

County Kildare Groundwater Protection Scheme

Volume I: Main Report

First Draft.

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Executive Summary

The Groundwater Protection Scheme for Kildare County Council provides a preliminary assessment of the relative risk to groundwater quality across the county. The main elements of the risk assessment are groundwater vulnerability (primarily subsoil thickness, subsoil permeability and karst features), aquifer potential, and source protection. The source protection element involves the delineation of protection areas around the recharge areas for selected public and group scheme groundwater supplies.

The results can't be used as a substitute for site investigation for particular developments, but have proved very useful in providing Kildare County Council with an independent, defensible, planning tool for a wide range of new developments:

- *Major developments (e.g. for landfill site selection, developments requiring waste management and integrated pollution licensing):* helping to short-list suitable sites for detailed site investigation.
- *Minor developments (e.g. domestic wastewater treatment systems):* helping to prioritise the allocation of Local Authority planning staff resources.

The main output of the Protection Scheme is a digital Geographic Information System which is designed to be compatible with existing Kildare County Council planning tools. It provides 'Groundwater Protection Responses' for all areas of the county. These responses incorporate the potential hazard posed by selected activities with the vulnerability, aquifer and source protection assessments to provide site suitability guidance for all areas of the county. The activities in question currently include landfill, IPC landspreading of piggery/poultry wastes, and domestic wastewater treatment systems. The responses are developed through a collaboration of the Geological Survey of Ireland, the EPA and the Department of the Environment and Local Government.

An additional output comprises paper maps of the protection scheme, and two report volumes. Volume I outlines the basis for the vulnerability and aquifer zones delineated in the paper maps and GIS. Explanations include assumptions made, calculations/data sources used, and limitations. Volume II outlines the basis for the source protection zones delineated in the maps and GIS. Again, the text includes assumptions made, calculations and data sources used, and limitations.

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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 pose increasing risks to groundwater quality: there is widespread disposal of domestic, agricultural and industrial effluents to the ground, and 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, more than 90% can comprise groundwater in summer. If groundwater becomes contaminated, the rivers can also be affected and so the protection of groundwater resources is an important aspect of sustaining surface water quality.
- Groundwater generally moves slowly through the ground and so the impact of human activities can last for a relatively long time.
- Polluted drinking water is a health hazard and once contamination has occurred, drilling of new wells is expensive and in some cases not practical. Consequently ‘prevention is better than cure’.
- Groundwater may be difficult to clean up, even when the source of pollution is removed.
- Unlike surface water where flow is in defined channels, groundwater is present everywhere.
- EU policies and national regulations are requiring that polluting discharges to groundwater must be prevented as part of sustainable groundwater quality management.

1.2 Groundwater – A Resource at Risk

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

- Lack of awareness of the risks of groundwater contamination, because groundwater flow and contaminant transport are generally slow and neither readily observed nor easily measured.
- Contamination of wells and springs.
- Widespread application of domestic, agricultural and industrial effluents to the ground.
- Generation of increasing quantities of domestic, agricultural and industrial wastes.
- Increased application of inorganic fertilisers to agricultural land, and usage of pesticides.
- Greater volumes of road traffic and more storage of fuels/chemicals.
- Manufacture & distribution of chemicals of increasing diversity and often high toxicity, used for a wide range of purposes.

The main threats to groundwater are posed by:

- (a) Point contamination sources: waste water treatment sites discharging to streams and groundwater, farmyard wastes (silage effluent, soiled water), effluent from on-site systems (septic tanks), leakages, spillages, non-agricultural pesticides, landfill leachate, contaminated sinking streams;
- (b) Diffuse sources – spreading of organic wastes, 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 groundwater 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 Preventing Groundwater Pollution

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 are currently available: **Groundwater Protection Responses for On-Site Systems for Single Houses ('septic tanks')**, **Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses for Landspreading of Organic Wastes**. Similar 'responses' publications will be prepared in the future for other potentially polluting activities, such as underground storage tanks and farmyards.

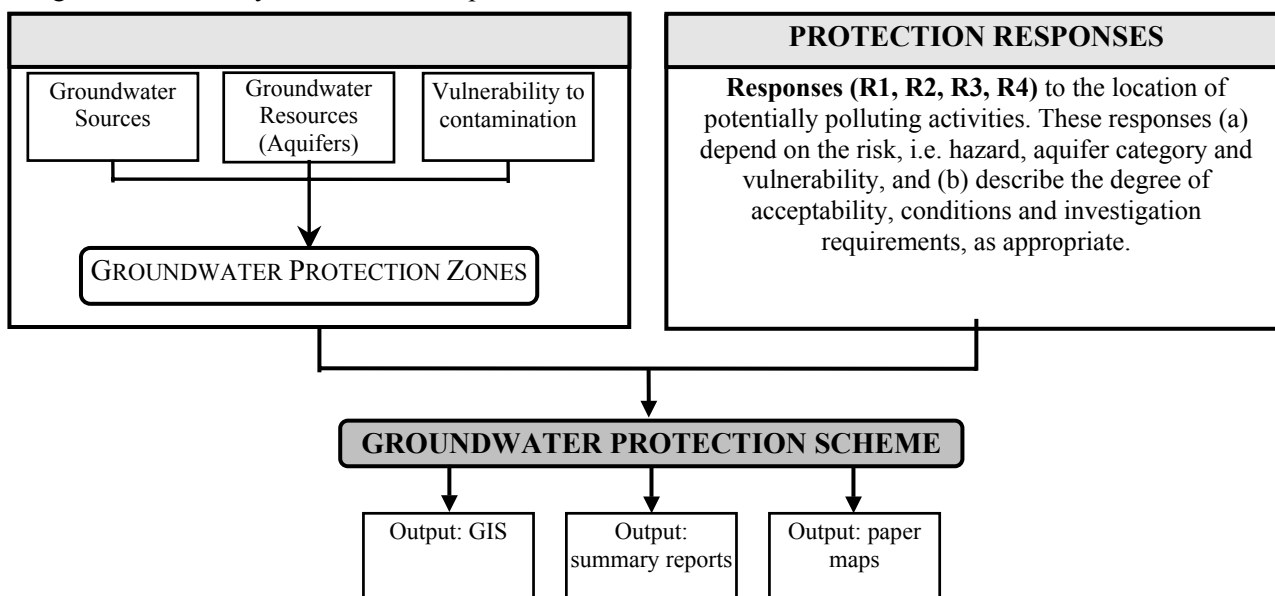
There are two main components of a Groundwater Protection Scheme shown schematically in Figure 1.1:

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

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

Figure 1.1 Summary of the main components of a Groundwater Protection Scheme



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 inter-linked in a protection scheme.

Two of the main sections 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 County Kildare Groundwater Protection Scheme

The overall aim of the Groundwater Protection Scheme is to preserve the quality of groundwater in County Kildare for drinking purposes and other beneficial uses, 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, but to 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 should be qualified by site-specific considerations.

1.6 Scope of County Kildare Groundwater Protection Scheme

The Groundwater Protection Scheme is the result of co-operation between Kildare County Council and the Geological Survey of Ireland.

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

- (i) delineation of aquifers
- (ii) assessment of the groundwater vulnerability to contamination
- (iii) delineation of protection areas around seven public supply wells and springs, identified by Kildare County Council (Lipstown/Narraghmore; Kilteel; Kilkea; Castlemitchell; Curragh Camp Wells; Athy; Usk/Gormanstown)
- (iv) production of a Groundwater Protection Scheme which relates the data to possible land uses in the county and to groundwater protection responses for potentially polluting developments.

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

This study compiles, for the first time, all readily available geological and groundwater data for the county and sets in place 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 accompany the report. These are as follows:

- (i) Primary Data or Basic Maps
 - Bedrock geology map: Map 1
 - Subsoils (Quaternary) geology map: Map 2
 - Outcrop and depth to bedrock map: Map 3
 - Hydrogeological data map: Map 4
- (ii) Derived or Interpretative Maps
 - Aquifer map: Map 5
 - Groundwater vulnerability map: Map 6
 - Source protection areas: Map 8
- (iii) Land-use Planning Map
 - Groundwater Protection Scheme maps: Map 7 (resource protection zones) and Map 8 (source protection zones).

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

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

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

1.7 Kildare County Development Plan

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

1.8 Structure of Report

The structure of this report is based on the information and mapping requirements for land surface zoning. The Groundwater Protection Zone Map (Map 7) is obtained by combining the Aquifer (Map 5) and Groundwater Vulnerability maps (Map 6). The Aquifer Map, in turn, is based on the Bedrock Map (Map 1) boundaries and the aquifer categories as derived from an assessment of the available hydrogeological data (Map 4). The Groundwater Vulnerability Map is based on the Subsoils Map (Map 2), the Depth To Bedrock Map (Map 3), and an assessment of specifically relevant permeability and karstification information. This is illustrated in Fig. 1.2.

Similarly, the Source Protection Zone Map (Map 8) results from combining vulnerability (Map 6) and source protection areas (Map 8). The source protection areas are based largely on assessments of hydrogeological data. This is illustrated in Fig. 1.3.

The Kildare Groundwater Protection Scheme has been divided into two volumes, with Sections 1 to 6 in Volume I, and Sections 7 to 16 in Volume II.

Volume I: Sections 2 and 3 provide brief summaries of the bedrock and subsoils geology, respectively. Section 4 summarises and assesses the hydrogeological data for the different rock units, explains the basis for each of the aquifer categories, and describes the potential for future groundwater development. Section 5 describes the subsoil permeability distribution and the derivation of the groundwater vulnerability categories. Section 6 draws the report together and summarises the final groundwater protection zones delineated for Co. Kildare.

Volume II: Section 7 outlines the available information on regional-scale groundwater quality patterns in the county. Sections 8 to 14 provide an assessment of seven of the larger public groundwater supply sources currently in use in the county. Section 15 discusses source protection issues in relation to the domestic, group scheme and industrial supplies in Kildare.

1.9 Acknowledgements

The preparation of this Groundwater Protection Scheme involved contributions and assistance from many people:

- Kildare County Council staff, particularly John Lahart, David Reel, Earnán McGee and many others.
- Eileen Loughman, South Western Area Health Board, for additional groundwater sampling and for the provision of the results of laboratory sampling and analyses.
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- GSI Quaternary Section: Clare Glanville mapped the Quaternary deposits for the southern half of the county and produced the subsoils map.
- GSI Cartography Section: Preparation of specialist diagrams and maps.
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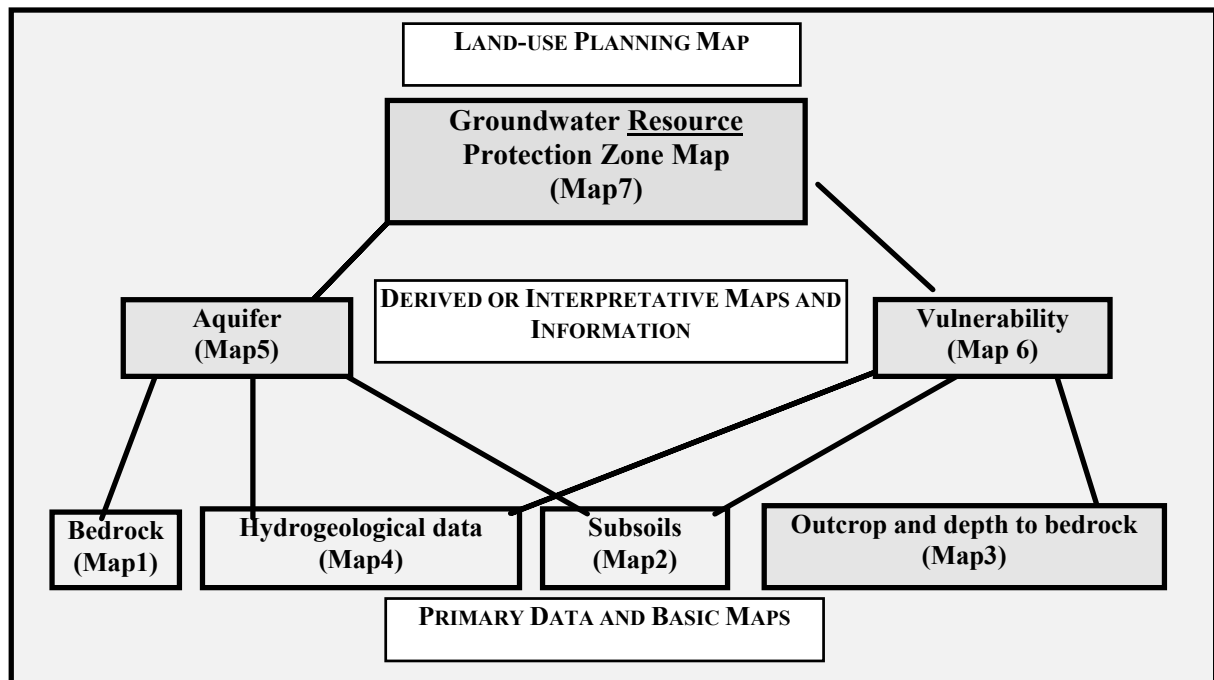


Figure 1.2 Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

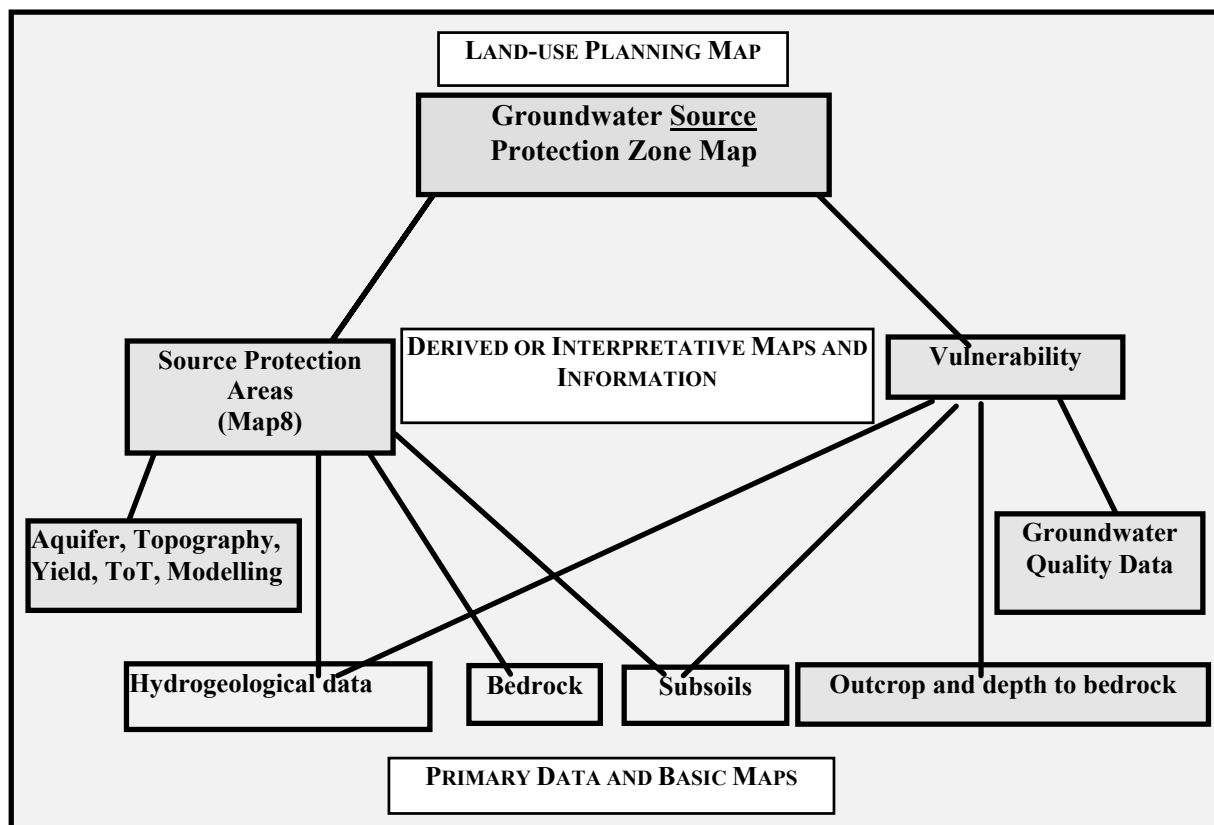


Figure 1.3 Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

2 Bedrock Geology

2.1 Introduction

This Section presents a brief description of the elements of the bedrock geology of Co. Kildare that are relevant to the hydrogeology, namely the rock composition (lithology) and the rock deformation that occurred during the long geological history of the county. A brief outline of the geological succession is presented in Table 2.1. The distribution of the bedrock geology is given in Map 1. The rocks range in age from the Lower Palaeozoic (c. 510 million years old) to the Carboniferous (c. 300 million years old) and are mainly sedimentary in origin, consisting of limestones, sandstones and shales. Geological information was taken from a desk-based survey of available data, which comprised the following:

- Bedrock Geology 1:100,000 Map Series, Sheet 16, Kildare-Wicklow. Geological Survey of Ireland. (Mc Connell *et al.*, 1994).
- Information from geological mapping in the nineteenth century (on record at the GSI).

The landscape of Co. Kildare reflects its varied underlying geology. The flattish-undulating low-lying region of the county occupying the middle and western parts of the county are underlain by the easily eroded and dissolved Carboniferous Limestones. The eastern hillier region is underlain by the more resistant and older Ordovician and Silurian rocks; as is the Chair of Kildare (hence its protrusion through the plains of Kildare). Occupying the most southern tip of the county there is a portion of the Leinster Granite, intruded into the sedimentary sequence about 405 million years ago.

Each of the main rock types are described in Sections 2.2 to 2.5 in the context of composition, distribution and structures.

2.2 Lower Palaeozoic Rocks

These are the oldest rocks in Kildare, exposed as the Chair of Kildare (“Kildare Inlier”)¹ and in the foothills of the Wicklow mountains. They comprise Ordovician and Silurian aged rocks. The specific formations with their descriptions are given in Table 2.1.

Rocks of the “Kilcullen Group” comprise most of the Lower Palaeozoics in the foothills of the Wicklow mountains occupies. The Group mostly comprises greywackes² and shales. The group is subdivided on the basis of structure. The Athgarret Fault is a north trending fault structure with the Tipperkevin and Carrighill Formations are exposed to the west of the fault and the Pollaphuca, Slate Quarries and Glen Ding Formations are exposed to the east of the fault. Large major folds are seen parallel to the fault on the western side of the fault but to the east these folds are not seen.

2.3 The Leinster Granite

The Leinster Granite is an large intrusion, exposed in Dublin, Wicklow, Carlow, Kildare, Kilkenny and Wexford occupying an area of over 1500 km² (Mc Connell *et al.*, 1994). The portion that is found in Kildare is referred to as the Tullow pluton³. It intruded into the sedimentary succession around 405 Ma (Mc Connell *et al.*, 1994) and the composition is described in Table 2.1.

¹ Inlier is a geological term for a group of older rocks surrounded by younger rocks

² Greywackes are sandstones or siltstones that are cemented by a high proportion of mud deposited from currents loaded with sediment on subaqueous slopes.

³ A pluton is an igneous intrusion formed at depth, often dome-like and is usually coarse grained.

Table 2.1: Outline of The Geological Succession in Co. Kildare (youngest on top)

STRATIGRAPHIC DIVISIONS		SUCCESSION		DESCRIPTION	
Upper Carboniferous (325 Ma)	Namurian		Undifferentiated Namurian	Black pyritic, phosphatic shales interbedded with calcareous grits and siliceous limestones.	
Lower Carboniferous (342 Ma)	Visean Limestones	Carboniferous Volcanics	Ballyadams Formation	Pale grey thick bedded limestones	
			Milford Formation	Variable dark grey limestones	
			Rickardstown Formation	Dark grey limestones, commonly cherty, partly dolomitised	
			Edenderry Oolite ⁴ Member	Oolitic Limestone	
			Allenwood Formation	Pale grey, clean limestone, commonly dolomitised	
			Calp Limestones	Dark grey to black limestones and shales	
			Tober Colleen Formation	Calcareous shale and limestone conglomerate.*	
			Waulsortian Limestones	Pale grey often massive limestone, commonly dolomitised	
	Courceyan Limestones		Boston Hill Formation	Muddy limestone with subordinate shale, commonly dolomitised	
			Ballysteen Formation	Medium to dark grey muddy limestone	
			Feighcullen Formation	Variable limestone	
			Cloghan Sandstone Formation	Light grey thick bedded sandstone with subordinate limestone and shale	
			Ferbane Mudstone Formation	Shale and sandstone	
			Quinagh Formation	Shale and sandstone	
			Old Red Sandstone	Conglomerate, sandstone and siltstone	
Devonian (405 Ma)	Leinster intrusion	Granite	Tullow Pluton	Fine to coarse grained granite	
Lower Palaeozoic (510 Ma)	Kilcullen Group		Carrihill Formation	Calcareous greywacke** and shale	
			Tipperkevin Formation	Medium to fine grained greywacke sandstones and shales	
			Glen Ding Formation	Dark green-grey greywacke sandstone and shale	
			Slate Quarries Formation	Dark grey slates	
			Pollaphuca Formation	Coarse grey greywacke sandstones and shales	
	Kildare Inlier		Dunmurry Formation	Green grey greywacke sandstone and shale	
			Rahilla Formation	Mudstones	
			Guidenstown Formation	Black shales	
			Kildare Limestone Formation	Fossiliferous limestone and mudstones	
			Grange Hill Formation	Fossiliferous siltstone and shale	
			Allen Andesite Formation	Basaltic and andesites	
			Grange Cottage Formation	Fossiliferous sandstones and siltstones	
			Conlanstown Formation	Dark green grey shales and siltstones	
Silurian					
Ordovician					

*Conglomerate is a sedimentary rock comprising large rounded fragments (pebbles, cobbles, boulders) in a finer matrix

** Greywackes are sandstones or siltstones that are cemented by a high proportion of mud deposited from currents loaded with sediment on subaqueous slopes

⁴ Spherical sand sized grains composed of carbonate with a concentric structure.

2.4 The Carboniferous Succession

The Carboniferous succession comprises fifteen identified and mapped individual formations with additional volcanic rocks that occur during Carboniferous period. Limestones dominate the succession and essentially comprise "shelf" (generally shallow water limestones) and "basinal" (generally deep water limestones) type limestone rocks. Shelf limestones tend to be "cleaner", lighter coloured limestones than basinal limestones because of the smaller proportions of clay in shallow water environments. This has implications for karst and aquifer potential (refer to Section 1). The Kildare Inlier and the Leinster Massif (Lower Palaeozoic and Leinster Granite) form important controls on the formation of the different types of limestones. Shelf limestones tend to be found close to the structural highs such as the Kildare Inlier and the Wicklow Mountains, both of which would also have represented high ground at the time the limestones were deposited. Basinal limestones tend to be found further away from these structural highs (e.g. near Dublin and Portarlington). The composition of rocks in the succession is provided in Sections 2.4.1 to 2.4.13 and in Table 2.1.

2.4.1 Old Red Sandstone

This unit consists of reddish conglomerates, sandstones, siltstones and mudstones, with minor greenish equivalents (Mc Connell *et al*, 1994). It occupies poorly exposed areas of the Kildare Inlier and small slivers around Kill and Ballitore (refer to Map 1). A thickness of 100 m has been inferred for the unit.

2.4.2 Quinagh, Ferbane and Cloghan Formations

These units are considered together and are often referred to as the "Lower Limestone Shales". They consist of interlaminated siltstones, sandstones, mudstones and shales. They are generally well bedded, with thicker beds toward the top of the succession in the Cloghan Sandstone Formation. They occupy areas of the Kildare Inlier and the Quinagh Formation also occupies a narrow band separating the Kilcullen Group from the Carboniferous succession.

2.4.3 Feighcullen Limestone Formation

The occurrence of the Feighcullen Formation is similar to that of the Quinagh Formation: occupying parts of the Kildare Inlier and a narrow band along the edge of the Leinster massif. It is a highly variable limestone, essentially consisting four distinct members, comprising oolites⁵, micrites⁶, shales and sandstones. It is inferred to have a maximum thickness of about 130 m. It is poorly exposed along the Leinster massif where it is regarded as being more shaley than where it is exposed in the Kildare Inlier.

2.4.4 Ballysteen Limestone Formation

This formation is one of the more widespread rock types in Kildare, occupying a large swathe of the county; from about 5 km south of Celbridge right past Athy and into County Carlow. It is variable but essentially comprises a lower unit of well bedded relatively clean limestone which passes up into a finer grained more shaley unit.

2.4.5 Boston Hill Formation

This rock unit comprises argillaceous fossiliferous limestones and subordinate shales. The formation occupies large areas of either side of the Kildare Inlier. It is a thick formation - estimated to be over 600 m in some areas (Mc Connell *et al*, 1994). It is heavily faulted around the Wheatfield area (refer to Map 1).

2.4.6 Waulsortian Limestone Formation

This unit comprises pale grey massive limestones. The formations tend to be quite thick although this can change over very short distances. A maximum thickness of 400 m is recorded (Mc Connell *et al*, 1994). Waulsortian limestone occupies areas east, west and north east of the Kildare Inlier.

⁵ Oolite: A limestone containing sand-sized carbonate grains.

⁶ Micrite: fine grained limestone.

2.4.7 Calp Limestones

The Calp limestones generally consists of muddy dark grey to black limestones and shales. It occupies large areas of North Kildare and is exposed along sections of the M50 and N4. It comprises several units but only the Tober Colleen Formation is distinguished in Kildare.

