			n/a		0/0/1/1/2	**Ll**
	Gyleen Formation	GY		n/a	n/a	routine	3/2/3/3/4	**Ll**
	Ballytrasna Fm	BS		n/a	n/a	routine	0/4/4/16/15	**Ll**
	Toe Head Fm	TH		n/a	n/a	insufficient data		**Pl**
	Castlehaven Fm	CE		n/a	n/a	insufficient data		**Pl**
ORS	Gun Point Fm	GP			n/a		0/0/0/1/1	**Ll**
	Caha Mountain Fm	CH			n/a		0/0/0/0/5	**Pl**
	Glenflesk Chloritic Sst Fm	GC			n/a			**Ll**
	Slaheny Sandstone Fm	Sl			n/a			**Ll**
	Bird Hill Fm	BH			n/a			**Pl**
	Old Red Sandstone (undiff)	ORS		n/a	n/a	occasional/common		**Ll**

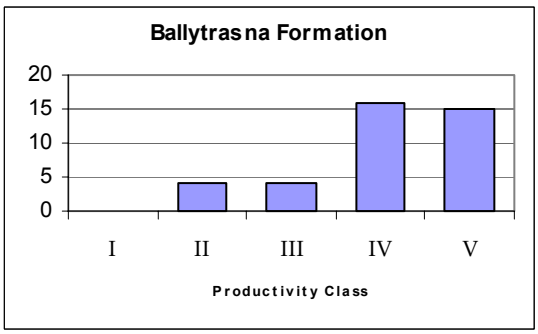
Notes:
(1) While there are >2800 well records for South Co. Cork, most have neither drawdown data to enable the specific capacities to be calculated, nor maximum yield information.
(2) Karst features include swallow holes, caves, collapses, turloughs, dry valleys, karst springs.

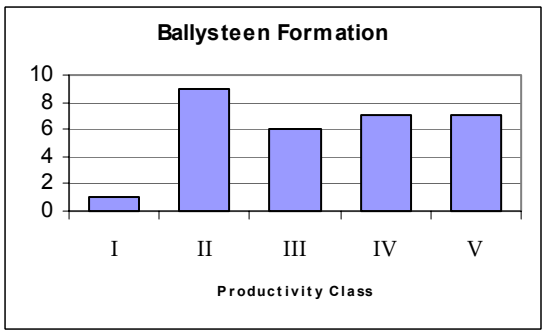












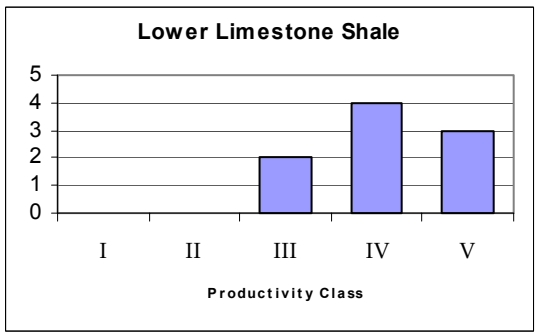


Figure 3.1: Productivity Charts for main formations

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

3.6 Old Red Sandstone (ORS) formations

The Old Red Sandstones in South Cork can be divided into the major formations with a lot of available well data and those which have very little data (perhaps because they are such poor aquifers). It is possible to pick out some of the upper units as more productive (such as the Ballytrasna and Gyleen Formations) and the lower units as being less productive (the Caha Mountain and Bird Hill Formations for example). The lower units do have their exceptions, however, as will be seen in the description of the Glenflesk Chloritic Sandstone Formation.

The Gortanimill Formation, a medium-grained sandstone with thick sequences of fine-grained sandstone and siltstone, has useful well data for 13 wells, 5 of which are 'good' wells (yields ranging from 130 to 261 m^3/d), although no specific capacity data are available. Productivity values are available for 5 wells in classes III, IV and V. Because of its geological nature and the number of good wells, this formation is classified as a **locally important aquifer, which is moderately productive only in local zones** (**Ll**).

The Ballytrasna Formation, consisting of mainly mudstones with some sandstones, has a lot of useful well data available for an assessment of its aquifer potential, owing to its very large areal extent. 104 wells show a distribution of 23 'good' wells, but no records of any 'excellent' wells in this formation. Productivity values are available for almost 40 wells, mostly in classes IV and V. This formation is classified as a **locally important aquifer, moderately productive only in local zones** (**Ll**).

The Gyleen Formation also consists mainly of mudstones with some sandstone, and is found conformably overlying the Ballytrasna Formation in many places. No attempt has been made to distinguish the aquifer characteristics of the different members within the formation. Yields are available for 17 wells, mostly in the 'good' or 'moderate' categories. One 'excellent' well at Togher (Southern Fruit) recorded a yield of 576 m^3/d and a specific capacity of 74 $m^3/d/m$ (class II), and there are 6 'good' wells. 16 productivity values exist, spread across all classes. If these were representative, a 'Lm' category might be justified, but it is suspected that a larger sample would not support such a rating. This unit is therefore considered to be a **locally important aquifer, moderately productive only in local zones** (**Ll**).

There are many well records for other ORS formations. Once again, most of these fall into the 'moderate' yield category. There are 4 other wells with yields over 100 m^3/d ('good') but no specific capacity data are available for these. A specific capacity of 0.6 $m^3/d/m$ is available for a 'moderate' well. 17 other wells fall into the 'poor' category with specific capacities ranging 0.4 - 0.5 $m^3/d/m$. No well data are available for the **Glenflesk Chloritic Sandstone Formation**. It is described as a medium-grained sandstone, conglomerate and pebbly sandstone, together with green and purple siltstone. Work on aquifer classification of the Old Red Sandstone rocks in Co. Kerry (Conlon & Wright, 1998), found that this formation can be considered a "**locally important aquifer, moderately productive only in local zones**" (**Ll**). This classification is used here in the absence of any other well data.

Another coarser sandstone formation of the Old Red Sandstone for which almost no well data are available is the **Slaheny Sandstone Formation**. This formation, described as a siltstone-rich sequence with medium to coarse-grained micaceous sandstones and occasional intraformational conglomerates, is also classified in Kerry as **Ll** (**a locally important aquifer, moderately productive only in local zones**) and it is assumed that this classification will hold true in South Cork.

The **Gun Point Formation** is described as medium and coarse-grained sandstones, which are locally pebbly, with some thin interbedded purple siltstones. There are 5 'poor' wells in this formation but only two productivity values (classes IV and V). There is possibly one 'good' well in this formation, yielding 218 m^3/d, but its location is uncertain and therefore the information is unreliable. However, from its geological description this rock unit is coarser than some of the underlying formations and as such the Gun Point Formation is classified as a **locally important aquifer, moderately productive only in local zones** (**Ll**).

There is very little well data available for the finer grained formations of the Old Red Sandstone such as the **Bird Hill** and **Caha Mountain** formations. The Bird Hill Formation consists of fine grained sandstones and has been classified in Co. Kerry as a poor aquifer. In South Cork, only one well with useful information has been found for this formation, which indicates a 'poor' well yielding 17.4 m^3/d and a class V productivity. The Caha Mountain Formation mainly consists of siltstones and sandstones. There are 3 'moderate' wells (yielding between 49 and 82 m^3/d) and 5 'poor' wells, all with class V productivities. This formation is classified in Kerry as a poor aquifer. Therefore, these two formations are classified as **poor aquifers, which are generally unproductive except for local zones (Pl)**.

The two remaining formations of the Old Red Sandstone are the Castlehaven and Toe Head formations. Very little well data exists for these formations. The Castlehaven Formation is described as a mixture of mudstones and siltstones with interbedded sandstone dominant units. There are also some areas with local calcareous material as well as mud clast breccias. A well in Foilnamuck, near Schull in West Cork, yields 43.6 m^3/d and has a class V productivity. Although this is not much information to base a classification on, the geological description indicates that this formation is a **poor aquifer, which is generally unproductive except for local zones (Pl)**.

The **Toe Head Formation** is described as dominated by sandstones with minor mudstones. There is very little well data for this formation but one 'good' well is recorded with a yield of 109 m^3/d but no specific capacity data. As in Kerry, the classification of a **locally important aquifer, moderately productive only in local zones (Ll)** is carried through to South Cork.

The permeability of the ORS in South Cork appears to vary depending on the nature of the rock type and the proportion of sandstones/conglomerates. Permeability is higher in the sandstones and somewhat lower in the units with mudstones and siltstones.

Groundwater may be confined in places under the lower permeability units but in general most of the flow is likely to be in the upper few metres of fractured, weathered rock. A good area for groundwater development in the ORS units is likely to be near the vicinity of the boundary with the overlying Lower Limestone Shale where groundwater will be confined. These rocks are suitable for smaller public supplies and group water schemes provided that the high permeability zones can be located.

3.7 Lower Limestone Shale (LLS)

The Lower Limestone Shale is a relatively thin unit with minimal outcrop area in South Cork and little available data to enable the hydrogeological characteristics to be assessed. These rocks are predominantly muddy limestones and shales with minor sandy units.

The **Crow's Point Formation** is described as being up to 92% sandstone in places and may therefore have higher permeabilities than the other LLS units. It is the lateral equivalent of the Cuskinny and Pig's Cove members of the Kinsale Formation. This unit is also found in Co. Waterford (Hudson *et al*, 1997) and is classified there as a **locally important aquifer which**

is moderately productive only in local zones (Ll), based on *some* well data. Without any more data in South Cork, this classification is used here also.

The **Mellon House** and **Ringmoylan formations**, further up the sequence, are considered to have lower permeabilities because of their higher shale content. There is a lack of useful well data to help in the classification of these two units, so geological descriptions are used. The rocks of the Mellon House Formation are thin-bedded skeletal limestones with silty mudstones. The Ringmoylan Formation is a fossiliferous, calcareous mudstone with subsidiary limestone. The Co. Waterford classification of a locally important aquifer may not apply to South Cork because of the very limited areal extent so this aquifer unit of undifferentiated LLS is classified as a **poor aquifer, which is generally unproductive except for local zones (Pl)**. Boreholes should preferably be drilled through to the underlying more productive Old Red Sandstone or at least into the Crow's Point Formation.

3.8 Cork Group

The Cork Group consists of marine clastic rocks that were deposited in the South Munster Basin during the late Devonian and early Carboniferous. The Group comprises the Old Head Sandstone, Kinsale, Courtmacsherry, Lispatrick and White Strand formations. These rocks are generally mud-dominant with few limestone units and as such are generally thought to be fairly unproductive. There is a lot of well data for the Group and some of the individual formations have enough data to be considered separately in aquifer classification terms.

The **Old Head Sandstone Formation** consists of massive sandstones and minor mudstones. According to Sleeman *et al*. (1994), the middle part of the Old Head Sandstone Formation consists mainly of sandstone beds and perhaps has potential for development. Limited specific capacity data are available for this unit, giving four productivity values (III, IV, V and V). Two 2 'good' wells are recorded, with yields of 109 and 218 m^3/d. It is classified as a **locally important aquifer, which is moderately productive only in local zones (Ll)**.

The **Kinsale Formation** is a mud-dominant succession of mudstones and sand-lensed mudstones with some sandstones. It has a total of 64 wells with useful information to categorise the aquifer unit. The different members of this formation have not been considered separately. There are no 'excellent' wells located in this formation, but there are over 18 wells with yields greater than 100 m^3/d ('good' wells). The public supply well at Doonavanig, Robert's Cove, has a specific capacity of 19.65 m^3/d/m and a transmissivity of 10 - 12 m^2/d. Of 27 wells with specific capacity data, one is in Productivity Class I, 4 in Class II, 8 in III, 4 in IV and 10 in V.

This aquifer is considered to be locally important. Where it has been mapped in more detail between Kinsale and Crosshaven many major faults are apparent. These rocks are generally described as mudstones and it is thought that their permeability is quite low with a low throughput. However there are areas, which are quite faulted and are thought to have higher permeability zones. As such this aquifer unit is classified as a **locally important aquifer,** which is **moderately productive only in local zones (Ll)**.

The **Courtmacsherry Formation**. is described as calcareous and non-calcareous nodular mudstones, which may have subsidiary limestones. This formation has several 'good' wells. Six wells have specific capacity data, falling into Productivity classes II, III (3 no.), IV and V. It is classified as a L**ocally Important aquifer,** which is **moderately productive only in local zones (Ll)**.

The **Lispatrick Formation**, which lies just above the Courtmacsherry, is described as comprising fissile and blocky mudstones with interbedded bands of iron-rich dolomite. The

mudstones can be extremely pyritic and can often weather to a pale ash-grey colour. The fissile nature of these rocks, although they are mainly mudstones, can lead to slightly higher than expected permeabilities. The dolomitic nature of parts of the formation is also expected to lead to higher permeabilities in places. Data from 3 useful wells are available. One of these wells is classified as 'excellent' and the other two as 'good', and the specific capacity data place them in Productivity classes II, III and III. This unit is classified as a **locally important aquifer,** which is **moderately productive only in local zones (Ll)**.

The **White Strand Formation**, described as mainly sandstones interbedded with brittle, commonly pyritic, grey-black mudstones, also has some well data available. In the Cloyne Syncline it comprises grey silty mudstones and dark-grey to greeny-grey medium to coarse grained sandstones. The 6 wells with useful data are all located in the Cloyne Syncline between an area just north of Innishannon to around Carrigaline. There are 2 'poor' wells, one with a specific capacity of 4.79 m^3/d/m. The other wells are all classed as 'moderate' with yields ranging from 54.5 to 65 m^3/d, but no specific capacity data exist. This is classified as a **poor aquifer,** which is **generally unproductive except for local zones (Pl)**.

3.9 Ballysteen Limestone (BA)

The Ballysteen Limestone in South Cork is very restricted in areal extent. There is a lack of any useful data from this unit and its classification is based mainly on geological characteristics as well as some well data and classifications from other parts of the country.

From descriptions of the Ballysteen Limestone in Clare (Deakin & Daly, 1999 draft), Limerick (Deakin *et al*, 1998) and Waterford (Hudson *et al*, 1998), the permeability of these limestones is seen to be quite variable throughout the succession. The underlying Ballymartin Limestone (combined with the Ballysteen Limestones on the bedrock map) has a relatively high shale and muddy limestone content and is considered to be of slightly lower permeability than the cleaner limestones of the Ballysteen unit. Towards the top of the Ballysteen Limestones, the rocks become more muddy once more and may have similar permeabilities to the Ballymartin Limestone. Groundwater flow in these limestones is often concentrated in the upper few metres of fractured bedrock.

Most of the available data for wells in the Ballysteen Formation in southwest Ireland are from Co. Limerick, and show a broad range of productivities. 'Excellent' wells or 'Class I' productivities appear to be rare, but 'good' wells and 'Class II' productivities appear common enough for a 'Lm' category to be considered. However, it is believed that the better wells in Limerick occur in a purer 'middle Ballysteen' unit, which is not known in South Cork, and it is also likely that the more intense deformation in South Cork will have reduced, rather than enhanced, the permeability in the shaly limestones of the Ballysteen. The Ballysteen Limestone in South Cork is similar and laterally equivalent to the Ballysteen in Waterford and as such is classed as a **locally important aquifer, which is moderately productive only in local zones (Ll)**.

3.10 Waulsortian Limestone (WA)

This formation is described as comprising clean, pale-grey, fine-grained, massive, fossiliferous limestones, which formed in mud-mound structures. They are also intensely karstified in some areas. There are many accurately located wells providing useful information to assess the Waulsortian Limestones for their aquifer potential. The general characteristics of the rocks and the degree of karstification have also been used.

The Waulsortian limestones of South Cork and neighbouring areas have a large number of excellent and good wells, with the majority having specific capacity data. Most of these wells are between 40 and 60 m deep. Most of those with specific capacity data are from industrial wells or public supply wells, including those for the Cloyne/Aghada Supply. Most wells have class I or II productivities.

Karstification in these rocks is also very important. From the GSI karst database, 48 karst features occur in the Waulsortian Limestone. 26 of these are caves, 8 are karst springs, 6 are swallow holes, as well as 2 enclosed depressions, 4 turloughs and 2 boreholes with evidence of karst features.

The Waulsortian limestone is classed as a **regionally important karstified aquifer (Rk)**. Karstification appears to be quite widespread throughout the formation. Because of the prevalence of 'good' and 'excellent' wells and the lack of many failed wells in our records, the karstification in these rocks appears to be of a diffuse nature.

The general characteristics of these rocks are typical of a highly karstified regime:

- the lithologies are all clean, pale to medium grey limestones;
- there are many karst features such as swallow holes, collapses, and closed depressions evident at the surface;
- there are extensive cave systems (e.g. at Cloyne, Carrigtohill, Ovens, Shanagarry, and Midleton);
- groundwater quality is variable and often contains bacteria;
- the region is drained by a large number of springs which range in size from small to large, but which have reliable discharges.

3.11 Other Carboniferous Limestones

The other Carboniferous Limestones in South Cork are treated here as one aquifer unit. Very few well data are available for the Loughbeg, Cork Red Marble and Clashavodig Formations, although some exist for the Little Island Formation. There are also some high yielding wells which may be abstracting from either the Cork Red Marble/Waulsortian or the Little Island Formation/Waulsortian, since the exact locations of these wells are not known. This may also explain the very high yields and specific capacities from Carboniferous Limestone formations other than the Waulsortian Limestones.

The **Little Island Formation** is a uniform thick succession of mainly mudbank limestones, with massive crinoidal wackestones at the top of the formation. It is thought to have significant permeability in parts, according to Sleeman *et al* (1994), which may account for 3 'good' wells, which are found with yields of between 109 and 272 m^3/d. At least 4 'poor' wells are also found with discharges between 17 and 32 m^3/d representing the lower permeability parts of the formation. However it is thought that the permeability of this (and the other Carboniferous Limestones) has developed in response to structural movements and karstification to deeper drainage levels which existed in the past (Sleeman *et al*, 1994). As well as this, a lot of these limestones are overlain by sands and gravels which are in hydraulic continuity with the limestones and provide them with additional storage.

The Little Island Formation is classified as a **regionally important** aquifer where fissure flow **(Rf)** is dominant. Only 2 or 3 karst features occur in this formation so it is not considered to be karstified enough to warrant an **Rk** classification.

