County Kilkenny Groundwater Protection Scheme

Volume I: Main Report July 2002



Dunmore Cave, County Kilkenny (photograph Terence P. Dunne)

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Table of Contents

1	INTRODUCTION	5
	1.1 GROUNDWATER PROTECTION – A PRIORITY ISSUE FOR LOCAL AUTHORITIES	
	1.2 GROUNDWATER – A RESOURCE AT RISK	5
	1.3 GROUNDWATER PROTECTION THROUGH LAND-USE PLANNING: A MEANS OF PREVENTING	
	CONTAMINATION	6
	1.4 'GROUNDWATER PROTECTION SCHEMES' – A NATIONAL METHODOLOGY FOR PREVENTING	
	GROUNDWATER POLLUTION	6
	1.5 OBJECTIVES OF THE COUNTY KILKENNY GROUNDWATER PROTECTION SCHEME	7
	1.6 SCOPE OF COUNTY KILKENNY GROUNDWATER PROTECTION SCHEME	
	1.7 KILKENNY COUNTY DEVELOPMENT PLAN	9
	1.8 STRUCTURE OF KEPORT	9
	1.9 ACKNOWLEDGEMENTS	9
2	BEDROCK GEOLOGY	12
	2.1 INTRODUCTION	
	2.2 CAMBRIAN ROCKS.	
	2.3 ORDOVICIAN ROCKS	
	2.4 IGNEOUS ACTIVITY	
	2.5 SILURIAN	
	2.6 DEVONIAN	16
	2.7 LOWER CARBONIFEROUS ROCKS	17
	2.7.1 Courceyan Rocks	17
	2.7.2 Visean Rocks	
	2.8 UPPER CARBONIFEROUS ROCKS	19
	2.8.1 Namurian Rocks	
	2.8.2 Westphalian Rocks	
	2.9 POST CARBONIFEROUS KOCKS	
	2.10 STRUCTURAL HISTORY	
3	SUBSOIL (QUATERNARY) GEOLOGY	22
	3.1 INTRODUCTION	22
	3.2 SUBSOIL TYPES	22
	3.2.1 Till	22
	3.2.2 Sands and gravels	22
	3.2.3 'Till with gravel'	
	3.2.4 Alluvial deposits	
	3.2.5 Peat	
	3.2.6 Lake deposits	
	3.3 DEPTH TO BEDROCK	
	3.4 ICE FLOW DIRECTION	
4	HYDROGEOLOGY AND AQUIFER CLASSIFICATION	25
		25
	4.1 INTRODUCTION 42 DATA AVAILABILITY	23
	4.3 RAINFALL EVAPOTRANSPIRATION AND RECHARGE	25
	4.4 GROUNDWATER USAGE	26
	4.5 BACKGROUND TO AOUJEER CLASSIFICATION	26
	4.5.1 Introduction	
	4.5.2 Bedrock Aquifers	
	4.5.3 Sand/Gravel Aquifers	27
	4.5.4 Aquifer Classification Criteria	
	4.6 CLASSIFICATION OF THE SOUTHERN UPLANDS SLATE, SANDSTONE AND GRANITE AQUIFERS	32
	4.7 CLASSIFICATION OF THE ORDOVICIAN VOLCANIC AQUIFER (CA, CARS, KI, FV, IV)	35
	4.8 CLASSIFICATION OF THE KILTORCAN SANDSTONE AQUIFER (KT AND PG)	
	 4.8 CLASSIFICATION OF THE KILTORCAN SANDSTONE AQUIFER (KT AND PG) 4.9 CLASSIFICATION OF THE LOWER LIMESTONE SHALE AQUIFER (BV, BT) 	

	4.11	CLASSIFICATION OF THE WAULSORTIAN LIMESTONE AQUIFER (WA)	. 39
	4.12	CLASSIFICATION OF THE CROSSPATRICK, KILSHEELAN AND SILVERSPRING AQUIFERS (CS, SS, KS).	. 41
	4.13	CLASSIFICATION OF THE AGHMACART, DURROW AND BUTLERSGROVE LIMESTONE AQUIFER (AG, I	ЭW,
	BU)	42	
	4.14	CLASSIFICATION OF THE DOLOMITE AQUIFER (BADO, WADO, BUDO, AGDO)	43
	4.15	CLASSIFICATION OF THE KARST LIMESTONE AQUIFER (BM, BMDO, CL)	45
	4.16	CLASSIFICATION OF THE NAMURIAN AND WESTPHALIAN SHALE AQUIFER (LS, KN, KNCF, BE, MC	
	CQ, LF	F, LFGC)	. 48
	4.17	CLASSIFICATION OF THE SWAN AND CLAY GALL SANDSTONE AQUIFERS (CQSS AND CG)	49
	4.18	CLASSIFICATION OF THE SAND AND GRAVEL AQUIFERS	. 50
	4.18	.1 Introduction	. 50
	4.18	.2 Kilmanagh River Gravels	. 51
	4.18	3.3 Nore Gravels	. 52
	4.18	2.4 Nuenna Gravels	. 53
	4.18	2.5 Dinin Gravels	. 54
5	GR	OUNDWATER VULNERABILITY	. 55
	51 D		
	5.1 IP		. 33
	5.2 S	OURCES OF DATA	. 30
	5.5 F.	EKMEABILITY OF THE SUBSOILS	. 50
	5.2	1 Methodology	. 50
	5.3.2	2 LOW Fermedollily	. 50
	5.3.	9 Moderale Fermedollity. 4 High Dormoghility	. 59
	534	 Itign 1 er medululy Areas where rock is close to the surface 	. 01
	531	6 Made Ground	. 02
	54 T	HICKNESS OF THE UNSATURATED ZONE	. 02
	5.4 D	IFICKINESS OF THE ONSATURATED ZONE	. 02
	5.5 D	ROUNDWATER VIII NERABII ITY DISTRIBUTION	. 05
,		AUNDWATED DEATECTION ZONES AND DESDONSES	. 05
0	GRU	UUNDWATER PROTECTION ZONES AND RESPONSES	. 04
	6.1 IN	NTRODUCTION	. 64
	6.2 G	ROUNDWATER PROTECTION MAPS	. 64
	6.3 G	ROUNDWATER SOURCE PROTECTION REPORTS AND MAPS	. 64
	6.4 In	NTEGRATION OF GROUNDWATER PROTECTION ZONES AND RESPONSES	. 65
	6.5 C	ONCLUSIONS	. 65
R	EFERE	NCES	. 67

Appendix I: Extract from: 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

Appendix II: Paper by Michael Conry: Kilkenny's 'Golden Vein': it's Soils, Land-use and Agriculture (Conry, 1974).