2.4.8 Allenwood Formation & Edenderry Oolite Member

This unit consists of pale grey massive shelf limestones. It occupies areas around Monasterevin, Rathangan and Allenwood. It is estimated to be over 400 m thick in places. It is often difficult to distinguish the Allenwood Formation from the Waulsortian Formation, and cores show that the two rock types are occasionally interwoven where they are in contact.

The Edenderry Oolite is a member of the Allenwood Formation and occupies large areas of eastern County Offaly. In Kildare it occupies a small area just north of Edenderry.

2.4.9 Rickardstown Formation

Variable cherty limestones make up the lower part of this formation and the upper part generally consists of dark grey fine grained dolomite with abundant chert. It occupies an area around Rickardstown and its distribution outside this area is uncertain.

2.4.10 Milford Formation

This unit occupies a large area between Kildare town and Athy and extends beyond Athy right down into Carlow. It comprises generally cleaner limestones and dolomites⁷.

2.4.11 Ballyadams Formation

This rock type comprises pale grey shelf limestones and occupies areas of south west Kildare. The thickness of the unit is in the order of 400-700 m. It is variable, but generally comprises clean, coarser grained limestones.

2.4.12 Namurian Rocks

A small area in north Kildare between Enfield and Kilcock is underlain by Namurian rocks which are not distinguished into individual members that are known to comprise the Namurian in other parts of the country. This area of Namurian rocks comprises black shales interbedded with grits and thin limestones.

2.4.13 Volcanic rocks in the Carboniferous

In north west Kildare, just east of Edenderry there are two very small areas of volcanic rocks which consist of fine to coarse grained volcanic ash and are thought to represent small individual volcanoes (Mc Connell *et al*, 1994).

2.5 Structure and Geological History

The regional structure of the area is influenced by at least one major structural event known as the Caledonian Orogeny (mountain building event). The Caledonian Orogeny marked the collision of two continents and the boundary between the continents is a suture line running from the Shannon Estuary to Silvermines, Navan and Clogher Head. The collision affected the older Ordovician and Silurian rocks, causing them to become metamorphosed and faulted. It also caused the intrusion of the Leinster granites. The Caledonian orogeny is the main influence on the structural features that are mapped across Kildare. Subsequent, structural events have tended to follow the orientation of the Caledonian structures. The main structural trend across the area is north easterly and this can be observed in the spatial distribution of the formations, i.e., the contacts of each formation trend north east. The axis of the Kildare Inlier is also north east trending. Several of the main faults and fold axes are also north

⁷ Dolomite: this rock is described in Section 4.4

east trending. A number of large cross-cutting faults with an opposite sense of trend (south east) are mapped but these are regarded as being tentative and uncertain (Mc Connell, *et al*, 1994).

3 Subsoil (Quaternary) Geology

3.1 Introduction

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

During the 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 bedrock and was subjected to different processes within, beneath and around the ice. Some were deposited randomly and so are unsorted and have varying grain sizes, while others were deposited by water in and around the ice sheets and are relatively well sorted and coarse grained. Mapping of subsoils and compilation of subsoil information in Kildare was undertaken by the Quaternary Section of the GSI. This mapping formed the foundation of subsequent subsoil permeability assessments (described in Section 5). Subsoil distribution is presented in Maps 2N and 2S, and discussed briefly in Section 3.2.

3.2 Subsoil Types

There are five subsoil types identified in Co. Kildare and shown on Maps 2N and 2S:

- ◆ till
- ◆ sands and gravels
- ◆ till with gravel
- ◆ alluvium
- ◆ peat

Areas where bedrock comes close to the ground surface are shown on the maps as "rock close".

3.2.1 Till

Till (often referred to as boulder clay, drift or overburden) is the most widespread subsoil in Kildare as can be seen on Maps 2N and 2S. It is a diverse material which is deposited sub-glacially and it has a wide range of characteristics due to the variety of parent materials and different processes of deposition.

3.2.2 Sands and gravels

Deposition of sands and gravels takes place mainly when the glaciers are melting. This gives rise to large volumes of meltwaters with great erosive and transporting power. The subsoils deposited in this environment are primarily well rounded 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.

Kildare has some extensive developments of sand and gravel, the largest of which is associated with the Curragh. These deposits are widely quarried throughout the county. The presence of sand and gravel is often reflected in the topography as ridges (eskers), hummocks and hollows (kames and kettle holes) or in large fan shaped deposits (outwash deltas). There are numerous small eskers in Kildare.

3.2.3 'Till with gravel'

This term encompasses those areas where till and gravel are intimately mixed, either vertically or horizontally, or both, so that individual areas of one sediment or the other cannot be delineated. One area of this type is mapped immediately north of Newbridge.

3.2.4 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 they may also contain organic detritus. Alluvial deposits in Kildare are mostly associated with the main rivers in Kildare such as the Liffey, Barrow, Greese and Boyne.

3.2.5 Peat

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and un-decomposed plant matter which has accumulated in a waterlogged environment. Peat has an extremely high water content averaging over 90% by volume. Two main types of peat bog are distinguished in Ireland: blanket bog, which is characteristic of upland areas with excessive rainfall, and raised bog, which is characteristic of lowland areas with impeded drainage. The main peat type associated with Kildare is the raised bogs of the central midlands, namely Allen, Boora and Clonast Raised Bogs. There are also large tracts of reclaimed peat areas. Peat is also found in Pollardstown Fen, which is located about 4.5 km north of the Curragh Camp.

3.3 Depth to Bedrock

The depth-to-bedrock (i.e. subsoil thickness) is a critical factor in determining groundwater vulnerability. Subsoil thicknesses vary considerably over the county, from very thin (rock at surface) to depths of more than 20 metres. The direction of ice movement has spatially influenced the subsoil thicknesses.

Broad, regional-scale variations in depth to bedrock have been interpreted across the county by the Groundwater Section of the GSI, using information from the GSI databases, from field mapping and air photo interpretation. Depth-to-rock data maps (Maps 3N and 3S) show areas where rock crops out at surface and depth-to-rock data from borehole records.

Kildare can be described in two distinct regions: a generally low-lying region occupying the western and mid part of the counties which is part of the Central Plains of Ireland and a generally hillier region occupying the eastern part of the county which are the lower slopes of the Dublin-Wicklow mountains. The depth to bedrock is strongly influenced by these two regions. Generally the depth to bedrock tends to be quite thick over the low-lying region. Depth to rock in this region is typically in excess of 5m, often in excess of 10m and occasionally in excess of 50m. Depth to rock is much reduced over the hillier regions to the east (typically less than 3m). Thus the depth to bedrock can be generally expected to increase from east to west. Note that the Chair of Kildare, where there are several hills that protrude out above the low-lying central plains of Kildare, provides one exception to this pattern.

4 Hydrogeology and Aquifer Classification

4.1 Introduction

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

4.2 Data Availability

All available drilling, abstraction and pump testing data from Geological Survey, Kildare County Council, and consultants' files (306 wells and springs in total) were compiled and entered into a computer database at the Geological Survey.

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

- Groundwater abstraction rates for local authority sources, group scheme sources, and for a limited number of other high yielding private wells and springs.
- Specific capacity and discharge data for approximately 300 wells in Kildare and surrounding counties.⁸
- Information on large springs.
- Reports by engineering and hydrogeological consultants
- General hydrogeological experience of the GSI, including work carried out in adjacent counties, particularly counties, Laois, Offaly and Wicklow.

4.3 Rainfall, Evapotranspiration and Recharge

According to Met Éireann information, mean annual rainfall in Kildare for 1961–1990 varied from 750 mm in the lowlands to 1000 mm over the eastern uplands (Fitzgerald and Forrestal, 1996). Potential recharge has been estimated for more localised areas around public supply sources using Met Éireann rainfall and potential evapotranspiration data.

The actual annual recharge (i.e. potential recharge less surface water runoff) depends on the relative rates of infiltration and surface runoff, which is, in turn, influenced by subsoil permeability and saturation. In low permeability or waterlogged areas, actual recharge may be less than 5% of the potential recharge.

4.4 Background to Aquifer Classification

4.4.1 Introduction

The factors used in aquifer classification are outlined in Section 4.4.4 The classifications of each rock unit in Kildare and of the sand and gravel bodies which have aquifer potential are provided in Sections 4.5 to 4.17. 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**)

⁸ Specific capacity is the rate of abstraction per unit drawdown: units are $\text{m}^3 \text{d}^{-1} \text{m}^{-1}$

(iii) Bedrock which is Moderately Productive only in Local Zones (**LI**)

Poor (**P**) Aquifers

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

4.4.2 Bedrock Aquifers

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

- the overall potential for groundwater development in each rock unit;
- the localised nature of higher permeability zones (e.g. fractures) in many of the bedrock units;
- the highly karstic nature of some of the limestones;
- all bedrock types will generally give enough water for domestic supplies and therefore all are called ‘aquifers’.

Karstification and dolomitisation are two processes which strongly influence the development of secondary permeability and aquifer potential in Irish bedrock units. Each are explained briefly below. The terms will occur in several of the classifications provided in Sections 4.5 to 4.17.

Karstification

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

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

- **Rk^c** are those aquifers in which the degree of karstification limits the potential to develop groundwater. They have a high ‘flashy’ groundwater throughput, a large proportion of flow is concentrated in conduits, numerical modelling using conventional programs is not usually applicable, well yields are variable with a high proportion having low or minimal yields, large springs are present, storage is low, locating areas of high permeability is difficult and therefore groundwater development using bored wells can be problematical.
- **Rk^d** aquifers are those in which flow is more diffuse, storage is higher, there are many high yielding wells, and development of bored wells is less difficult. These areas also have caves and large springs, but the springs have a more regular flow. In general, these aquifers can be modelled (at an appropriate scale) using conventional programs.

Dolomitisation

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

4.4.3 Sand/Gravel Aquifers

Sand/gravel deposits have a dual role in groundwater development and supply. Firstly, in some cases they can supply significant quantities of water for supply and are therefore classed as aquifers, and secondly, they provide storage for underlying bedrock aquifers. A sand/gravel deposit is classed as an aquifer if the deposit is highly permeable, more than 10 m thick and greater than one square kilometre in aerial extent. The thickness of the deposit is often used rather than the more relevant saturated zone thickness as the information on the latter is rarely available. In many instances it may be assumed that a deposit with a thickness of 10 m will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief (for example eskers or deposits in high topographic areas) as these gravels are often dry.

Table 4.1 Sand/gravel Aquifer Classification

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

Sand/gravel aquifers are therefore classified based on the permeability, aerial extent, and the thickness of the unsaturated zone (see Table 4.1). In the absence of permeability test data, gravels with a fines content of less than approximately 8% are generally considered to have sufficient permeability for aquifer development (O'Suilleabhain, 2000).

A regionally important gravel aquifer should have an aerial extent of *at least* 10 km². This is to ensure that, assuming an average annual recharge of 400 mm, there will be enough recharge to provide a supply of one million cubic metres per year from the whole aquifer.

4.4.4 Aquifer Classification Criteria

As yield is one of the main concerns in aquifer development projects, yields from existing wells are conceptually linked with the main aquifer categories outlined in Section 4.4.1:

- Regionally important (**R**) aquifers should have (or be capable of having) a large number of 'excellent' yields: in excess of approximately 400 m³/d (4000 gph).
- Locally important (**L**) aquifers are capable of 'good' well yields 100-400 m³/d (1000-4000 gph).
- Poor (**P**) aquifers would generally have 'moderate' or 'low' well yields - less than 100 m³/d.

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

- Permeability and transmissivity⁹ data from formal pumping tests, where discharge and water levels readings have been taken over a period of many hours or days.
- Productivity data from wells where either formal pumping tests have been undertaken or where at least one combined reading of discharge and drawdown data are available. The GSI has developed the concept of 'productivity' as a semi-quantitative method of utilising limited

⁹ Transmissivity is the product of permeability and the effective saturated thickness of the aquifer

well test data (Wright, 2000). A 'productivity index' is assigned to a well from one of five classes: I (highest), II, III, IV, and V, using a graphical comparison of well discharge with specific capacity.

- Occurrence of springs with 'high' flows (greater than 2160 m³/day total flow).
- Occurrence of wells with 'excellent' yields (greater than 400 m³/day discharge).
- Hydrological information such as drainage density where overlying strata are thin, and baseflows or flows in rivers (better aquifers will support higher baseflows and summer flows).
- Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water. Clean washed and sorted sands and gravels for example, are more permeable than poorly sorted glacial tills. Clean limestones are also more permeable than muddy limestones. Areas where folding and faulting has produced extensive joint systems tend to have higher permeabilities than areas where this has not occurred.
- Aquifer assessments from Groundwater Protection Schemes in neighbouring counties and from existing reports.

All seven factors are considered together; productivity and permeability data are only given 'precedence' over lithological and structural inferences where sufficient data are available. Data from neighbouring counties in similar geological environments are included.

The classification of all rock units and of sand and gravel aquifers in Kildare is presented in Sections 4.5 to 4.17. A summary can be found in , and on Map 5.

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

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

Table 4.2 Summary of Aquifer Classification in County Kildare

Aquifer Grouping	Geological Units	Occurrence in Kildare	Aquifer Class*	Main basis for Classification	Section #
Sand and Gravel	Mid Kildare (Curragh) Gravel		Rg	Dimensions & well data & river recharge	4.17.2
	Blessington/Ballymore Eustace Gravels		Lg	Dimensions & well data	4.17.3
	River Greese Gravels		Lg	Dimensions & yields & river recharge	4.17.4
	Baltinglass Gravels		Lg	Dimensions & well data	4.17.5
	Barrow - Athy Gravels		Rg	Dimensions & well data	4.17.6
	North Kildare: Sallins, Kill, Boyne, Rathangan, Clonagh/Johnstown.		Lg	Dimensions & well data	4.17.7 to 4.17.10
	North Kildare: Robertstown		Lg	Productivity data	4.17.12
Volcanics		North west Kildare	Lm	Lithology	4.16
Namurian sandstones and shales		Central North Kildare	PI	Lithology	4.15
Calp Limestones		Northern Lowlands	LI	Lithology, productivity	4.14
Ballyadams Limestones		South west Kildare	Rk^d	Lithology, karst data, productivity	4.13
Edenderry Limestones		North western tip	Lm	Lithology, productivity.	4.12
Allenwood, Milford, Rickardstown Limestones		Central Plains	Rk	Productivity data	4.11
Waulsortian Limestones		East, north, west of Kildare Inlier	LI	Productivity data	4.10
Ballysteen Dolomite	Ballysteen (do)	Southern tip of county	Rf	Lithological inferences	4.9
Ballysteen Limestones	Ballysteen, Boston Hill, Feighcullen	Margins of Kildare Inlier and Leinster Massif	LI	Productivity data	4.9
Lower Limestone Shale	Ferbane Mudstone, Quinagh, Cloghan	Kildare Inlier, Leinster Massif	PI	Lithological inferences	4.8
Old Red Sandstone		Kildare Inlier, western margin of Leinster Massif	LI	Productivity data and lithological inferences	4.7
Leinster Granite		Southern tip of county	PI	Productivity data	4.6
Lower Palaeozoic Sandstones and Shales	Conlanstown, Grange Cottage, Allen Andesite, Grange Hill, Kildare Limestone, Guidenstown, Rahilla, Dunmurry Carrighill, Slate Quarries	Kildare Inlier	Pu	Productivity data and lithological inferences.	4.5
	Glen Ding, Tipperkevin, Pollaphuca	Kildare Inlier	PI	Productivity and well yield data and lithological inferences.	4.5

**Rk: Regionally important karstic. Rf: Regionally important fractured. Lm: Locally important moderately productive. LI: Locally important only in local zones. PI: Poor generally unproductive except for local zones. Pu: Poor Aquifers which are generally unproductive*

Table 4.3 Groundwater Supplies from the Aquifers of Kildare

Aquifer Grouping	Aquifer Classification*	Known Public or Group Scheme Groundwater Supplies in each Aquifer	Total Population Served in 2002 by the Known Public or Group Scheme Groundwater Supplies
Gravel	Rg and Lg	Hare Park (Curragh), McDonagh (Curragh), Lughill (Monasterevin), Gormanstown, Narraghmore, Gallery (Athy).	3900
Calp Limestone	Ll	Clonuff, Clogherinkoe, Newtown.	290
Ballyadams Limestone	Rk	Churchtown (Castlemitchell) and Housing (Castlemitchell)	>400
Edenderry Limestones	Lm	Ballindoolin	
Allenwood, Milford, Rickardstown Limestones	Rk	Ballykelly Bore (Monasterevin), Ballykelly Spring (Monasterevin), Quarry (Castlemitchell), Woodstock (Athy), Ballylane (Athy)	> 8250
Ballysteen Limestones	Ll and Rf	Kilkea	200
Lower Palaeozoic sandstones and shales	Pl and Pu	Wolfstown, Killeel, Redbog, Bullock Park.	~200

**Rk: Regionally important karstic. Rf: Regionally important fractured. Lm: Locally important moderately productive. Ll: Locally important only in local zones. Pl: Poor generally unproductive except for local zones. Pu: Poor Aquifers which are generally unproductive*

4.5 Classification of the Lower Palaeozoic Aquifers

The Lower Palaeozoic rocks in Kildare generally comprise sandstones and shales, and are divided into the Kildare Inlier (known as the Chair of Kildare) and the Kilcullen Group. The distribution of the rock types is presented in Map 1, while the aquifers are depicted in Map 5.

4.5.1 Kildare Inlier

The *Kildare Inlier* comprises the Conlanstown, Grange Cottage, Allen Andesite, Grange Hill, Kildare Limestone, Guidenstown, Rahilla and the Dunmurry Formations. These formations are considered together because they occur in one geographic unit and because they consist largely of rocks which are not normally associated with major groundwater development projects in Ireland. The exception is the Kildare Limestone, comprising limestones and mudstones. It is included with the other units for aquifer classification as it is extremely small in aerial extent (much less than 1 km²). Productivity data is limited to one "Poor" (Class V) well located in the Conlanstown Formation. None of the wells on record in this formation have 'good' or 'excellent' yields.

On the basis of a comparison with rocks of similar structural and material characteristics in County Wicklow (Woods and Wright, 2001), the rocks of the Kildare Inlier are classed as **Poor Aquifers which are generally unproductive (Pu)**.

4.5.2 Kilcullen Group

The *Kilcullen Group* comprises the Pollaphuca, Slate Quarries, Glen Ding, Tipperkevin and the Carrighill Formations. The rocks consist of greywackes, sandstones and shales. The coarser, thicker sandstone units are likely to have a greater degree of 'cleaner' fracturing than the shales. Woods and Wright (2001) suggest that the water levels are variable but are usually less than 10 m below ground surface and the aquifers are generally unconfined. Water level data collected over a ten year period for a 26 m deep well located in the Carrighill Formation at Eadestown is shown in Figure 4.1, and as can be seen the water levels fluctuate by up to 8m annually. The large annual fluctuation in the hydrograph, indicates the low storage potential and/or bulk permeability for these rock units.

Figure 4.1 Well hydrograph in the Carrighill Formation [grid reference: N 29320 21700]

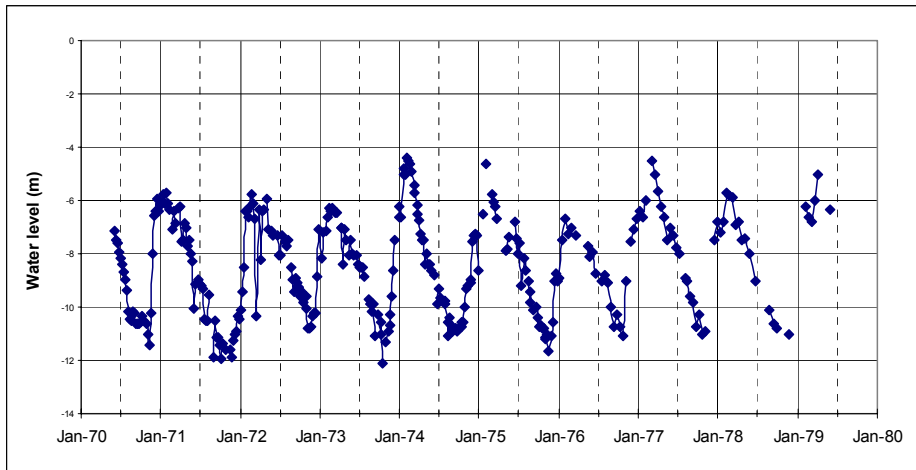


Figure 4.2 demonstrates the contrast between a section of the hydrograph from the Carrighill Formation with a section from a sand & gravel aquifer body which has high storage capabilities.

Figure 4.2 Comparison of two well hydrographs; one from the Carrighill Formation and the other from a sand & gravel aquifer

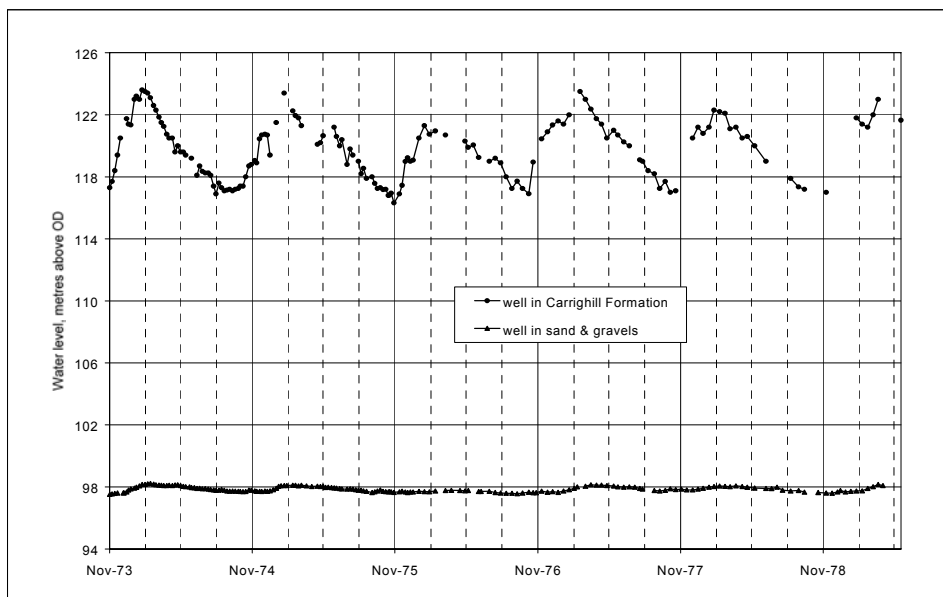


Figure 4.3 shows productivity data for the Tipperkevin and Pollaphuca units and Figure 4.4 shows productivity data for the Carrighill, Slate Quarries and Glen Ding Formations. The Tipperkevin and the Pollaphuca units are apparently more productive than the others in the group and two "good" yields are also recorded in these units. No 'good' yields are on GSI records for the Carrighill, Slate Quarries and Glen Ding Formations. No 'high' yielding springs are on record for any of the Lower Palaeozoic aquifers. The productivity data suggest that the Tipperkevin and Pollaphuca units are more productive than the Carrighill, Slate Quarries and Glen Ding Formations. There are two small public and group scheme groundwater supplies in the Glen Ding Formation (one of which is a spring), one small public supply in the Pollaphuca Formation, and one small supply in the Carrighill Formation.

These sources are thought to supply no more than 200 people in total (refer to Table 4.3). There are no yield or productivity data for these sources, but abstraction rates for the borehole sources are low. Further, discharge at the spring source at Kilteel is thought to be supported by the presence of a small gravel pocket (refer to Volume II). Consequently, these public and group scheme supplies have not been used to influence the aquifer categorisation of the formations.

Figure 4.3 Well Data from the Tipperkevin and Pollaphuca Formations in Kildare and Wicklow

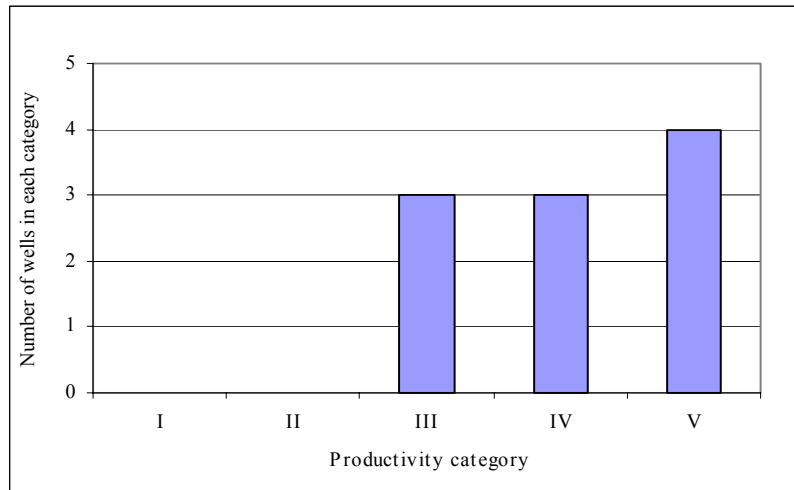
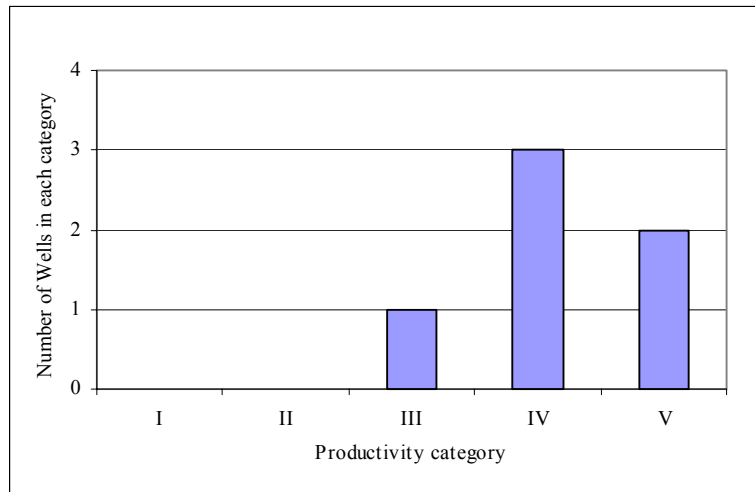


Figure 4.4 Well Data from the Carrighill, Slate Quarries and Glen Ding Formations in Kildare and Wicklow



On the basis of lithology, productivity data and classifications in County Wicklow (Woods and Wright, 2001), the Carrighill, Glen Ding and Slate Quarries, are classed as **Poor Aquifers which are generally unproductive (Pu)**.