The **Loughbeg Formation** (cherty and nodular calcareous mudstone with occasional beds of silicified crinoidal limestone), the **Cork Red Marble** (grey cherty calcisiltites, red crinoidal breccias and cherts in a red mudstone matrix) and the **Clashavodig Formation** (clay-rich limestones, oolitic grainstones and cherty calcilutites) formations may be less permeable than the other Carboniferous Limestones discussed in this section., but few reliable well data exist for these formations and they are also classified as **Rf**.

3.12 Sand/Gravel Aquifers

The sand and gravel deposits of South Cork have not been extensively mapped on a county-wide basis. However, some of the larger gravel deposits have been investigated in the past for use as aquifers, as around the Brinny and Carrigtwohill areas. None of the sand/gravel deposits in South Cork is large enough to be considered a regionally important aquifer. Their hydrogeological significance is variable and largely a function of their permeability, thickness and extent. However as can be seen from existing well data and from any information that *is* available on the nature of some of these gravels, several are considered to be locally important aquifers.

Brinny

The gravels at Brinny along the Bandon River have been exploited for groundwater by industry since about 1974. These gravels are 15 km long and 0.5 to 1 km wide, with an area of approximately 12.5 km^2. Borehole logs and well records indicate the subsoils are 10 - 24 m thick. Saturated thicknesses are estimated from well records at between 12 and 20 m. The aquifer consists of 14 m of coarse gravel which is considered to be semi-confined by layers of silt and clayey gravel. GSI well records indicate 6 'excellent' wells abstracting from the gravels at Brinny (yields > 400 m^3/d) with sample specific capacities being 54.5, 101 and 288 m^3/d/m. There is also one 'good' well with a yield of 327 m^3/d and a specific capacity of 25 m^3/d/m. A well at St. Patrick's Institution, Upton, also tapped a thinner continuation of these gravels, with a yield of 238 m^3/d and a specific capacity of 14.8 m^3/d/m.

The Brinny/Upton deposit extends from Mishells (in the west), about 4 km west of Kilpatrick, to almost as far as Halfway (in the east). A GSI borehole investigated the eastern end in 1980 in the alluvial flat of the Owenboy River at Annagh More, to a depth of 9 m, encountering an aquifer of fine gravel at 4.3 to 8.0 m below ground. Pumping this borehole suggested a possible yield of 327 m^3/d. This gravel aquifer is over 10 km^2 in area but its saturated thickness probably exceeds 5 m only in some places (namely Brinny and Upton), so by GSI criteria this aquifer is classed as a **locally important sand/gravel aquifer (Lg).**

Carrigtohill

Another important gravel aquifer occurs at Carrigtohill, where it was initially developed for the Youghal Carpets factory, and later for the I.D.A. industrial estate. This deposit extends to over 40 m below sea level (Sleeman *et al,* 1994). Exploratory boreholes at this site encountered gravels interbedded with lower permeability material such as clay and silt. In some cases the boreholes had up to 34 m of sand and/or gravel, described as loose and well graded at lower levels. Typical yields were 500 – 1000 m^3/d.

Minane Bridge

The small sand and gravel aquifer at Minane Bridge is also significant as it supplies a Council scheme supply from an infiltration gallery. Kelly & Wright (2000) outline this deposit in a Source Protection report. The infiltration gallery is currently abstracting 98 m^3/d, but is capable of more. Work done by Geoff Wright in the 1970s on this aquifer estimates an area of

about 3 km^2 and an available resource of approximately 400,000 gallons per day (approx. 1810 m^3/d).

Dunmanway - Enniskean

A potential gravel aquifer lies along the Bandon River between Dunmanway in West Cork and Enniskean. It is about 15 km long and 250 m to 1 km wide. Within South Cork its total area is estimated at 2.4 km^2. A 36 m deep well in the Enniskean area seems to be located at the easternmost limit of this deposit, but no information is available on its yield or the nature of the gravels.

Lee Valley

Smaller sand and gravel deposits are also found along the River Lee (Dunisky) and the Sullane River in West Cork (Ballyvourney, Sullane Bridge and Carrigaphooca). The Ballyvourney gravel aquifer is an alluvial flat beside the River Sullane, between Ballyvourney and Ballymakeery. The deposit lies mainly north of the river, is about 1.1 km^2 in area and is described as coarse gravels. In 1979, Cork County Council obtained a yield of 130 m^3/d with a specific capacity of 145 $m^3/d/m$ from a borehole drilled into these gravels. However the deposit is very thin, with a saturated thickness of only about 3 m. It is considered to be a locally important aquifer. Two smaller gravel deposits nearby at Sullane Bridge and Carrigaphooca have not been investigated enough to know their groundwater resources and are just under 1 km^2 in area. The Dunisky deposit is also very small and has not yet been investigated.

Gravels have also been encountered in the Cloyne area of East Cork. A trial well for the Cloyne/Aghada Scheme (at Commons East) yielded 1772 m^3/d from gravel, with a specific capacity of 492 $m^3/d/m$, but this appears to be a local gravel pocket.

Site investigation may prove other sand/gravel deposits to be aquifers, but in the absence of more detailed information, the smaller deposits and those of unknown thickness or suspected thin saturated zones are not included here. Some of the larger morainic gravel deposits (when mapped) may prove, on further investigation, to contain lenses of cleaner gravel, which meet the classification criteria.

3.13 Summary of Aquifer Categories

The aquifers in South Cork are summarised in Table 3.4.

Table 3.4 Aquifer Classifications

Aquifer Category	Subdivision	Geological Unit
Regionally important (R)	Sand/gravel (**Rg**)	n/a
	Karst limestone (**Rk**) 153.5 km^2 5.6% of South Cork	Waulsortian Limestones
	Fissure flow (**Rf**) 84.8 km^2 3% of South Cork	Little Island Formation, Cork Red Marble, Clashavodig Fmns (Carboniferous Limestones)
Locally important (L)	Sand/gravel (**Lg**) 22.8 km^2 0.8% of South Cork	Brinny; Carrigtohill; Minane Bridge; Crookstown; other local gravel aquifers
	Bedrock which is generally moderately productive (**Lm**)	(none)
	Bedrock which is moderately productive only in local zones (**Ll**) 2246 km^2 81% of South Cork	Glenflesk Chloritic Sandstone Fmn (ORS) Gortanimill Fmn (ORS) Slaheny Fmn (ORS) Gun Point Fmn (ORS) *Ballytrasna Fmn (ORS)* Gyleen Fmn(ORS) Old Head Sandstone Fmn (Cork Group) Kinsale Fmn (Cork Group) *Courtmacsherry Fmn (Cork Group)* Lispatrick Fmn (Cork Group) Crow's Point Fmn (LLS) Ballysteen Limestone Formation
Poor (P)	Bedrock which is generally unproductive except for local zones (**Pl**) 250.8 km^2 9% of South Cork	Bird Hill Fmn (ORS) Caha Mountain Fmn (ORS) *Castlehaven Fmn (ORS)* *Toe Head Fmn (ORS)* White Strand Fmn (Cork Group) Mellon House and Ringmoylan Fmns (LLS)
	Bedrock which is generally unproductive (**Pu**)	n/a

4. Hydrochemistry and Water Quality

4.1 Introduction

An assessment of the quality of groundwater in South Cork is given in a separate report to Cork County Council (Southern Division) by the GSI (Kelly & Wright, 2000b). This chapter presents the main conclusions of that report.

4.2 Overall Assessment

- The hydrochemistry of groundwater in County Cork is primarily influenced by the nature of the subsoil and bedrock that it passes through. The groundwater in the limestone areas (mainly East Cork and in the synclines extending as far west as Crookstown) is hard and can be classed as calcium bicarbonate ($Ca(HCO_3)_2$) type water. Softer waters are found in the remaining areas (the Cork Group rocks to the south around Kinsale and the Old Red Sandstone rocks to the west and north of Cork City), where the bedrock comprises mainly sandstones, siltstones and shales.

- The main groundwater quality problems in South Cork are:
  (a) high nitrate levels in several important sources;
  (b) high iron (Fe) and manganese (Mn);
  (c) bacteriological pollution;
  (d) low pH levels in some Council supplies and many private supplies.

- Nitrate concentrations are probably the main concern regarding groundwater quality in South Cork. Nitrate levels were above the EU MAC (50 mg/l NO_3) in 3 public supply wells sampled in April and September 1999. Many supplies (18 out of 29) also had levels greater than 25 mg/l in samples analysed. These included Aghabullogue, Ballyshoneen/Berrings, Cloyne/Aghada (Town Parks, Lissanly and Farranamannagh bores), Coolyhane, Grenagh (Quarryhall), Killeagh (pumphouse 1), Robert's Cove, Ryefield and Stoneview/Blarney. There are also data from County Council files which highlight problems (past or present) at Ballymacoda and Riverstick. Nitrate contamination is likely to be caused by point sources, such as septic tank systems as well as landspreading practices in large areas of Cork, especially where tillage farming dominates.

- The high iron (Fe) and manganese (Mn) concentrations are caused mainly by the natural conditions in the ground and the natural chemistry of the groundwater. They may occur in areas underlain by peat, muddy limestones, and mainly in the Old Red Sandstones and rocks of the Cork Group, where reducing conditions result in solution of Fe and/or Mn from the geological materials. This causes taste and aesthetic problems. High manganese levels may also occur from pollution by silage effluent.

- Another important groundwater quality issue in South Cork is the presence of faecal bacteria in public and private water supplies. A significant proportion of the public groundwater supplies (7out of 24 in September 1999) contained faecal bacteria during GSI sampling of raw waters. In certain areas, a high proportion of private wells (>50%) are also likely to be polluted, at least intermittently. The presence of faecal bacteria is not only a problem in itself, but is an indicator of the possible presence of viruses and, in exceptional circumstances, Cryptospiridium.

- The bacteriological pollution of a significant proportion of groundwater supplies in South Cork is due to the following:

  (e) the 'extremely' vulnerable conditions in many areas, where there are thin subsoils providing very limited protection for groundwater;

  (f) the karstic nature of much of East Cork, where groundwater flow velocities are rapid, purification in the limestone is minimal and microbes can be carried large distances;

  (g) poorly designed, located and constructed septic tank systems and farmyards;

  (h) landspreading of organic wastes;

  (i) poor siting and construction of wells.

- There is also some cause for concern about low pH levels in some groundwater supplies in South Cork. However, this is a natural problem, due to the lack of carbonate buffering in the sandstones, particularly of the Devonian succession.

The national Private Well Grant Scheme, administered by the Council, is helping to deal with the problem of contaminated wells by assisting householders to drill new wells and/or to install water treatment systems.

4.3 Future Actions

- As a good database on groundwater quality is required, to enable an improved and continuing assessment:

  (j) Sampling of raw water from the public supplies (rather than treated water) should be carried out on a regular basis (at least twice a year until the background situation and trends in each source are defined).

  (k) full analyses (including all major ions) should be carried out on at least some of the samples from each source to enable a fuller picture of groundwater quality and contaminant movements to be obtained.

  (l) where there is evidence of significant contamination, the sampling frequency should be increased.

- Disinfection should be maintained at all public supplies to provide protection against microbial contamination of the supply. A recommendation to provide for adequate disinfection should be made to private group schemes, particularly in areas identified as extremely vulnerable.

- The existing programme of delineating groundwater protection zones around public and group scheme supplies, using the DELG/EPA/GSI guidelines, should be continued.

- Routine checking of sanitary protection at the well-head of Council sources and any other sources investigated should take place. This is to address the potential contamination of sources by storm waters and spillages at ground level.

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/EPA/GSI, 1999).

The vulnerability of groundwater depends on:

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

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. Along with vertical hydraulic gradients, 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 type and permeability of the subsoils that overlie the groundwater

(ii) the thickness of the unsaturated zone through which the contaminant moves

(iii) the recharge type – whether point or diffuse

Details of the hydrogeological basis for vulnerability assessment can be found in the publication 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999). 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 characteristics. The vulnerability 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. The map is intended as a guide to the likelihood of contamination of groundwater if a contamination event occurs. It does not replace the need for site investigation. The characteristics of individual contaminants are not considered.

Away from sites where point recharge occurs (e.g. swallow holes) the vulnerability depends on the type, permeability and thickness of the subsoils. Each subsoil type described in Chapter 3 is assessed here in terms of its permeability. The vulnerability map is then derived by overlaying the permeability categories with the depth to rock. There are three subsoil permeability categories: high, moderate and low; and four depth to rock categories: less than 3 m, 3 to 5 m, 5 to 10 m and greater than 10 m. The resulting vulnerability classifications are shown in Table 5.1.

5.2 Sources of Data

The vulnerability maps presented in Maps 5E, 5W and 5S were based on the following data sources:

- Depth to bedrock map, using data compiled from GSI well logs and county council reports, and the auguring carried out as part of the preparation of this Groundwater Protection Scheme.
- Subsoils map, compiled by the Teagasc-FIPS Project. This gives the basic subsoil permeability boundaries: peats and lake clays are usually low permeability; 'clean' gravels are usually high permeability; tills and 'dirty' gravels are usually moderate or low permeability.
- Map of superficial deposits in the country around Cork City and Harbour: Geological Survey of Ireland (1905). One inch to the mile map to accompany a memoir entitled "The Geology of Cork and Cork Harbour", Cork District, Drift Series.
- Field permeability mapping. This was used to further assess inferences made on the basis of subsoils and soils maps. Assessments included:

Table 5.1 Geological and Hydrogeological Conditions Determining Vulnerability Mapping Categories

Subsoil Thickness	Hydrogeological Requirements				
	Diffuse recharge Subsoil permeability and type			Point Recharge	Unsaturated Zone
	high permeability (*sand/gravel*)	Moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	*(swallow holes, losing streams)*	(*sand & gravel aquifers only)*
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

Notes: (i) N/A = not applicable.
(ii) Permeability classifications relate to the material characteristics as described by the subsoil description and classification method.
(iii) Release point of contaminants is assumed to be 1–2 m below ground surface.
(adapted from DELG/EPA/GSI, 1999)

a) Description of the engineering properties of subsoils using techniques based on BS5930:1999 (British Standards Institution, 1999).

b) Collection of subsoil samples for laboratory particle size analyses.

c) Assessments of recharge acceptance indicators such as drainage density and vegetation.

Details of analytical methodologies are presented in section 5.3.1.

- GSI karst database. This was used to give information on areas or sites of point recharge.
- Bedrock geology maps (Maps 1E, 1W and 1S).

5.3 Permeability of the Subsoils

5.3.1 Methodology

The permeability categories, and resulting vulnerability categories depicted on the groundwater vulnerability map (Maps 5E, 5W and 5S), 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 (e.g. fissures/cracks, plant roots and isolated higher permeability beds or lenses) and density/compactness. In poorly sorted sediments (glacial tills), which are the most common subsoils in South Cork, these characteristics also determine the engineering behaviour of the materials (Swartz, 1999) as described using the subsoil description and classification method, derived from BS5930:1999 (British Standards Institution, 1999). This method is therefore used to assess the permeability of the subsoils at each exposure, supported by recharge and drainage observations in the surrounding area for a regional, three-dimensional classification.

Each of the approaches used in assessing the permeability is discussed briefly here:

1. *Subsoil description and classification method (derived from BS5930).* 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, which are sorted and have a low fines content are considered to have a high permeability. In some instances it was found that subsoils described as 'clayey SAND' had a high enough proportion of clay to behave as low permeability materials.
2. *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 analyses, show a predominance of grain sizes at just one end of the scale. Glacial tills, on the other hand, are highly variable. Despite their complexity, evaluation of the grain size analyses for a range of tills in Ireland has established the following relationships: (i) samples with moderate permeability secondary indicators usually have less than 35% silt and clay. (ii) samples with low permeability secondary indicators usually have greater than 50% silt and clay. (iii) samples with moderate permeability secondary indicators usually have less than 12% clay. (iv) samples with low permeability secondary indicators usually have greater than 14% clay.
3. *Parent material.* The parent material, usually the bedrock, plays a critical role in providing the particles which 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.

4. *Recharge characteristics.* Examining the drainage and recharge characteristics in an area gives an overall representative assessment of the permeability. Poor drainage and vegetation suggest 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).
5. *Soils map.* No detailed soils map (i.e. of agricultural soils) exists for South Cork. However, the Teagasc-FIPS-IFS project plans to produce a map in the near future.
6. *Quantitative analyses.* The boundary between moderate and low permeability is estimated from limited piezometer data over the country to be in the region of 10^{-9} m/s at the field scale (Swartz, 1999). Using limited country-wide pumping test data, the moderate to high boundary is estimated to be in the region of 10^{-4} m/s (O Suilleabhain, 2000). However, permeability measurements are highly scale dependent: laboratory values, for example, are often up to two orders of magnitude lower than field measurements which in turn are lower than regional assessments measured from large scale pumping tests. Consequently, qualitative assessments, incorporating the engineering behaviour of the subsoils and recharge characteristics are considered more appropriate for regional vulnerability mapping than specific permeability measurements.

In any one area, as many of these factors as possible were considered together in order to try to obtain a balanced, defensible permeability decision. In order to allow extrapolation from point data to areal assessments, the county was divided into permeability regions, usually on the basis of similar bedrock, subsoil and/or soil 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 South Cork, 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 5.3.2 to 5.3.5. Vulnerability maps are presented on Maps 5E, 5W and 5S. Details of the supporting data for each permeability decision can be found in Appendix II. Results of particle size analysis can be found in Appendix III.

5.3.2 Low Permeability

In South Cork, the deposits, which have low permeabilities are clayey glacial tills, lacustrine clays and peat. Clayey tills are the most common of these low permeability deposits.