Appendix III: Permeability Regions in County Kilkenny.

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

1.2 Groundwater – A Resource at Risk

Groundwater 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: farmyard wastes (silage effluent, soiled water), effluent from onsite systems (septic tanks), leakages, spillages, non-agricultural pesticides, landfill leachate, contaminated sinking streams;
- (b) diffuse sources spreading of fertilisers (organic and inorganic) and pesticides.

While point sources have caused most of the contamination problems identified to date, there is evidence that diffuse sources are increasingly impacting on groundwater.

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

There are a number of ways of preventing 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:

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

These are shown schematically in Fig. 1.1.

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



Figure 1.1: Summary of the Main Components of a Groundwater Protection Scheme

There are three main hydrogeological elements to land surface zoning:

- Division of the entire land surface according to the **vulnerability** of the underlying groundwater to contamination. This requires 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.

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

1.5 Objectives of the County Kilkenny Groundwater Protection Scheme

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

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

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

- (i) delineation of aquifers
- (ii) assessment of the groundwater vulnerability to contamination
- (iii) delineation of protection areas around eight public supply wells and springs, identified by Kilkenny County Council (Bennettsbridge, Callan, Glenmore, Paulstown, Piltown, Thomastown, Urlingford-Johnstown, and Graiguenamanagh)
- (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 area maps: Maps 8 and 9

(iii) Land-use Planning Map

• groundwater protection scheme maps: Map 7 (resource protection zones) and Map 10 (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 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 in that they will be of direct relevance to the planning process.

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

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

1.7 Kilkenny County Development Plan

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

1.8 Structure of Report

The structure of this report is based on the information and mapping requirements for land surface zoning. The Groundwater 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 10) results from combining vulnerability (Map 9) and source protection area maps (Map 8). The source protection areas are based largely on assessments of hydrogeological data. This is illustrated in Fig. 1.3.

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

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

Volume II: Chapter 7 outlines the available information on regional-scale groundwater quality patterns in the county. Chapters 8 to 15 provide an assessment of eight of the public groundwater supply sources currently in use in the county. Chapter 16 discusses source protection issues in relation to the domestic, group scheme and industrial supplies in Kilkenny.

1.9 Acknowledgements

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



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

2 Bedrock Geology

2.1 Introduction

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

The rocks range in age from Cambrian (c. 510 million years old) to the Westphalian of the Upper Carboniferous (c. 300 million years old) and are mainly sedimentary in origin, consisting of limestones, sandstones and shales (see Table 2.1).

The landscape of Co. Kilkenny reflects its varied underlying geology. The South Kilkenny Uplands from Graiguenamanagh in the east across to Windgap in the west consist largely of resistant Devonian sandstone with older, less competent Cambrian, Ordovician and Silurian aged rocks in their cores. The younger and more soluble Carboniferous aged limestones underlie the Central Lowlands area from Goresbridge to Callan. The youngest rocks in Kilkenny comprise mainly sandstones and shales, with minor amounts of coal, and are found in the upland area in the north of the county which stretches from Castlecomer to the Slieveardagh hills.

The geology of the county is complex with both temporal and lateral changes in rock composition (see Table 2.1 for a summary). A brief description of the different rock units and their inter-relationships is given in this report; a more detailed description is given in Archer et al (1996), Tietzsch-Tyler and Sleeman (1994a), Sleeman and McConnell (1995), and Tietzsch-Tyler and Sleeman (1994b). In describing the rock units the emphasis is placed on the rock lithology or composition because this is the feature of most relevance to groundwater flow. The formal rock formation name and letter code is also given to enable hydrogeologists to link the brief descriptions in this report to the more detailed descriptions in the literature. The rocks are described in groups according to their age, starting with the oldest:

- (i) Cambrian Rocks^{*};
- (ii) Ordovician Rocks^{*};
- (iii) Silurian Rocks *;
- (iv) Caledonian intrusions (granite);
- (v) Devonian Old Red Sandstones;
- (vi) Lower Carboniferous Rocks;
- (vii) Namurian (Upper Carboniferous) Rocks;
- (viii)Westphalian (Upper Carboniferous) Rocks.

The bedrock geology of the area is shown in Map 1. This map was compiled from the Bedrock Geology 1:100,000 scale GSI map series, Sheets 18, 19, 22 and 23. (Archer et al, 1996, Tietzsch-Tyler and Sleeman, 1994a, Sleeman and McConnell, 1995 Tietzsch-Tyler and Sleeman, 1994b).

2.2 Cambrian Rocks

The Cambrian rocks are the oldest rocks in Kilkenny, cropping out in only one area to the south, around Carricktriss Gorse. They are known as the **Carricktriss Formation (CK)**. They originated in

^{*}The Cambrian, Ordovician and Silurian rocks are also collectively referred to as the Lower Palaeozoic rocks.

a volcanically active region in an oceanic environment where they accumulated as layer upon layer of mud, interspersed with volcanics. They are described as green pyroclastic rocks and dark silty slates, and are estimated to be 800 m thick.

2.3 Ordovician Rocks

During Ordovician times, the south east of Ireland is believed to have been part of a large north east trending trough on the base of an ocean known as the Iapetus. Fine material accumulated in this trough having been washed in from a landmass which probably lay some distance to the south-east. At the present day, these lower Ordovician rocks underlie the area between Graiguenamanagh and Waterford. Collectively they are known as the Ribband Group and a brief description of each rock unit is given below, beginning with the oldest:

Maulin Formation (MN)	Dark blue-grey slate, phyllite and schist.
Oldcourt Member (MNoc)	Schists, garnet-quartzites.
Brownsford Member (MNbf)	Dark grey semi-pelitic, psammitic schists.
Ballyneale Member (MNbn)	Andesitic, rhyolitic volcanics and slates.