On the basis of slightly higher reported well yields and classifications in County Wicklow, the Tipperkevin and Pollaphuca Formations are classed as **Poor Aquifers which are generally unproductive except for local zones (Pl)**.

4.6 Classification of the Granite Aquifer

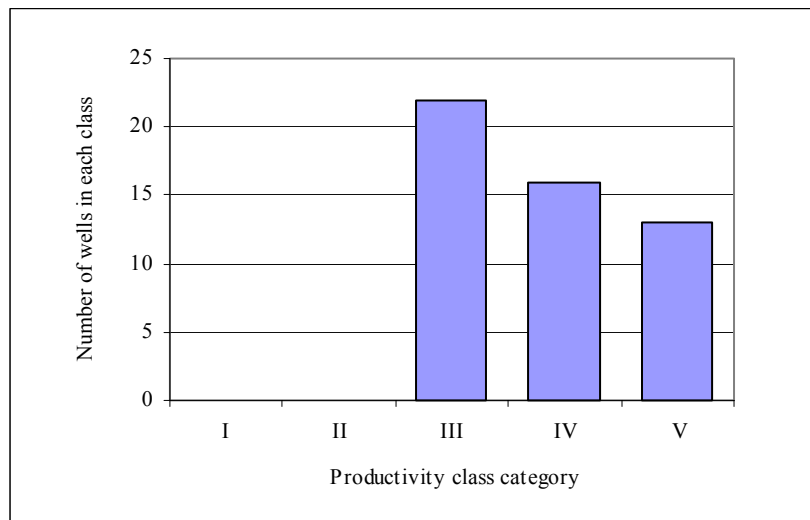
The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. In general, Irish granites do not provide large groundwater supplies but can generally provide reliable water supplies for domestic and farm supplies. In Kildare, the hydrogeological data is sparse: only 6 wells recorded in the aquifer. Thus data from Wicklow, Kilkenny and Carlow is included in the analysis. Fifty productivity records were examined, most of these from Wicklow. The data breaks down as follows: 22 Class III, 16 Class IV and 13 Class V and is presented in Figure 4.5. There are only two wells with "good" yields (both are county council supplies in Wicklow). A comparison between the full data set and the data only from Kildare is provided below. As can be seen the results are very similar, justifying the use of the data from neighbouring counties.

<i>Data</i>	<i>Median Yield ($m^3 d^{-1}$)</i>	<i>Median Specific Capacity ($m^3 d^{-1} m^{-1}$)</i>
Kildare subset (6 records)	26	8
Full data set (50 records)	25	8

On the basis primarily of productivity data the Granite aquifer is classed as a **Poor Aquifer - generally unproductive except for local zones (PI)**.

Note: levels of uranium and radon may occur in the granite areas of south county Kildare.

Figure 4.5 Well data from the Granite Aquifer in Kildare, Wicklow, Kilkenny and Carlow



4.7 Classification of the Old Red Sandstone (ORS) aquifer

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The rocks are generally described as sandstones and siltstones. It has a relatively low bulk permeability in general apart from the upper few metres and in the vicinity of fault zones (Daly *et al*, 1998). Well yields are usually adequate for domestic supplies (10-30m³/d), with higher yields (up to several hundred cubic metres per day) obtainable along the fault zones (Daly *et al*, 1998). Four records are available for examination; two from Laois; one from Offaly and one from Kildare. These breakdown as follows; one Class I, two Class III and 1 Class V. The well in Kildare is located in the Lyons Estate and has a reported maximum yield of 390 m³ d⁻¹ with a specific capacity of 20 m³ d⁻¹ m⁻¹. The log of this borehole indicates that the thickness of the unit is about 70 m in this locality. This Class I well

suggests the elevated productivity of the ORS in certain localised fracture zones. Despite the extent of the ORS in Kildare and the limited data this unit is classed as a **Locally Important aquifer that is moderately productive in local zones (LI)**.

4.8 Classification of the Lower Limestone Shales

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The aquifer grouping generally comprises interbedded limestone, sandstone and shale, and includes the Ferbane Mudstone, Cloghan sandstone and the Quinagh Formations in County Kildare. The units are limited in thickness and are restricted to two narrow strips; on the eastern side of the Kildare Inlier, and the western side of the Leinster Massif. Bulk permeability is regarded to be low, particularly in the Ferbane Mudstone. Several major faults are mapped in the area where these rocks occur in Kildare. The well bedded nature of the units is likely to cause a degree of fracturing that is likely to improve the permeability. There is no productivity data for the aquifer in Kildare. There is very limited data for Laois, Offaly and Kilkenny. On the basis of lithology, data for other parts of the country and the classifications in other counties the Lower Limestone Shales are classified as a **Poor Aquifer which is locally productive (PI)**.

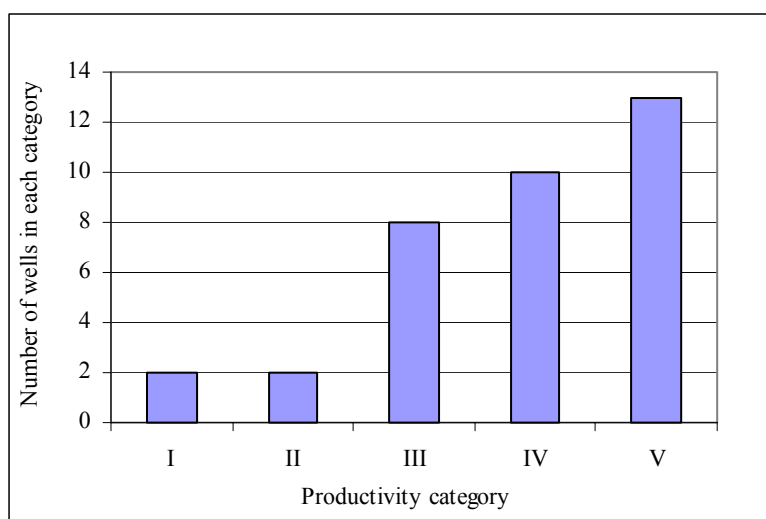
4.9 Classification of the Ballysteen-Type Limestone Aquifers

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The aquifer grouping generally comprises shaley limestones and includes the Boston Hill, Ballysteen and Feighcullen Formations in County Kildare. They are examined together as a single aquifer grouping as they are lithologically similar, in geological continuity and of similar age. They are faulted and are locally dolomitised. For example, the Ballysteen Formation is mapped as dolomitised in the southernmost tip of Kildare, while the Boston Hill Formation is noted to be dolomitised in the Wheatfield area. Dolomitisation often increases bulk permeability locally (refer to Section 4.4.2).

There are four known public and group scheme supplies in this formation, supplying over 400 people in 2002 (refer to Table 4.3).

Thirty six well records are on GSI records; from which thirty five productivity values are available. The data are scattered across all five classes but there is a concentration in classes III, IV and V as can be seen in Figure 4.6. Two excellent wells were recorded (both from the Ballysteen in Co. Laois).

Figure 4.6 Well data from the Boston Hill, Ballysteen and Feighcullen Limestone Formations in Kildare, Offaly, Laois and Kilkenny



On the basis primarily of productivity data and lithology, the Ballysteen type Limestones are classed as a **locally important aquifers** which are **moderately productive only in local zones (LI)**. This is supported by similar classifications in Laois and Kilkenny.

Note that a higher aquifer classification of **Regionally Important fissured bedrock aquifer (Rf)** has been assigned to the portion of Ballysteen in south Kildare which has been mapped as 'dolomitised'. This is on the basis of classifications for large, contiguous areas of dolomitised Ballysteen limestone in County Kilkenny (Buckley and Fitzsimons, 2002).

4.10 Classification of the Waulsortian Limestone Aquifer

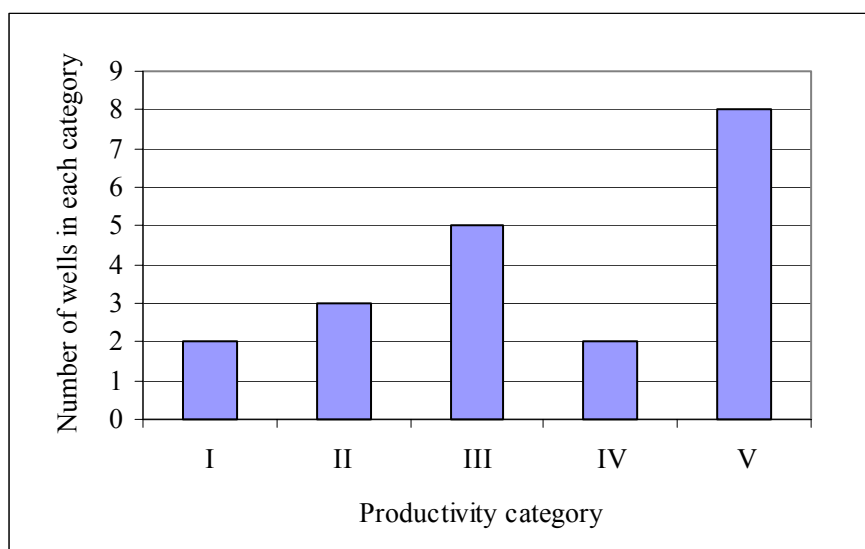
The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. Waulsortian limestone consists of massive (i.e. few bedding parting) generally clean fine-grained limestones. As the Waulsortian Limestone is relatively pure, it might have been expected to be a good aquifer. However, its massive, unbedded nature has meant that jointing and fissuring is not widely developed except in the vicinity of fault zones, at the top of the rock or perhaps along the axes of anticlines. Unless good geological and/or geophysical information is available, locating successful high yielding water supplies is difficult and unpredictable (Daly *et al*, 1998).

Twenty five well records (ten from Kildare) have been used to assess the aquifer classification of this unit. There is a spread across all classes. Ten fall into Classes I, II and III and ten fall into classes IV and V. Figure 4.7 shows how the data is spread across the productivity categories. It is known that wells regularly fail in the Waulsortian but that failed wells can occur very close to more successful wells. This indicates the unpredictability of this rock unit in terms of providing a water source.

On the basis primarily of productivity data and lithology the Waulsortian Limestone Formation is classed as a **locally important aquifer** which is **moderately productive only in local zones (LI)**.

Note that the same formation has been assigned a much higher aquifer classification in areas of Ireland to the south of Clonmel, due to the greater frequency of fracturing in these areas.

Figure 4.7 Well data from the Waulsortian Limestone Formation in Kildare and Offaly



4.11 Classification of the Allenwood, Milford and Rickardstown Limestone Aquifers

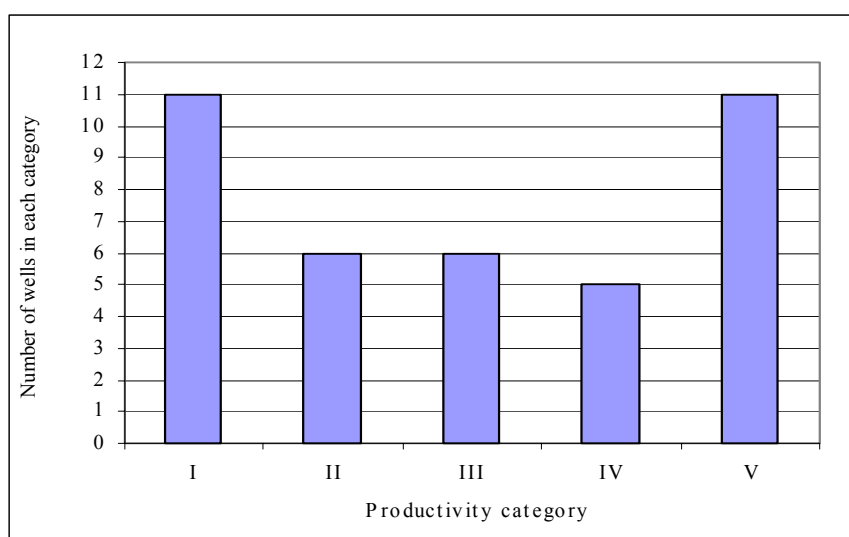
The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The aquifer grouping generally comprises clean limestones of similar age and depositional history. Local dolomitisation is common in these limestones and a more continuous dolomitised zone has been delineated in the Milford Formation at the southernmost tip of Kildare. The largely clean and partially dolomitised nature of these formations suggests that these rocks should prove to be good aquifers (refer to Section 4.4.2). There is evidence (surface karst features and cavities in borehole logs) that these rocks are karstified in Laois and Offaly. The well records that exist for the Milford Formation in the vicinity of Athy indicate cavities and dolomite in the borehole logs (Daly, E. P., 1982, 1987, 2000). The well records for the Rickardstown Formation in Co. Kildare indicate fissures and several water entries in the borehole logs. The Rickardstown Formation is quite variable even over short distances, for example there are excellent yielding wells in close proximity to poor yielding wells in the Osberstown area with transmissivities of only $1 \text{ m}^2 \text{ d}^{-1}$ reported for one of the poor yielding wells. Wells with high yields are reported from these formations in Laois, Offaly and Kildare. Wells located near the Barrow River in the Milford Formation have piezometric levels higher than the land surface indicating that the aquifer is confined in places, particularly near the Barrow.

There are six known public and group scheme supplies in this aquifer grouping, supplying over 8000 people in 2002 (refer to Table 4.3).

Productivity data are presented in Figure 4.8. The data is spread across all productivity classes and breaks down as follows; ten Class I, six Class II, six Class III, five Class IV and eleven Class V. Examination of the well yield shows that there is a concentration toward the "excellent" and "good" well yields. The large relative numbers of "excellent" and "good" yields and the relatively high proportion of Class I and Class II productivity values suggest that these rocks are generally productive aquifers. Daly (1987) has reported a transmissivity of $140 \text{ m}^2/\text{day}$ for the one of the Athy public supply boreholes. These boreholes draw water from the Milford Formation (refer to Volume II).

On the basis of productivity data, lithology and classifications in other counties these rocks are classed as **Regionally Important Karstified aquifers (Rk)**.

Figure 4.8 Well data from the Allenwood, Rickardstown and Milford Limestone Formations in Kildare, Laois and Offaly



4.12 Classification of the Edenderry Oolite (limestone) Aquifer

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The Edenderry Oolite forms part of the Allenwood Limestone Formation but is classed separately under

the Offaly Groundwater Protection Scheme (Daly *et al*, 1998). It is a pure, medium-coarse grained limestone occupying a small part of the north western corner of County Kildare.

There is one small group scheme known to be drawing groundwater from this unit. The hydrogeological data are sparse for this rock unit, being restricted to two productivity values and seven well yield values. There is one Class IV and one Class V well, both in County Offaly. There are two wells with "Good" yields of 345 m³ d⁻¹ and 200 m³ d⁻¹. Based primarily on productivity data and well yield data from County Offaly the Edenderry Oolite is classed as a **Locally Important Aquifer that is moderately productive** (E).

4.13 Classification of the Ballyadams Limestone Aquifer

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The unit generally comprises clean limestone and occupies a small part of south Kildare.

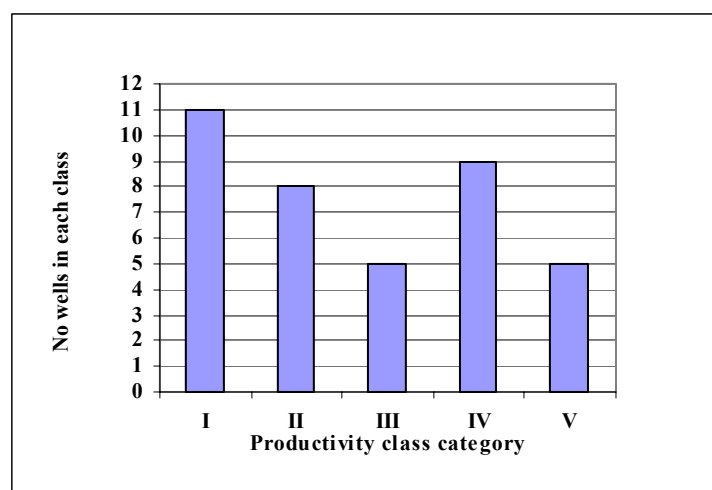
The clean nature of the limestone will also mean that the rocks will have been susceptible to dissolution. This is supported by the presence of a large number of karst features on record from Kilkenny (Buckley & Fitzsimons, 2002).

Table 4.3 indicates that there are two known public and group water schemes (Castlemitchell Churchtown and Housing water schemes) extracting groundwater from this aquifer in Kildare (supplying over 300 people in 2002). Several more large supplies occur in Laois and Kilkenny (for example Durrow and Paulstown). Forty-three productivity and/or yield values are available for the aquifer. Only one of these data points is located in Kildare; the rest are located in Kilkenny and Laois.

Productivity data are presented in Figure 4.9 which shows the data is spread across all the categories with a high proportion (50%) of the wells either Class I or II. Similarly, over half of the well yields are either "excellent" or "good". Due to the significant numbers of karst features and the variability of the productivity data this aquifer is considered to be a karst aquifer.

On the basis primarily of lithological, karst, and productivity data, this aquifer is classed as a **regionally important karst aquifer**, with some development potential (Rk^d).

Figure 4.9 Well data from the Ballyadams Limestone Aquifer in Laois, Kilkenny and Kildare



4.14 Classification of the Calp Limestone and Tober Colleen Limestone Aquifers

The distribution of the rock type is presented in Map 1, while the aquifer is depicted in Map 5. The aquifer grouping generally comprises dark-coloured shaley limestone and shales. In Kildare, the grouping includes the Calp and Tober Colleen Formations, which are considered together on the basis

of similarities in composition, age, and location. The Calp aquifer grouping occupies large areas of East Connaught, the Central Midlands and North Leinster.

While there appears to be some variation in the hydrogeological properties over the region, overall bulk permeabilities and well yields are relatively low. Groundwater flow tends to be concentrated in the upper fractured and weathered zone, along fractured fault zones and in cleaner limestone beds. Consequently, groundwater throughput is generally low and groundwater circulation is shallow and localised, often with short flow paths. The water table is usually fairly close to ground level and closely mirrors topography. A relatively high density of streams and surface ditches is common (Daly *et al*, 1998).

There are some unusual features associated with the Calp limestone. For example there are a number of warm springs situated around the Lucan and Celbridge areas (refer to Map 4). Typical temperatures of the springs ranges from 13°-25°C, which is significantly above the normal values expected for Irish groundwater. It is considered that the groundwater issuing from these springs comes from a much deeper source than most groundwater in Ireland (Burdon, 1983). The presence of warm springs has been associated with deep faults, which would allow deeper, warmer waters to the surface rapidly and it may be that they are more noticeable in poorer aquifers where the dilution effect of colder, shallower, younger waters is reduced.

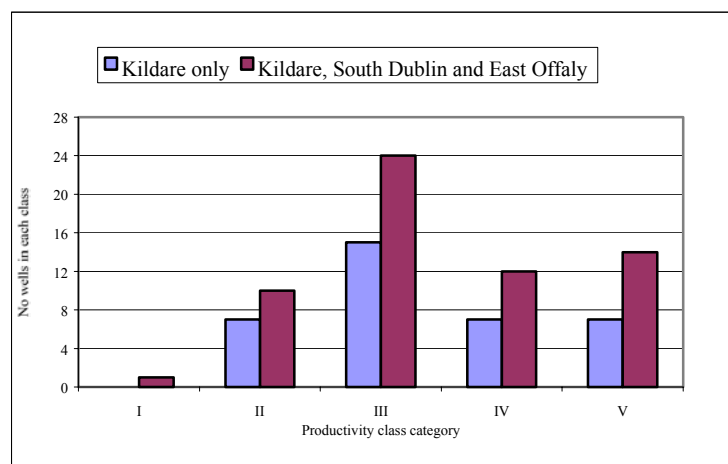
High concentrations of iron, manganese and hydrogen sulphide are also common, providing considerable problems for those with private wells. This effect is sometimes the result of contamination, but is often a consequence of the combination of both the natural iron sulphide in the shalier parts of the rock formation, and the generally slow groundwater circulation.


There are three known public and group scheme groundwater supplies (Clonuff, Clogherinkoe, Newtown) in this aquifer, supplying over 250 people in 2002 (refer to Table 4.3).

The classification of the Calp limestones as a single aquifer is quite problematical. This is because of its large aerial extent and its lithological and structural variability on a local and regional scale. This geological variability is reflected in highly variable yields across the country. For example yields in East Galway are generally much lower than those in South Meath/North Dublin (Woods and Wright, 2001).

Calp areas between South Meath and East Galway appear to have yields which generally fall between these two extremes. This central area has a structural setting and depositional history which includes the Calp in Kildare. Productivity data from the central region of Ireland are presented in Figure 4.10. A visual comparison of this data suggests that the dataset from the central region as a whole is a good representation of the more local situation in Kildare.

Figure 4.10 Well data from the Calp Limestone Aquifer

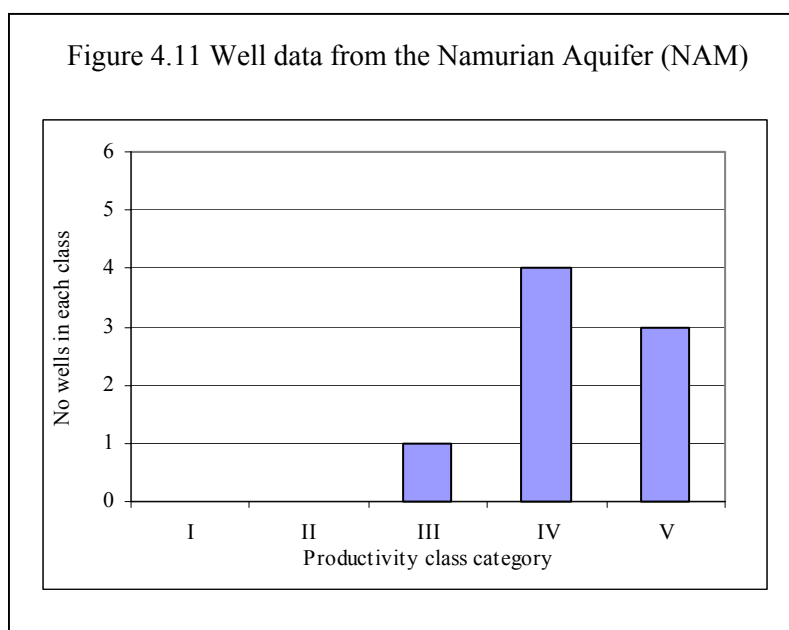


The data are spread across all productivity categories with a concentration toward the "poorer" end of the productivity categories. The data breaks down as follows: one Class I; ten Class II; twenty-five Class III; twelve Class IV and fourteen Class V. Transmissivity¹⁰ values have been calculated for five wells in the Straffan area; ranging from 10-20 m² d⁻¹. The boreholes from which this data is derived are quite deep (90 metres). Examination of test pumping data reveals that the specific capacity¹¹ data is relatively constant for the duration of the tests. In addition extrapolation of the drawdown curve beyond the test time shows that the specific capacity is still relatively constant (Wright, pers. comm.).  specific capacities from the Straffan testing were moderate to low, ranging from 6 to 15 m³d⁻¹m⁻¹. This suggests that the permeability is relatively constant over the depth of the boreholes and not just confined to the upper few metres.

On the basis, primarily on the productivity data, lithology and transmissivity data the Calp Limestone Aquifer (CD) is classed as a **Locally Important aquifer that is productive in local zones (LI)**.

4.15 Classification of the Namurian Aquifer

The Namurian Aquifer generally comprises sandstone and shale and occupies a small area in northern most Kildare just west of Kilcock (Map 1 and 5). The lithology described is generally not associated with important aquifers. In addition there are no mapped structural features evident that are likely to have improved the bulk permeability (refer to Map 1). There are no public or group scheme groundwater supplies located in this aquifer. Available well data is very sparse and GSI records comprise two wells in County Kildare, five in County Laois, two in County Kilkenny and one in County Carlow. The well yields for the wells in County Kildare are very low: both classed as "Poor". The well data is presented in Figure 4.11 and it can be seen that the data is restricted toward the poorer productivity classes. There are no Class I or II wells, thus on the basis of lithology, productivity data and on the classification of the Namurian in South Meath under the Meath Groundwater Protection Scheme (Woods et al., 1998) the Namurian Limestone Aquifer is classed as a **Poor Aquifer that is productive in local zones (PI)**.