Permeability Region 1: Meadstown – Ballynaloughy Plateau (Rising Sun Unit)

A low undulating upland tract in the western part of the Cloyne Syncline between Carrigaline and Innishannon, Ballinhassig and Riverstick, The underlying bedrock comprises a mixed sequence of silty mudstones and medium to coarse-grained sandstones. Mudstones provide a source of fine clay size particles, which can contribute to clayey low permeability subsoils. The subsoils in this region are described by Teagasc (2001) as sandstone and shale tills with a clayey texture, with one small area of alluvium also mapped. The memeoir accompanying the Cork City and Harbour Drift map (GSI, 1905) describes the boulder clay in this area as “a stiff yellowish stoney clay”. It is described as being “apparently of considerable thickness in the lower ground” and making “a wet clayey land on the long slopes and in the hollows, as, for example, in the tracts extending east and west in the vicinity of Ballinaboy, Sligga Bridge and Meadstown.”

Of the eight field subsoil descriptions from this region, six are 'CLAY' and two 'SILT/CLAY'. Grain size analysis on 'CLAY' samples confirmed low permeability with >14% clay. Grain size analysis of one of the 'SILT/CLAY' samples found 12% clay, with 41% fines. Overall this area is relatively poorly drained, the artificial drainage density is high with many fields having perimeter drains. Vegetation is predominantly grassland. The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'low'.

Permeability Region 2a: Cloyne Syncline East

A relatively flat low lying area in the eastern part of the Cloyne Syncline between Cloyne and Shanagarry. The area is limited to the east by an area of shallow rock, to the north and south by sandstone ridges and to the east by the transition to a less clayey. The subsoil descriptions are of 'CLAY' and 'SILT/CLAY', which support a low permeability classification. All samples analysed for grain size distribution had >14% clay and > 50% fines (1 sample 46% fines), well within the range for low permeability subsoils.
The vegetation in the area, does not particularly reflect the presence of low permeability subsoils, the land use being a mix of grazing and tillage. A low effective rainfall and good farming practices may mask the influence of low permeability subsoils on the vegetation. There is no widespread evidence of drainage difficulties however drainage ditches are present in some fields. Despite the inconclusive nature of the recharge characteristics, the grain size data and subsoil descriptions strongly indicate low permeability material.

Permeability Region 3a: Cork Syncline East (Mogeely, Ladysbridge, Killeagh Gortaroo)

The area is part of a relatively flat low-lying valley stretching from east of Midleton to Youghal Bay. The region is limited to the north and south by sandstone ridges to the west by an area of shallower subsoils. Subsoil descriptions are all 'CLAY', which supports a low permeability classification. The majority of samples analysed for grain size distribution had >14% clay and >50% fines, indicating low permeability subsoils. As in permeability region 2 the vegetation does not particularly reflect the presence of low permeability subsoils however field drains are common particularly around Ballyfleming. In several boreholes in the region a surface layer of sandy till of 2-3m was found above the clayey till. At the northern margin of the valley, over 10m of gravel was recorded beneath 8m of clayey till. Despite the inconclusive nature of the recharge characteristics, the grain size data and subsoil descriptions strongly indicate low permeability material.

Permeability Region 4a:Small pockets of Low Permeability (Mawbrin, Knocknamanagh, Ballyvrin)

The areas described together as this permeability unit are discontinuous areas of low permeability till that have been delineated within the moderate permeability units 7 and 9. These areas have been identified based on samples and field observations of subsoils, vegetation and drainage density. All subsoil descriptions were of 'CLAY' and grain size results had >50% fines. The low permeability is confined to quite small areas. It is possible that other such small concentrations of low permeability material occur within the wider moderate permeability regions 7 and 9 that were not identified at the scale of this study. A detailed soils map would be useful in assessing whether other small pockets of low permeability subsoils can be delineated in this region.

5.3.3 Moderate Permeability

In South Cork, the deposits, which have moderate permeabilities are silty and sandy glacial tills, alluvium, and poorly sorted sand and gravel deposits.

Permeability Region 5a: Old Red Sandstone ridge in the northern part of South Cork Area

An Old Red Sandstone ridge running from east to west across the northern part of the South Cork region. This area is bounded to the south by Lee valley and a change in bedrock type and extends in the north to the boundary of the South Cork region. The area generally consists of good quality farmland with field drains rarely observed. To the west there is a gradual transition to poorer land, which is accompanied by a higher average effective rainfall and a greater percentage of shallow subsoils. The underlying Old Red Sandstone rocks contribute to the sandy nature of the tills while the mudstone elements contribute a proportion of finer grained material. Subsoils descriptions are primarily of SANDs, SILTs and sandy SILT/CLAYs. Subsoils described as ‘CLAY’ are occasionally recorded with grain size data indicative of low permeability material, however, these were found to be isolated occurrences and not characteristic of the region as a whole. The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'moderate'.

Permeability Region 5b: Western Uplands

This region includes the upland and mountainous area to the west of the Awboy River. Subsoils are mainly glacial till are generally quite shallow. There is a large amount of rock outcrop and shallow rock in this area. Subsoils are generally quite sandy reflecting the coarse grained sandstones which dominate the bedrock formations in this area. Subsoil descriptions and particle size analysis suggest generally moderate permeability subsoils. (Appendix II) Areas of blanket peat occur in this permeability region but because of they are thin the underlying subsoils are considered to control the overall permeability.

Permeability Region 6: Great Island Anticline

This region comprises the Old Red Sandstone ridge known as the Great Island Anticline, running through the centre of the South Cork region from Knockadoon Head in the east, through Great Island, and across to the western boundary of South Cork. Subsoils are generally quite shallow. The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'moderate'. This area generally consists of good quality farmland, with tillage common and field drains rarely observed. There is a gradual transition to poorer land when moving west across the region, which is accompanied by a higher average effective rainfall. Subsoil descriptions and particle size analysis throughout the region suggest generally moderate permeability subsoils. Subsoils descriptions are primarily of SANDs, SILTs and sandy SILT/CLAYs.

Permeability Region 7: Cork Group

This area consists of the southwestern part of the South Cork region, west of Cork Harbour and south of Ballinhassig and the Great Island Anticline, extending to the western boundary of South Cork at Enniskeane. Deposits of alluvium and sands and gravel within the area are described as separate permeability regions. Subsoils descriptions are primarily of SANDs and SILTS with frequent sandy SILT/CLAYs. Subsoils described as ‘CLAY’ are occasionally recorded with grain size data indicative of low permeability material, however, these were found to be isolated occurrences and not characteristic of the region as a whole. In general

while there is a clay element in the tills of this area, the overall character of the tills is that of moderate permeability. Vegetation and drainage characteristics support a moderate permeability classification.

Permeability Region 8: Carrigaline Peninsula

This region involves small areas of >3m subsoil east of Carrigaline. The area is mainly underlain by Waulsortian Limestone, a regionally important karstified aquifer. Depth to bedrock records indicate that the surface of the limestone is very irregular. Although one subsoil sample from the region is described as 'CLAY' with grain size data indicating low permeability, the general characteristics of the area (vegetation, land use, drainage characteristics) indicate an overall moderate permeability.

Permeability Region 9: Whitegate – Ballycotton

Area between Whitegate and Ballycotton, limited to the south by the coast and to the north by the Cloyne valley. This permeability region consists of small areas of >3m subsoil occurring generally in small depressions or along stream valley within an area of predominately shallow subsoil. Vegetation and drainage characteristics in these areas indicate moderate permeability. Subsoil samples are described primarily as SANDs, SILTs, and SILT/CLAYs. The general weight of evidence supports a 'moderate' permeability classification for this region.

Permeability Region 2b: Shanagarry, Titeskin-Ballyfin Valley and south of Saleen

This region consists of discontinuous areas of moderate permeability subsoil occurring within the Cloyne Syncline: in the Rostellan, Titeskin, Ballyfin valley; south of Saleen, and an area around Shanagarry. These are areas that do not fit the low permeability classification applied to the rest of the Cloyne Syncline (Region 2a). Near Shanagarry the till shows some influence from the underlying limestone bedrock, also alternating layers of clay, sand and sandy gravel have been observed in boreholes. In the Titeskin/Ballyfin valley gravelly and silty sand layers were found beneath SILT/CLAY and CLAY. In the area south of Saleen there is a region of much shallow sandy and silty subsoils. In general in these areas the subsoils seem to have a higher sand and silt content and are more suitably described as moderate permeability subsoils.

Permeability Region 3b: Midleton, Castlemartyr-Knockane, Kilmountain

This region includes the central portion of the Cork Syncline from Midleton to Dunkettle and some discontinuous areas of moderate permeability subsoil occurring in the eastern part of the Cork Syncline at Kilmountain and east of Castlemartyr. General characteristics of topography and land use are the same in these areas. There are frequent occurrences of shallow rock. The general weight of evidence suggests that this region has moderate permeability subsoils. At Castlemartyr and Mogeely grain size analysis and subsoil descriptions indicate that these areas do not fit the low permeabiliy classification applied to the surrounding lands. The subsoils in these areas are shallow and more likely to be influenced by the underlying clean limestone. Further east towards Midleton the general character of the subsoil is that of moderate permeability.

Permeability Region 10: River Bride Valley – Cork SynclineWest

This region consists of discontinuous areas of moderate permeability glacial till occurring in the western portion of the Cork Syncline between Cork Harbour and Crookstown. Cork City and Ballincollig cover much of the western half of the region. The area south of Ballincollig is covered by generally gravely glacial till. West of Ballincollig small areas of till have been

delineated within the extensive gravel and alluvium deposits. Subsoil descriptions are of sandy and gravelly SILT/CLAYs and support a moderate permeability classification for the subsoils in this region.

Permeability Region 11: Alluvium

These deposits are found in narrow strips along streams and rivers throughout the county. The largest developments of alluvium occur along the Lee, Bride, Bandon and Blarney Rivers, with thinner deposits along the smaller streams throughout the county. Although these alluvial deposits are found throughout the county, at a range of elevations and underlain by a wide variety of rock-types, they all share a common origin and are expected to consist of a mix of sands, silts and clays. This makes it most likely that they will have a moderate permeability. In the larger valleys such as those of the Rivers Lee, Bride and Bandon the alluvium generally overlies gravel deposits and, in areas where there is a sufficient thickness, offers a degree of protection to the higher permeability gravels.

5.3.4 High Permeability

In South Cork, the deposits that have high permeabilities are well-sorted sand and gravels often associated with large rivers, such as the Lee and Bandon. Sand and gravel deposits were identified from the Teagasc FIPS-IFS Subsoil Map (Maps 2E,2W and 2S), additional areas of sands and gravels were identified around Cork City and Harbour from the 1905 Geological Survey 1" to 1 mile Drift Map.

Permeability Region 12: Sand and Gravel Deposits:

The main concentration of sand and gravel deposits occur in the valleys of the Rivers Lee, Bride, Bandon, Sullane and Blarney. There are also smaller discontinuous sand and gravel deposits occurring within other permeability regions throughout the South Cork area. Some deposits are identified at the surface by their hummocky topography and the frequent presence of sand and gravel pits, others occur in river valleys, often covered by thin layers of alluvium, and are revealed in borehole logs. Permeability classifications are applied based on the nature of the gravels in areas where there is insufficient information about the thickness and nature of the overlying alluvium. Samples are described as 'GRAVEL'. There are a large number of sand/gravel pits in the main units, which suggests that these deposits have enough of a uniform grade to be mined. The vegetation, lack of field drainage ditches and stream also infer very good drainage capacity. These deposits are considered to be highly permeable.

5.3.5 Areas with thin subsoils

Areas with <3m subsoil are automatically given an 'Extreme vulnerability' rating due to the fact that, irrespective of its nature, there is not a sufficient thickness of subsoil to protect groundwater from contamination (release point of contaminants assumed to be 1-2m below ground surface). Permeability classifications have not been attached to regions with <3m subsoil. Assigning regional permeability classifications to areas with 1-3m subsoil is difficult due to the variability and uncertainty associated with subsoil permeability in thin subsoils. The permeabilities of these areas can differ from those of deeper deposits due to variations in the amount of weathering and glacial abrasion they have undergone. While this does not affect the groundwater protection scheme maps, subsoil permeabilities in these areas will need to be taken into account for surface water protection

In order to assist decision-makers considering activities where the point of release of contaminants is at the ground surface, areas of outcrop and 'rock close' (areas where depth to

bedrock is generally less than 1m), and karst features are highlighted as a sub-category within the extreme (E) vulnerability areas on vulnerability maps.

5.3.6 Made Ground

The subsoils map, compiled by the Teagasc FIPS-IFS Project, identifies areas of made ground. In South Cork these are built-up areas and amount to some 84.8 km^2. In such areas where construction and paving makes augering and subsoil examination difficult, permeability categories were assigned using information from the surrounding areas and in the case of Cork city, Midleton and Carrigtohill, using information from the GSI Drift Map of Cork and Cork Harbour (Geological Survey of Ireland 1905).

5.4 Thickness of the Unsaturated Zone

The thickness of the unsaturated zone is relevant in vulnerability mapping only in areas of sand/gravel aquifers (see Table 5.1). The water table is generally more than 3 m deep, except where the sand/gravel is in a low-lying area, usually close to major rivers. In these areas, the top layer is generally recent alluvium laid down during the winter floods, which should generally increase the travel time of percolating groundwater. Therefore, the thinner unsaturated zone generally found close to the major rivers is not considered to significantly influence the overall vulnerability.

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 outline of subsoil thicknesses is given in Section 2. The source data are shown in Maps 3E, 3W and 3S.

5.6 Groundwater Vulnerability Distribution

The vulnerability maps (Maps 5E, 5W and 5S) are derived by combining the contoured depth to bedrock data with the inferred subsoil permeabilities. Areas are assigned vulnerability classes of low, moderate, high or extreme. The distribution is summarised in Table 5.2 below and Appendix I provides an outline of the principles used.

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 require site investigations in order to assess the risk to groundwater. Detailed subsurface investigations and permeability measurements would reduce the area of high vulnerability and would probably reduce the area of extreme vulnerability. However, the vulnerability maps 5E, 5W and 5S are considered to provide a good basis for decision-making in the short and medium term.

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

The large areas of extreme vulnerability where rock is generally at or close to the surface include many upland areas which have little development or potential for development. When these are excluded, the proportion of the county's groundwater that is extremely vulnerable is significantly reduced. Also, many small (unmapped) pockets of deeper subsoil are likely to exist even within areas where rock outcrop is common. This is particularly likely in karst limestone areas.

There are few areas of low vulnerability, which are found only where the subsoils have a low permeability and the depth to bedrock information indicates thicknesses of over 10 metres. However such thick deposits may not be a uniform till but may include interbedded sands and gravels in places; further confirmation by site investigation is essential to verify the vulnerability for specific developments.

Table 5.2. Summary of Vulnerability Classification of South Cork

Vulnerability Rating	Hydrogeological Setting
Extreme 49.8%	• Areas where rock is at the ground surface • Areas where the subsoil is known or interpreted to be <3m thick • Areas of *sand/gravel aquifer* where the water table is <3m below surface
High 46.3%	• Areas of *high* permeability subsoil known or interpreted to be >3m thick • Areas of *moderate* permeability subsoil known or interpreted to be 3-10m thick • Areas of *low* permeability subsoil known or interpreted to be 3-5m thick • Areas of *sand/gravel aquifer* and water table >3m
Moderate 3.2%	• Areas of *moderate* permeability subsoil known or interpreted to be >10m thick • Areas of *low* permeability subsoil known or interpreted to be 5-10m thick
Low 0.01%	• Areas of *low* permeability subsoil known or interpreted to be >10m thick

Note: approximately 0.7% of the county is occupied by lakes/reservoirs

6 Groundwater Protection Zones and Responses

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 South Cork. This chapter draws these together to give the ultimate elements of land surface zoning – the groundwater protection scheme map and the source protection maps. It is emphasised that these maps are not intended as 'stand alone' elements, but must be considered and used in conjunction with the groundwater protection responses for potentially polluting activities. Three such responses have been published: for **Landfills, Landspreading of Organic Wastes** and **On-site Waste Water Treatment Systems for Single Houses** (DELG/EPA/GSI, 1999, 2000). Further responses are planned.

6.2 Groundwater Protection Maps

The groundwater protection map (Map 6) was produced by combining the vulnerability map (Map 5) with the aquifer map (Map 4). 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

Table 6.1 Matrix of Groundwater Resource Protection Zones

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf	Lg	Ll	Pl	Pu
Extreme (E)	Rk/E 1.17%	Rf/E 0.65%	Lg/E 0.12%	Ll/E 40.8%	Pl/E 6.54%	*Pu/E* *absent*
High (H)	Rk/H 2.73%	Rf/H 1.37%	Lg/H 0.70%	Ll/H 38.74%	Pl/H 2.27%	*Pu/H* *absent*
Moderate (M)	Rk/M 1.19%	Rf/M 0.95%		Ll/M 0.59%	Pl/M 0.21%	*Pu/M* *absent*
Low (L)	Rk/L 0.004%	Rf/L 0.001%		Ll/L 0.002%	*Pl/L* *absent*	*Pu/L* *absent*

the groundwater resource (aquifer category). Not all of the possible hydrogeological settings are present in South Cork; those, which are present, are shown in Table 6.1.

6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around eight public water supply sources in South Cork: Ballinspittle, Cloyne (Cloyne-Aghada supply), Coachford, Crookstown, Dower (Womanagh Regional supply), Grenagh, Minane Bridge, and Robert's Cove. These have been produced as separate reports.

6.4 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 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. Table 6.2 presents a summary of the responses to three potentially polluting activities.

The important feature of the hydrogeology of South Cork is that the regionally important aquifers are concentrated in a relatively small area (approximately 240 km^2, or 8.7% of the total area), but about two-thirds of this area is rated as highly or extremely vulnerable to pollution. Hence it is important that the natural resources represented by these aquifers should be given careful protection from potentially polluting developments.

Table 6.2 Response Percentages for Currently Identified Potentially Polluting Activities

Activity	Response			
	Not acceptable R4	Not generally acceptable (with certain exceptions) R3	Probably acceptable subject to certain conditions R2	Acceptable subject to normal good practice R1
Landfill	8.4%	1.8%	89.8%	<0.01%
Landspreading *(IPC licensable)	0.8%	14.9%	34.9%	49.0%
On-site Treatment Systems		0.6%	53.1%	46.3%

Note: The percentages for landspreading are approximate and involve some interpolation from the figures for areas with <1m subsoil and areas with <3m subsoil; this is because the acceptability for landspreading requires at least 1m of subsoil over Locally Important and Poor Aquifers, and 2m of subsoil over Regionally Important Aquifers and in Outer Source Protection Areas.