It is noteworthy that the youngest member of the Maulin Formation hints at the onset of volcanic activity related to ocean closure.

Ballylane Formation (BY)	Green and grey slate with thin siltstone.
Oaklands Formation (OA)	Green, red-purple, buff-slate, siltstone.
Kilmacthomas Formation (KI)	Green, purple and grey slates, usually laminated with siltstones, also some tuffs (rare). Of equivalent age to the Oaklands formation. Found in only one small area in south Kilkenny.

From Upper Ordovician through to Silurian times the Iapetus Ocean began to close due to the subduction of oceanic crust at its margins. By late Ordovician times, an island arc had developed, giving rise to the volcanic rocks of the Duncannon Group/Campile Formation (to be found in the extreme south of the county around Cheekpoint):

Campile Formation (CA)	Rhyolitic volcanics, grey and brown slates.		
Ross Member (CArs)	Dark grey slates with thin siltstones.		

Age		Main Succession		East Kilkenny		South Kilkenny		West Kilkenny	
Upper Corboniference	Westphalian	Coolbaun (CQ)	Shale and sandstone with thin coals						
Carbonnerous		Swan Sandstone (CQss)	Laminated dark-grey siliceous sandston	e					
		Clay Gall Sandstone	Feldspathic, quartzitic sandstone					Lickfinn (LF)	Sandstone,
		(CG)							fireclay, coal
	(210 Million	Movedd Coel (MC)	Shale giltetone and minor conditione					Clangaala Caal	seams
	(310 Willion years)	Moyadu Coar (MC)	Shale, suistone and minor sandstone					(LFgc)	Coal scall
	Namurian	Bregaun Flagstone (BE) Killeshin Siltatone (KN)	Thick flaggy sandstone and siltstone						
		Carlow Flagstone (KNcf)	Fine, grey, flaggy sandstone						
	(325 Million	Luggacurren Shale (LS)	Mudstone and shale with chert and lime	stone					
Y	years)					[
Lower Carboniferous	Visean	Clogrennan (CL)	Cherty bluish crinoidal limestone	Clogrennan (CL)	See main succession				
		Ballyadams (BM)	Crinoidal wackestone/packstone	Ballyadams (BM)	See main succession				
		Durrow (DW)	Shaley fossiliferous and oolitic						
			limestone						
		Aghmacart (AG)	Dark shaley micrite, peloidal limestone	Butlersgrove (BU)	Very dark grey argillaceous	Kilsheelan (KS)	Limest	ones, occasionally cher	rty
					limestone	61 (60)	D 11		
	Courcevan	Crosspatrick (CS) Waulsortian (WA)	Pale-grey cherty crinoidal limestone			Silverspring (SS)	Beddec	d cherts and dark limes	tones
	Courceyan	Ballysteen (BA)	Fossiliferous dark-grey muddy limeston	e					
		Bullockpark Bay (BAbb)	Oolitic limestones, locally dolomitised						
		Ballymartin (BT)	Limestone and dark-grev calcareous sha	le					
		Ballyvergin Shale (BV)	Non-calcareous mudstone and siltstone						
	(355 Million yrs.)	Porter's Gate (PG)	Sandstone, shale and thin limestone						
Devonian		Kiltorcan (KT)	Yellow and red sandstone and green mu	dstone					
	(410 Million yrs.)	Carrigmaclea (CI)	Red, brown conglomerate and sandstone	e					
Silurian		South Lodge (SL)	Greenish greywacke and slate						
		Rathclarish (RA)	Grey graded greywacke	-1					
	(438 Million yrs.)	Alleliny (AY) Brownstown (AVbr)	Conglomerate and greywacke	cke					
Ordovician	(456 Willion yis.)	Campile (CA)	Rhyolitic volcanics grey and brown slat	tes					
ordovielui		Oaklands (OA)	Green, red-purple, buff slate, siltstone			Kilmacthomas (KI)	Green	purple and grev slates	
		Ballylane (BY)	Green and grev slates with thin siltstone			(11)	,	F F 8)	
		Maulin (MN)	Dark blue-grey slate, phyllite and schist						
		Ballyneale (MNbn)	Andesitic, rhyolitic volcanics and slates						
		Brownsford (MNbf)	Dark grey semi-pelitic, psammitic schist	t					
	(510 Million yrs.)	Oldcourt (MNoc)	Schists, garnet-quartzites						
Cambrian		Carricktriss (CK)	Green pyroclastic rock and dark silty sla	ate					

 Table 2.1 Sedimentary Bedrock Succession in Co. Kilkenny

2.4 Igneous Activity

During the Ordovician, igneous rocks formed in the southern half of the county. Some, especially in the early Ordovician, were brought to the surface by violently erupting volcanoes, while others were intruded into the sedimentary rocks, deforming and heating them. The intrusive igneous rocks were emplaced during the upper Ordovician, along with more volcanic rocks. The igneous rocks formed during this time are:

Granites (Gr)	Pale, coarsely crystalline intrusive igneous rock, comprising mainly quartz and feldspar.
Dolerite (D)	Fine grained iron and magnesium-rich igneous rock, intruded as thin sheets close to the surface. Contains little or no quartz and is a fine-grained version of gabbro.
Diorite (Di)	Intrusive igneous rock which is compositionally between granite and gabbro.
Felsic Volcanics (fv)	Pale coloured, feldspar and quartz-rich volcanic rock.
Intermediate Volcanics (iv)	Extrusive igneous rock which contains a mix of quartz and iron and magnesium-rich minerals.
Rhyolite (R)	Fine grained, hard, quartz-rich volcanic rock.

2.5 Silurian

Rocks of mid Silurian age in Kilkenny are to be found to the east of Slievenamon. During their deposition, enormous quantities of land-derived sediment were deposited into what remained of the Iapetus Ocean. The rocks may be generally described as a series of mudstones, inter-layered with beds of muddy sandstones (greywackes) and conglomerates. A brief description of each rock unit is given below, beginning with the oldest:

Ahenny Formation (AY)	Grey and blue slate, minor tuffs and wacke. Approximately 3000 m thick.
Brownstown Member (AYbr)	Conglomerate and greywacke. Approximately 200 m thick.
Rathclarish Formation (RA)	Grey graded greywacke. Approximately 340 m thick.
South Lodge Formation (SL)	Greenish calcareous greywacke and slate. Approximately 3000 m thick.