¹⁰ Transmissivity is the product of permeability and the effective saturated thickness of the aquifer

¹¹ Specific capacity is pumping rate divided by drawdown.

4.16 Classification of the Volcanics occurring in the Carboniferous

Volcanic rocks occupy two small areas of north west Kildare near Edenderry in Co. Offaly. One of the areas of volcanic rock straddles the border with Offaly at Edenderry. Two public supply wells are located in this patch of volcanic rock in Offaly. Both yields are "excellent". Problems with collapse of the borehole sides were encountered during drilling (Daly *et al*, 1998). However, there are no wells on record in this rock unit in Kildare and the classification is taken directly from the classification used in the Offaly Groundwater Protection Scheme (Daly *et al*, 1998). Thus, the volcanics are classed as a **locally important aquifer**, which is **generally moderately productive (Lm)**.

4.17 Classification of the Sand & Gravel Aquifers

4.17.1 Introduction

Kildare has some extensive deposits of sand & gravels, the largest of which is the well known Curragh (mid-Kildare) aquifer. Other deposits are associated with the Barrow, Boyne, Liffey and Greese Rivers. Most of them have not been significantly developed and their resource availability is therefore not proven. Until exploratory drilling data become available, therefore, they should be regarded as *potential* gravel aquifers. Site investigation may also prove other 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.

4.17.2 The Mid-Kildare (Curragh) gravel aquifer

The Mid-Kildare Gravel Aquifer lies in a shallow trough, oriented NE-SW, in the surface of the limestone bedrock. To the southeast this trough is bounded by the Lower Palaeozoic rocks (slates, etc) of the Leinster Massif, and to the northwest by the low ridge of the Chair Hills - notably Dunmurry Hill, Grange Hill, the Chair of Kildare and the Hill of Allen - again mainly composed of pre-Carboniferous rocks.

Between these hills, the trough is underlain by bedded limestones and dolomites. Into this trough the last glaciation deposited a mixture of sediments which included a high proportion of sand and gravel, up to 70 m thick in places.

The boundaries of the aquifer are quite well defined on its northwest and southeast sides but to the northeast and southwest they are much harder to make out. For the purposes of this evaluation the aquifer has been defined by the existence of at least 5 metres of saturated sand/gravel as seen from the borehole evidence. On this criterion, the area of the aquifer is approximately 180 km². It is roughly ovoid in shape, with a maximum length of 21 km and a maximum width of 13 km, and extends from near Naas in the northeast to Nurney in the south, and from Kildare town in the west to Kilcullen in the east (Wright, 1988).

Wright (1988) described this aquifer as the "best" example of a sand & gravel aquifer in the country, extensive enough to be exploited on a large scale. Wright contoured areas of saturated thickness resulting in the following estimates:

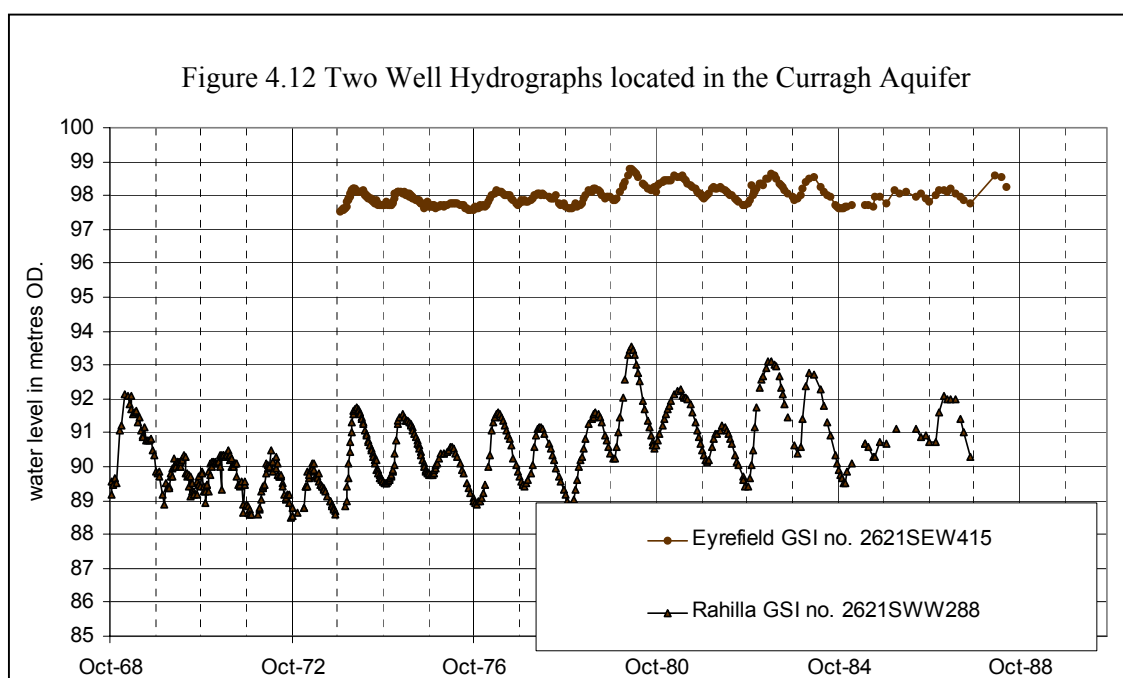
Saturated thickness (m)	Area (km ²)
>25	6
>15	47
>10	81
>5	180

The Mid-Kildare aquifer is a feeder for the Grand Canal and is an important source of baseflow for the streams and rivers. This is supported by the estimated flow from the aquifer to the Milltown Feeder at Pollardstown Fen of approximately 25,000 m³/day (Daly, D. 1981). It is also supported by high

specific dry weather flow for the Tully stream which is calculated as $3.9 \text{ l sec}^{-1} \text{ km}^{-2}$ (figures in excess of $2 \text{ l sec}^{-1} \text{ km}^{-2}$ are considered to be an indication of significant baseflow). The aquifer provides baseflow for the major river catchments in Kildare, namely the Liffey, the Barrow and the Boyne. The Pollardstown Fen also derives its water from the aquifer. A major user of the aquifer are the Defence Forces, using groundwater to supply the Curragh Camp (refer to Table 4.3 and Volume II of this report).

Grain size data are available for eight of twenty-six samples taken from a well drilled by the GSI in 1980 at the Curragh Camp (GSI well number 2621SEW214). The particle size distribution curves are reproduced in Appendix II and all eight samples have fines of less than 8%. Note however that this borehole also shows the variability of the aquifer material, consisting largely of sand & gravel horizons and occasional till horizons. Cross-sections drawn by GSI and KT Cullen indicate that there are till horizons evident throughout the domain. At the surface there are large areas of till capping the sand & gravel aquifer. Variability in the aquifer material influences the hydrogeological behaviour of the aquifer and this can be seen in the hydrographs presented in Figure 4.12. The aquifer is unconfined in most places. Porosities are estimated to be in the order of 30-40% (Hayes, 2001).

Productivity data is sparse but some data is available from tests carried out at wells around the Curragh Military Camp. There is up to 20 years monitoring well data available for two wells located in the eastern and western part of the aquifer. In addition, as part of the current work being done on the Kildare by-pass there is regular monitoring of wells around the aquifer to provide information on the aquifers response to the construction of the by-pass. All the data indicates the good aquifer properties of this large aquifer. All the wells around the Curragh Camp are very productive, with high specific capacities and excellent yields. Yields range from $1000\text{-}4000 \text{ m}^3 \text{ d}^{-1}$, specific capacities¹² range from $163\text{-}2000 \text{ m}^3 \text{ d}^{-1} \text{ m}^{-1}$. Permeabilities are estimated from test pumping to be in the order of $15\text{-}50 \text{ m d}^{-1}$. The bulk permeability of the aquifer is estimated to be 100 m d^{-1} for the purposes of the modelling of the aquifer (Hayes, T., 2001). Monitoring data are available for two wells located in the Curragh Aquifer and the data is presented in Figure 4.12. These well hydrographs give indications of the aquifer properties; such as permeability and storage. The seasonal variation is in the order of 1.25-2.5 m, with the lowest levels occurring in October and the highest in February (Hayes, T., 2001).



¹² Specific capacity is pumping rate divided by drawdown.

The annual variation is typical of important sand & gravel aquifers, suggesting high permeabilities and/or high storage capabilities. This is also supported by the high base flow associated with the Tully stream, which discharges from the aquifer just south of Kildare town.

Primarily on the basis of our current understanding of the extent, thickness, the saturated thickness and the available hydrogeological data the Mid-Kildare (Curragh) Sand & Gravel aquifer is classed as a **regionally important sand & gravel aquifer (Rg)**.

4.17.3 Sand & Gravel aquifers of the Blessington & Ballymore Eustace region

There are a number of discontinuous sand & gravel deposits that have been mapped in the vicinity of these two towns along the border between Wicklow and Kildare. Four sand & gravel aquifers are identified (Three of these aquifers classified by the Wicklow Groundwater Protection Scheme (Woods & Wright 2001)). All four potential aquifers are described below and are presented in Map 5.

- Blessington Gravel aquifer: The aquifer surrounds Blessington village covering an area of approximately 10 km², most of which lies in Co. Wicklow. The deposit varies in thickness, averaging 10 to 40 m. Well data indicate transmissivities¹³ in the range of 140-1500 m² d⁻¹; specific capacities in the order of 90-2000 m³ d⁻¹ m⁻¹ and yields in the order of 350-600 m³ d⁻¹. Water table depths in this area ranged from 10 to 20 m below ground. In this area of Co. Kildare and Co. Wicklow, most private groundwater supplies are obtained from the sand and gravel deposits, with many housing estates being supplied by group scheme wells, sourced in the sand and gravel (Woods & Wright, 2001). Primarily due to the extent, depth and yield data, this deposit is considered to be a **Locally Important Sand & Gravel aquifer (Lg)**.
- West Blessington & Ballymore Eustace Gravel aquifers.

The West Blessington aquifer lies four kilometres north of Blessington. Sand & gravel deposits occupy the area between the townlands of Baltracey, Blackhall, Walshetown, Rathmore and Eadestown. This sand & gravel deposit has an aerial extent of about 4.5 km² and an interpreted depth to bedrock of over 10 m.

The Ballymore Eustace aquifer comprises two separate gravel deposits occupying areas around Dowdenstown, Briencan and Tinnycross. The overall aerial extent is 5 km² and the interpreted depth to bedrock is in excess of 10 m. This series of deposits are considered as one because it is assumed that they are connected beneath the narrow stretches of alluvium that separate them on the surface. There are a number of small domestic wells in both sand & gravel deposits, however, there is no test pumping data available and very few yield values. Water level data are sparse and variable. On the basis of aerial extent, depth to bedrock and the number of small domestic wells in the area both these deposits are classed as **Locally Important sand & gravel aquifers (Lg)**.

- Lemonstown potential gravel aquifer. This deposit lies about five kilometres south of Ballymore Eustace and occupies an area of about 7 km², straddling the Wicklow - Kildare border. It is identified as a potential sand & gravel deposit in the Wicklow Groundwater Protection Scheme. It has an interpreted depth to bedrock over 10 m. Primarily due to the extent and depth of the sand & gravel deposit it is considered to be a potentially **Locally Important Sand & Gravel aquifer (Lg)**.

4.17.4 Narraghmore Gravel Aquifer.

Sand & gravels occupy a large area extending from approximately seven kilometres east of Kilcullen as far as Moone. The portion of this deposit with an interpreted depth of over 10 m occupies an area of considerably more than 10 km². It is a relatively long, narrow and sinuous deposit, trapped between the foothills of the Dublin-Wicklow mountains to the east and Bullhill and Old Kilcullen to the west. There are numerous sand & gravel quarries. There is a large group scheme located in this portion known as the Lipstown-Narraghmore Group Water Scheme. The yield of this spring is in the order of

¹³ Transmissivity is the product of permeability and the effective saturated thickness of the aquifer

1300-1800 m³d⁻¹ which under the GSI classification for spring yields is an "Intermediate" sized spring. There are source protection zones delineated for this important groundwater source and are discussed and presented in detail in Volume II of this report. Baseflow figures are obtainable for the River Greese in this area from EPA river flow measurements taken at Ballitore River Gauge and are calculated to be approximately 2.0 l sec⁻¹ km⁻², a figure that is interpreted to reflect contributions from the sand & gravel deposits during summer periods. The underlying bedrock (Carrighill Formation) is regarded to be a poor aquifer, thus is unlikely to account for the high summer baseflow. Though the aquifer appears to be thick enough and extensive enough to merit the highest aquifer classification, particle size, permeability, or yield test data are not available for the aquifer and there are no high yielding springs on GSI records in the aquifer. Consequently, the Narraghmore gravels are classed as a **Locally Important sand & gravel aquifer (Lg)**.

4.17.5 Baltinglass - Castledermot Gravel Aquifer

A sand & gravel deposit extends from Baltinglass, Co. Wicklow southwestwards into Co. Kildare, then westwards through Castledermot and on as far as the River Barrow. A portion of this, from Baltinglass almost as far as Castledermot is considered as being thick enough to constitute a sand & gravel aquifer. Under the Wicklow GWPS the portion that occupies the area inside Co. Wicklow is considered to be a potential sand & gravel aquifer and is classed as a Locally important sand & gravel aquifer. The deposit occupies a total (Kildare & Wicklow) area of about 9 km², but rock outcrops are common and the gravel thickness is believed to be quite variable. The portion in Kildare occupies about 4.5 km². There are several domestic wells in the area and at least one decommissioned public supply (Castledermot). Though 'good' yields have been achieved in the aquifer, the thickness is believed to be variable and the deposit is classed as a **Locally Important sand & gravel aquifer (Lg)**.

4.17.6 Athy - River Barrow Gravel Aquifer

This sand & gravel deposit is located along the floodplain of the River Barrow and extends from Athy southwards into County Carlow. A portion of this deposit is also located in County Laois, extending from Tankardstown as far as Shrile. The deposit covers an area of about 40 km² in County Kildare, with most of it thicker than 10 m. In the Athy area there are a number of water supply wells that exploit the sand & gravel deposit and the underlying bedrock aquifer. An infiltration gallery yielding up to 1360 m³ d⁻¹ is located in the town exploiting the permeability of the sand & gravels. Further details of the infiltration gallery are presented in Volume II of this report. In addition, a public supply borehole exploiting the aquifer in Graysland, Athy is now disused but was reported to have a yield of up to 500 m³/day (Daly, 1987).

Investigations and well surveys undertaken by the GSI in the 1980s (Daly, 1987) indicate that the gravel deposit is generally 5-15 m thick in the Athy area, and that the deposit generally thickens from west to east. They also show that the narrow stretch of alluvium along the floodplain is less than 2 m thick and that the sand & gravels are continuous beneath the alluvium layer. Water levels appear to be generally less than 2 m below ground surface, indicating that the saturated thickness of the deposit is generally greater than 5 m.

Particle size analyses were carried out on a number of samples taken from the sand & gravel deposits in Athy; all of these analyses show that the fines account for less than 8% of the sample, suggesting the deposit will have a 'high' permeability in places. These data are presented in appendix III.

Forty-four well records were examined with one Class I well (the Graysland borehole), two wells with "excellent" yields and five wells with "good" yields. The Graysland borehole was tested at 736 m³ d⁻¹ with a drawdown of around 11 m giving a specific capacity of approximately 67 m³ d⁻¹ m⁻¹. Using salt tracer test information, Daly (1987) has estimated permeabilities to be in the order of 8 m d⁻¹.

On the basis of extent, saturated thickness and well data, the sand & gravel deposit is classed as a **Regionally Important sand & gravel aquifer (Rg)**.

4.17.7 Sallins Gravels

Two sand & gravel deposit occupy an area of about 4 km² and lie just to the north of Naas. The first is an elongate deposit located at the townland of Bodinstown and the Maudlings Interchange on the N7. It is about 800 m at its widest. At the surface it is divided by the Grand Canal running through the central part of the deposit but it is assumed the sand & gravel deposit extends beneath the canal. There are few wells on GSI records for this area but there is one well with a "good" yield. Primarily on the basis of extent and thickness it is classed as a **Locally Important sand & gravel aquifer (Lg)**.

The second occupies 1.7 km² in the vicinity of Barrettstown. On the surface it comprises three smaller units of sand & gravel which are separated by thin layers of alluvium, till and the canal. It is assumed that the sand & gravel extends beneath the thin layer of alluvium and the canal. On the basis of aerial extent and thickness the deposit is classed as a potentially **Locally Important sand & gravel aquifer (Lg)**.

4.17.8 Kill Gravels

A sand & gravel deposit is mapped around the village of Kill in north east Kildare and it occupies an area of about 5.5 km². There is considerable geological, geotechnical and hydrogeological information available from site investigations carried out in the Arthurstown area (near Kill). The geology of the deposits in Arthurstown is quite variable, but, in general, sand & gravels overlies till and the entire sequence thickens to the north west toward Kill (Long & Mc Cullen, 1999). The sand & gravel varies in thickness, up to 6 m in places. There is no data for the rest of the deposit but it is assumed that the sand & gravels thickens toward Kill. The depth to bedrock is quite variable around Kill and the thickness over the extent of the deposit is interpreted to be greater than 10 m. Particle size analyses show that the sand & gravel has less than 8% fines. Long & Mc Cullen (1999) report that permeabilities of the sand & gravel at Kill are in the order of 6.1×10^{-4} to $6.9 \times 10^{-7} \text{ m s}^{-1}$ and the numerical average is $2.1 \times 10^{-4} \text{ m s}^{-1}$ (equivalent to 18 m/day). An "excellent" yielding well (GSI well number 2921NWW120) is located in the northern part of the deposit, indicating approximately 14 m of "drift" with a recorded water level at 1 m below ground. Water levels are also close to the ground surface in the southern end of the deposit in the Arthurstown area. Site investigation data suggest that the saturated thickness is generally greater than 5 m. Primarily on the basis of extent, thickness, particle size analyses, permeabilities and water levels the deposit is classed as a **Locally Important sand & gravel aquifer (Lg)**.

4.17.9 River Boyne Gravel Aquifer

There are extensive sand & gravel deposits along the River Boyne in north west Kildare. They extend from Grange West in the south to Clonard New in the north. The deposit occupies an area of about 7 km² in County Kildare. It extends a short distance into county Meath. The interpreted depth to rock is greater than 10 m. There is a cluster of eskers located on top of these sand & gravel deposits in the northern half of the deposit around the townlands of Kilrathmurry and Ballinlig. Two wells with "good" yields occur in GSI records for this aquifer. On the basis of extent, thickness and well data this deposit is classed as a **locally important sand & gravel aquifer (Lg)**.

4.17.10 Rathangan Gravel Aquifer

A sand & gravel deposit extends from Rathangan southwards as far as the townland of Tullylost. It occupies an area of approximately 7.5 km² and has an interpreted thickness of greater 10 m over almost the entire extent of the deposit. K.T. Cullen consultants Cullen (2001) have undertaken yield tests on the aquifer, finding eight wells with "excellent" yields and four wells with "good" yields. One of the wells drilled has recorded 20 m of saturated sand & gravels. Based primarily on these well data, the deposit is classed as a **Locally Important sand & gravel aquifer (Lg)**.

4.17.11 Johnstown Bridge Gravel Aquifer.

A site investigation by K.T Cullen consultants in north Kildare as part of Kildare County Councils Water Strategy revealed a sand & gravel deposit occupying about 2.0 km² in area close to Johnstown Bridge (Cullen, 2001). It is located in the townlands of Dysart and Clonagh. Till and peat occupy the surface layers. It is a relatively low-lying area with a high water table which is generally less than 3 m from the ground surface. The site investigation reveals that there are up to 20 m of saturated gravels in places, however, general saturated gravel thicknesses are in the order 5-10 m. On the basis of extent, geological information and water level data, the deposit is classed as a **Locally Important sand & gravel aquifer (Lg)**. Note that this aquifer has not been mapped at surface and the boundaries are delineated on the basis of drilling data. As such, the boundaries may change when new site investigation data become available.

4.17.12 Robertstown Gravel Aquifer

A sand & gravel deposit is located at Robertstown that is in the order of 2-7 m thick (Cullen, 2001). The gravel is primarily overlain by till, and there is no indication at the surface that there is a sand & gravel deposit present. The evidence for the extent of the gravel comes entirely from borehole data. Boreholes with saturated gravel appear to coincide with the occurrence of a slight topographic depression which occupies the lowest lying land in the vicinity. This depression is approximately coincident with the Ordnance Survey's 80m topographic contour, and, until more drilling data becomes available, this contour has been used to define the limits of the aquifer. The total area is approximately 5 km².

The gravels are almost entirely saturated. "Excellent" yields of over 760 m³ d⁻¹ were reported for three of the wells drilled by K.T. Cullen consultants (Cullen, 2001) into the gravels. The total yield of the well-field drilled into the aquifer has been estimated to be in the order of 4,000 m³/day on the basis of a four week well-field pump test. Clearly, this anticipated yield suggests the presence of an aquifer of regional importance. The total area currently delineated by GSI for the aquifer is not sufficient to capture sufficient recharge to maintain the predicted yields, but it may be that the aquifer receives additional recharge from surface water, particularly during pumping conditions. However, until the source of the anticipated recharge to the gravels can be determined, and until the extent of the aquifer can be delineated with more confidence, it is classed as a **Locally Important sand & gravel aquifer (Lg)**.

4.17.13 Kilkea Gravel Aquifer

A small gravel deposit is located in the vicinity of Kilkea Demesne. The area is mapped as till but three boreholes in the area indicate approximately 10 m of saturated gravels. There are no data on particle size distribution or permeability and all yields in the area are derived from boreholes which are thought to draw from both gravel and bedrock. On the basis of inferences on the extent and thickness of the deposit (derived from borehole geological data), it is classed as a **Locally Important sand & gravel aquifer (Lg)**.

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 quantity of contaminants which reach groundwater is 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

Apart from sites where point recharge occurs (e.g. swallow holes), groundwater vulnerability is mapped on the basis of the type, permeability and thickness of the subsoils. Each subsoil type described in Section 3 is assessed here in terms of its permeability. The vulnerability map is then derived by assessing the potential for point recharge and then 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”. Table 5.1 describes how the criteria combine to derive a vulnerability assessment.

Further details of the hydrogeological basis for vulnerability assessment can be found in the DELG/EPA/GSI 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.

Note that the vulnerability map shows the vulnerability of groundwater (in the uppermost aquifer

Table 5.1 Vulnerability Mapping Criteria (adapted from DELF/EPA/GSI, 1999)

Subsoil Thickness	Hydrogeological Requirements				
	Diffuse recharge			Point Recharge	Unsaturated Zone
	Subsoil permeability and type				
	high permeability (sand/gravel)	moderate permeability (sandy subsoil)	low permeability (clayey subsoil, clay, peat)	(swallow holes, losing streams)	(sand & gravel aquifers <u>only</u>)
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.					

encountered) 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.

5.2 Sources of Data

The vulnerability maps presented in Maps 6N and 6S were based on the following data sources:

- Subsoils map, compiled by the Quaternary Section of the Geological Survey of Ireland (GSI). This gives the main permeability boundaries. Peat and lake clays are usually low permeability. ‘Clean’ gravels are usually high permeability. Tills and ‘dirty’ gravels are usually moderate or low permeability. In Kildare the region to the south of Naas and Rathangan has been mapped in significantly more detail (Glanville, 1997) than the region to the North.
- Depth to bedrock map, compiled by the Groundwater Section of the Geological Survey of Ireland, using data compiled from GSI and county council reports, along with purpose-drilled auger holes.
- Soils map of Kildare (Conry, 1970). This gave additional, indirect information on subsoil permeability in the areas mapped by Quaternary Section as ‘till’.
- Field permeability mapping. This was used to further assess inferences made on the basis of subsoils and soils maps. Particular attention was paid to tills and ‘dirty’ gravels. Assessments were based on drilling of one hundred and sixteen subsoil sampling holes and included:
 - Description of the engineering properties in the vicinity of the drilled locations using techniques based on BS5930:1999 (British Standards Institution, 1999).
 - Collection of subsoil samples for laboratory particle size analyses (76 samples in total).
 - Assessments of recharge acceptance indicators such as drainage density and vegetation.Details on analytical methodologies are presented in Sections 5.3 and 5.4.
- Geological Survey of Ireland karst database. This was used to give information on areas of point recharge.
- Bedrock geology maps (Maps 1N and 1S).

5.3 Permeability Assessment Criteria

The permeability and vulnerability categories 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. cracks, plant roots and isolated higher permeability beds or lenses) and density/compactness. In glacial tills, which are the most common subsoils in Kildare, these permeability 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.