Areas of open water have been discounted.

6.5 Conclusions

This groundwater protection scheme will be a valuable tool for Cork County Council in helping to achieve sustainable water quality management as required by national and EU policies. It will enable the 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 will be an important means of preventing groundwater contamination.

It is important to note that:

(a) the scheme is intended to provide guidelines to assist decision-making in South Cork 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.

The Council will 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 investigation requirements depend mainly on the degree of hazard provided by the contaminant loading and, to a lesser extent, on the availability of hydrogeological data. The onus is on a developer to provide new information, which might enable the zonation, and, in certain circumstances, the planning or regulatory response to be changed.

The scheme has the following uses for Cork 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 as a 'first-pass' warning system before site visits and investigations are made
- it shows generally suitable and unsuitable areas for potentially hazardous developments
- 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 of 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;
(iii) the thickness of the unsaturated zone through which the contaminant moves.

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

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

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

Table A.1 Vulnerability Mapping Guidelines

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			Unsaturated Zone	Karst Features
	high permeability (*sand/gravel*)	moderate permeability (e.g. *sandy subsoil*)	low permeability (e.g. *clayey subsoil, clay, peat*)	(*sand/gravel* aquifers only)	(<30 m radius)
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.

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;
(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.

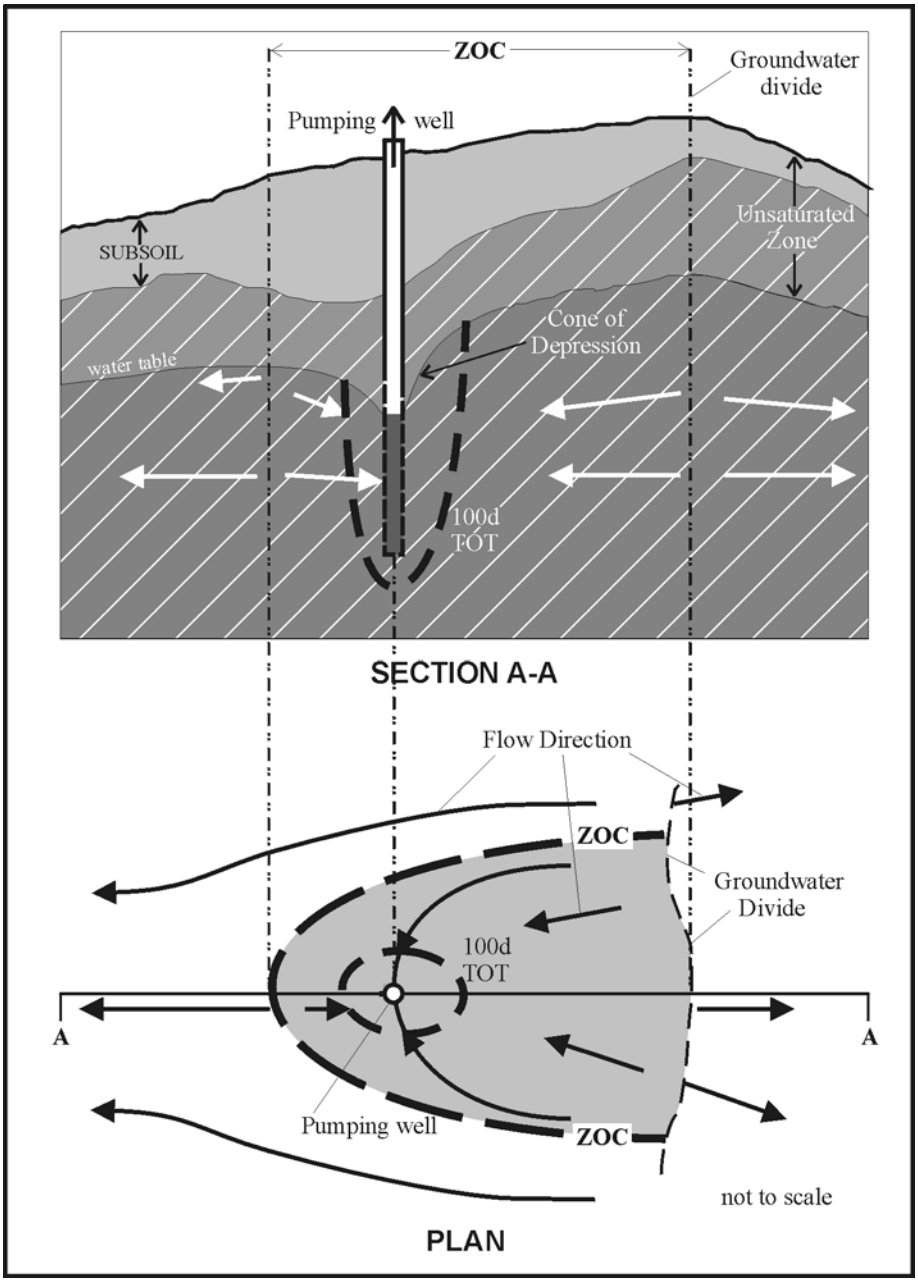


Fig. A.1 Conceptual model of the zone of contribution (ZOC) at a pumping well (adapted from US EPA, 1987)

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.

Table A.2 Matrix of Source Protection Zones

VULNERABILITY RATING	SOURCE PROTECTION	
	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

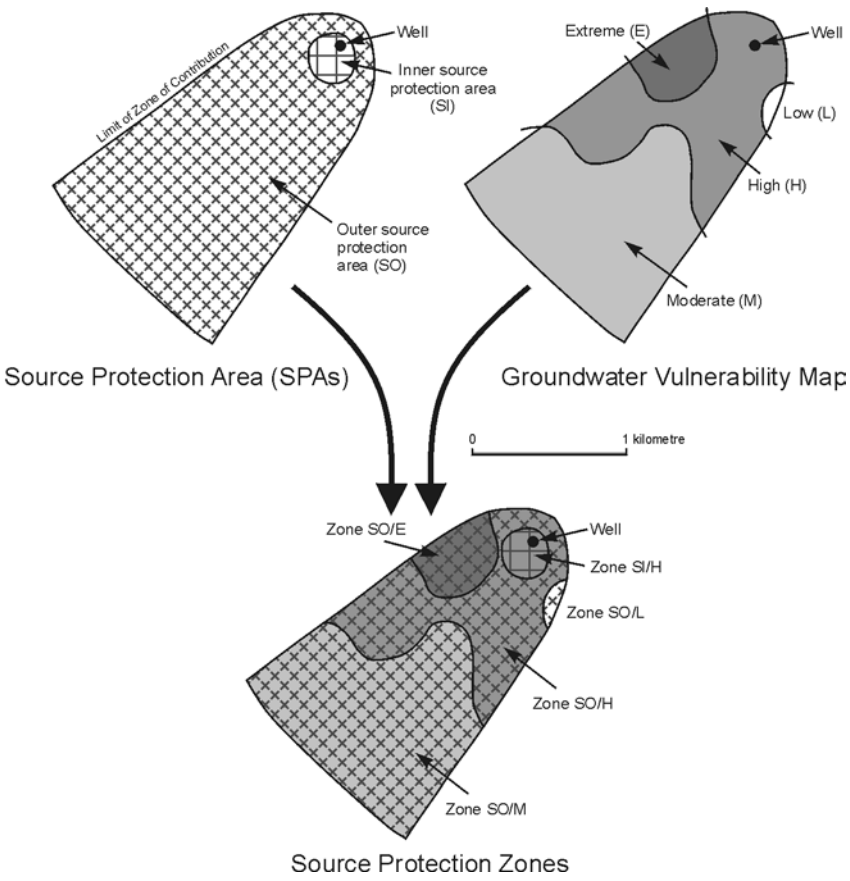


Fig. A.2 Delineation of Source Protection Zones Around a Public Supply Well from the Integration of the Source Protection Area Map and the Vulnerability Map

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
(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

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 Responses

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 ($\rightarrow\downarrow$) indicate directions of decreasing risk, with $\downarrow$ showing the decreasing likelihood of contamination and $\rightarrow$ showing the direction of decreasing consequence. The contaminant loading aspect of risk is indicated by the activity type in the table title.

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

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

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)

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 responses have been developed for three potentially polluting activities: landfills, landspreading of organic wastes, and single house systems (septic tanks, etc.). Additional responses for other potentially polluting activities will be developed in the future.

Appendix II

Permeability Regions in County Cork (Southern Region) – Data Summary

List of Permeability Units in South Cork Area

1	Meadstown - Ballynaloughy
2a	Cloyne Syncline East
2b	Cloyne Syncline Moderate
3a	Cork Syncline East - Moogely, Ladysbridge, Killeag, Gortaroo
3b	Cork Syncline East Moderate
4	Low Permeability Areas
5a	Northern Old Red Sandstone (ORS) Unit
5b	Western Uplands
6	Great Island Anticline
7	Cork Group
8	Carrigaline Peninsula
9	Whitgate - Ballycotton
10	River Bride Valley
11	Alluvium
12	Sand & Gravel Deposits

Summary of Permeability Data and Analyses for Permeability Unit 1. Meadstown-Ballynaloughy .

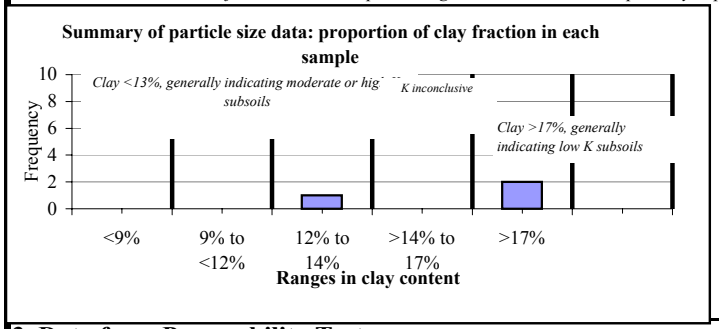
Description of unit location:	A low undulating upland tract, in the western part of the Cloyne Syncline between Carrigaline and Innishannon, Ballinhassig and Riverstick. The boundaries of this permeability region are based on topographic and drainage features, vegetation and land use. The area is limited to the northwest by the sharp descent into the Owenboy River valley, to the northeast by the high ground and shallow subsoils of Ballea, to the southeast by a sandstone ridge at Doolieve and to the southwest by the onset of improved drainage and thinner subsoils.
Why is this a single K unit?	Relatively uniform topography, bedrock, soils and land use

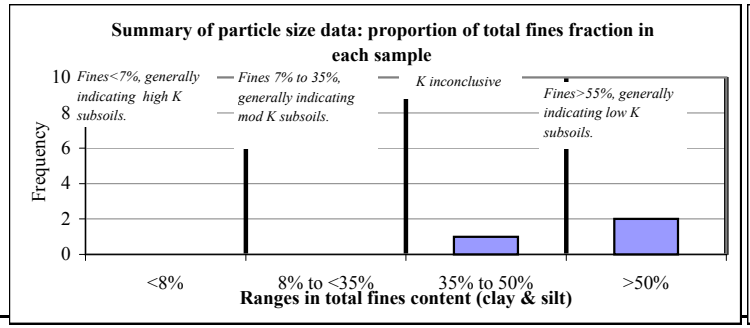
1. General Permeability Indicators and Region Characteristics

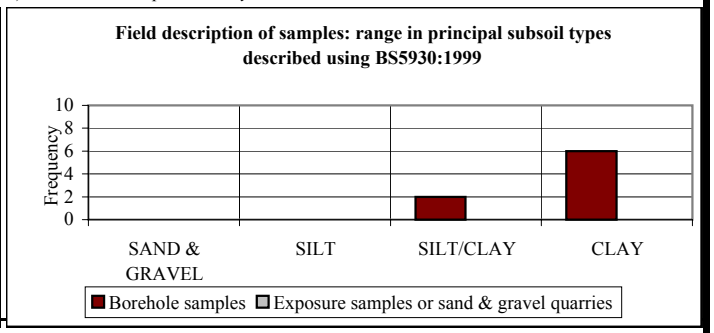
Rock type	Mainly White Strand Fmn (WS) - mixed sequence of silty mudstones and medium to coarse grained sandstones, with some Lispatrick Fmn (LP) - mudstones, and Kinsale Fmn Cuskinny Member (KNcu) - sandstones and mudstones; Aquifer category Poor (Pl)
Depth to bedrock	Typically 3-10m, occasionally >10m, some areas <3m
Subsoil type	Clayey (shale and sandstone) tills, with one small area of alluvium
Soil type	Not mapped
Vegetation and land use	Predominantly grassland; tillage rare.
Artificial drainage density	High - approximately 50% of fields have perimeter drains
Natural drainage density	Intermediate to High (approx. 35km of stream in area of 3248.8 ha: ~ 10.77m/ha)
Topography and altitude	An undulating plateau above the Owenboy River valley. Elevation range 50-100m O.D.
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr, lowest in the east and highest in the western uplands

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	Mudstones provide a source of fine clay sized particles which can contribute to clayey low permeability subsoils.	>>>	Low to Moderate
Quaternary / subsoil origin	Clayey tills	>>>	Low to Moderate
Soil type	Not mapped	>>>	-
Land use	Grazing	>>>	Moderate to Low
Artificial drainage density	High	>>>	Low
Natural drainage density	Intermediate to High	>>>	Low to Moderate
Particle size data	2 samples >14% clay (field BS 'CLAY'), 1 sample 12% clay (BS SILT/CLAY), All 3 > 35% fines	>>>	Low
Field description data	8 samples, 6 'CLAY', 2 'SILT/CLAY'	>>>	Low
Permeability test data	No data	>>>	-
	Overall conclusion	>>>	**Low**

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'low'. The underlying bedrock provides a source of fine clay sized particles, the subsoil type is described as clayey, field BS descriptions are mostly CLAY, grain size data confirm samples with BS descriptions CLAY as low permeability with >14% clay and SILT/CLAY sample with 12% clay falls within range for low permeability subsoils. Drainage ditches are present in fields in the area.

Summary of Permeability Data and Analyses for Permeability Unit 2a. Cloyne Syncline East .

Description of unit location:	Relatively flat low-lying area in the eastern part of the Cloyne Syncline
Why is this a single K unit?	Relatively uniform topography, bedrock, subsoils, and land use.

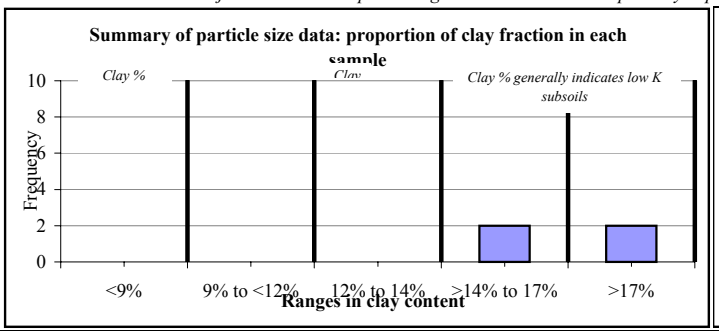
1. General Permeability Indicators and Region Characteristics

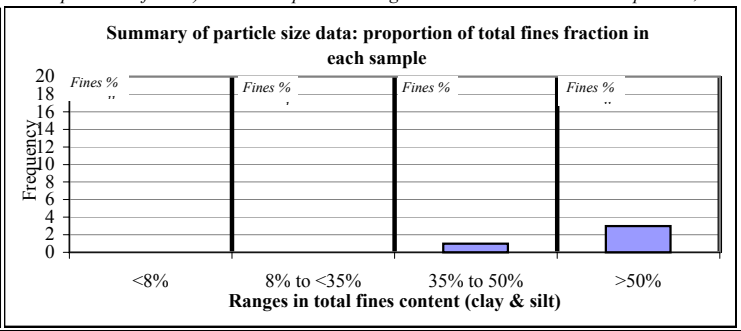
Rock type	Mainly Waulsortian Lmst (WA) - clean limestone; Aquifer category Regionally Important (Rk)
Depth to bedrock	Generally 5-10m, small number of areas of outcrop and shallow rock, occasionally >10m possibily infilling in cavities in the limestone
Subsoil type	Mapped as sandstone till - not locally derived. Two small areas of glacial sands and gravels mapped in west near Cloyne
Soil type	Not mapped
Vegetation and land use	Grassland and tillage (beet)
Artificial drainage density	some field drains
Natural drainage density	intermediate
Topography and altitude	Lowlying relatively flat synclinal valley. Elevation range 0-33m OD.
Ave. effective rainfall (mm)	Range for East Cork 433 - 908mm/yr

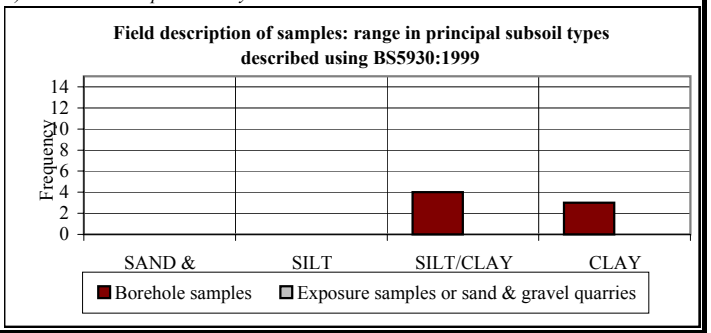
2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

(6 BH PSA, 6CL)

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	Clean limestones - locally derived tills should have relatively low clay content, but Teagasc subsoils mapping indicates that locally derived till is confined to the eastern end of the Cloyne Syncline.	>>>	-
Quaternary / subsoil origin	Mapped by Teagasc as sandstone till	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Grazing and beet cultivation	>>>	Moderate
Artificial drainage density	Intermediate	>>>	Moderate to Low
Natural drainage density	Intermediate	>>>	Moderate to Low
Particle size data	4samples >14% clay (2 'CLAY', 2 'SILT/CLAY'), 3samples > 50% fines, 1sample ('SILT/CLAY') 46% fines	>>>	Low
Field description data	7 samples, 4 SILT/CLAY, 3 CLAY	>>>	Low
Permeability test data	No data	>>>	-
		Overall conclusion >>>	**Low**

5. COMMENTS: This area is identified as low permeability. While vegetation and drainage characteristics are relatively inconclusive, grain size data which show clay contents of 16% - 26 %, combined with the BS descriptions, strongly indicate low permeability material. Low effective rainfall and good farming practices may mask the influence of low permeability subsoils on the vegetation.