2.6 Devonian

Deposition of the Old Red Sandstone (ORS) rocks took place in a sub-equatorial arid environment, where there was intense erosion and then deposition of gravel, sand, silt and some clay in the flood plains of meandering rivers. These rocks unconformably overly the older Lower Palaeozoic rocks and are the most extensive rock type in the Southern Upland areas of Kilkenny. They consist primarily of yellow, white and brown/red coarse and fine-grained sandstones and conglomerates with some

siltstones and mudstones. The red colour reflects the arid, terrestrial (as opposed to 'marine') conditions under which these rocks were formed. The coarser grained sediments are usually present towards the base of this rock unit, with greenish-grey siltstones becoming more common towards the top. There are two main formations identified in Kilkenny:

Carrigmaclea Formation (CI)	Red, brown conglomerate and sandstone. Thickness varies from 190 m to 460 m.
Kiltorcan Formation (KT)	Yellow and red sandstone and green mudstone. Approximately 235 m thick at Kiltorcan Hill, which is known for its fossils.

2.7 Lower Carboniferous Rocks

The Lower Carboniferous was a period of marine deposition as warm tropical seas transgressed northwards over the Devonian Old Red Sandstone continent. This transgression did not happen all at once and, during the early Carboniferous, the 'terrestrial' Kiltorcan Formation was still being deposited in Kilkenny. The first marine sediments were the shallow water sandstones and limestones of the Porter's Gate Formation. At the same time, earth movements caused the sea bed to subside into a large basin, the Shannon Trough, along the present day Shannon Estuary. A great variety of sediments were laid down depending on the depth and the turbulence of the waters, and their position in relation to the developing basin. Clean limestones (such as the limestones in Central Kilkenny) were laid down in shallower water. In the deeper basinal waters, where subsidence was faster than deposition, more shaley limestones (such as the limestones around Knocktopher) were formed.

2.7.1 Courceyan Rocks

Porter's Gate (PG)	Sandstones, shales and thin limestones, incorporating the transition from terrestrial to marine sediments and equivalent to the Mellon House Beds in other areas (40 m thick).
Ballyvergin Shale (BV)	Thin, distinctive non-calcareous mudstone and siltstone. Identified at Granny Ferry, 5 km north west of Waterford City. Useful as a marker horizon as it seems to represent a rapid influx of sediment from the north west. It can be found from Galway to Kerry. Maximum thickness is 10 m.
Ballymartin Limestone (BT)	Interbedded limestones and dark grey calcareous shales. They are not always identifiable from the overlying Ballysteen Formation, in which case the two formations are referred to as BA e.g. in the south west of Kilkenny around Piltown. The thin beds and high proportion of argillaceous material, coupled with the fact that they are commonly found at low elevations makes groundwater circulation at depth unlikely.
Ballysteen Limestone (BA)	Fossiliferous dark-grey muddy limestone, around 300 m thick. The lower part consists of well-bedded relatively clean coarse limestones which grade up into finer-grained, more muddy limestones. Much of the formation is dolomitised, particularly the cleaner limestones. Also includes the underlying Ballymartin Limestones (thin pale grey muddy limestones and dark grey calcareous shales) which are not always differentiated on the maps.

Bullockpark Bay Member (BAbb)	Oolitic limestones, locally dolomitised. It occurs some 50 to 60 m above the base of the formation and indicates a temporary shallowing of the sea. It is found in south west Kilkenny between Waterford City and Piltown.
Waulsortian Limestone (WA)	Massive pale grey fine-grained clean unbedded fossiliferous limestone which formed in mound structures. It is widely dolomitised, particularly at the top and along faults. In the north west at Galmoy the dolomitisation is associated with lead and zinc ore deposition. Average thickness is ~200 m.

It is important to note that a change in depositional character occurred next in the area. Unlike the underlying limestones, the Visean rocks were deposited in a variety of depositional environments which has resulted in different successions across the county (described in Table 2.1).

2.7.2 Visean Rocks

Silverspring Limestone (SS)	Bedded chert and dark-grey limestones. Maximum thickness is 100 m at Mooncoin. Equivalent to the Crosspatrick Formation (CS) in north west Kilkenny and the Butlersgrove Formation (BU) in the east.
Crosspatrick Limestone (CS)	Pale-grey cherty crinoidal limestones. Maximum thickness is 60 m. Equivalent to the Silverspring and lower Butlersgrove limestones.
Butlersgrove Limestone (BU)	This is a new name for a poorly exposed formation found overlying the dolomitised Ballysteen and Waulsortian limestones in the Stonyford area. It consists of very dark grey argillaceous limestones, which when polished is used as 'Kilkenny black marble'. The lower part is likely to be laterally equivalent to the Silverspring and Crosspatrick Limestone, while the upper part is partially equivalent to the Aghmacart and Kilsheelan Formations.
Kilsheelan Limestone (KS)	Pale to dark grey limestones, occasionally cherty. Maximum thickness in neighbouring counties is 900 m. It outcrops north of Mooncoin, and is partially equivalent to the Aghmacart and upper Butlersgrove Formations.
Aghmacart Limestone (AG)	Very dark grey fine-grained clay-rich limestones with thin dark- grey shales, which were probably deposited in shallow water. Their average thickness is 200 m, and they are partially equivalent to the Kilsheelan and upper Butlersgrove Formations.
Durrow Limestone (DW)	Shaley fossiliferous and oolitic limestone. This is a new name for a formation which probably indicates a change to more open- water limestones. Average thickness is 200 m. It is found in the Callan and Urlingford areas.
Ballyadams Limestone (BM)	Classic "Burren" type limestone. Pale-grey thick-bedded clean fossiliferous limestone intermittently separated by clay wayboards. It is thought to have formed in a shallow tropical sea with clay representing soil development during exposure at surface. The average thickness is 200 m, and the unit is

widespread across the northern half of Kilkenny, where it overlies both the Durrow and the Butlersgrove Formations. It can be seen in Ballykeefe quarry near Kilmanagh.