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 has been found that subsoils described as ‘clayey SAND’ have 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 analysis, 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, including Kildare, have 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 of the subsoil.* 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, shaley 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 if iron pans, underlying low permeability bedrock, high water tables, or excessively high rainfall can be ruled out. Well-drained land suggests a moderate or high permeability if artificial drainage can be ruled-out (Lee, 1999). As lands in the west and north of Kildare are highly managed, with large amounts of artificial drainage, this approach is quite difficult to use successfully. During the nineteenth century the Duke of Leinster provided financial assistance, encouraging large areas to be improved (Conry, 1970).
5. *Soils map.* A soils map exists for the whole of Co. Kildare. This data was used to assess drainage characteristics where specific site recharge observations were not available. Poorly drained soils such as surface water gleys¹⁴ can often be related to underlying low permeability subsoils, while the more free draining soils such as the brown earths and grey brown podzolics are more typical of the sandy and silty moderate permeability subsoils.
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^{-8} m/s to 10^{-9} m/s at the field scale (Swartz, 1999). Using limited country-wide pump test data, the boundary between 'moderate' 'high' permeability 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 smaller than field measurements which in turn are smaller 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.

5.4 Mapping Permeability over Large Areas

In order to allow extrapolation from point data to aerial assessments, the county was divided into permeability units, usually on the basis of similar bedrock, subsoil and/or soil characteristics. The process of mapping permeability over large areas involved two key phases:

¹⁴ Gley soils are often associated with poorly drained land.

- *Assess permeability unit boundaries:* Areas with apparently similar subsoil permeability characteristics were grouped into 'permeability units'. The boundaries of these units were determined on the basis of subsoil and soil mapping. The boundaries of the glacial tills, gravels and peats were determined by GSI Quaternary subsoil mapping. As tills can have either a 'moderate' or 'low' bulk permeability, the Teagasc soil maps of Kildare (Conry, 1970) were used to subdivide the till areas into different permeability units.
- *Identify the general permeability of each unit:* Once the permeability unit boundaries had been assessed, a typical subsoil permeability rating ('high', 'moderate', or 'low') was assigned to each unit. This permeability was assigned using the criteria set-out in Section 5.3. Particle size data for the gravel areas are presented in Appendix II. The permeability assessment of each of the units within the till areas of Kildare is presented in Appendix III.

In any one permeability unit, as many of these factors as possible were considered together in order to try to obtain a balanced, defensible permeability decision. It is intended that the assessments will allow a broad overview of relative permeabilities across the county, in order to help focus field investigations for future development projects on areas of interest. In mapping an area the size of County Kildare, the process cannot comprehensively account-for variations in subsoil permeability at a site-specific level. Consequently, it is stressed that these permeability assessments are not a substitute for site investigations for specific developments. Brief descriptions of the permeability assessments are presented in Sections 5.5.1 to 5.5.3. Vulnerability maps are presented on Maps 6N and 6S.

5.5 Results of Permeability Mapping

5.5.1 Permeability Units Mapped as 'Low' Permeability

In Kildare, the deposits which have low permeabilities are clayey glacial tills, lacustrine deposits and peat. They are depicted in Map 2.

- Peat areas and lacustrine deposits delineated by Quaternary mapping have all been classed as low permeability.
- Certain till areas mapped by Quaternary Section of GSI have also been classed as low permeability. This is primarily on the basis of field descriptions and grain size analyses. Permeability units with generally low permeability characteristics tended to coincide with the distribution of surface water gleys and peaty soils as mapped by Conry (1970). The largest area coincides with Conry's 'Straffan Complex' of soils. The decision making criteria are presented in Appendix III.

5.5.2 Permeability Units Mapped as 'Moderate' Permeability

In Kildare, the deposits which have moderate permeabilities are silty and sandy glacial tills, alluvium, and poorly sorted sand and gravel deposits. They are depicted in Map 2.

- *Alluvium:* There are only limited developments of alluvium along rivers, the most extensive of these being along the Liffey, Barrow and Greese. Alluvial deposits are generally a complex mixture of coarse and fine particles and they are generally assumed to have a moderate permeability.
- *Tills:* Within the till areas mapped by the Quaternary Section of GSI, generally moderate permeability units have been identified on the basis of field descriptions and grain size analyses. These till units have typically coincided with the distribution of grey-brown podzolics and brown earth's as mapped by Conry (1970). Examples include the 'Fontstown' and 'Elton' soil types (refer to Appendix III).

5.5.3 Permeability Units Mapped as ‘High’ Permeability

In Kildare, the deposits which have high permeabilities have been mapped-out as gravel by the Quaternary Section of GSI. They are depicted in Map 2, and are generally associated with the Curragh and with large rivers, such as the Barrow, Boyne, Greese and Liffey. These areas are often characterised by numerous gravel pits, (some quite large), hummocky topography and a mix of light textured and medium heavy grey brown podzolics and brown earths (Athy Complex). Particle size data are available for the Curragh gravels, and the gravels in the Kill and Athy areas. These data are reproduced in (Appendix II).

5.5.4 Areas Where Rock Is Close To The Surface

These areas are generally indicated by the location of bedrock outcrops. The subsoil deposits in these areas are generally too thin to enable adequate permeability mapping over wide areas. They most commonly occur in the Chair of Kildare and in upland areas throughout the eastern part of the county. The distribution of these areas are depicted on Map 2.

5.6 Thickness of the Unsaturated Zone

The thickness of the unsaturated zone is only relevant in vulnerability mapping over unconfined sand and gravel aquifers. As described in Table 5.1, the critical unsaturated zone thickness is 3m; unconfined gravels with unsaturated zones thicker than 3m are classed as having a ‘high’ vulnerability, while those with unsaturated zones thinner than 3m are classed as having an ‘extreme’ vulnerability.

In the unconfined gravels in Kildare, the water table is thought to be generally more than 3 m deep. Thinner unsaturated zones are expected very close to major rivers, and zones of extreme vulnerability have been mapped along the River Barrow gravel aquifer at Athy (Map 6S). The width of this extreme vulnerability zone is 300m on each side of the river and has been determined on the basis of site investigation data (Daly, 1987). In general, however, river gravels are overlain by alluvium. This alluvium will increase the travel time of percolating groundwater and will partially compensate for the reduced protection afforded by the thinner unsaturated zone in the gravels. Therefore, the thinner unsaturated zone generally found close to most of the major rivers in Kildare is not considered to significantly influence the overall vulnerability in Kildare. Other gravel areas mapped as extreme vulnerability on the basis of unsaturated zone thickness include the immediate vicinity of the Narraghmore springs and a thin strip of land rimming Pollardstown Fen.

5.7 Depth to Bedrock

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

5.8 Recharge at Karst Features

Bypassing of the protecting layers of subsoil can occur where water flows rapidly underground, with minimal attenuation, at karst features such as swallow holes and dolines. Therefore, groundwater is classed as ‘extremely’ vulnerable within 30 m of karstic features, including along the area of loss of sinking streams, and within 10 m on either side of losing streams upstream of the area of loss. The distances can be varied depending on the circumstances, for instance, they can be increased where overland surface runoff is likely. The locations of karst features on GSI records are presented in Map 4.

5.9 Groundwater Vulnerability Distribution

The vulnerability maps (Maps 6N and 6S) 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. 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 6N and 6S are considered to provide a good basis for decision-making in the short and medium term.

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. Consequently, there are probably more areas of moderate and low vulnerability than are currently depicted on Maps 6S and 6N. As more information becomes available, the maps should be up-dated.

The areas of extreme vulnerability where rock is generally at or close to surface include upland areas which have little existing development or potential for development. When these are excluded, the proportion of the county's groundwater that is extremely vulnerable is significantly reduced. Similarly, many small pockets of deeper subsoil are likely to exist even within areas where rock outcrop is common. The areas of low vulnerability have been mapped where the subsoils (tills) 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 have interbedded sands and gravels in places; further confirmation by site investigation is essential to verify the vulnerability for specific developments.

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

6 Groundwater Protection Zones and Responses

6.1 Introduction

The general Groundwater Protection Scheme guidelines were outlined in Section 1, and in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice (responses) for potentially polluting activities – was described (see also Appendix I). Subsequent sections described the different geological and hydrogeological land surface zoning elements as applied to County Kildare. This Section 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 supplementary publications are currently available: **Groundwater Protection Responses for On-Site Systems for Single Houses (‘septic tanks’)**, **Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses for Landspreading of Organic Wastes**. Similar ‘responses’ publications will be prepared in the future for other potentially polluting activities, such as underground storage tanks and farmyards.

6.2 Groundwater Protection Maps

The groundwater protection map (Map 7) was produced by combining the vulnerability map (Map 6) with the aquifer map (Map 5). Each protection zone on the map is defined by a code which represents both the vulnerability of the groundwater to contamination and the value of the groundwater resource (aquifer category). Most of the possible hydrogeological settings are present in County Kildare; those which are present are given in Table 6.1.

6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around seven selected public water supply sources in Co. Kildare: Lipstown/Narraghmore; Kilteel; Kilkea; Castlemitchell; Curragh Camp Wells; Athy; Usk/Gormanstown. These have been produced as separate sections in Volume II, and are delineated in Map 8.

6.4 Integration of Groundwater Protection Zones and Responses

Table 6.1 Matrix of Groundwater 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/Rg/E	Lm/Lg/E	Ll/E	Pl/E	Pu/E
High (H)	Rk/H	Rf/Rg/H	Lm/Lg/H	Ll/H	Pl/H	Pu/H
Moderate (M)	Rk/M	Rf/Rg/M	Lm/Lg/M	Ll/M	Pl/M	Pu/M
Low (L)	Rk/L	Rf/Rg/L	Lm/Lg/L	Ll/L	Pl/L	

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. Appendix I provides more information on the use of groundwater protection responses.

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

Table 6.2 Site Suitability Response Levels in Kildare

Activity*	Percentage of Kildare Occurring within Each Response Level		
	Least restrictive response level ('R1')	Intermediate response levels: ('R2' and 'R3')	Most restrictive response level ('R4')
	Risk to groundwater can be managed using normal good practice guidelines.	Higher risk to groundwater. In order to manage the risk, additional requirements over and above normal good practice are recommended. Requirements can relate to site-specific ground conditions, construction, operation, and the number of existing developments in the area. If the required site-specific ground conditions do not occur at a particular site, or if the density of existing developments is too high, the activity would be regarded as 'unacceptable'.	Additional requirements will not reduce the risk to groundwater to acceptable levels.
Landfill	18%	57%	25%
IPC Landspreading**	87%	13%	<1%
On-site Treatment Systems	83%	17%	-

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

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

6.5 Conclusions

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

In considering the Groundwater Protection Scheme, it is important to remember that: (a) a scheme is intended to provide guidelines to assist decision-making in County Kildare 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 available data. Kildare County 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 would enable the zonation to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

The scheme has the following uses for Kildare 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 social and economic factors
- it acts as a guide and provides a ‘first-off’ warning system before site visits and investigations are made
- it shows generally suitable and unsuitable areas for potentially hazardous developments such as landfill sites and piggeries
- it can be adapted to include risk to surface water
- it will assist in the control of developments and enable the location of certain potentially hazardous activities in lower risk areas
- it helps ensure that the pollution acts are not contravened.

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Appendix I Extract taken from Groundwater Protection Schemes (DELG, EPA, GSI, 1999)

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

Land Surface Zoning

Vulnerability Categories

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

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

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

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

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

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

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.

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.					

Source Protection Zones

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

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

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

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

These elements are integrated to give the source protection zones.

Delineation of Source Protection Areas

Two source protection areas are recommended for delineation:

Inner Protection Area (SI);

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

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

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires little technical expertise. However, it can both over- and under-protect. It usually over-protects on the downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

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

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

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

Inner Protection Area (SI)

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

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

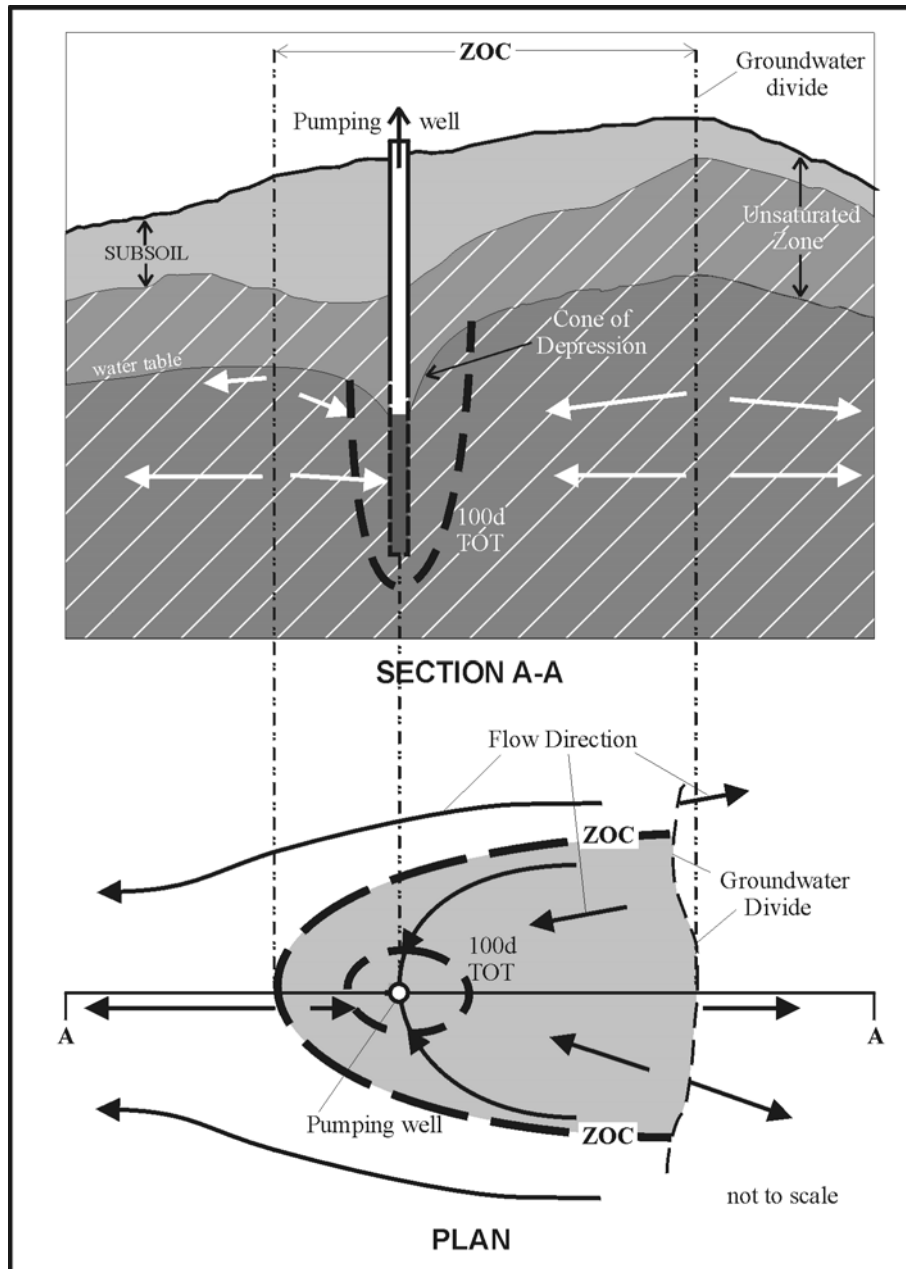
Outer Protection Area (SO)

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

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

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

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



Delineation of Source Protection Zones

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

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

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**)

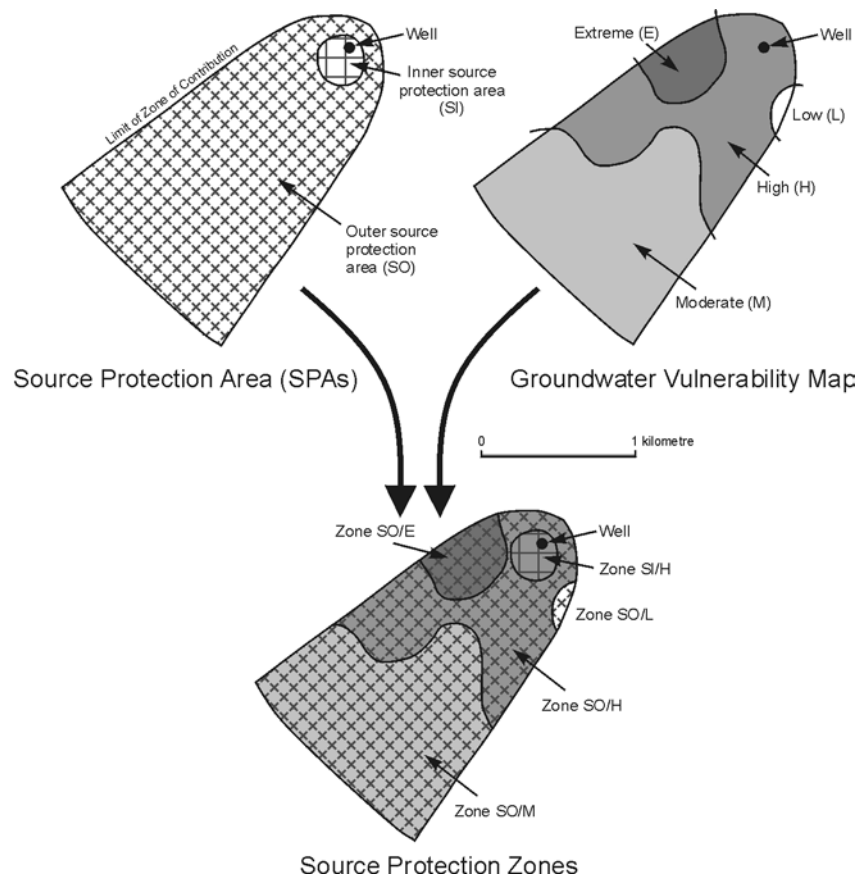


Fig. A.2 Delineation of Source Protection Zones Around a Public Supply Well from the Integration of the Source Protection Area Map and the Vulnerability Map

(iii) Bedrock which is Moderately Productive only in Local Zones (**LI**)

Poor (P) Aquifers

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

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

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

Flexibility, Limitations and Uncertainty

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

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

Groundwater Protection Responses

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.

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	LI	PI	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	LI/E	PI/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	LI/H	PI/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	LI/M	PI/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	LI/L	PI/L	Pu/L

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

R1 Acceptable subject to normal good practice.

R2^{a,b,c,...} Acceptable in principle, subject to conditions in note a,b,c, etc. (The number and content of the notes may vary depending on the zone and the activity).

R3^{m,n,o,...} Not acceptable in principle; some exceptions may be allowed subject to the conditions in note m,n,o, etc.

R4 Not acceptable.

Integration of Groundwater Protection Zones and Response

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

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

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

It is advisable to map existing hazards in the higher risk areas, particularly in zones of contribution of significant water supply sources. This would involve conducting a survey of the area and preparing an inventory of hazards. This may be followed by further site inspections, monitoring and a requirement for operational modifications, mitigation measures and perhaps even closure, as deemed necessary. New potential sources of contamination can be controlled at the planning or licensing stage, with monitoring required in some instances. In all cases the control measures and response category depend on the potential contaminant loading, the groundwater vulnerability and the groundwater value.

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

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

VULNERABILITY RATING	SOURCE PROTECTION		RESOURCE PROTECTION						
	Inner	Outer	Regionally Imp.		Locally Imp.		Poor Aquifers		
			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)

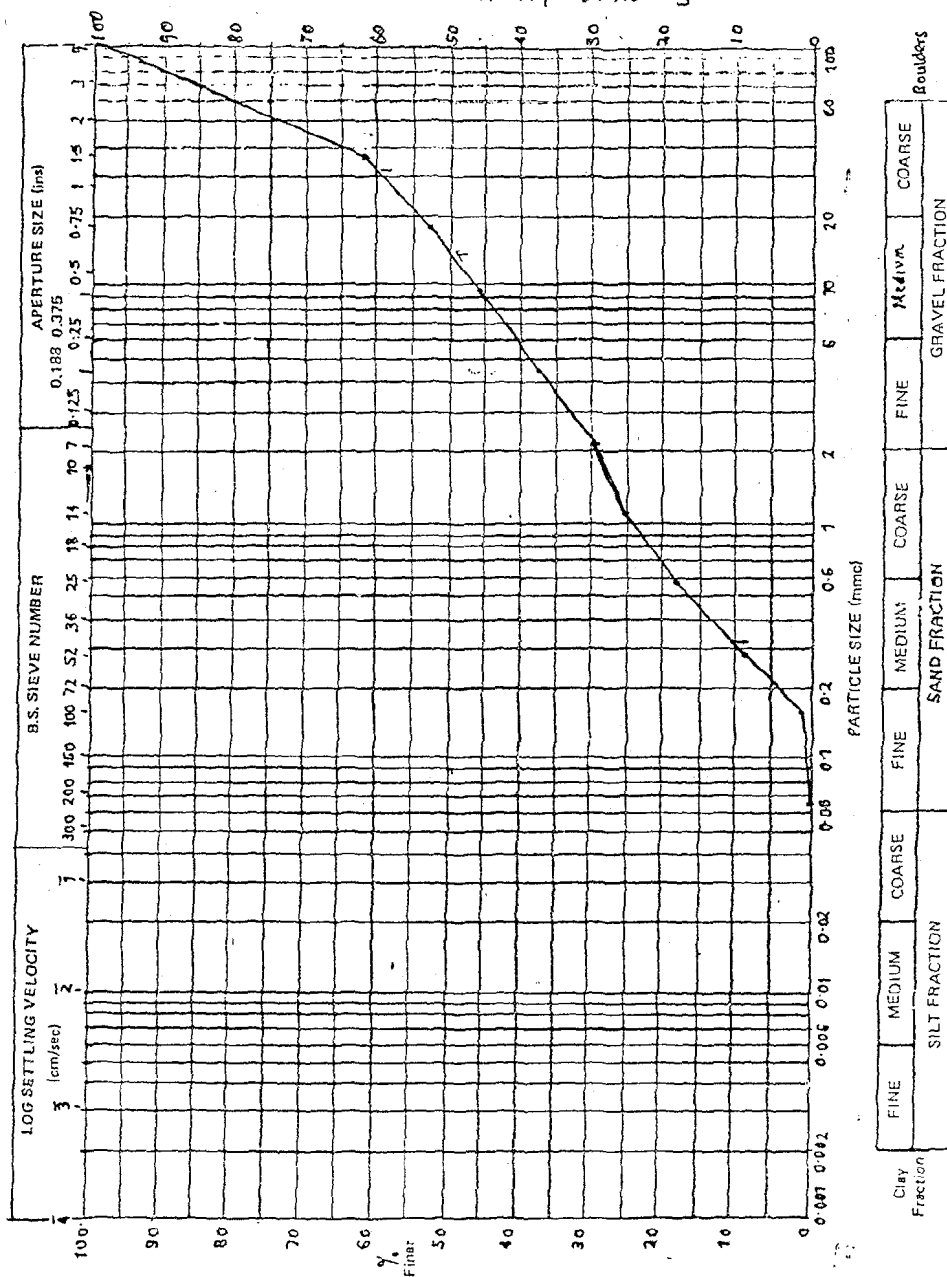
Use of a Scheme

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: IPC-licensable landspreading of organic wastes (primarily piggeries and poultry waste), domestic wastewater treatment systems, and landfills. Additional responses for other potentially polluting activities will be developed in the future.