Summary of Permeability Data and Analyses for Permeability Unit 2b. Cloyne Syncline Moderate .

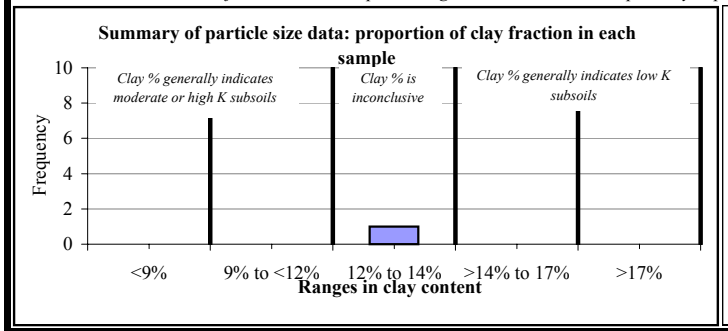
Description of unit location:	This region consists of discontinuous areas of moderate permeability subsoil occurring within the Cloyne Syncline: in the Rostellan, Titeskin/Ballyfin valley; south of Saleen, and an area around Shanagarry.
Why is this a single K unit?	General characteristics of topography and land use are the same in these areas.

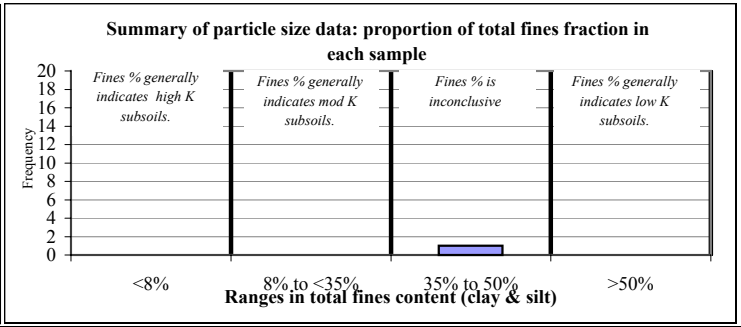
1. General Permeability Indicators and Region Characteristics

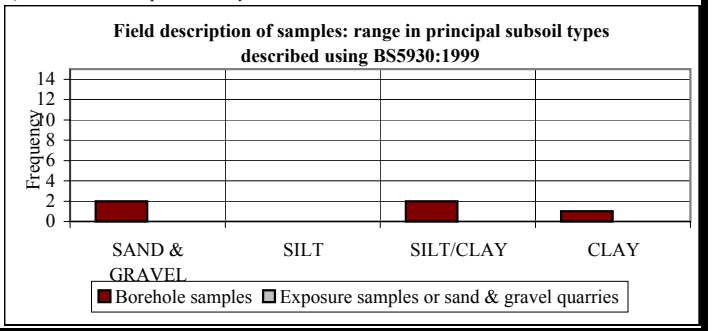
Rock type	Mainly Waulsortian Lmst (WA) - clean limestone; Aquifer category Regionally Important (Rk)
Depth to bedrock	Generally 5-10m, small number of areas of outcrop and shallow rock, occasionally >10m possibly infilling in cavities in the limestone
Subsoil type	Western areas, Ballyfin/Titeskin and south of Saleen mapped as sandstone till, with some small areas of glacial sand and gravel. Shanagarry area mapped as limestone till.
Soil type	Not mapped
Vegetation and land use	Grassland and tillage
Artificial drainage density	Low
Natural drainage density	Intermediate
Topography and altitude	Lowlying relatively flat areas, elevation range 0-31m OD.
Ave. effective rainfall (mm)	Range for East Cork 433 - 908mm/yr

2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples. *(6 BH PSA, 6CL)*

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







3. Data from Permeability Tests.

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

4. Summary and Analysis

Criteria	**Comments**	**Implications of each criterion for assessment of subsoil permeability**	
Rock type	Clean limestones.	>>>	Moderate
Quaternary / subsoil origin	Sandstone and limestone tills of variable texture. Limestone till is confined to area around Shanagarry. Remaining areas mapped as sandstone till.	>>>	Moderate to Low
Soil type	Not mapped	>>>	-
Land use	Grazing and beet cultivation	>>>	Moderate
Artificial drainage density	Low	>>>	Moderate
Natural drainage density	Intermediate	>>>	Moderate
Particle size data	Inconclusive	>>>	
Field description data	Mostly SAND and SILT/CLAY, frequently encounter alternating layers of SILT/CLAY, CLAYand SAND	>>>	Moderate
Permeability test data		>>>	
		Overall conclusion >>>	**Moderate**

5. COMMENTS: These are areas within the Cloyne syncline that do not fit the low permeability classification applied to the rest of that area. Near Shanagarry an area of limestone till has been identified, also alternating layers of clay, sand and sandy gravel have been observed in boreholes. In the Titeskin/Ballyfin valley gravelly and silty sand layers were found beneath SILT/CLAY and CLAY. In the area south of Saleen there is a region of much shallow subsoils with more sandy and silty subsoils. In general in these areas the subsoils seem to have a higher sand and silt content and are more suitably described as moderate permeability subsoils.

Summary of Permeability Data and Analyses for Permeability Unit Cork Syncline East - Mogeely, Ladysbridge, Killeag, Gortaroo

Description of unit location:	Relatively flat low-lying area in the eastern part of the Cork Syncline - Mogeely, Ladysbridge, Killeagh, Gortaroo
Why is this a single K unit?	Relatively uniform topography, bedrock, subsoils, and land use.

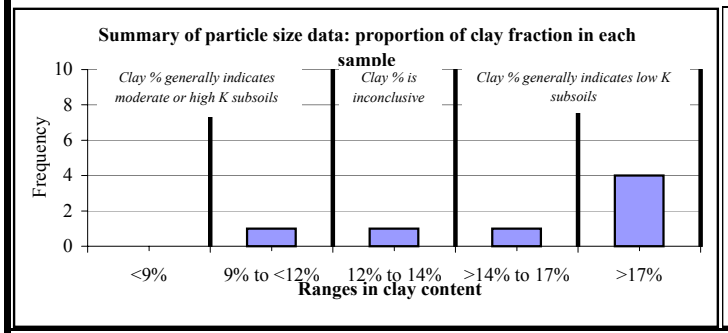
1. General Permeability Indicators and Region Characteristics

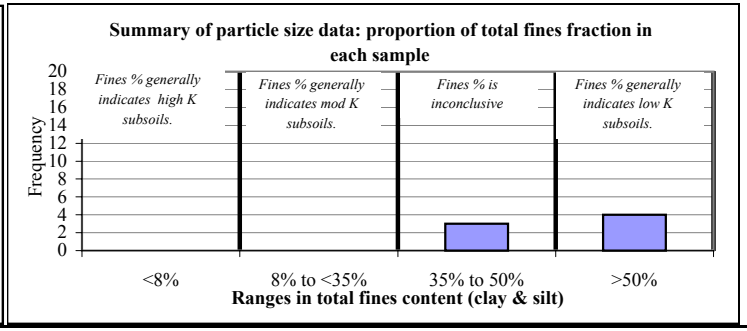
Rock type	Mainly clean limestone; Aquifer classification Regionally important, Formations WA (Rk), CK(Rf), Ll (Rf), CK (Rf), CV (Rf)
Depth to bedrock	Typically 5-10m, some areas of shallow rock, deeper at valley margins
Subsoil type	Mapped as sandstone till - not locally derived, some sand and gravel pockets, some alluvium, till underlain by gravels at northern margin of valley.
Soil type	Not mapped
Vegetation and land use	Grassland, beet cultivation and some corn
Artificial drainage density	Field drains common
Natural drainage density	Intermediate
Topography and altitude	Lowlying relatively flat synclinal valley. Elevation range 0-32m OD
Ave. effective rainfall (mm)	Range for East Cork 433 - 908mm/yr

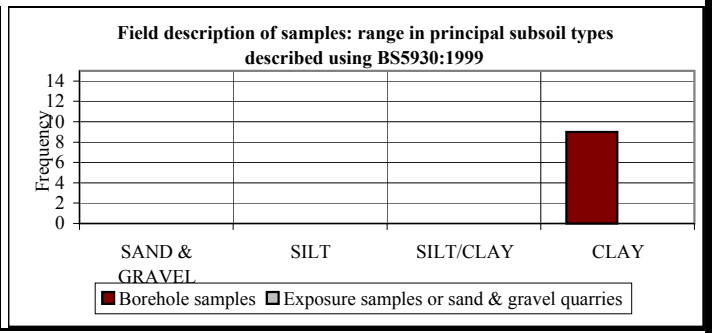
2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

(14 BH PSA, All CL)

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	Till not locally derived, limited influence of underlying bedrock	>>>	-
Quaternary / subsoil origin	Mapped by Teagasc as sandstone till	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Grazing and tillage	>>>	Moderate
Artificial drainage density	Intermediate to High	>>>	Moderate to Low
Natural drainage density	Intermediate	>>>	Moderate to Low
Particle size data	Of 7 samples 5 samples with >14% clay, 1 sample 12% clay, 1 sample 11% clay; 4 samples > 50% fines, 3 samples 40%, 46%, 50% fines respectively.	>>>	Low
Field description data	All samples described as 'CLAY'	>>>	Low
Permeability test data		>>>	-
		Overall conclusion >>>	**Low**

5. COMMENTS: This area is identified as low permeability. While vegetation and drainage characteristics are relatively inconclusive, grain size data, combined with the BS descriptions, strongly indicate low permeability material. Low effective rainfall and good farming practices may mask the influence of low permeability subsoils on the vegetation.

Summary of Permeability Data and Analyses for Permeability Unit 3b. Cork Syncline East Moderate .

Description of unit location:	This region includes the central portion of the Cork Syncline from Midleton to Dunkettle and some discontinuous areas of moderate permeability subsoil occurring in the eastern part of the Cork Syncline at Kilmountain and east of Castlemartyr.
Why is this a single K unit?	General characteristics of topography and land use are the same in these areas. There are frequent occurances of shallow rock.

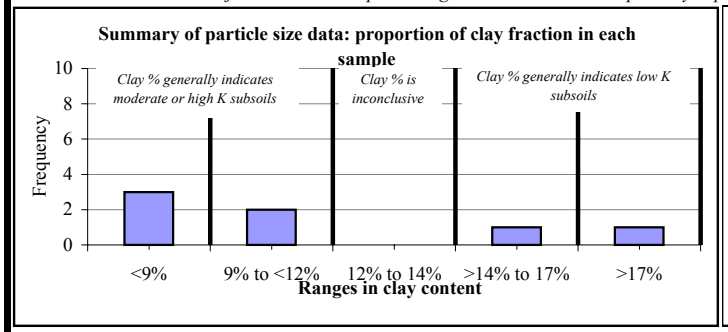
1. General Permeability Indicators and Region Characteristics

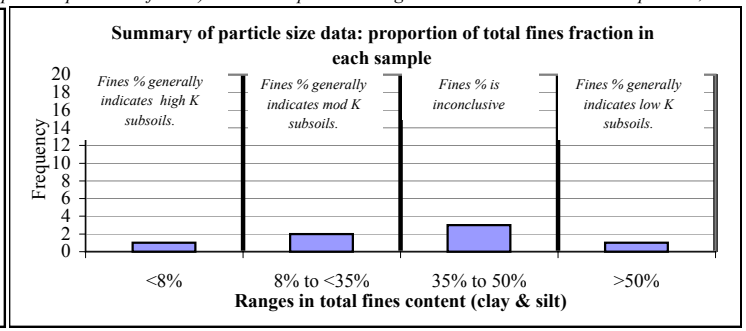
Rock type	Mainly clean limestone; Aquifer classification Regionally Important, Formations WA (Rk), CK(Rf), Ll (Rf), CK (Rf), CV (Rf)
Depth to bedrock	Typically 5-10m west of Midleton, 3-5m south and east of Midleton, around Kilmountain, and east of Castlemartyr. The region is divided by frequent occurrences of shallow rock.
Subsoil type	Mapped as sandstone till, some small deposits of sand and gravel.
Soil type	Not mapped
Vegetation and land use	Grassland, beet and some corn
Artificial drainage density	Low
Natural drainage density	Low
Topography and altitude	Part of relatively flat valley floor, elevation range 0-34m OD.
Ave. effective rainfall (mm)	Range for East Cork 433 - 908mm/yr

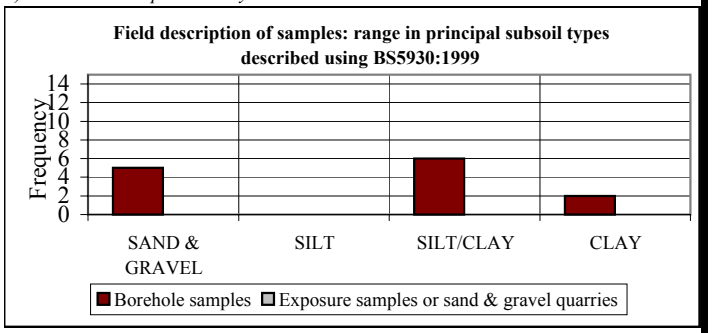
2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

(14 BH PSA, All CL)

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	Mainly clean limestones	>>>	Moderate
Quaternary / subsoil origin	Mapped by Teagasc as sandstone till	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Grazing and tillage	>>>	Moderate
Artificial drainage density	Low	>>>	Moderate to Low
Natural drainage density	Low	>>>	
Particle size data	Generally indicate moderate or high permeability subsoils.	>>>	
Field description data	Generally SAND, SILTS and SILT/CLAY, occasional sandy CLAY and CLAY	>>>	Moderate
Permeability test data		>>>	
		Overall conclusion >>>	**Moderate**

5. COMMENTS: This general weight of evidence suggests that this region has moderate permeability subsoils. At Castlemartyr and Mogeely grain size analysis and subsoil descriptions indicate that these areas do not fit the low permeability classification applied to the surrounding lands. The subsoils in these areas are shallow and more likely to be influenced by the underlying clean limestone. Further east towards Midleton the general character of the subsoil is that of moderate permeability.

Summary of Permeability Data and Analyses for Permeability Unit 4. Low K Areas .

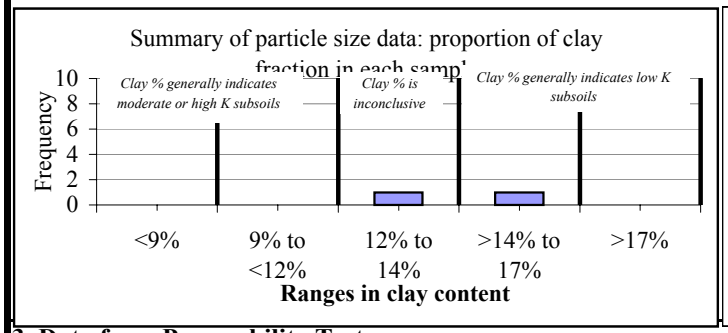
Description of unit location:	Discontinuous areas designated as Low K within the Moderate K Whitegate-Ballycotton(Region 7) and Cork Groups areas (Region 9), located at Mawbrin, Knocknamanagh, Ballyvrin. The areas are limited in size and were identified as a result of field assessment, BS description and grain size analysis.
Why is this a single K unit?	All areas consist of small pockets of low peremeability within moderate permeability areas, they have similar subsoil, vegetation a

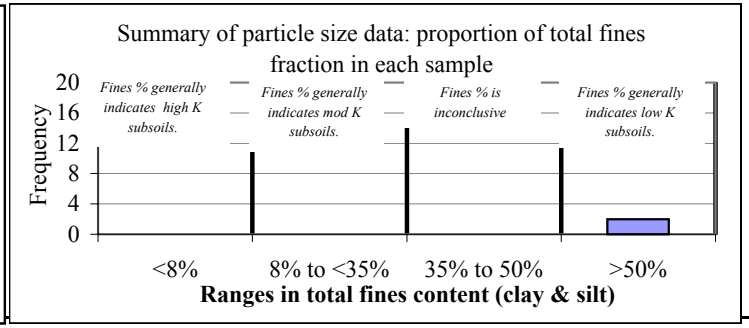
1. General Permeability Indicators and Region Characteristics

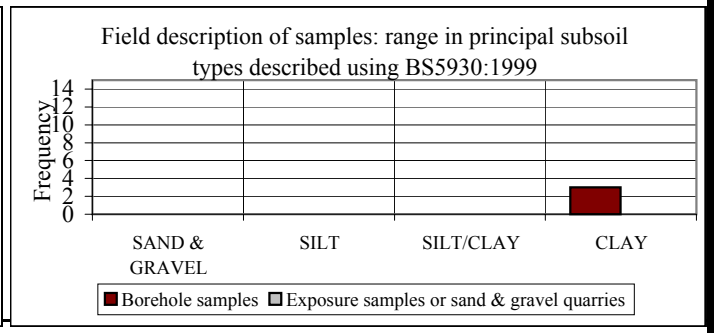
Rock type	Mudstones, Formations KNpc and KN
Depth to bedrock	Typcially 5-10m, occasionally >10m
Subsoil type	Mapped as Sandstone till and Sandstone and shale till with texture variable from sandy to clayey
Soil type	Not mapped
Vegetation and land use	Grassland dominant, tillage common.
Artificial drainage density	Field drains common within these small areas
Natural drainage density	None of these areas have streams running through them
Topography and altitude	Mawbrin, shallow basin 30 - 40 mOD, Knocknamanagh small dip on a north facing gentle hill slope 55-70 m OD, Ballyvrin south facing gentle hill slope 45 - 60 mOD
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

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	Mudstones provide a source of fine clay sized particles which can contribute to clayey low permeability subsoils.	>>>	Low to Moderate
Quaternary / subsoil origin	Mapped as variable sandy and clayey tills	>>>	Moderate to Low
Soil type	Not mapped	>>>	-
Land use	Mixed grassland and tillage	>>>	Moderate
Artificial drainage density	High	>>>	Low
Natural drainage density	-	>>>	
Particle size data	Knocknamanagh sample 16% clay Ballyvrin sample 14% clay, both > 50% fines	>>>	Low
Field description data	Samples from all areas described as 'CLAY'	>>>	Low
Permeability test data		>>>	-
		Overall conclusion >>>	**Low**

5. COMMENTS: The areas described together as this permeability unit are discontinuous areas of low permeability till that have been delineated within the moderate K permeability units 7 and 9. These areas have been identified based on samples and field observations of subsoils, vegetation and drainage density (described above). The low permeability is confined to quite small areas. It is possible that other such concentrations of low permeability material in small areas occur within the wider moderate permeability regions 7 and 9 that have not been picked up at the scale of this study. A detailed soils map would be useful in assessing whether other small pockets of low permeability subsoils can be delineated in this region.