2.8 Upper Carboniferous Rocks

2.8.1 Namurian Rocks

The boundary between the Lower Carboniferous Limestones and the Namurian rocks above is marked by an unconformity, an abrupt break in deposition which is clearly visible as a scarp in areas such as Freshford. This records a change from shallow tropical seas to a quiet deep water environment. Deep water shales were laid down first, followed by alternating sandstones, siltstones and mudstones. These were relatively unstable times when thick sandstone beds were deposited in the water by large density (turbidity) currents, triggered by earthquakes. By the end of the Namurian, the marine basin had filled to become a coastal plain with extensive mudflats and river deltas. The Namurian rocks now underlie north Kilkenny.

Luggacurren Shale (LS)	Black to dark grey shales and mudstones with thin cherts and limestones. The unit is typically 80 m thick and is only found above the Clogrennan Formation in north east Kilkenny. In the north west, the unit is absent and the Clogrennan is overlain by the Killeshin Formation		
Killeshin Siltstone (KN)	Grey poorly bedded muddy siltstone and silty mudstone, which can be almost 300 m thick in the Castlecomer and Slieveardagh coalfield areas.		
Carlow Flagstone Member (KNcf)	Fine, grey, flaggy sandstone with slump features. Occurs about 60 r above the base of the Killeshin Formation in the Slieveardagh an Gattabaun areas and the western portion of the Castlecomer Plateau.		
Bregaun Flagstone (BE)	Thick flaggy sandstone and siltstone with some silty shales. Average thickness 300 m. Rippled surfaces are common indicating shallower water.		

2.8.2 Westphalian Rocks

By latest Namurian times the deposition of silts and sands was greater than subsidence of the sea floor and terrestrial sediments began to be deposited. During Westphalian times, silty swamps were formed which spread between the sand-filled channels of large rivers in a deltaic environment. Peaty marshlands with large ferns and mosses developed, and these are now preserved as coal. The entire Westphalian succession is about 300 m thick. Coal-bearing rocks are found in Kilkenny in the Castlecomer Plateau area and in the Slieveardagh Hills. In the two areas, the successions are different and so different formation names exist. Workable coal seams account for only a fraction of the overall coal measure rocks and most of these have been dug out. All the coal is of anthracite grade. Westphalian rocks are not commonly found in Ireland. In the UK they have supported an extensive coal mining industry.

Clogrennan limestone (CL) Thinly bedded bluish-grey clean limestones, regularly cherty. Average thickness 100 m. Together with the underlying Ballyadams Formation, it was formerly known as the Cullahill Limestone.

Moyadd Coal (MC)	Black shale, siltstone and minor sandstone, typically 55 m thick. The <i>Gastriaceras subcrenatum</i> marine band, the international boundary between the Namurian and the Westphalian occurs within it. This boundary occurs between two worked coal seams. It occurs in the Castlecomer area and is believed to be equivalent to the upper part of the Bregaun Formation in Slieveardagh.
Lickfinn Coal (LF)	Sandstones, shales, fireclay (fossil soil) and up to eight coal seams. In Kilkenny, the unit is only found in two small localities; both around the Gortnagap area of Slievardagh.
Glengoole Coal Member (LFgc)	Coal seam. The only area of it in Kilkenny is found on the hill south of the Gortnagap Crossroads.
Clay Gall Sandstone (CG)	Medium and fine grained quartz sand with some feldspar. Varies in thickness from 30 m to 50 m, and occurs in the Castlecomer Plateau area. The name derives from the occurrence of sandstone enclosing pebbles of shale. A coal seam occurs at the top of the formation.
Coolbaun Formation (CQ)	Shale and sandstone with thin coals found in the Castlecomer Plateau area. Fireclay, an aluminium-rich fossil soil, also occurs within this formation and this is quarried to make refractory bricks. The Jarrow Coal occurs towards the top of the formation and this, although it has now been worked out, was famous for its amphibian fossils.
Swan Sandstone Member (CQss)	Laminated dark grey fine-grained siliceous sandstone between 5-20 m thick.

2.9 Post Carboniferous Rocks

A gap of at least 280 million years occurs between the top of the Carboniferous rocks in Kilkenny and the next deposits to be preserved in the area, which were laid down during the numerous glaciations of the Quaternary Period. A debate is ongoing as to what happened to the rocks across Ireland which were laid down in the intervening time. There must have been considerable deposition as the presence of high-grade anthracite coals indicate that the Carboniferous (and older) rocks have been subjected to metamorphism as a result of deep burial.

2.10 Structural History

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

The earlier Caledonian orogeny marked the collision of two continents, Gondwana and Laurentia which were once separated by an ancient ocean (The Iapetus Ocean). The boundary between the continents is a suture line running from the Shannon Estuary to Silvermines, Navan and Clogher Head. The collision affected the older Cambrian, Ordovician and Silurian rocks, causing them to become metamorphosed and faulted (these are seen in the south-east of the county). It also caused the intrusion of the Leinster granites, the western-most exposure of which is seen in the Inistioge area.

The Variscan Orogeny was a north-south compression event which occurred towards the end of the Carboniferous Period. The effects of this mountain building event are evident across Kilkenny as east-west trending folds (anticlines and synclines) and numerous north-south faults. In the north, these folds are quite gentle. In the south (around Mooncoin and Piltown), the folding and faulting is much more intense. Rocks will have reacted differently to these pressures, depending, amongst other factors, on their strength. More competent, cleaner limestones and sandstones will generally have deformed in a more brittle manner than shales and muddy limestones.

3 Subsoil (Quaternary) Geology

3.1 Introduction

This chapter deals primarily 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 in Kilkenny was undertaken by the Quaternary Section of the GSI. This mapping formed the foundation of subsequent subsoil permeability assessments (described in Chapter 5). Subsoil distribution is presented in Maps 2N and 2S, and discussed briefly in Section 3.2. An overview of evidence for ice flow directions has been provided in Section 3.4.

3.2 Subsoil Types

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

- ♦ till
- sands and gravels
- till with gravel
- ♦ alluvium
- ♦ peat
- lake deposits

Areas where bedrock comes within about 1 m of the surface are shown on the maps as "rock close".