Appendix II: Particle size data for gravel aquifers

ATHY GRAVELS

B3



PARTICLE SIZE ANALYSIS

VISUAL DESCRIPTION *Grey predominantly sub-rounded gravel.*

Athy Bridge

Report No:

Borehole No: *L-3*

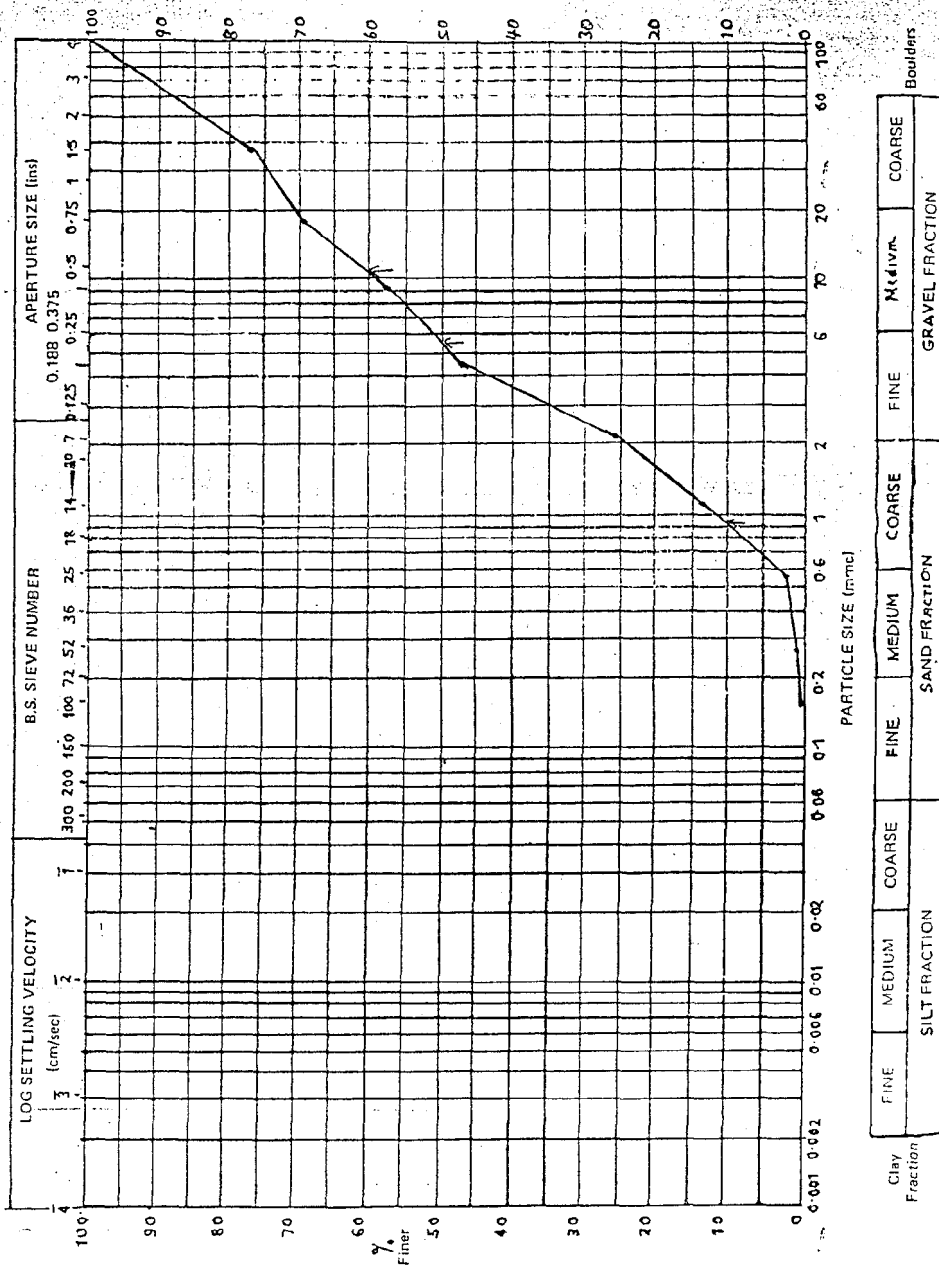
Sample No:

2109

Depth

2.50

ATHY GRAVELS



PARTICLE SIZE ANALYSIS

VISUAL DESCRIPTION

SAND AND SUB-ANGULAR GRAVEL

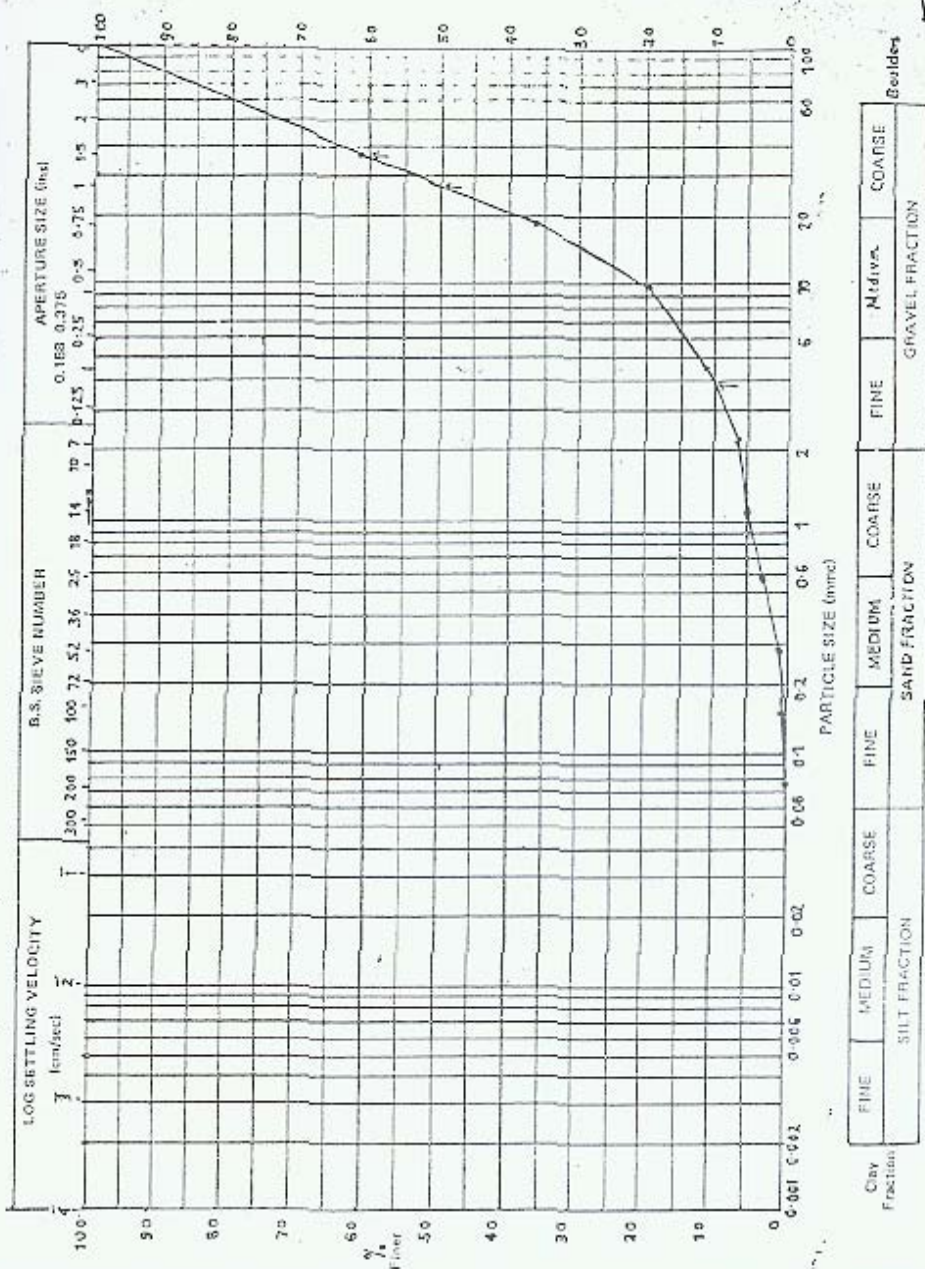
Irish Soil Laboratories Limited

GREEN CORNELL, STURROCK
CO. KILDARE

Athy River	Report No:	Borehole No: B-2
	Sample No: 24924	Depth: 5.50

ATHY GRAVELS.

B1



PARTICLE SIZE ANALYSIS

VISUAL DESCRIPTION *Gray angular gravel.*

Athy Bridge

Report No:

Borehole No:

L-2

Sample No:

2114

Depth

1.65

Location

Arthurstown

Soil description

22 Borehole 8 pits Various levels

Job Ref

Borehole/pit no.

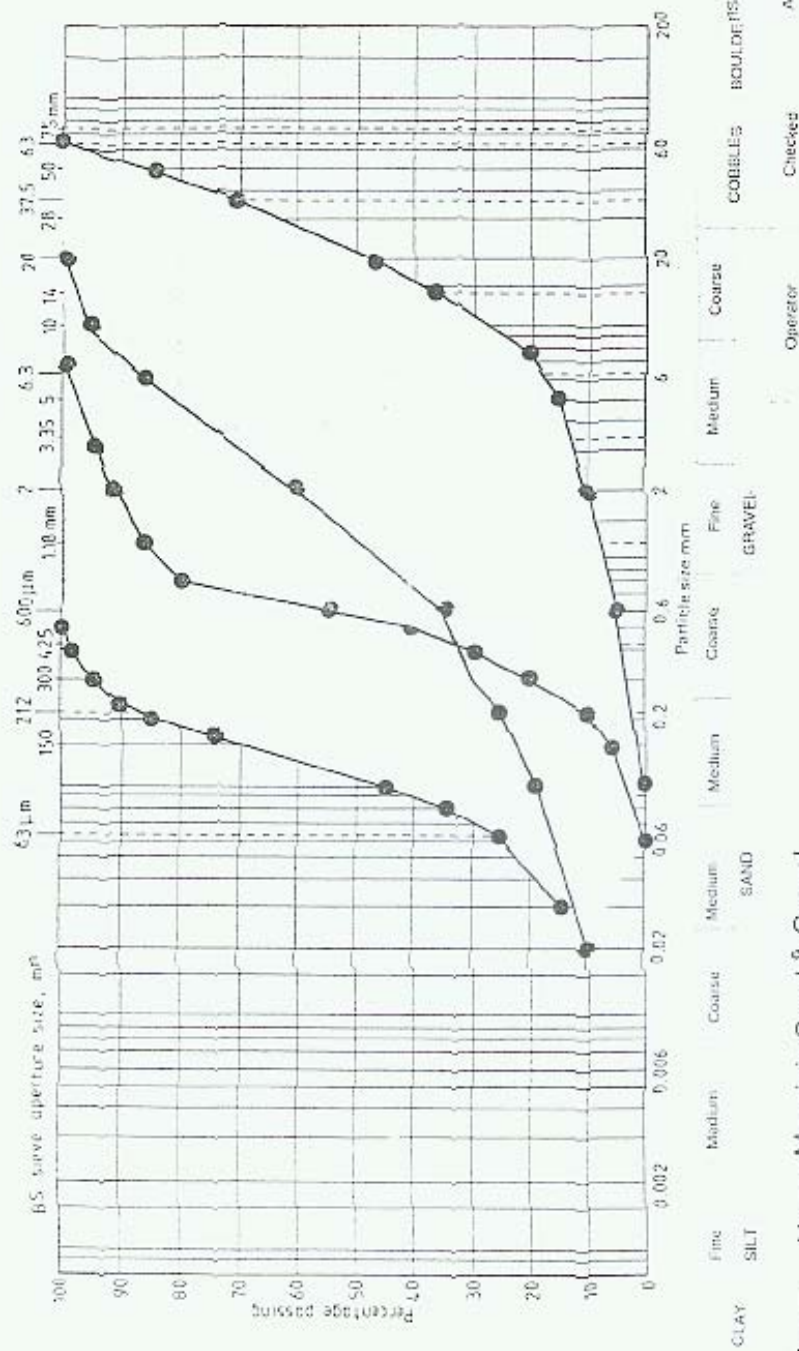
Sample no.

Depth

Date

Test method

BS-PART 2: 1990-9-2

**Fig. 3** Upper Morainic Sand & Gravel

Location...CURRAGH

Sample No ... S 7

Depth 17.5 m

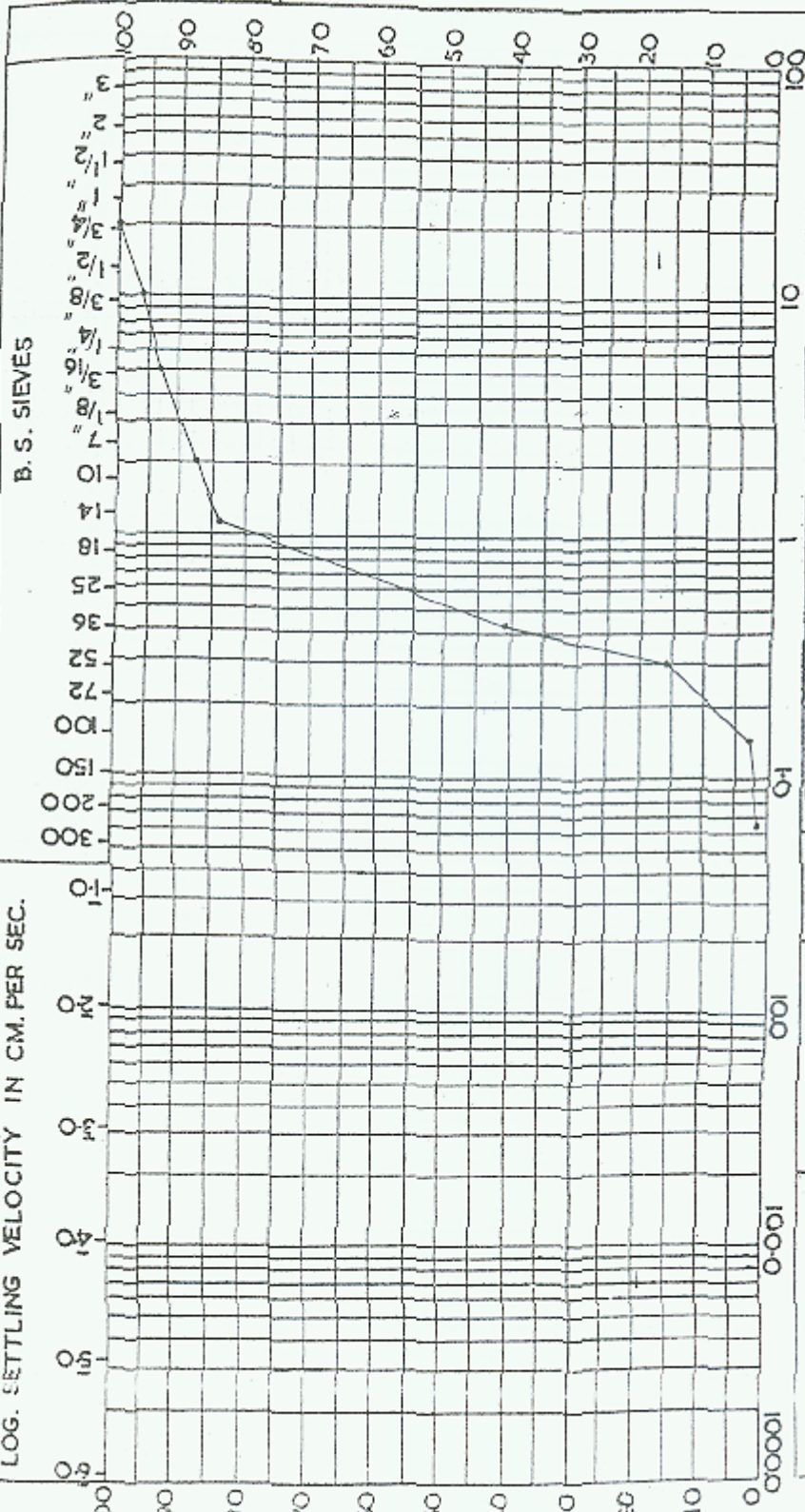
Date of test Aug. 1980

Description...SAND & A LITTLE GRAVEL

Dry sieve

LOG. SETTLING VELOCITY IN CM. PER SEC.

B. S. SIEVES



PARTICLE SIZE IN MM.

Engineering School,
K. P. R. S.

CURRAGH GRAVELS

Location... CURRAGH NO 1

Sample No ... 8 10 Depth 23 m

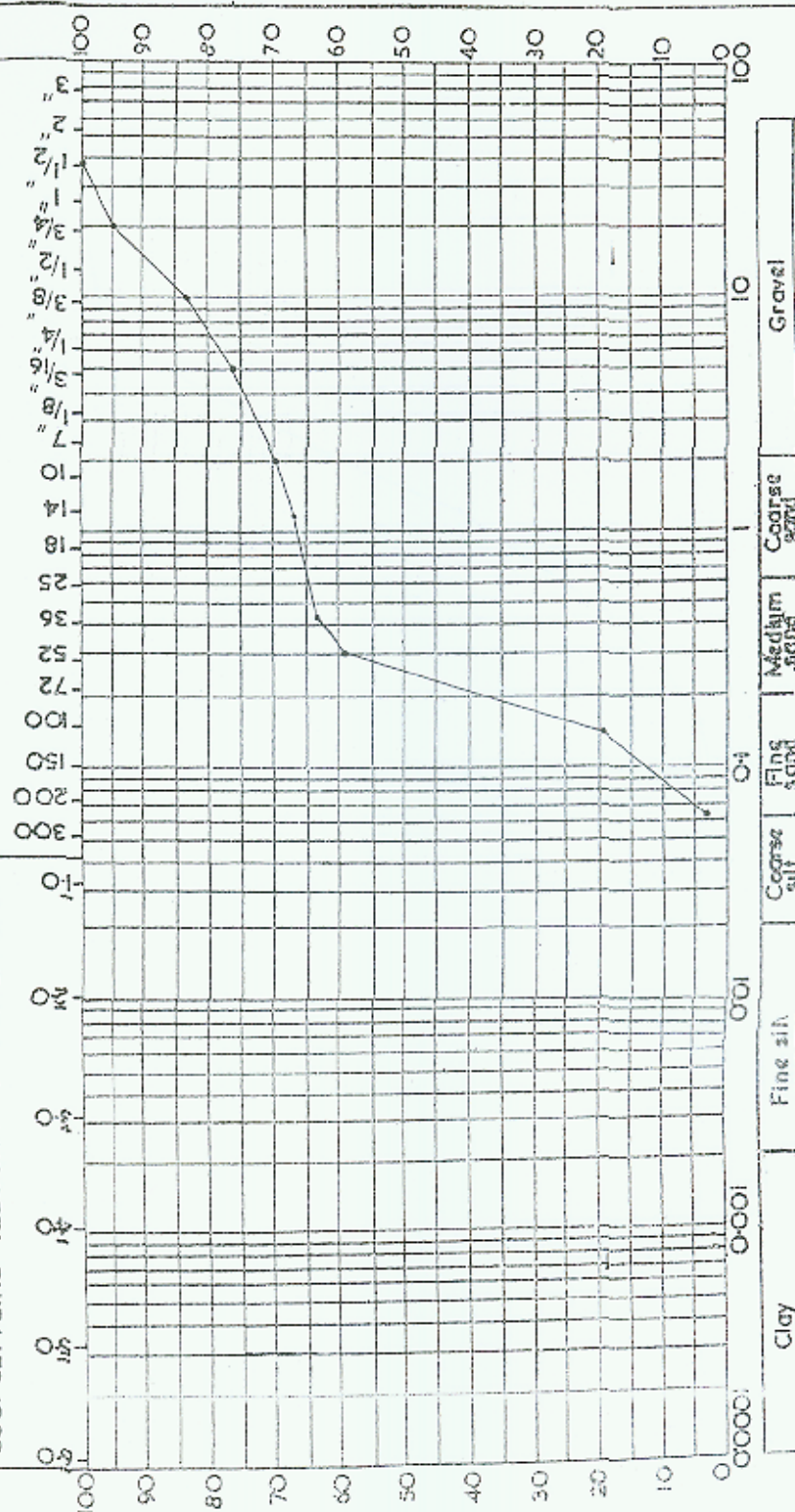
Date of test Aug, 1980

Description... SAND & GRAVEL

Dry sieve

LOG. SETTLING VELOCITY IN CM. PER SEC.

B. S. SIEVES



Engineering School,
K. L. B. S.

Location...CURRAGH No 1.