Summary of Permeability Data and Analyses for Permeability Unit 5a. Northern ORS Unit .

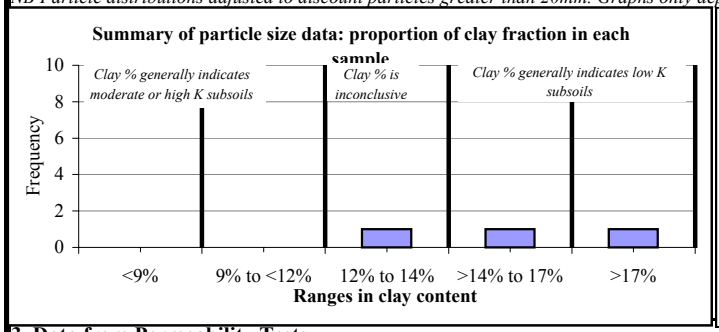
Description of unit location:	Old Red Sandstone ridge running from east to west across the northern part of the South Cork region. This area is bounded to the south by Lee valley and a change in bedrock type and extends to the north, to the boundary of South Cork, and to the west, as far as the Awboy River. There is a gradual transition to poorer land when moving west across the region which is accompanied by a higher average effective rainfall and a greater percentage of shallow subsoils.
Why is this a single K unit?	Same bedrock and till type, similar topography and land use

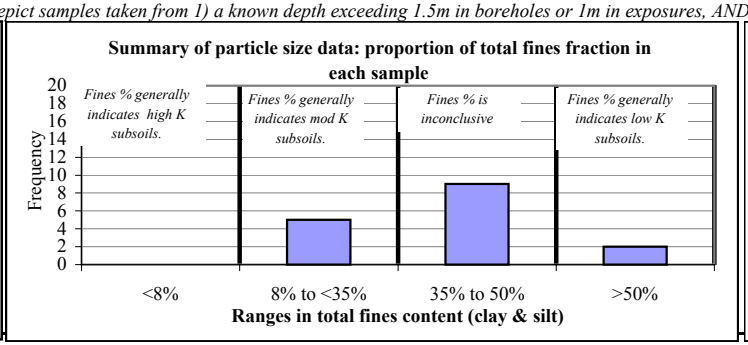
1. General Permeability Indicators and Region Characteristics

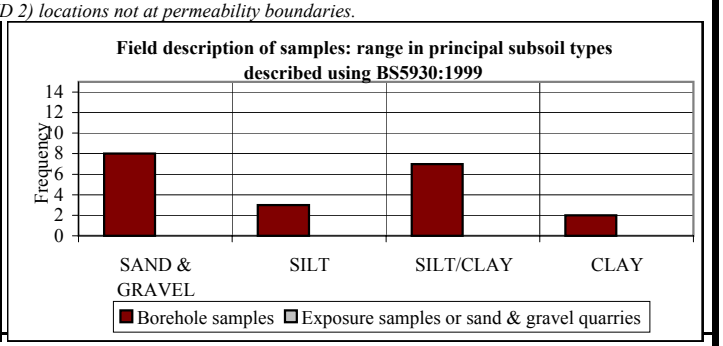
Rock type	Old Red Sandstone Fmns; Ballytrasna Fmn - mudstones with subordinate fine to medium grained sandstones and Gyleen Fmn - dominated by cross bedded sandstones; Aquifer category Ll
Depth to bedrock	Variable 0-10m, frequent rck close particularly near stream gullies
Subsoil type	Mapped as Sandstone till with sandy texture
Soil type	Not mapped
Vegetation and land use	Good grassland (less grain than in south) & forestry, some beet, mostly cattle & dairy
Artificial drainage density	Low. Field drains rarely observed
Natural drainage density	Intermediate
Topography and altitude	Elevation range 40-230m OD
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

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	Sandstones - a source of sand size grains, while mudstones provide a source finer clay size particles	>>>	Moderate to Low
Quaternary / subsoil origin	Mapped as sandy tills	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Good grassland, some areas of poorer grassland and foresetry, especially towards the north and west	>>>	Moderate to Low
Artificial drainage density	Low	>>>	Moderate
Natural drainage density	Inermediate	>>>	Moderate
Particle size data	Grain size analyses were only carried out on borederline samples - hence the particle size data are skewed towards the low permeability end of scale. Of 4 samples analysed 2 had grain size distributions that indicated low k	>>>	Moderate occasionally Low
Field description data	Majority of samples are SAND, SILT and sandy SILT/CLAY.	>>>	Moderate
Permeability test data		>>>	-
		Overall conclusion >>>	**Moderate**

5. COMMENTS: This region generally consists of good quality farmland with field drains rarely observed. The underlying Old Red Sandstone rock contributes to the sandy nature of the tills while the mudstone elements contribute a proportion of finer grained material. Subsoil descriptions are primarily of SAND, SILT and sandy SILT/CLAY. Subsoils described as 'CLAY' are occasionally recorded with grain size data indicative of low permeability material, however, these were found to be isolated occurrences and not characteristic of the region as a whole. There was not sufficient supporting evidence from vegetation and/or drainage characteristics to merit identifying these points as individual low permeability regions. The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'moderate'

Summary of Permeability Data and Analyses for Permeability Unit 5b. Western Uplands .

Description of unit location:	This region includes the upland and mountainous area to the west of the Awboy River.
Why is this a single K unit?	Abundent rock close and rock outcrop, similar topography, subsoils and underlying bedrock.

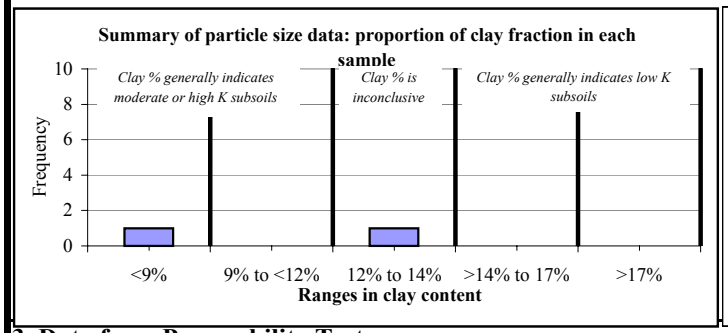
1. General Permeability Indicators and Region Characteristics

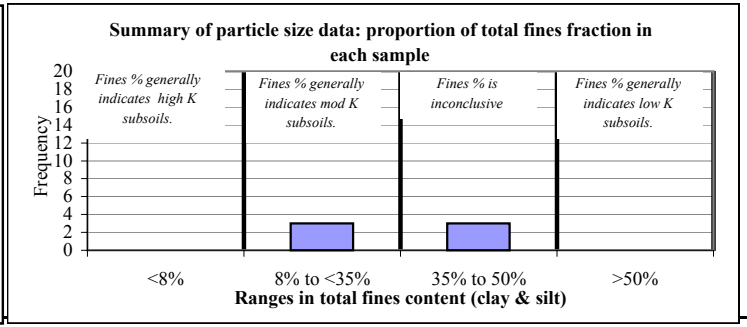
Rock type	Generally coarse grained dominated sandstones and siltstones of the western succession of the Old Red Sandstone, Gortanimill (GM) Caha Mountain (CH) and Bird Hill (BH) Fmns.
Depth to bedrock	Frequently <3m, range 0-10m, typically < 5m.
Subsoil type	Mapped as sandstone till, sandy texture, lots of shallow rock and outcrop, some alluvium and glacial sands and gravels.
Soil type	Not mapped
Vegetation and land use	Grassland, forestry and blanket bog
Artificial drainage density	intermediate to high
Natural drainage density	intermediate to high
Topography and altitude	Elevation range 100-650m OD
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

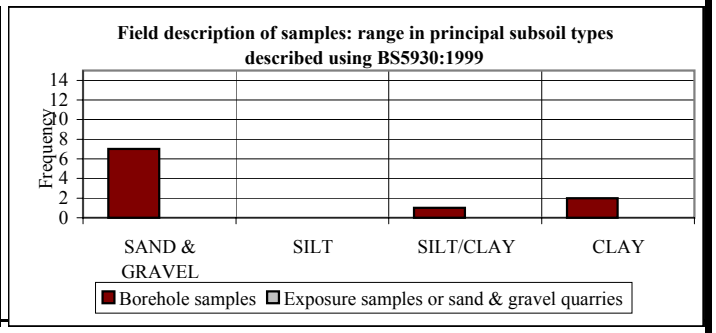
2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

(3 BH PSA, 1 CL, 3 Fines)

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	Sandstones provide source of sand grains	>>>	Moderate
Quaternary / subsoil origin	Mapped as mostly sandy tills with small areas of alluvium and glacial sands and gravels	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Grazing - poor grassland with rushes (Influence of high rainfall)	>>>	Moderate to Low
Artificial drainage density	Intermediate to High - (Influence of high rainfall)	>>>	Moderate
Natural drainage density	Intermediate to High	>>>	Moderate
Particle size data		>>>	Moderate
Field description data	SAND, sandy SILT/CLAY	>>>	Moderate
Permeability test data		>>>	-
		Overall conclusion >>>	**Moderate**

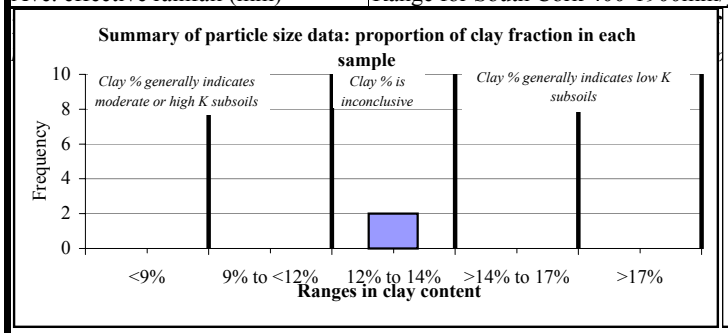
5. COMMENTS: Subsoils in this region are mainly glacial till and generally quite thin. There is a large amount of rock outcrop and shallow rock in this area. Subsoils are generally quite sandy reflecting the coarse grained sandstones which dominate the bedrock formations in this area. Subsoil descriptions and particle size analysis suggest generally moderate permeability subsoils. Areas of blanket peat occur in this permeability region but because they are thin the underlying subsoils are considered to control the overall permeability.

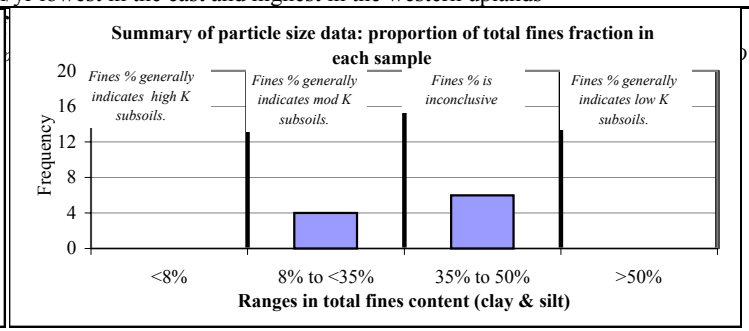
Summary of Permeability Data and Analyses for Permeability Unit 6. Great Island Anticline .

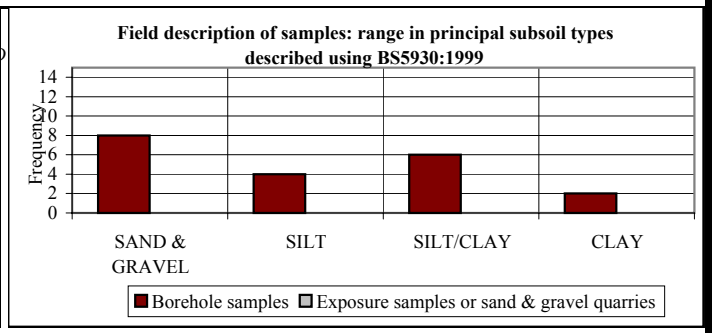
Description of unit location:	Old Red Sandstone ridge known as the Great Island Anticline, running through the centre of the South Cork region from Knockadoon Head in the east, through Great Island and across to the western boundary of South Cork. The region is limited to the north by the Lee Valley and to the south by the transition from a sandstone till to a sandstone and shale till and a
Why is this a single K unit?	Similar topography and land use, relatively shallow subsoils throughout, same bedrock and till type.

1. General Permeability Indicators and Region Characteristics

Rock type	Old Red Sandstone Fmns; Ballytrasna Fmn - mudstones with subordinate fine to medium grained sandstones and Gyleen Fmn - dominated by cross bedded sandstones, and Old Head Sandstones (OH); In the west Gortanimill (GM), Caha Mountain (CH), and Bird Hill (BH) formations - the generally coarse grained dominated sandstones and siltstones of the western succession of the Old Red Sandstone.
Depth to bedrock	Frequently <3m, generally not > 5m. Pockets of deeper subsoil to west but also more frequent shallow rock.
Subsoil type	Mapped as Sandstone till, sandy texture. Increasingly frequent shallow rock towards west and on slopes.
Soil type	Not mapped
Vegetation and land use	Mixed grassland, grain and beet/vegetable crops.
Artificial drainage density	Low. No apparent field drains except for small area west of Cork Airport.
Natural drainage density	Intermediate
Topography and altitude	Sandstone ridge. Elevation range 20-220m OD.
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands







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	Sandstones - a source of sand size grains, while mudstones provide a source of finer clay size particles		>>>	Moderate to Low
Quaternary / subsoil origin	Mapped as sandy tills		>>>	Moderate
Soil type	Not mapped		>>>	-
Land use	Mixed grassland, grain and beet/vegetable crops, decrease in tillage to the west.		>>>	Moderate
Artificial drainage density	Low. No apparent field drains except for small area west of Cork Airport.		>>>	Moderate
Natural drainage density	Intermediate		>>>	Moderate
Particle size data	Representative range of samples analyed for grain size distribution. All samples found <46% fines		>>>	Moderate
Field description data	Majority of samples are SAND, SILT and sandy SILT/CLAY,		>>>	Moderate
Permeability test data	No data		>>>	-
		Overall conclusion	>>>	**Moderate**

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'moderate' . This region generally consists of good quality farmland, with tillage common and field drains rarely observed. Subsoil descriptions and particle size analysis support a moderate permeability classification.

Summary of Permeability Data and Analyses for Permeability Unit 7. Cork Group .

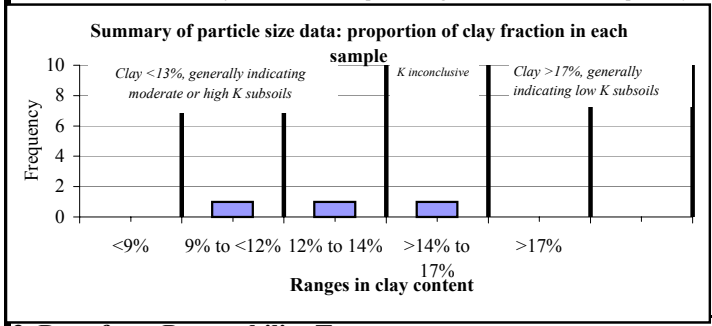
Description of unit location:	Area covering the southwestern part of the South Cork region, west of Cork Harbour and south of Ballinhassig and the Great Island Anticline, extending to the western boundary of South Cork at Enniskeane. Deposits of alluvium and sands and gravel within the area are described as separate permeability regions.
Why is this a single K unit?	Similar topography, landuse and subsoil type. Same underlying bedrock.