3.2.1 Till

Till (often referred to as boulder clay) is the most widespread subsoil in Kilkenny 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.

Boundaries based on till texture are not shown on the subsoils map, but symbols indicate the texture at specific locations. A number of particle size analyses were carried out and results are discussed in the context of subsoil permeability and groundwater vulnerability in Chapter 5.

3.2.2 Sands and gravels

Deposition of sands and gravels takes place mainly when the glaciers are melting. 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.

Kilkenny has some extensive developments of sand and gravel, the largest of which is associated with the River Nore. 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). A few small eskers occur in Kilkenny and perhaps the best developed of these is in Clarabricken, 7km east of Kilkenny City.

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. Only one small area of this deposit has been mapped in Kilkenny, north-west of Urlingford.

3.2.4 Alluvial deposits

Alluvial sediments deposited by rivers and include unconsolidated materials of all grain sizes, from coarse gravels down finer silts and clays, and they may also contain organic detritus.

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 bogs, which are characteristic of lowland areas with impeded drainage. Blanket bog is not found to any great extent in Kilkenny, and where present, it is likely to be only a meter or two thick. One or two very small pockets of it occur on the Castlecomer Plateau. One area of raised bog exists in the north-west of the county. This is the eastern extent of a much larger development of midlands raised bog. Both types of bog have been worked for peat, whether on a commercial basis with machinery (the raised bog) or on a local scale (the blanket bog).

3.2.6 Lake deposits

One small area of lake deposits has been mapped, in the extreme south-east of the county, east of Kilmacow. These sediments are typically silty and clayey material, similar to the finer type of alluvium.

3.3 Depth to Bedrock

The depth-to-bedrock (i.e. subsoil thickness) is a critical factor in determining groundwater vulnerability. Subsoil 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 Quaternary 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. Generally speaking, the thickest deposits are tills or gravels, and they are found scattered throughout the county.

3.4 Ice Flow Direction

The following extract is taken from Hegarty (2001):

"As ice flows over a terrain it erodes the underlying bedrock surface and deposits the material it has picked up further down the course of the glacier. This means that it should be possible to reconstruct former ice flow directions using small and large-scale lineaments expressed in the modern topography, as well as looking at the fabric of basal tills and the provenance of their clasts.

Kilkenny is no different in this regard from any other relict-glaciated area. There are a number of features that allow us to tentatively reconstruct former paths of ice-flow. Previous to the current mapping programme a number of striae were recorded on the nineteenth century GSI bedrock maps. These striae tie in with what has been observed in the current mapping programme, and record a flow of ice from the north-west to southeast in the north west of the county, while a flow from north to south is evident from the two sets of striae in the south of the county on the Devonian sandstone Plateau.... These also tie in with striae at St Mullins cave which also describe a north-south flow of ice over the Devonian Sandstone Plateau during Last Glacial Maximum (LGM).

A streamlined hill at Graigue, Galmoy, also points to ice moving in a north west-south east direction. This hill is actually a crag and tail, with bedrock exposed on the up-ice side of it and till plastered on the lee side of the slopes. It is only one in a number of such structures in the area, the rest being located in Counties Laois and Tipperary.

Striae to the south east of the Castlecomer Plateau, as well as a till fabric [assessment] carried out on a basal till section at Dysart Bridge, indicate that ice streamlined around the Plateau. This, however, may well have been [a different] ice [mass] flowing ... southwards, and not the ice [mass] that was flowing [from Galmoy].... This latter icemass had its origin possibly somewhere in the Galway region, as judged by the amount of Galway granite to be found in the gravels down as far south east as Bennettsbridge. This would mean that two ice masses were coexistent within Kilkenny and, at LGM, flowed together southwards from their confluence in the area of the Nore.

Ice flowed over the Devonian Plateau southwards as mentioned earlier down into Waterford and towards the present Celtic Sea. The lack of any major end moraine suggests this. There are however some small patches of gravels that point to halt stages in the retreat of the ice sheets. These are more visible in the western ice sheet, which retreated to the north west, leaving small pockets of gravels in the area to the north of Callan and across to just north of Kilkenny. To the east of the county, such retreat stages are not as clearly seen, perhaps because of the subglacial topography of the area, which provided natural barriers to ice flow."

4 Hydrogeology and Aquifer Classification

4.1 Introduction

This chapter summarises the relevant and available hydrogeological and groundwater information for County Kilkenny. A brief description of the hydrogeology of each rock unit 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, County Council, and consultants' files (2704 wells and springs in total) were compiled and entered into a computer database at the Geological Survey.

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

- A hydrogeological study of the Nore River Basin, undertaken by the Geological Survey of Ireland in the 1970's and 1980's. Several reports are available.
- 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 some 200 wells in Kilkenny and the surrounding counties. (Specific capacity is the rate of abstraction per unit drawdown; the unit used is m³/d/m.)
- More detailed pumping tests carried out by consultants on 2 public supplies.
- 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, Tipperary, and Waterford.

4.3 Rainfall, Evapotranspiration and Recharge

Using Met Eireann data, mean annual rainfall in Kilkenny for 1961–1990 varied from just over 820 mm in the mid-Kilkenny lowlands, to just under 1100 mm in Mullinavat, on the southern slope of the South Kilkenny Uplands (Fitzgerald and Forrestal, 1996). Recharge has been estimated for more localised areas around public supply sources using Met Eireann rainfall and potential evapotranspiration data (Chapters 8 to 15 in Volume II).

Data from OPW and EPA stream gauging stations can give a regional-scale overview on average annual volumes of potential recharge (i.e. excess soil moisture available for both surface runoff and infiltration to groundwater). Data from 1991 to 1998 suggest that potential recharge ranges from 1060 mm/year on the Castelcomer plateau (gauge in Castlecomer) to 800 mm/year in the South Kilkenny Uplands (gauge at Mullinavat) to 360 mm/year in some parts of the Central Lowlands. This last figure was obtained from difference between gauge data from Mount Juliet (Nore), John's Bridge (Nore) and Annamult (Kings River).

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 potential recharge.