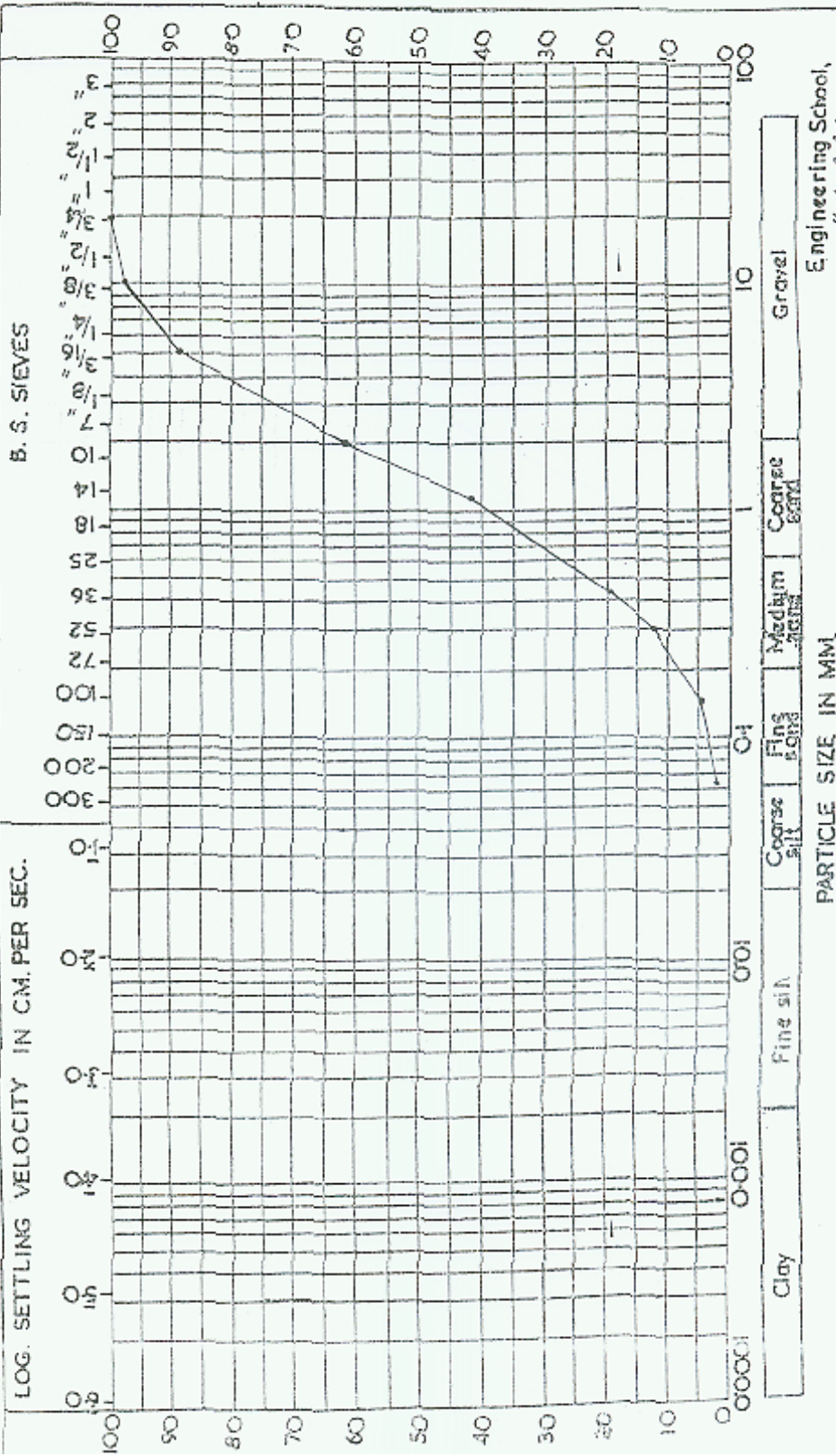
Samplers

Depth 26.5 m

Date of test... Aug 1980

Description SAND & GRAVEL

Dry sieve



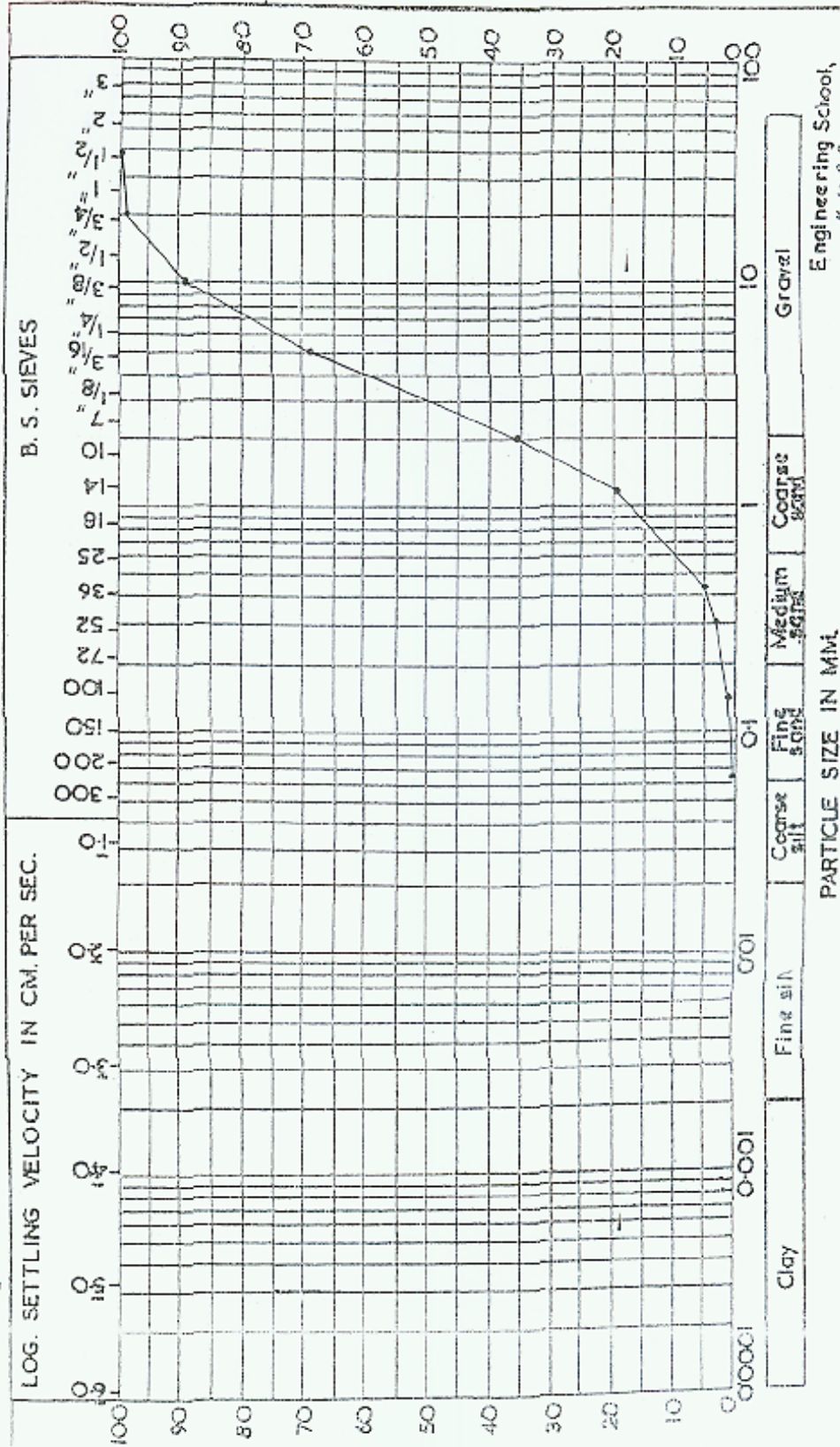
Location... CURRACH No 1

Sample No ... S 14

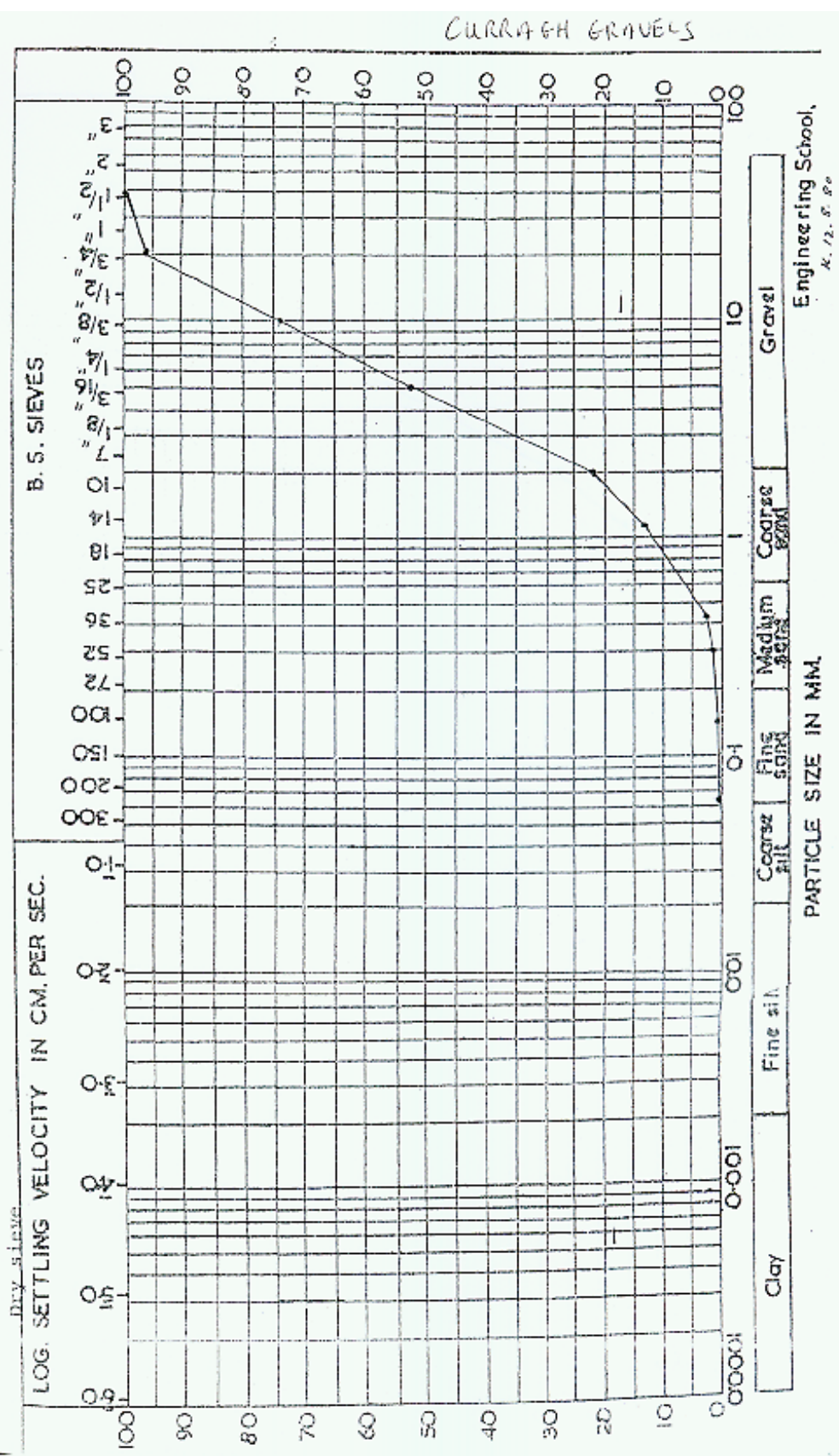
Depth 30 m

Date of test, Aug. 1980

Description... SAND & GRAVEL
Dry sieve.

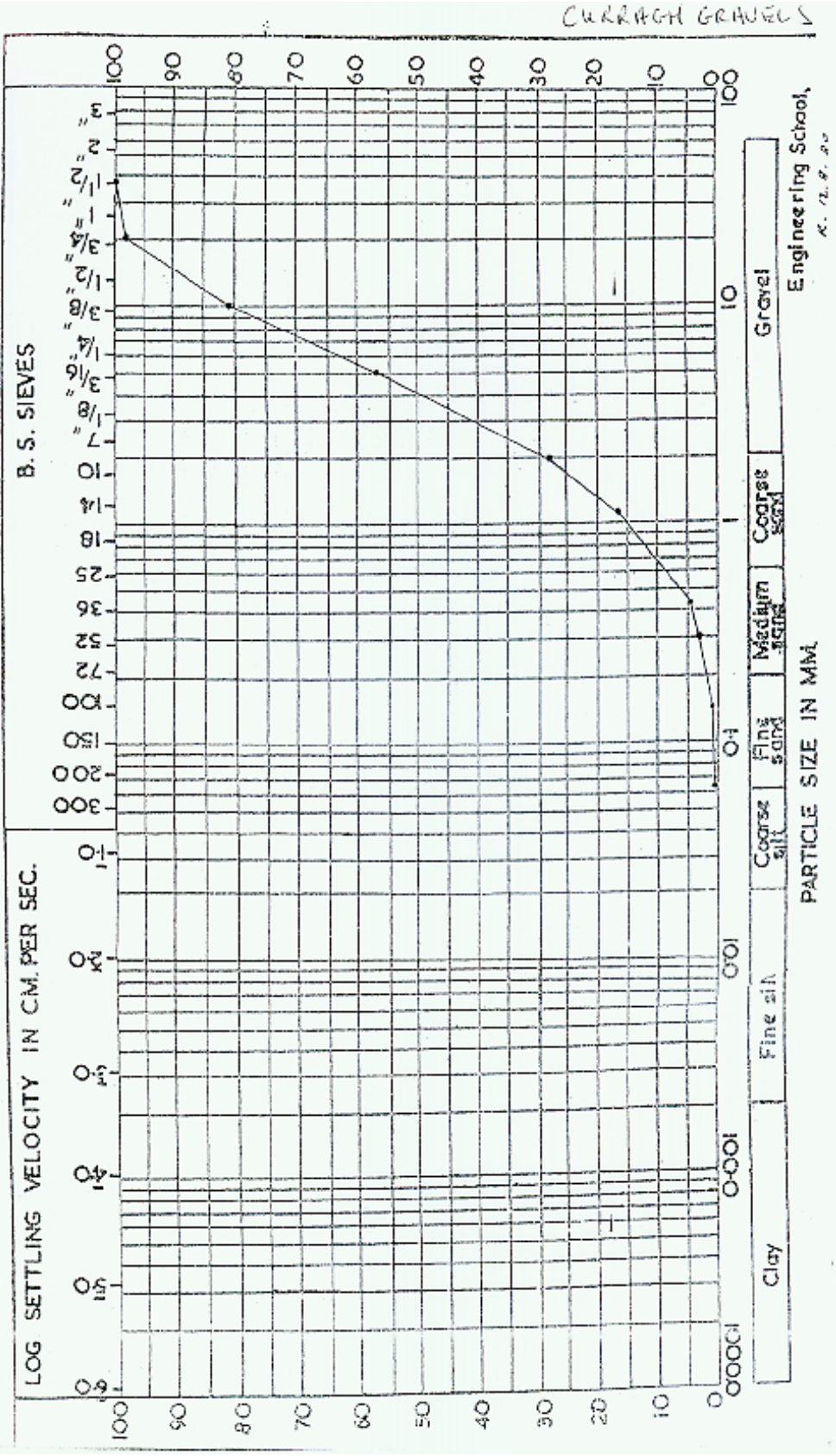


Location... CURRAGH NO 1 Sample No ... S 16 Date of test ... Aug. 1980
 Description... SANDY GRAVEL



Location... CURRAGH NO. 1 Sample No ... S 18 Depth 38.5 m Date of test... Aug 1980

Description... GRAVEL & SAND
Dry sieve



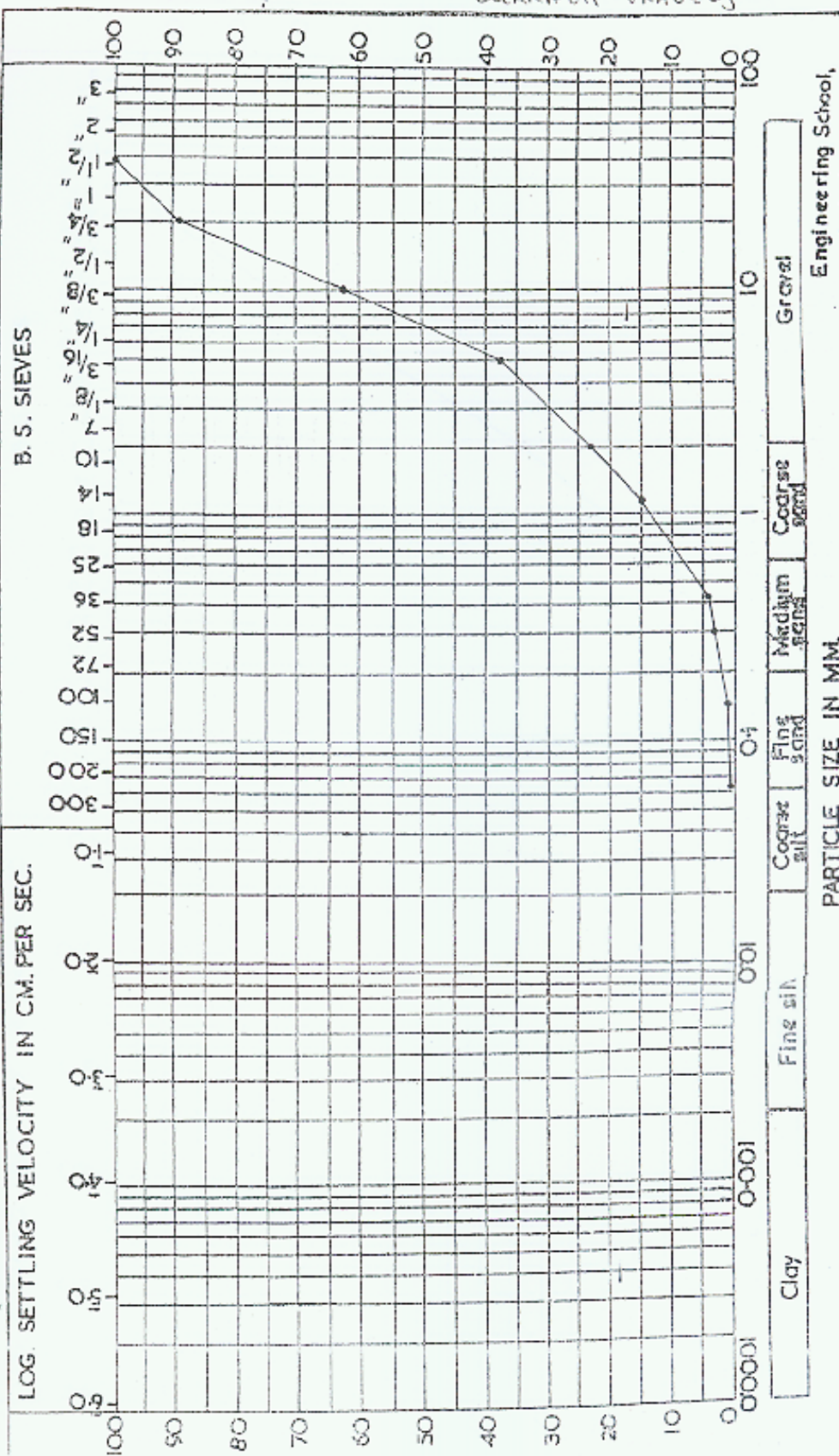
Location...CURRACH No 1

Sample No ... S 24

Depth 54.6 m

Date of test Aug 1980

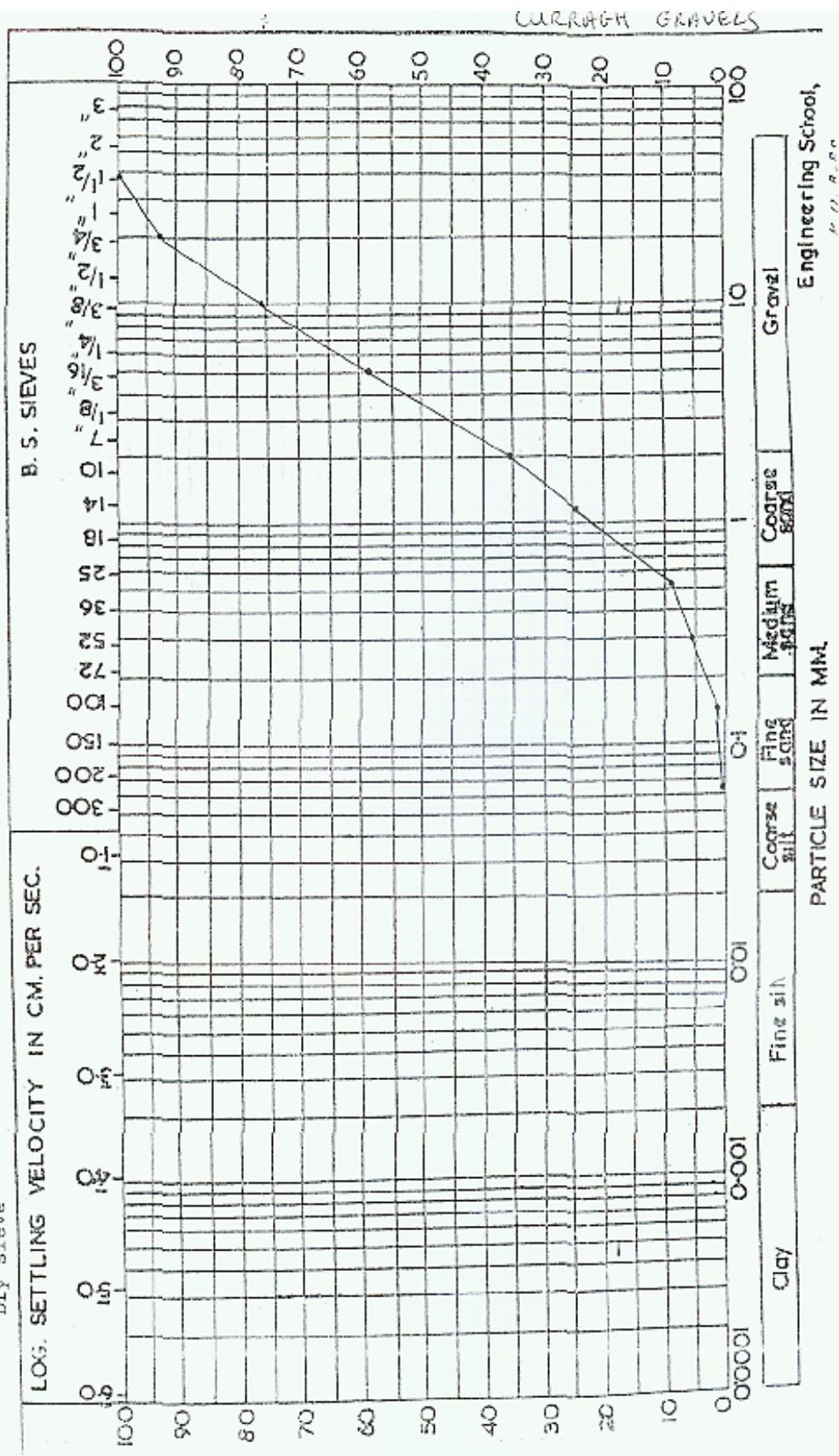
Description...SANDY GRAVEL
Dry sieve.



Engineering School,
A. S. S. S. S.

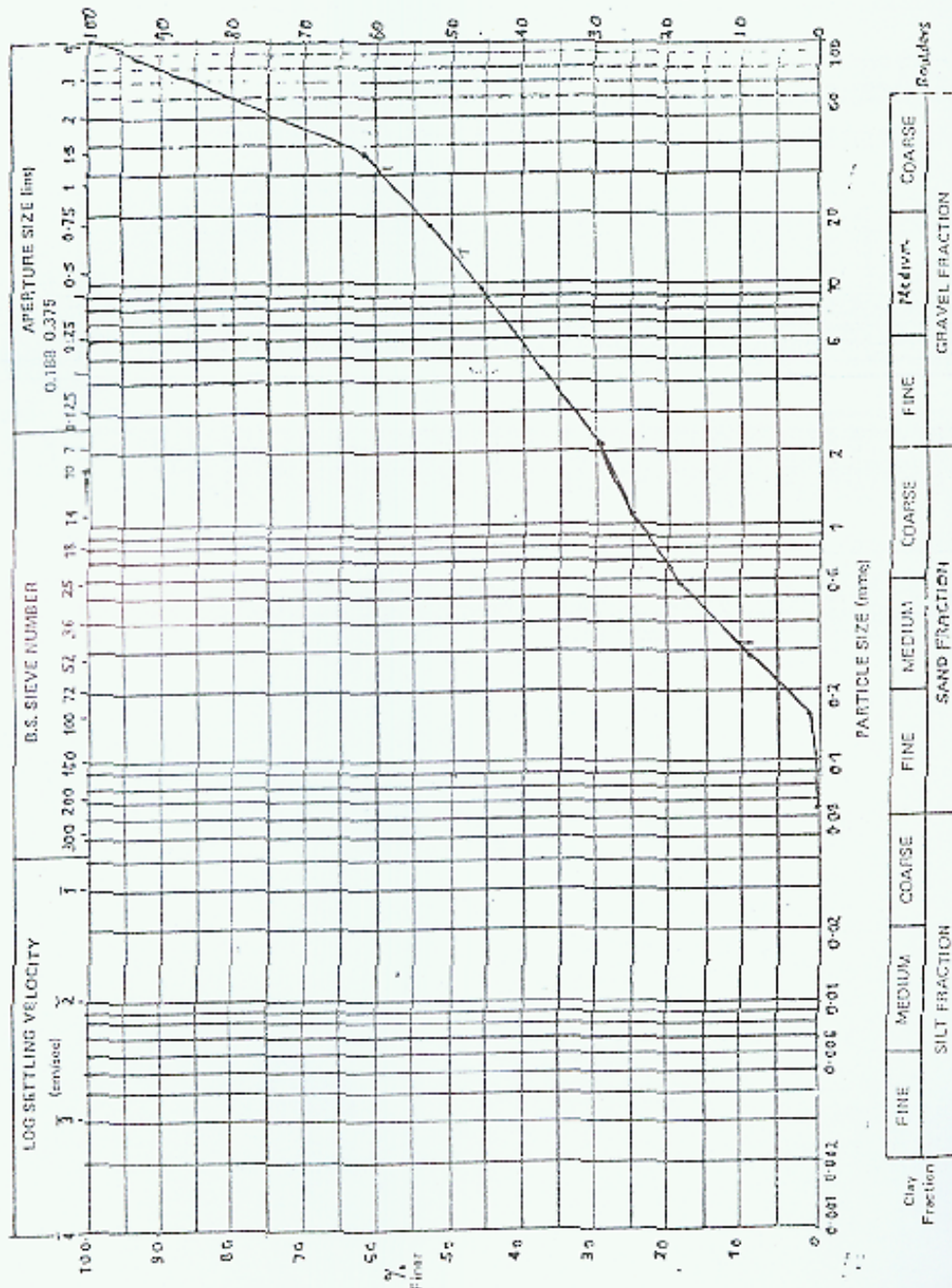
Location... CURRAGH No 1 Sample No ... S 26 Depth 60.5 m Date of test Aug 1980

Description... SAND & GRAVEL
Dry sieve



ATHY GRAVELS

B3



PARTICLE SIZE ANALYSIS

VISUAL DESCRIPTION *Grey predominantly sub-rounded gravel.*

Athy Bridge

Report No:

Borehole No:

Sample No:

2109

Depth

2.50

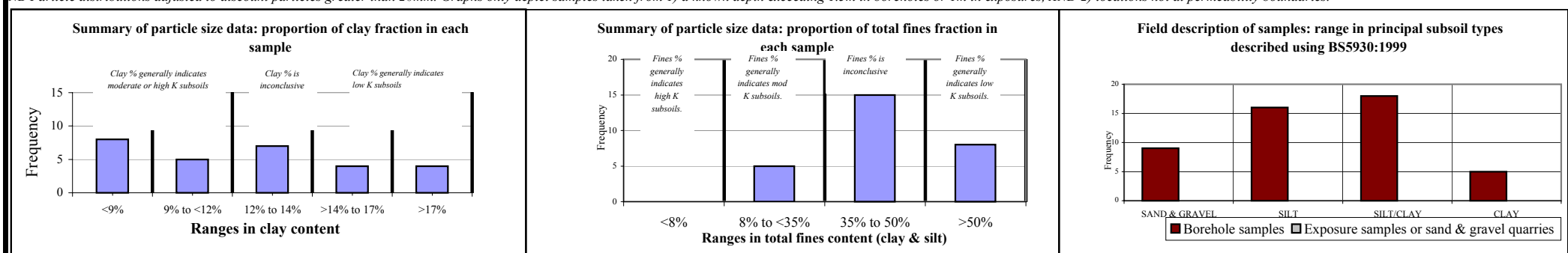
Appendix III: Subsoil permeability decision-making criteria in till areas

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Fontstown Series Soils

Description of unit location:	Undulating to flat. Mostly in the southern half of the county. Strong correlation between fontstown soil type and tillage areas.
Why is this a single K unit?	Occupies 22% of county, largely southern and western parts.
1. General Permeability Indicators and Region Characteristics	
Rock type	Limestone
Depth to bedrock	Generally >3m
Subsoil type	Till
Soil type	Fontstown is the main type. Mylerstown, Mortartstown and Kilpatrick groundwater gley series are included where they are mapped in low-lying Fontstown areas. 28 samples
Vegetation and land use	Pasture and tillage
Artificial drainage density	Few drains
Natural drainage density	Low
Topography and altitude	Undulating-flat topography. 60-150m OD.
Ave. effective rainfall (mm)	The mean ppt is 750-875mm per annum

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

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



3. Data from Permeability Tests.

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

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Limestone Till	>>>	M-L
Particle size data	Wide variation	>>>	M-L
Field description data	Generally silty subsoils	>>>	M
Soil type	Well - excessively drained soil	>>>	M
Artificial drainage density	Generally very low density, but higher density occurs in localised areas.	>>>	M
Natural drainage density	Generally low	>>>	M
Permeability test data	-	>>>	-
Rock type	Limestone (occasionally shaley limestone)	>>>	L-M
Land use	Tillage & Pasture	>>>	M
Overall conclusion		>>>	Moderate

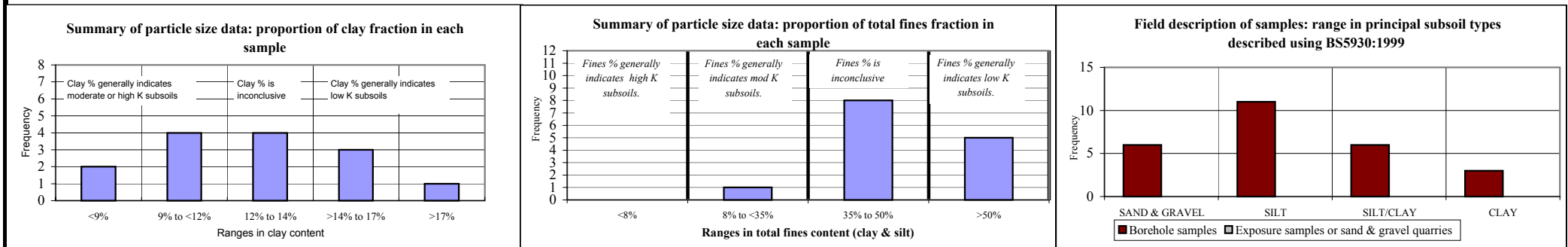
5. COMMENTS: Subsoil permeability indicators are variable, but the soil maps indicate that the area is generally excessively well drained, and field descriptions were mainly silty or sandy subsoils, on balance, a moderate permeability has been assigned. It is likely that the very frequency sand and gravel units mapped on the margins of this unit, are in fact interspersed within it. This would help to increase the overall subsoil permeability.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Elton Series Soils

Description of unit location:	Undulating-flat. Mostly east & north of county. 25% of county.
Why is this a single K unit?	Occupies 25% of the county & largely eastern and northern parts of county.
1. General Permeability Indicators and Region Characteristics	
Rock type	Carrighill, Ballysteen and Calp Formations.
Depth to bedrock	Wide variety of depth to bedrock
Subsoil type	Limestone till, some admixture of shale/granites closer to the wicklow border. Undifferentiated till in the north.
Soil type	Dominantly Elton series. Dunnstown (groundwater gley) is included as the Elton and Dunnstown are associated, with Dunnstown occupying the lower-lying areas. A small pocket of the mortarstown series is also included as it occurs within the Elton series. Fourteen samples were used for Particle Size Analysis.
Vegetation and land use	Pasture/stud farms are found on this soil type.
Artificial drainage density	Low on the elton, some artificial drainage on the dunnstown, particularly around Martinstown.
Natural drainage density	Low
Topography and altitude	Undulating - flat; normally <150m
Ave. effective rainfall (mm)	Precipitation is variable (750-<1000mm)

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

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



3. Data from Permeability Tests.

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

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Limestone till	>>>	M-L
Particle size data	A wide variation	>>>	M
Field description data	Generally silty subsoils	>>>	M
Soil type	Well - excessively drained soil	>>>	M-L
Artificial drainage density	Generally very low density, but higher density occurs in localised areas.	>>>	M
Natural drainage density	Generally low	>>>	M
Permeability test data	-	>>>	-
Rock type	Generally muddy limestones	>>>	L-M
Land use	Tillage and pasture	>>>	M
Overall conclusion		>>>	M

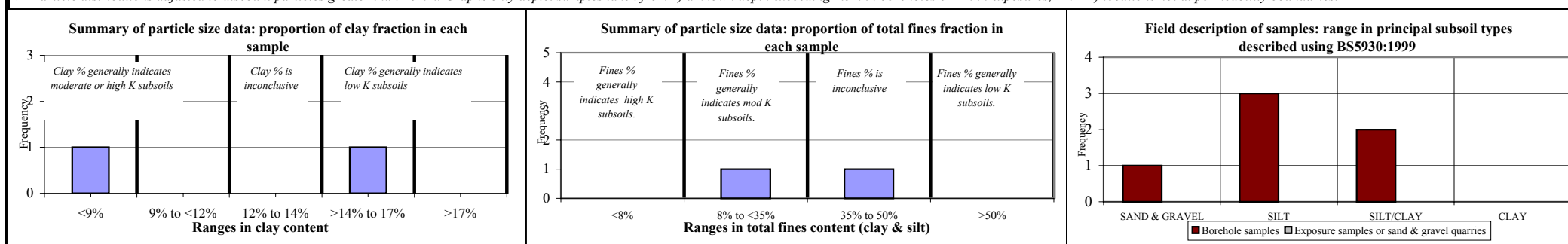
5. COMMENTS: Subsoil permeability indicators are variable, but the soil maps indicate that the area is generally excessively well drained, and field descriptions were mainly silty or sandy subsoils, on balance, a moderate permeability has been assigned. It is likely that the very frequency sand and gravel units mapped on the margins of this unit, are in fact interspersed within it. This would help to increase the overall subsoil permeability.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Kennycourt Series Soils

Description of unit location:	Rolling. 4% of county, eastern part bordering wicklow and dublin.
Why is this a single K unit?	Occupies the lower slopes of the Wicklow mountains.
1. General Permeability Indicators and Region Characteristics	
Rock type	Greywackes & shales
Depth to bedrock	Generally 3-5m
Subsoil type	Limestone till
Soil type	Kennycourt - stony loam, well drained. Six samples.
Vegetation and land use	Pasture
Artificial drainage density	low
Natural drainage density	low
Topography and altitude	150-240 m OD, rolling, 4 degree slopes.
Ave. effective rainfall (mm)	875-1000mm ppt.