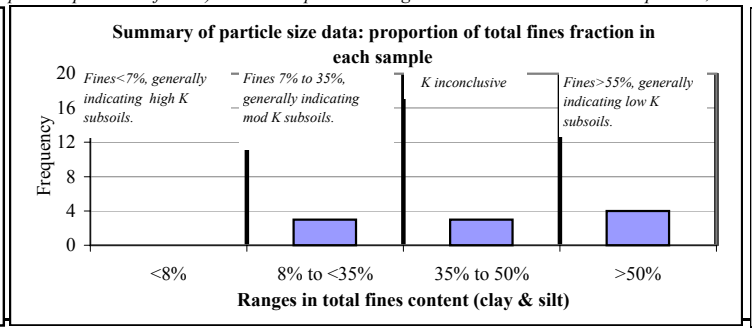
1. General Permeability Indicators and Region Characteristics

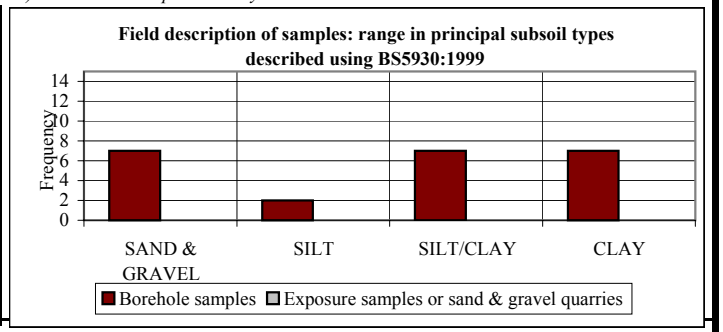
Rock type	Cork Group Fmns, marine clastic rocks of latest Devonian and Carboniferous age, predominantly mudstones with sandstone. Aquifer Category Locally important (Ll) (Fmns:KNcs, OH,TH, KN, KNnc, KNpc, also small areas of CY, WS)
Depth to bedrock	Variable 0 -10m, generally 3-5m especially near coast, occasionally 5-10m especially in north and northeast of the area, frequent occurrences of rock outcrop and rock close particularly in river and stream valleys;
Subsoil type	Mapped as Sandstone and shale till, variable texture sandy to clayey. Some areas of alluvium and sands and gravels.
Soil type	Not mapped
Vegetation and land use	Mostly grassland with moderate amounts of grain and beet and vegetable crops.
Artificial drainage density	Low
Natural drainage density	Intermediate
Topography and altitude	Undulating with occasional steep sided stream/river valleys, elevation range 10-200m OD.
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr, lowest in the east and highest in the western uplands

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

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







3. Data from Permeability Tests.

T' tests: # Results	# Tests T<1 min/25mm	# 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	Mudstones and sandstones	>>>	Moderate to Low
Quaternary / subsoil origin	Mapped as sandy and clayey till	>>>	Moderate to Low
Soil type	Not mapped	>>>	-
Land use	No evidence of low peremability subsoils	>>>	Moderate
Artificial drainage density	No evidence of drainage difficulty	>>>	Moderate
Natural drainage density	Intermediate	>>>	Moderate
Particle size data	Grain size analyses were only carried out on samples which were considered borderline between moderate and low permeability hence the particle size data above does not adequately represent the extent of moderate permeability subsoils in the area.	>>>	Moderate to Low
Field description data	Predominantly SAND and SILT with frequent sandy SILT/CLAY. Occasional SILT/CLAY, sandy CLAY and CLAY.	>>>	Moderate to Low
Permeability test data		>>>	-
		Overall conclusion >>>	**Moderate**

5. COMMENTS: Subsoils descriptions are primarily of SAND and SILT with frequent sandy SILT/CLAY. Subsoils described as CLAY are occasionally recorded with grain size data indicative of low permeability material, however, these were found to be isolated occurrences and not characteristic of the region as a whole. In gerenal while there is a clay element in the tills of this area, the overall character of the tills is that of moderate permeability. Vegetation and drainage characteristics support a moderate permeability classification.

Summary of Permeability Data and Analyses for Permeability Unit 8. Carrigaline Peninsula .

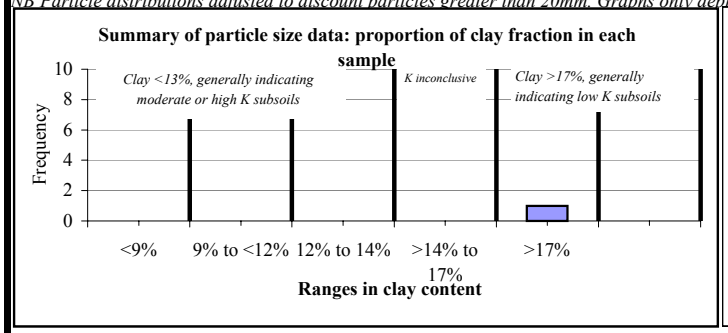
Description of unit location:	Small areas of >3m subsoil on the Carrigaline Peninsula - east of Carrigaline to Ringaskiddy and Currabinny
Why is this a single K unit?	Doesn't fit into Area 1:Meadstown-Ballynaloughy Group (shows no surface characteristics of low permeability subsoil, no frequent occurrences of field drains have been observed) different in topography and character to Area 6:Great Island Anticline,

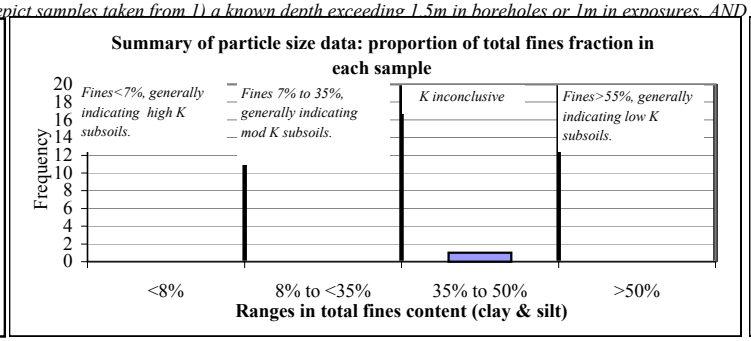
1. General Permeability Indicators and Region Characteristics

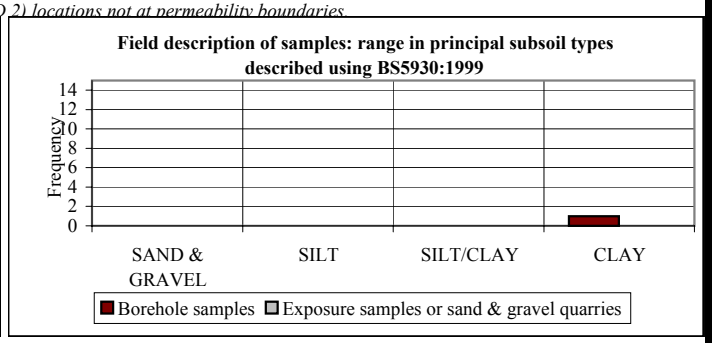
Rock type	Mainly Waulsortian Lmst - clean limestone, with small amounts of other limestone, mudstone and sandstone formations. Formations BA, WA, CY, LP, KNcu, KNcs,KNpc, OH, and Gyl
Depth to bedrock	Typically >5m, generally shallower to the west, recorded range 0-13m, possibly deeper over limestone where cavities have been infilled, frequent rock outcrop.
Subsoil type	Mainly glacial till. Several till types mapped - Sandstone till, Sandstone and shale till, Limestone till.
Soil type	Not mapped
Vegetation and land use	Mixed grassland, grain, beet and vegetable crops. A lot of made ground/industrialised area.
Artificial drainage density	Low
Natural drainage density	Low
Topography and altitude	Elevation range 10-92 mOD
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

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	Limestones, Mudstones and Sandstones	>>>	Moderate to Low
Quaternary / subsoil origin	Variable to Sandy Tills	>>>	Moderate to Low
Soil type	Not mapped	>>>	-
Land use	Mixed grassland grain and sugar beet	>>>	Moderate
Artificial drainage density	Low	>>>	Moderate
Natural drainage density	Low	>>>	Moderate
Particle size data		>>>	Low
Field description data		>>>	Low
Permeability test data		>>>	
		Overall conclusion >>>	**Moderate**

5. COMMENTS: Although the one subsoil sample is described as CLAY with grain size data indicating low permeability, the general characteristics of the area (vegetation, land use etc) indicate moderate permeability. Further subsoil sampling and analysis would be useful to confirm the moderate permeability assessment.

Summary of Permeability Data and Analyses for Permeability Unit 9. Whitgate - Ballycotton .

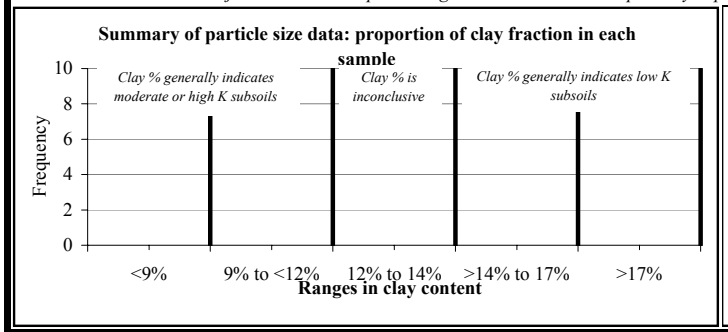
Description of unit location:	Area between Whitegate and Ballycotton, limited to the south by the coast and to the north by the Cloyne valley.
Why is this a single K unit?	Relatively uniform bedrock, subsoils, land use and topography.

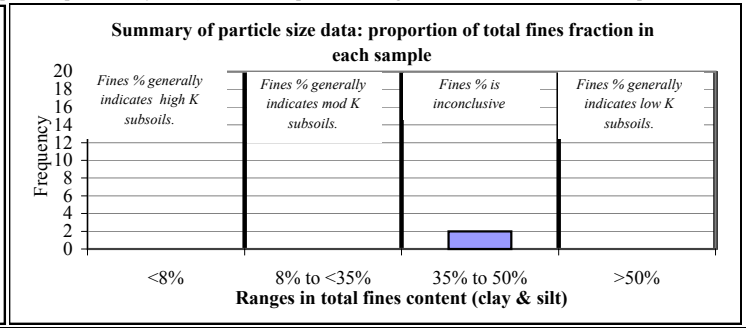
1. General Permeability Indicators and Region Characteristics

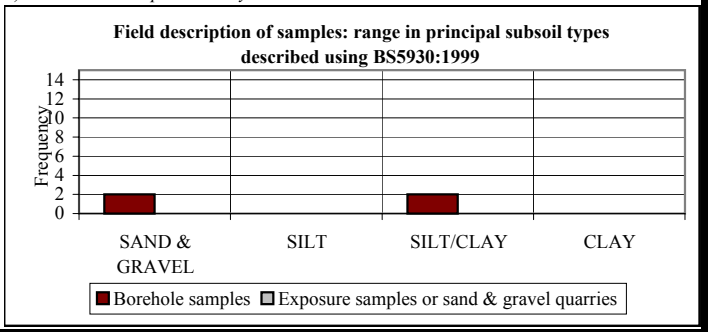
Rock type	Sandstones, siltstones and mudstones, Formations KNcu, OH, GYbn, GY, BS
Depth to bedrock	Typically 3-5m. Large areas of <3m subsoil in this area
Subsoil type	Mapped as Sandstone till, some alluvium, frequent scattered rock outcrop.
Soil type	Not mapped
Vegetation and land use	Grassland dominant, tillage common
Artificial drainage density	Low, field drains rare.
Natural drainage density	Intermediate
Topography and altitude	Gently undulating, elevation range 10-83m OD.
Ave. effective rainfall (mm)	Range for East Cork 433 - 908mm/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	Sandstones, siltstones and mudstones	>>>	Moderate to Low
Quaternary / subsoil origin	Sandy Tills	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Mixed grassland and tillage	>>>	Moderate
Artificial drainage density	Low - no drainage difficulties	>>>	Moderate
Natural drainage density	Intermediate	>>>	Moderate
Particle size data	2 SILT/CLAY samples, fines % inconclusive though 37% and 40% fines are on moderate end of scale	>>>	Moderate
Field description data	Samples described as sandy SILT, SILT/CLAY and SAND	>>>	Moderate
Permeability test data		>>>	-
		Overall conclusion >>>	**Moderate**

5. COMMENTS: This permeability region consists of small areas of >3m subsoil occurring generally in small depressions or along stream valley within an area of predominantly thin subsoil. Vegetation and drainage characteristics in these areas indicate moderate permeability. Subsoil samples are described primarily as SAND, SILT, and SILT/CLAY. The general weight of evidence supports a 'moderate' permeability classification for this region.

Summary of Permeability Data and Analyses for Permeability Unit 10. River Bride Valley .

Description of unit location:	This region consists of discontinuous areas of moderate permeability glacial till occurring in the western portion of the Cork Syncline between Cork Harbour and Crookstown.
Why is this a single K unit?	This region occurs in a relatively flat limestone valley bordered to the north and south by sandstone ridges with similar subsoils, la

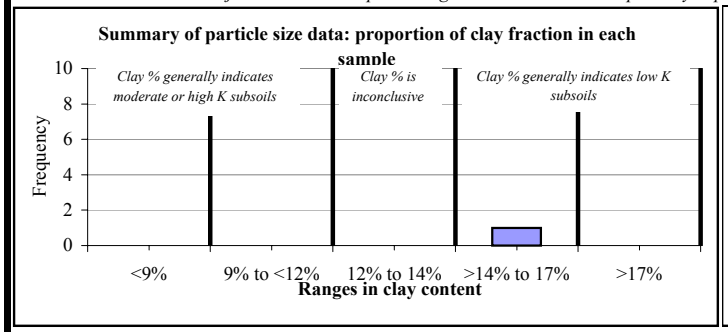
1. General Permeability Indicators and Region Characteristics

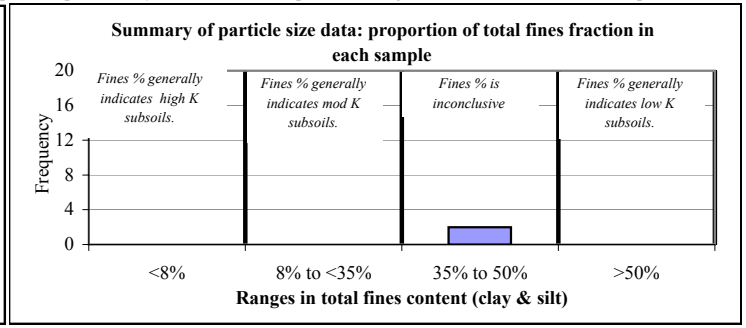
Rock type	Mostly clean limestones with some sandstones and minor mudstones
Depth to bedrock	Variable 0-10m, some areas of shallow rock near Crookstown, Ballincollig and in the south of Cork City.
Subsoil type	Mapped as sandstone till . Extensive deposiits of gravel and alluvium in the area.
Soil type	Not mapped
Vegetation and land use	Grassland, beet and vegetable crops.
Artificial drainage density	Low
Natural drainage density	Low
Topography and altitude	Relatively flat lowlying areas within the limestone valley, elevation range 20-60mOD.
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

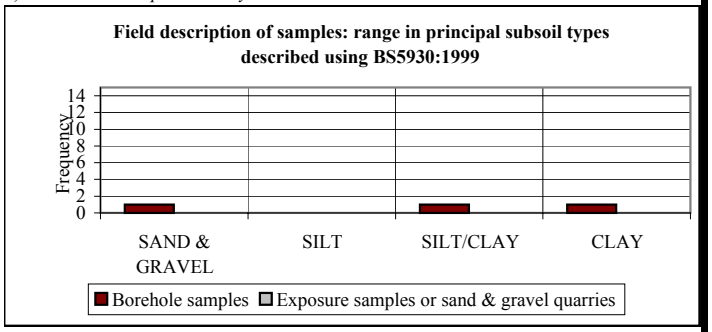
2. Summary of Particle Size Analysis and Field Descriptions of Subsoil Samples.

(4 BH PSA, 1 CL, 4 Fines)

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	Mostly clean limestones with some sandstones and minor mudstones	>>>	Moderate
Quaternary / subsoil origin	Mapped as sandy tills	>>>	Moderate
Soil type	Not mapped	>>>	-
Land use	Mixed grassland and tillage	>>>	Moderate
Artificial drainage density	Low - no signs of drainage difficulties	>>>	Moderate
Natural drainage density	Low	>>>	Moderate
Particle size data		>>>	
Field description data	sandy SILT/CLAY, SAND, sandy SILT, sandy CLAY	>>>	Moderate
Permeability test data		>>>	
	Overall conclusion	>>>	**Moderate**

5. COMMENTS: Cork City and Ballincollig cover much of the western half of the region. The area south of Ballincollig is covered by generally gravely glacial till. West of Ballincollig small areas of till have been delineated within the extensive gravel and alluvium deposits. Subsoil descriptions generally of sandy and gravelly SILT/CLAY with occasional gravelly and sandy CLAY. Overall subsoil descriptions along with vegetation and drainage characteristics support a moderate permeability classification for the subsoils in this region

Summary of Permeability Data and Analyses for Permeability Unit 11. Alluvium .

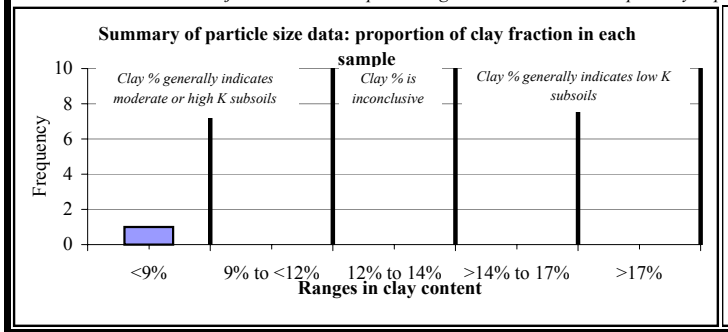
Description of unit location:	These deposits are found in narrow strips along streams and rivers throughout the county. The largest developments of alluvium occur along the Lee, Bride, Bandon and Blarney rivers, with thinner deposits along the smaller streams throughout the county.
Why is this a single K unit?	They are primarily fine-grained water-lain deposits found on the banks and flood-plains of rivers.

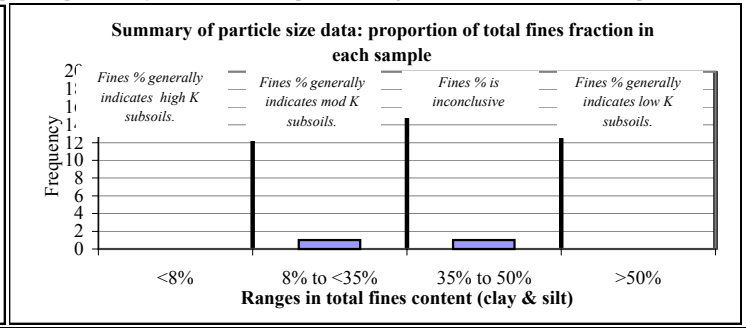
1. General Permeability Indicators and Region Characteristics

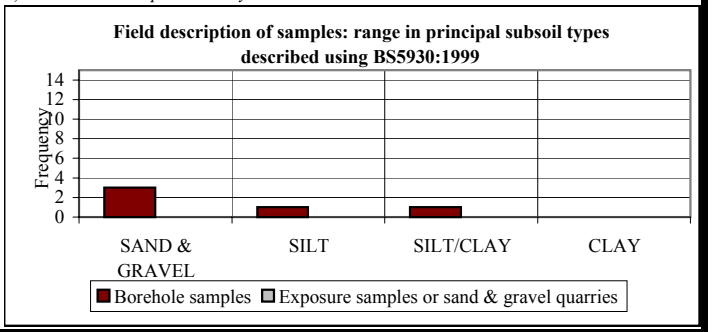
Rock type	Various
Depth to bedrock	Typically greater than 3m, often greater than 5m especially near larger rivers. The alluvium generally overlies till or gravel deposits, but are sometimes underlain by rock.
Subsoil type	Expected to be water-lain, bedded, fairly fine grained sediments.
Soil type	Not mapped. Groundwater gleys expected due to high water table.
Vegetation and land use	Immediately next to the rivers, the land is commonly water-logged and rushy. Where the alluvium is extensive, it may be tilled or grazed.
Artificial drainage density	High, reflecting the proximity of the watertable to the surface.
Natural drainage density	High.
Topography and altitude	Typically in valley flats throughout the county.
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

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	Various	>>>	-
Quaternary / subsoil origin	Interbedded sand, silts and clays; occasional gravel.	>>>	Moderate
Soil type	Not mapped.	>>>	-
Land use	Some tillage and grazing where land is not water-logged	>>>	Low-Moderate
Artificial drainage density	High	>>>	-
Natural drainage density	High	>>>	-
Particle size data	sandy SILT 33% fines and 8% clay.	>>>	Moderate
Field description data	SAND, sandy SILT, and sandy gravelly SILT/CLAY.	>>>	Moderate
Permeability test data		>>>	-
		Overall conclusion >>>	**Moderate**

5. COMMENTS: Although these alluvial deposits are found throughout the county, at a range of elevations and underlain by a wide variety of rock types, they all share a common origin and are expected to consist of a mix of sands, silts and clays. This makes it most likely that they will have a moderate permeability. In the larger valleys such as those of the Rivers Lee, Bride and Bandon the alluvium generally overlies gravel deposits and in areas where there is a sufficient thickness offers a degree of protection to the higher permeability gravels.