4.4 Groundwater Usage

There are at least 9 public supply schemes and at least 143 group schemes supplied by groundwater in Kilkenny. Based on data taken from the County Council and from M.C. O'Sullivan Consulting Engineers (1999), the total daily public water supply in Kilkenny is estimated to be approximately $29,000 \text{ m}^3/\text{d}$, of which groundwater comprises approximately $9,000 \text{ m}^3/\text{d}$ (one third of the total). Using additional data on the population served by each group scheme registered in Kilkenny, it is estimated that the total public and group scheme groundwater usage in Kilkenny is approximately $13,000 \text{ m}^3/\text{d}$. This estimate excludes households which are not served by the County Council or group water schemes. These households generally rely on individual private wells as their source of water.

4.5 Background to Aquifer Classification

4.5.1 Introduction

Section 4.5 provides an outline of the factors used in aquifer classification. The classifications of each rock unit in Kilkenny and of the sand and gravel bodies which have aquifer potential, are provided in Sections 4.6 to 4.18. According to the aquifer classification used by the GSI (DELG/EPA/GSI, 1999), there are three main aquifer categories, with each category sub-divided into two or three classes:

Regionally Important (R) Aquifers

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

Locally Important (L) Aquifers

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

Poor (P) Aquifers

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

4.5.2 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. As a result, 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 usually 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 4.6 to 4.18.

Karstification

Karstification is the process whereby limestones are slowly dissolved away by acidic waters moving through them. This most often occurs in the upper bedrock layers and along some of the pre-existing fissures and fractures in the rocks which become slowly enlarged. This results in the progressive development of distinctive karst landforms such as collapses, caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits. The degree of 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.

 \mathbf{Rk}^{c} are those aquifers in which the degree of karstification limits the potential to develop groundwater. They have a high 'flashy' groundwater throughput, but a large proportion of flow is concentrated in conduits, numerical modelling using conventional programs is not usually applicable, well yields are variable with a high proportion having low or minimal yields, large springs are present, storage is low, locating areas of high permeability is difficult and therefore groundwater development using bored wells can be problematical.

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

Dolomitisation

Dolomitisation is a weathering process where calcium ions are replaced by magnesium ions in the crystal lattice of dolomite (Ca Mg (CO₃)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, and the greater the resultant increase in bulk permeability will be.

4.5.3 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 areal extent. The thickness of the deposit is often used rather than the more relevant saturated zone thickness as the information on the latter is rarely available. In many instances it may be assumed that a deposit with a thickness of 10 m will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief (for example eskers or deposits in high topographic areas) as these gravels are often dry.

	Regionally important	Locally important
Aerial extent	$> 10 \text{ km}^2$	$1-10 \text{ km}^2$
Saturated thickness	> 5 m	> 5 m
Permeability	High	High

Table 4.1Sand/gravel Aquifer Classification

Sand/gravel aquifers are therefore classified according to the permeability, areal 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 km^2 . This is to ensure that, assuming typical Irish recharge rates, there will be enough recharge to provide a supply of one million cubic metres per year from the whole aquifer.

4.5.4 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 4.5.1:

- 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 $100 \text{ m}^3/\text{d}$.

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 transmissivity data from formal pumping tests, where discharge and water levels readings have been taken over a period of many hours or days.
- Productivity data from wells where either formal pumping tests have been undertaken or where at least one combined reading of discharge and drawdown data are available. The GSI has developed the concept of 'productivity' as a semi-quantitative method of utilising limited well test data (Wright, 2000). A 'productivity index' is assigned to a well from one of five classes: I (highest), II, III, IV, and V, using a graphical comparison of well discharge with specific capacity (discharge divided by drawdown).
- 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 and sorted sands and gravels for example, are generally more permeable than poorly sorted glacial tills. Clean limestones are also generally more permeable than muddy limestones. Areas where folding and faulting has produced extensive joint systems tend to have higher bulk permeabilities than areas where this has not occurred.

• Aquifer assessments from Groundwater Protection Schemes in neighbouring counties and from existing reports. In the case of Kilkenny, a considerable amount of aquifer assessment work had already been undertaken as part of the GSI's Nore River Basin study.

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 Kilkenny is presented in Sections 4.6 to 4.18. A summary can be found in Table 4.2, 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 Chapter 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.

Aquifer Grouping	Geological Units	Occurrence in Aquifer Kilkenny Class		Main basis for Classification	Report Ref.
Sand and	Dinin Gravel	Dinin River	Lg	Dimensions & river recharge	4.18.5
Gravel	Nuenna Gravel	Nuenna Catchment	Lg	Dimensions & grain size	4.18.4
	Nore Gravel	Nore valley	Rg to Lg	Dimensions & yields	4.18.3
	Kilmanagh Gravel	Tullaroan-Callan	Rg	Dimensions & permeability	4.18.2
Swan, Clay Gall Sst	CQss, CG	Castlecomer Plateau	Lm	Productivity data	4.17
Namurian and Westphalian Shales	Coolbaun (CQ), Moyadd Coal (MC), Luggacurren Shale (LS), Lickfinn Coal (LF), Glengoole Coal (LFgc)	Slieveardagh and Castlecomer Plateau	Pu	Lithology	4.16
	Killeshin Siltstone (KN, KNcf), Bregaun Flagstone (BE)		Pl	Lithology, productivity.	4.16
Karst Limestone	Clogrennan (CL), Ballyadams (BM, BMdo)	Central and Northern lowlands	Rk	Productivity and karst data	4.15
Aghmacart, Durrow, Butlersgrove Limestone	AG, DW, BU	Central and Northern lowlands	LI	Lithology, productivity.	4.13
Crosspatrick, Kilsheelan,	Crosspatrick (CS)	Northern lowlands	Lm	Structural, lithological and karst data.	4.12
Silverspring Limestone Kilsheelan (KS), Silverspring (SS)		Southern lowlands (Kilmacow)	Rk	Structural, lithological and karst data.	
Dolomite Aquifer	WAdo, with contiguous portions of AGdo, BUdo, BAdo	Central and Northern lowlands	Rf	Transmissivity, and productivity data	4.14
	Isolated portions of AGdo, BUdo, AGdo.		Lm	Lithological inferences	
Waulsortian	Northern area	Northern lowlands	Ll	Productivity data	4.11
Limestone	Southern area	Southern lowlands	Rk	Structural inferences and karst data.	
Ballysteen Limestone	Ballysteen (BA)	Central and southern lowlands	Ll	Productivity data	4.10
	Bullockpark Bay Member (BAbb)	Southern lowlands	Lm	Productivity data and lithological inferences	
Lower Limestone Shale	Ballymartin (BT), Ballyvergin Shale (BV)	Central and southern lowlands	Pl	Lithological inferences	4.9
Kiltorcan Sandstone	Porter's Gate (PG), Kiltorcan (KT)	Southern Uplands and southern lowlands	Rf	Productivity data	4.8
Ordovician Volcanics	Campile (CA), Kilmacthomas (KI)	Southern lowlands (Waterford)	Rf	Productivity data	4.7
Southern Uplands	Carrigmaclea (CI), Oaklands (OA), Maulin (MN, MNbn, MNbf, Mnoc).	Southern Uplands	LI	Productivity data and lithological inferences.	4.6
Slates, Sandstones, Granites	South Lodge (SL), Rathclarish (RA), Ahenny (AY), Brownstown (AYbr), Carricktriss (CK)	Southern Uplands	Pl	Productivity data and lithological inferences.	