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

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



3. Data from Permeability Tests.

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

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Limestone Till	>>>	M-L
Particle size data	Two samples of variable clay fraction.	>>>	H-M
Field description data	Generally silty subsoils	>>>	H-M
Soil type	Well-excessively well drained	>>>	M
Artificial drainage density	No artifical drainage	>>>	M
Natural drainage density	Low	>>>	M
Permeability test data	-	>>>	-
Rock type	Shales	>>>	L-M
Land use	Pasture	>>>	M
Overall conclusion		>>>	M

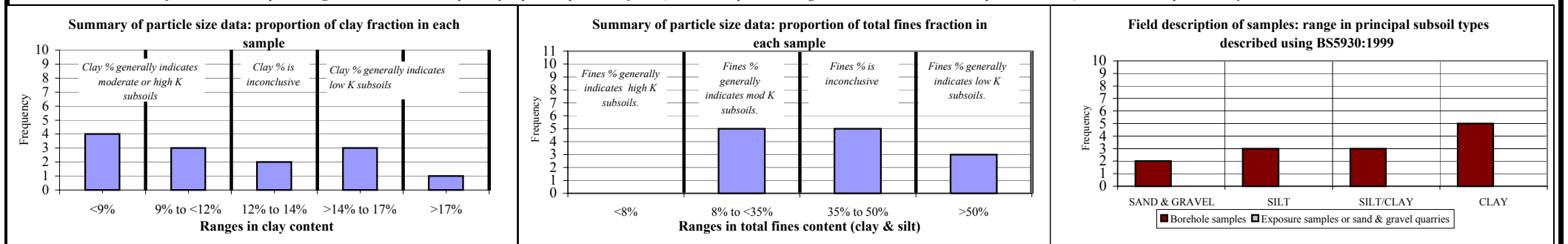
5. COMMENTS: Subsoil permeability indicators are variable, but the soil maps indicate that the area is generally well well drained, and field descriptions were mainly silty subsoils, on balance, a moderate permeability has been assigned. It is likely that the very frequency sand and gravel units mapped on the margins of this unit, are in fact interspersed within it. This would help to increase the overall subsoil permeability.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Straffan Complex

Description of unit location:	Flat - undulating, occupying large areas of North Kildare.
Why is this a single K unit?	Occupies 13% of the county largely north Kildare
1. General Permeability Indicators and Region Characteristics	
Rock type	Calp limestone
Depth to bedrock	Generally 3-5 & 5-10m
Subsoil type	Undifferentiated till
Soil type	Straffan complex comprises 6 soil series mostly gley soils. Thirteen samples were used in the analysis.
Vegetation and land use	Generally pasture, some tillage and some rushy areas.
Artificial drainage density	Considerable areas have undergone artificial drainage, comprising deepening of water courses and installing of closed field drains.
Natural drainage density	High
Topography and altitude	Flat - undulating; 60-90m OD
Ave. effective rainfall (mm)	precipitation is approximately 750mm

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

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



3. Data from Permeability Tests.

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

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability		
Quaternary / subsoil origin	Undifferentiated till	>>>	L-M	
Particle size data	Wide variation	>>>	L-M	
Field description data	Generally clayey subsoils	>>>	L	
Soil type	Mostly gleys, clay loams comprises 70% of complex	>>>	L	
Artificial drainage density	High	>>>	L-M	
Natural drainage density	High	>>>	L-M	
Permeability test data		>>>		
Rock type	Muddy Limestone (Calp Limestone)	>>>	L-M	
Land use	Generally pasture	>>>	M	
Overall conclusion		>>>	L	

5. COMMENTS: Subsoil permeability indicators are variable, but the soil maps indicate that the area is generally poorly drained and field descriptions were mainly clayey subsoils, on balance, a Low permeability has been assigned.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Allenwood Complex

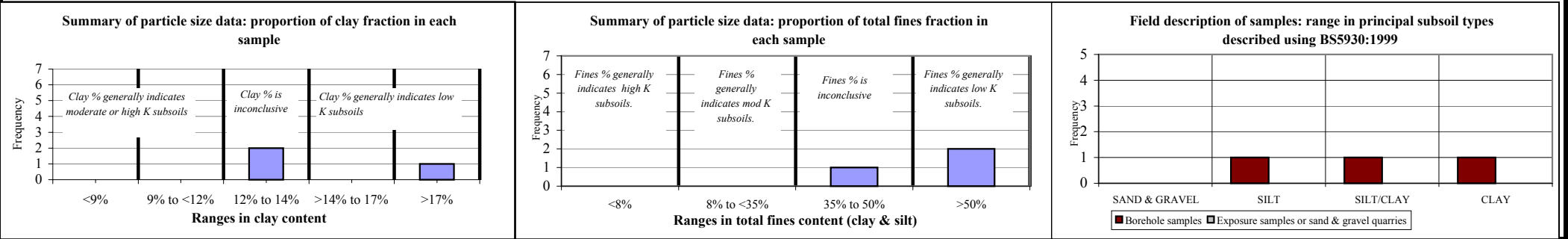
Description of unit location:	The allenwood complex occupies the margins of the peat/bogs (allen + banagher (reclaimed peat)) in the northern part of the county. It comprises the mylerstown gw gley and peaty gleys. Occupies 1% of county.
Why is this a single K unit?	Occupying the areas between the Fontstown/Elton soil series and the Banagher/Allen peat series.

1. General Permeability Indicators and Region Characteristics

Rock type	BN boston hill fmn - nodular muddy lst&shale
Depth to bedrock	Generally greater than 10m
Subsoil type	Undifferentiated till (clayey gravel/gravelly clay)
Soil type	Allenwood complex comprises the mylerstown groundwater gley & peaty gleys, thus a mixture of peaty soils and grey-brown podzolics. Three samples analysed.
Vegetation and land use	Rushes where it is not managed and pasture where it has undergone drainage.
Artificial drainage density	High
Natural drainage density	High
Topography and altitude	Flat.
Ave. effective rainfall (mm)	750-875mm of precipitation.

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

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



3. Data from Permeability Tests.

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

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Undifferentiated till	>>>	L-M
Particle size data	A variation from silty to clayey soils.	>>>	L-M
Field description data	A variation from silty to clayey subsoils.	>>>	L-M
Soil type	Loam-peaty loam-Peat	>>>	L-M
Artificial drainage density	High water table, big deep drains along perimeters and internal closed field drains	>>>	L-M
Natural drainage density	High water table, margins of peat bogs.	>>>	L-M
Permeability test data	-	>>>	none
Rock type	Muddy limestone	>>>	L-M
Land use	Where it has been drained there is rough pasture used for sheep grazing.	>>>	L-M
Overall conclusion		>>>	M

5. COMMENTS: Subsoil permeability indicators are inconclusive, on balance in order to be conservative it is given a moderate permeability.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by

Description of unit location:	Liffey regosol Occupies the flood plain alongside the River Liffey.									
Why is this a single K unit?	Occupies the flood plain alongside the River Liffey.									
1. General Permeability Indicators and Region Characteristics										
Rock type	Predominantly Limestone.									
Depth to bedrock	Generally greater than 10m									
Subsoil type	Limestone and undifferentiated till.									
Soil type	Liffey regosol - alluvium - loam-silty-clay loam. Three samples									
Vegetation and land use	Predominantly pasture									
Artificial drainage density	Low									
Natural drainage density	Low									
Topography and altitude	Generally 60m OD.									
Ave. effective rainfall (mm)	750-875 precipitation.									
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.										
<div>Summary of particle size data: proportion of clay fraction in each sample</div>			<div>Summary of particle size data: proportion of total fines fraction in each sample</div>			<div>Field description of samples: range in principal subsoil types described using BS5930:1999</div>				
3. Data from Permeability Tests.										
T' tests: # Results # Tests T<1 # Tests T>50 min/25mm			Variable head tests (m/sec): # Results Range Values Typical value			Pump tests # Results Range Values Typical value (m/sec):			Lab tests # Results Range Values Typical value (m/sec):	
4. Summary and Analysis										
Criteria	Comments	Implications of each criterion for assessment of subsoil permeability								
Quaternary / subsoil origin	Alluvium	>>> M								
Particle size data	Indicates moderate or high permeability subsoils	>>> L								
Field description data	Variation in the field description.	>>> L-M								
Soil type	Alluvium - well drained - loam	>>> M								
Artificial drainage density	Low	>>> M								
Natural drainage density	Low	>>> M								
Permeability test data	-	>>> -								
Rock type	Limestone	>>>								
Land use	Pasture	>>> M								
Overall conclusion										>>> M
5. COMMENTS: On balance subsoil indicators suggest that the alluvium alongside the River Liffey is moderately permeable.										

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by the Finnerly Complex

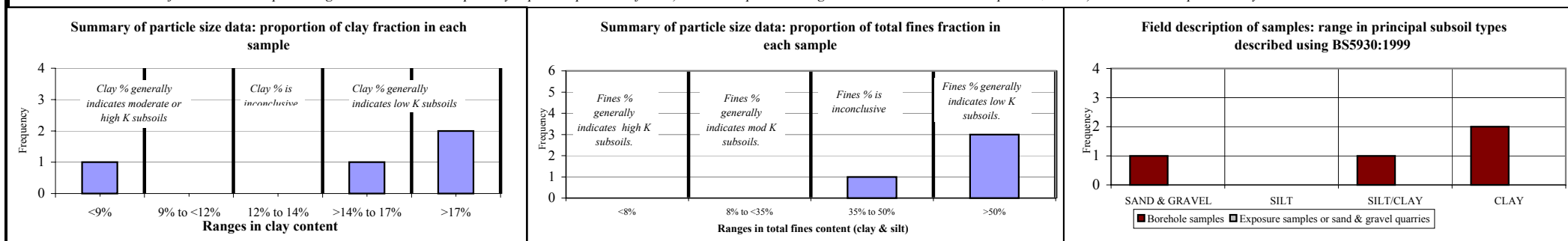
Description of unit location:	Occupying portions of the river valleys in the west of the county. Associated with a high water table all yr. Round. Mapped in Laois as Alluvium (subtypes Po & K), mapped in Limerick as the Camogue series
Why is this a single K unit?	Occupying the flood plains in the western part of Kildare, approximately 2.5% of the county.

1. General Permeability Indicators and Region Characteristics

Rock type	Largely clean shelf limestones.
Depth to bedrock	Generally 5-10 and greater than 10m.
Subsoil type	Alluvium.
Soil type	Finnerly complex comprises organic & mineral materials. Four samples were analysed.
Vegetation and land use	Largely restricted to rough summer grazing.
Artificial drainage density	Large open drains and closed field drains are common.
Natural drainage density	High
Topography and altitude	Flat and low-lying.
Ave. effective rainfall (mm)	Approximately 750mm of precipitation.

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

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



3. Data from Permeability Tests.

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

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Generally alluvium or till.	>>> L-M
Particle size data	Variable with a tendency toward the low permeability end.	>>> L-M
Field description data	Variable, a mixture of sandy and clayey subsoils.	>>> L-M
Soil type	Alluvium and peat	>>> M-L
Artificial drainage density	High	>>> L
Natural drainage density	High	>>> L
Permeability test data		>>> -
Rock type	Limestones.	>>> M-L
Land use	Pasture.	>>> L-M
Overall conclusion		>>> M

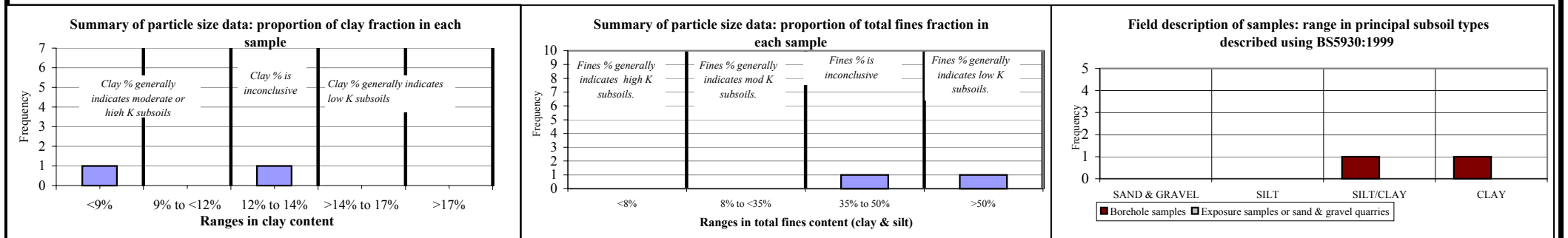
5. COMMENTS: On balance subsoil indicators are not conclusive, to be conservative the complex is given a moderate permeability rating. This is a similar rating to that used in Laois for similar deposits.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by the Garristown Soil Series.

Description of unit location:	Occupy a small area in the very north of kildare adjacent to meath
Why is this a single K unit?	A surface water gley occupying a distinct area in North Kildare.
1. General Permeability Indicators and Region Characteristics	
Rock type	Namurian shales NAM
Depth to bedrock	0-3;3-5m
Subsoil type	Undifferentiated till
Soil type	The Garristown soil series is aheavy textured clay loam of poor structure, and is a surface water gley. Two samples analysed.
Vegetation and land use	Pasture, rushes where there is no artificial drainage.
Artificial drainage density	Drained using closed field drains.
Natural drainage density	Several streams.
Topography and altitude	Rolling
Ave. effective rainfall (mm)	750-875mm of precipitation.

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

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



3. Data from Permeability Tests.

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

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Dense impermeable undifferentiated till	>>>	L-M
Particle size data	Variable and possibly not representative as there are patches of higher permeability material within the series	>>>	M-L
Field description data	Largely clayey subsoils.	>>>	M-L
Soil type	Clay Loam	>>>	L
Artificial drainage density	Closed field drains on sloping ground	>>>	L
Natural drainage density	High	>>>	L
Permeability test data	-	>>>	-
Rock type	Namurian shales (elsewhere in the country are typically associated with low permeability subsoils)	>>>	L
Land use	Pasture with rushy slopes where no field drains.	>>>	L
Overall conclusion		>>>	L

5. Comments Subsoil permeability indicators suggest low permeability and the soil maps indicate that the area is poorly or imperfectly drained, and field descriptions were mainly clayey subsoils, on balance, a Low permeability has been assigned.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Kellistown and Newtown soil series

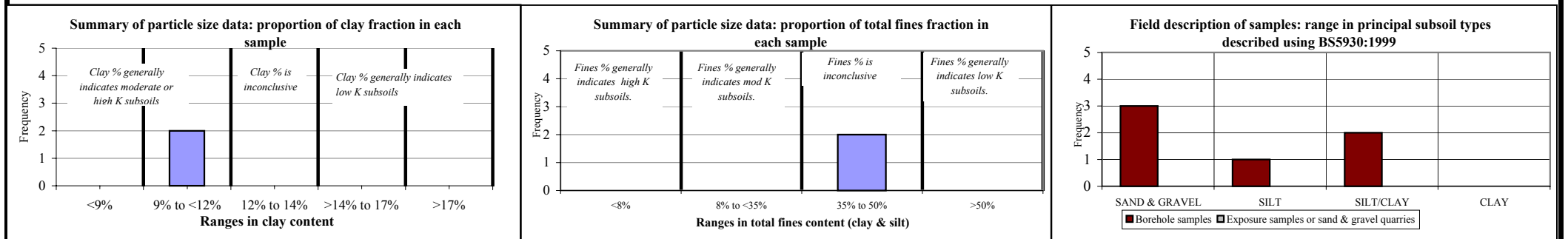
Description of unit location:	Mapped at the southern tip of kildare, intermingled with the Athy cpx and Newtown groundwater gley
Why is this a single K unit?	Occupies 1.6% of the county, confined to the southern tip of the county.

1. General Permeability Indicators and Region Characteristics

Rock type	Granite
Depth to bedrock	Largely 5-10m
Subsoil type	Limestone till
Soil type	The KELLISTOWN soil series, a sandy loam which is well drained. Six samples were used in the analysis.
Vegetation and land use	Largely tillage and pasture.
Artificial drainage density	Low
Natural drainage density	Low
Topography and altitude	Undulating to rolling; 60-120m OD
Ave. effective rainfall (mm)	750-875mm of precipitation.

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

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



3. Data from Permeability Tests.

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

4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability
Quaternary / subsoil origin	Limestone tills with less than 20% granite/shale admixture.	>>> M
Particle size data	Suggests moderate or high permeability subsoil.	>>> M-H
Field description data	Generally sandy or silty subsoils.	>>> M
Soil type	Generally a well drained sandy loam.	>>> M
Artificial drainage density	Low	>>> M-H
Natural drainage density	Low	>>> M-H
Permeability test data	-	>>> -
Rock type	Granite	>>> M
Land use	Tillage and pasture	>>> M
Overall conclusion		>>> M

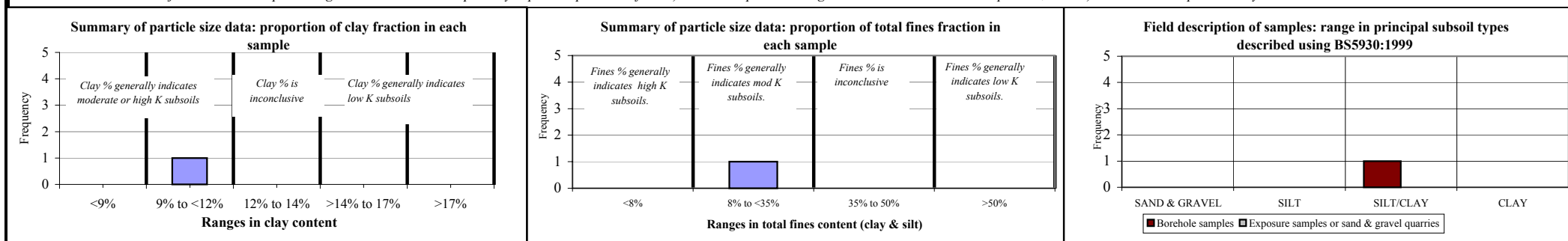
5. Comments: Subsoil permeability indicators suggest moderate-high permeability and the soil maps indicate that the area is generally excessively well drained, on balance, a moderate permeability has been assigned. It is likely that the very frequency sand and gravel units mapped on the margins of this unit, are in fact interspersed within it. This would help to increase the overall subsoil permeability.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Grange Series Soils

Description of unit location:	Extreme north east of kildare occupying 0.33% of the county.
Why is this a single K unit?	A unique soil type to Kildare, occupying a small area of the county.
1. General Permeability Indicators and Region Characteristics	
Rock type	Calp 1st (CD)
Depth to bedrock	generally <5m and <3m in parts with outcrop
Subsoil type	Limestone till
Soil type	Grange soil series - The 'C' horizon is a gritty to sandy loam with some gravel pockets. One sample taken.
Vegetation and land use	Pasture
Artificial drainage density	Low
Natural drainage density	Low
Topography and altitude	undulating (3-4degs), 70mOD
Ave. effective rainfall (mm)	precipitation approximately 750mm/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: # Results min/25mm	# Tests T<1	# Tests T>50	Variable head tests (m/sec):	# Results	Range Values	Typical value	Pump tests # Results (m/sec):	Range Values	Typical value	Lab tests # Results (m/sec):	Range Values	Typical value
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4. Summary and Analysis

Criteria	Comments	Implications of each criterion for assessment of subsoil permeability	
Quaternary / subsoil origin	Limestone Till	>>>	L-M
Particle size data	The one sample suggests moderate or high permeability	>>>	M
Field description data	The one sample suggests a silty to clayey subsoil.	>>>	L-M
Soil type	Well drained gritty sandy loam	>>>	M
Artificial drainage density	Low	>>>	M
Natural drainage density	Low	>>>	M
Permeability test data		>>>	
Rock type	Muddy limestone	>>>	L-M
Land use	Pasture	>>>	M
Overall conclusion		>>>	M

5. Comments: Subsoil permeability indicators suggest moderate-high permeability and the soil maps indicate that the area is generally excessively well drained, on balance, a moderate permeability has been assigned.

Summary of Permeability Data and Analyses for Subsoils Mapped as Till, and Overlain by Donaghcrumper Series

Description of unit location:	Extreme north east of kildare occupying 0.35% of the county.										
Why is this a single K unit?	A unique soil type to Kildare, occupying a small area of the county.										
1. General Permeability Indicators and Region Characteristics											
Rock type	Calp (muddy) limestone										
Depth to bedrock	generally <5m and <3m in parts with outcrop										
Subsoil type	Limestone till										
Soil type	Donaghcrumper Series - grey brown podzolic, moderately well drained loam-clay loam. One sample.										
Vegetation and land use	Generally pasture										
Artificial drainage density	Low										
Natural drainage density	Low										
Topography and altitude	Flattish to undulating; 61m OD										
Ave. effective rainfall (mm)	750mm precipitation approximately										
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.											
<div>Summary of particle size data: proportion of clay fraction in each sample</div>				<div>Summary of particle size data: proportion of total fines fraction in each sample</div>				<div>Field description of samples: range in principal subsoil types described using BS5930:1999</div>			
3. Data from Permeability Tests.											
T' tests: # Results # Tests T<1 # Tests T>50 min/25mm			Variable head # Results Range Values Typical value tests (m/sec):			Pump tests # Results Range Values Typical value (m/sec):			Lab tests # Results Range Values Typical value (m/sec):		
4. Summary and Analysis											
Criteria	Comments					Implications of each criterion for assessment of subsoil permeability					
Quaternary / subsoil origin	Limestone Till					>>> L-M					
Particle size data	Only one sample - inconclusive					>>> L-M					
Field description data	Only one sample that suggests clayey subsoil.					>>> L-M					
Soil type	Grey brown podzolic; loam to clay loam that is moderately well drained.					>>> M					
Artificial drainage density	Low					>>> M					
Natural drainage density	Low					>>> M					
Permeability test data	-					>>>					
Rock type	Muddy limestone					>>> L-M					
Land use	Pasture					>>> L-M					
Overall conclusion						>>> M					
5. Comments: Subsoil permeability indicators suggest moderate-low permeability and the soil maps indicate that the area is generally well drained, on balance, a moderate permeability has been assigned.											