Summary of Permeability Data and Analyses for Permeability Unit 12. Sand & Gravel Deposits .

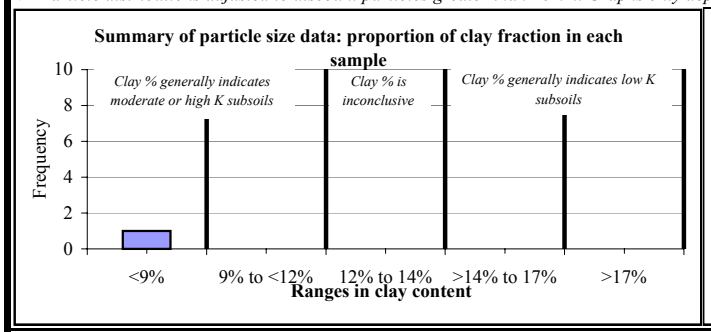
Description of unit location:	Extensive sand and gravel deposits occuring in the river valleys of the Lee, Bride, Bandon, Sullane and Blarney. There are also smaller discontinuous sand and gravel deposits occurring within other permeability regions throughout the South Cork area.
Why is this a single K unit?	Same subsoil type in all areas with similar characteristics of land use and drainage.

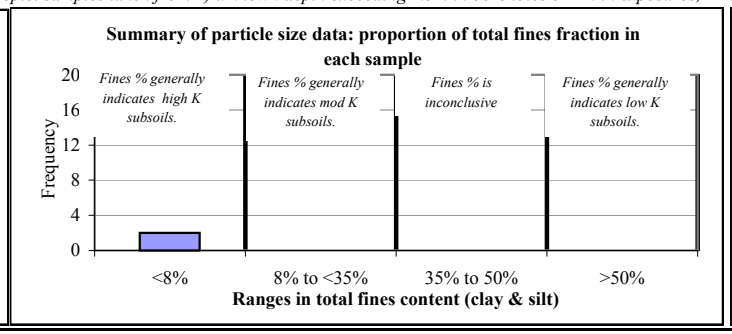
1. General Permeability Indicators and Region Characteristics

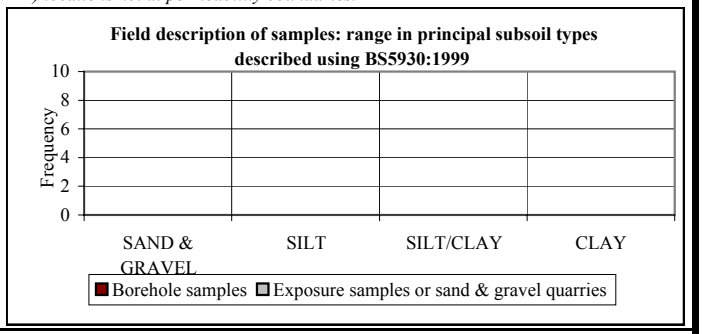
Rock type	Various.
Depth to bedrock	Typically greater than 3m, frequently > 10 in the larger river valleys
Subsoil type	Sands and gravels
Soil type	Not mapped
Vegetation and land use	Mostly grazing.
Artificial drainage density	Difficult to quantify - some of these units are small. Where noted, there is little artificial drainage.
Natural drainage density	
Topography and altitude	Usually undulating and hummocky, when covered by layer of alluvium in river valleys surface topography generally flat
Ave. effective rainfall (mm)	Range for South Cork 400-1900mm/yr lowest in the east and highest in the western uplands

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.







4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Rock type	Various	>>>	-
Quaternary / subsoil origin	Sands and Gravels	>>>	High
Soil type	Not mapped	>>>	-
Land use	Grazing	>>>	Moderate
Artificial drainage density	Where gravel deposits are large enough to tell, the drainage density is low.	>>>	Moderate to High
Natural drainage density	-	>>>	-
Particle size data	One sample with 6% fines and 2% clay; second sample has 7% fines.	>>>	High
Field description data	Generally described as sandy 'GRAVEL'	>>>	High
Permeability test data		>>>	-
		Overall conclusion >>>	**High**

5. COMMENTS: Some sand and gravel deposits are identified at the surface by their hummocky topography and the frequent presence of sand and gravel pits, others occur in river valleys, often covered by thin layers of alluvium, and are revealed in borehole logs. Permeability classifications are applied based on the nature of the gravels in areas where there is insufficient information about the thickness and nature of the overlying alluvium. Samples are described as GRAVEL. There are a large number of sand/gravel pits in the main units, which suggests that these deposits have enough of a uniform grade to be worked. The vegetation, lack of field drainage ditches and stream also infer very good drainage capacity. These deposits are considered to be highly permeable.

Appendix III

Results of Particle Size Analysis of Subsoil Samples

Results of Particle Size Analyses on Samples from Earth Auger drilling

Drilling ID	GSI Hole Name	Easting	Northing	Townland	Permeability Region	Depth to Rock (m)	Sample Depth (mbgl)	*Full Grain Size Results*				*Results Adjusted to exclude particles >20mm in diameter*			
								%Gravel	%Sand	%Fines	%Clay	%Gravel	%Sand	%Fines	%Clay
1405NED05	1405NEW196	163546	060787	Ballinaboy	1	4-4.5	3-3.5	38%	21%	41%	12%	38%	21%	41%	*12%*
1405NED07	1405NEW198	168552	61804	Meadstown	1	4	2.5-3	10%	18%	73%	21%	10%	18%	73%	*21%*
1405SED08	1405SEW205	164994	58548	Coruragh	1	4.5	1.5-2	13%	21%	65%	27%	13%	21%	65%	*27%*
1705NED07	1705NEW375	191756	65297	Balltfin	2a	>11	5	4%	27%	69%	17%	4%	27%	69%	*17%*
GSI 99/210	1705NEW210	192880	66980	Commons East	2a	4	1.5-3	14%	27%	60%	26%	14%	27%	60%	*26%*
GSI 99/212	1705NEW349	194830	67500	Ballymole Beg	2a	11	3.5-9	9%	24%	66%	25%	9%	24%	66%	*25%*
GSI 99/213	1705NEW350	196880	68700	Loughane	2a	5.5	0.5-5	28%	26%	46%	16%	28%	26%	46%	*16%*
1705NED10	1705NWW091	171245	65519	Ballinrea	2b	>10	3	30%	30%	40%	12%	30%	30%	40%	*12%*
GSI 99/209	1705NEW353	188690	66160	Ballydwyer	2b	>11.5	5	7%	43%	49%	13%	7%	43%	49%	*13%*
2007SWD04	2007SWW102	202851	72131	Ballyflemming	3a	8	6.5	9%	14%	78%	26%	9%	14%	78%	*26%*
2007SWD06	2007SWW104	201185	74637	Ballyling	3a	>11	3	6%	26%	68%	20%	6%	26%	68%	*20%*
GSI 99/206	1707SEW071	191770	74200	Clashduff	3a	>11	4-5	16%	29%	55%	17%	16%	29%	55%	*17%*
GSI 99/218	1707SEW074	198370	75950	Garnnejames	3a	>9.5	6-8	34%	26%	40%	12%	34%	26%	40%	*12%*
GSI 99/58	2007SWW057	207180	74520	Clonard West	3a	5.5	3	5%	13%	82%	29%	5%	13%	82%	*29%*
GSI 99/59	2007SWW058	202340	74400	Finisk	3a	5.8	3-4	29%	24%	46%	17%	24%	26%	50%	*18%*
GSI 99/62	1707SEW051	197380	70740	Rathcallan	3a	>6.6	1.5-4.5	5%	8%	87%	33%	5%	8%	87%	*33%*
1707SED06	1707SEW098	192040	71378	Gurteenina	3b	6.5	3.2-3.5	55%	25%	20%	7%	49%	28%	23%	*7%*
1707SED09	1707SEW101	185844	72527	Ballyvodock East	3b	9.5	2.5-3	25%	28%	47%	17%	25%	28%	47%	*17%*
GSI 99/207	1705NEW351	188760	59870	Bawnard	3b	>8	2-7.5	23%	27%	51%	19%	23%	27%	51%	*19%*
GSI 99/215	1707SEW073	198430	74310	Knockane	3b	3.5	2.3-3.3	11%	40%	49%	10%	11%	40%	49%	*10%*
GSI 99/217	2007SWW083	203140	77200	Burges Upper	3b	6	5.5-6	46%	28%	26%	8%	46%	28%	26%	*8%*
GSI 99/67	1707SEW052	195020	74250	Carragrine	3b	6	4.0-6.0	31%	65%	4%	1%	26%	70%	5%	*1%*
GSI 99/199	1405SEW185	161170	53630	Ballybrin	4	>5	3.0-5.0	14%	31%	55%	14%	14%	31%	55%	*14%*
GSI 99/203	1705SWW095	176640	55630	Ballinverrig	4	>4	3	23%	16%	61%	16%	23%	16%	61%	*16%*
1105NED01	1105NEW061	137821	67408	Dunisky	5a	7.5	3	44%	32%	24%	*N/A*	38%	36%	27%	*N/A*
1107NED03	1107NEW009	133918	81801	Rahalisk	5a	3.5	2-2.5	51%	24%	25%	*N/A*	41%	29%	30%	*N/A*
1407NED02	1407NEW178	167908	86023	Lyre	5a	4	3-3.5	31%	29%	41%	*N/A*	30%	29%	41%	*N/A*
1407NED06	1407NEW182	158482	84717	Greanagh North	5a	3.5	2-2.5	41%	18%	41%	*N/A*	41%	18%	41%	*N/A*
1407NWD03	1407NWW094	151294	84728	Rathcoola East	5a	5.0*	3	7%	32%	61%	14%	7%	32%	61%	*14%*

Results of Particle Size Analyses on Samples from Earth Auger drilling

Drilling ID	GSI Hole Name	Easting	Northing	Townland	Permeability Region	Depth to Rock (m)	Sample Depth (mbgl)	*Full Grain Size Results*				*Results Adjusted to exclude particles >20mm in diameter*			
								%Gravel	%Sand	%Fines	%Clay	%Gravel	%Sand	%Fines	%Clay
1407SWD02	1407SWW175	152316	79323	Kilclogh	5a	5	5	26%	30%	45%	*N/A*	26%	30%	45%	*N/A*
1407SWD08	1407SWW180	148561	78721	Derry	5a	7.5	*7-7.5*	28%	33%	39%	*N/A*	28%	33%	39%	*N/A*
1407SWD09	1407SWW181	140776	71446	Derry	5a	>10	2-2.5	51%	25%	25%	*N/A*	51%	25%	25%	*N/A*
1409SWD02	1409SEW015	167426	90538	Knockaunalor	5a	5.5	4.5	32%	32%	36%	*N/A*	32%	32%	36%	*N/A*
1707NED01	1707NEW049	195010	83890	Condonstown	5a	4	3	62%	18%	19%	*N/A*	55%	22%	23%	*N/A*
1707NED05	1707NEW050	*190450*	*84000*	Garrylaurence	5a	5	2-2.5	28%	30%	43%	*N/A*	26%	31%	44%	*N/A*
1707NED06	1707NWW065	*184440*	*82130*	Ballincurrig	5a	4.7	2	43%	33%	24%	*N/A*	39%	35%	26%	*N/A*
1707NWD01	1707NWW068	*177620*	*8086*	Shanballyreagh	5a	8	2.5-3	36%	30%	35%	*N/A*	36%	30%	35%	*N/A*
1107SED01	1107SEW114	133509	79342	Coolacoosane	5b	>10.5	3.5	24%	31%	45%	14%	24%	31%	45%	*14%*
1407NWD08	1407NWW099	140204	83280	Annagannihy	5b	9.2	3	33%	38%	29%	*N/A*	22%	44%	34%	*N/A*
GSI 99/176	1407SWW153	145750	73590	Coachford	5b	>8	6.0-8.0	26%	33%	41%	*N/A*	26%	33%	41%	*N/A*
GSI 99/178	1407SWW185	144300	77590	Aghagulloge	5b	5	2-2.5	38%	30%	32%	8%	35%	32%	34%	*8%*
GSI 99/21	1107SWW021	125410	77590	Bawntanaknock	5b	1.8	1.5-2	54%	35%	11%	*N/A*	53%	36%	11%	*N/A*
GSI 99/27	1107SEW027	128860	72670	Dromonig	5b	2.8	1.5	30%	35%	36%	*N/A*	30%	35%	36%	*N/A*
1105NED02	1105NEW062	138648	60332	Bengour West	6	4	3.5-4	61%	21%	18%	*N/A*	58%	23%	20%	*N/A*
1105SED04	1105SEW053	135737	59323	Rushfield	6	3	2.5-3	31%	27%	43%	*N/A*	31%	27%	43%	*N/A*
1105SED06	1105SEW055	138969	59068	Coolanagh	6	6	2	49%	28%	23%	*N/A*	48%	29%	23%	*N/A*
1405NED04	1405NEW195	162212	63830	Liskillea	6	5.5	4-4.5	27%	33%	40%	13%	27%	33%	40%	*13%*
1405NED13	1405NEW204	155342	65943	Mylane	6	3.25*	3-3.5	26%	28%	46%	*N/A*	26%	28%	46%	*N/A*
1405NWD08	1405NWW184	149353	64257	Curragheenbrien	6	7.5	4-4.5	27%	34%	39%	*N/A*	27%	34%	39%	*N/A*
1405SWD08	1405SWW233	143876	58949	Lisabanree	6	5	3-3.5	43%	24%	33%	*N/A*	43%	24%	33%	*N/A*
1705NWD03	1705NWW098	174526	63671	Rafeen	6	4.5	3.5	43%	32%	26%	*N/A*	43%	32%	26%	*N/A*
1705NWD12	1707NEW045	199038	87934	Knockanarrig	6	6*	3	35%	33%	32%	*N/A*	29%	36%	35%	*N/A*
2007SWD07	2007SWW105	201624	70283	Kilcredan	6	>10.3	3	25%	34%	41%	13%	25%	34%	41%	*13%*
1403NWD05	1403NWW086	148636	46852	Garrumdriog	7	5	3-3.5	30%	20%	51%	*N/A*	27%	21%	52%	*N/A*
1403NWD06	1403NWW087	150633	46995	Ardacrow	7	6.5	3	32%	15%	53%	*N/A*	32%	15%	53%	*N/A*
1405SED04	1405SEW201	160217	53310	Horsehill More	7	6.5	5	55%	19%	26%	9%	55%	19%	26%	*9%*
1405SED07	1405SEW204	164893	53212	Gortnalicky	7	3.5	1.5-2	44%	30%	27%	*N/A*	44%	30%	27%	*N/A*
1405SWD05	1405SWW230	150890	53777	Moanarone	7	>10	5	41%	20%	39%	*N/A*	38%	21%	41%	*N/A*

Results of Particle Size Analyses on Samples from Earth Auger drilling

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								%Gravel	%Sand	%Fines	%Clay	%Gravel	%Sand	%Fines	%Clay
1405SWD13	1405SWW238	150214	58547	Littlesilver	7	4.5	2.5-3	44%	21%	35%	*N/A*	44%	21%	35%	*N/A*
GSI 99/188	1403NEW188	159000	45680	Kilmore	7	>6	5.5-6	29%	35%	36%	*N/A*	29%	35%	36%	*N/A*
GSI 99/190	1403NWW190	153230	46740	Kilbritten	7	>3.5	2.8-3.5	49%	32%	19%	*N/A*	49%	32%	19%	*N/A*
1705NWD10	1705NWW100	179241	68170	Ballyleary	8	5	3-3.25	30%	25%	45%	19%	23%	27%	50%	*21%*
1705NED03	1705NEW367	190073	61741	Ba;;ubranagh	9		3	39%	25%	36%	*N/A*	37%	26%	37%	*N/A*
1705NED05	1705NEW372	197160	65533	Monagurra	9		3.5	64%	-4%	40%	*N/A*	64%	-4%	40%	*N/A*
1407SED14	1407SE W154	161752	70416	Carrigrohane	10	5	3.5	31%	26%	44%	16%	24%	28%	48%	*17%*
GSI 99/43	1405NWW142	150310	67340	Aherla	10	4	2	22%	32%	46%	11%	22%	32%	46%	*11%*
1405NED10	1405NEW201	168384	63270	Ballyduhig South	11	>10.3	5	40%	30%	30%	8%	34%	34%	33%	*8%*
GSI 99/182	1505NWW155	143640	65910	Faranduff	11	6.3	4.0-5.0	30%	21%	49%	*N/A*	30%	21%	49%	*N/A*

N/A - %Clay not obtained for this sample