Gauge	Catchment	Dry Weather Flow (DWF) in l/sec	Total Area to Gauge. km ²	Adjusted DWF (l/sec)	Adjusted Area to Gauge. l/sec/km ²	Specific DWF. l/sec/km ²	Main Aquifers within Adjusted Area to Gauge
Castlecomer	Dinin	110	153	110	153	0.72	Swan/Clay Gall, gravels.
Callan	Kings	20	201	20	201	0.10	Gravels, Westphalian shales and sandstones.
Annamult	Kings	250	443	230	242	0.95	Dolomite.
John's Bridge	Nore	2000	1605	740	362	2.0	Ballyadams, Nore gravels
Mount Juliet	Nore	2800	2316	550	268	2.1	Ballyadams, Dolomite.
Brownsbarn	Nore	3000	2388	200	72	2.8	Kiltorcan.
Poulanassa	Blackwater	20	40	20	40	0.5	Southern Uplands.
Scart	Blackwater	80	108	80	108	0.74	Southern Uplands.
Linguan Dale	Lingaun	180	84	180	84	2.1	Waulsortian (south).

Table 4.3: Summary of Selected Dry Weather Flow Data from Rivers in County Kilkenny

Notes: Dry weather flows from EPA data. Adjusted areas and flows are derived by subtracting contributing areas and dry weather flows from upstream gauges.

4.6 Classification of the Southern Uplands Slate, Sandstone and Granite Aquifers

This aquifer comprises the Carricktriss (CK), Maulin (MN), Oaklands (OA), Ballylane (BY), Ahenny (AY and AYbr), Rathclarish (RA), South Lodge (SL), and Carrigmaclea (CI) Formations, along with the Granites (Gr) and other igneous intrusions (D, Di). Note that the Carrigmaclea is equivalent to the lower part of the Old Red Sandstone in other counties.

These rocks form the core of the Southern Uplands, extending from Tullahought in the west to Graiguenamanagh in the east, underlying approximately 19% of the county (Map 1S). 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: slates, granites and greywackes. Greywacke is a poorly-sorted sandstone with a compact clayey matrix (Bates and Jackson, 1984).

The aquifer has undergone at least two phases of major structural folding and faulting which will have increased fracture densities and fracture permeability, particularly near the axes of the folds and in the immediate vicinity of the faults.

The Thomastown, Piltown and Glenmore public supplies, and the Tullahought group scheme occur in this aquifer in Kilkenny. Thomastown and Piltown are located in the Carrigmaclea sandstones, Glenmore is located in Oaklands Formation slates, while Tullahought is located in Ahenny Formation slates and greywackes. These supplies have been sampled as part of routine public health monitoring and as part of the Groundwater Protection Scheme for County Kilkenny. In addition, several more samples were taken from smaller wells and springs during a study of the Nore River Basin. Results are summarised in Figure 4.1. The most notable feature of the results is their variability, with waters ranging from 'soft' to 'hard' and hydrochemical signatures ranging from calcium bicarbonate to sodium chloride. Daly (1992) suggests that the groundwater chemistry in this aquifer is more influenced by the mineralogy of the subsoil and by the composition of rainwater than by the mineralogy of the rock itself. He suggests that harder waters are associated with the presence of thicker subsoils, which have been moved by ice from the limestone lowlands. Daly uses the close link

between subsoil and groundwater chemistry as evidence of short residence times and shallow groundwater flow in the aquifer.

Potential issues associated with the 'natural' water quality may include high iron and manganese, particularly in areas underlain by peat bogs. The limited pH buffering may mean that corrosivity is an issue in certain areas where the subsoils are thin or consist of peat bogs. Contamination by human activities is discussed in Chapter 7 of Volume II.

Many small springs can be observed on, and at the base of, slopes. In areas where the rock is exposed at the surface, the land is poorly drained, and the stream density is relatively high. Dry weather flows are available for a portion of the Blackwater River catchment upstream of Mullinavat (Table 4.3), which is underlain almost entirely by Carrigmaclea sandstone. Specific dry weather flows are low (less than 1 l/sec/km²), suggesting that the aquifer as a whole is not effective at storing water through to the summer months.

Drainage density, specific baseflow, and hydrochemical data suggest that flows in the aquifer are likely to be concentrated in a thin zone at the top of the rock, with flow paths rarely exceeding a few tens or hundreds of metres in length. Daly (1992) suggests that the weathered zone may be up to 15m thick in some places, with a zone of well fractured bedrock below this extending up to, perhaps, 30m in thickness in places, and a final zone of poorly fractured bedrock of up to 60m thickness. He goes on to suggest that the bulk permeability over the productive depth of the aquifer system (i.e. up to 100m depth) will typically lie between 0.01 m/day and 1 m/day. Drilling data from Thomastown public supply and from public supplies in the same aquifer in County Wicklow suggest that bulk permeabilities and the depth of groundwater flows may be greater than these figures:

- in the vicinity of large faults, or
- in the conglomerate layer which lies close to the base of certain parts of the Carrigmaclea Sandstone Formation. At Thomastown, the layer was encountered at depths of over 80m below ground.

Available transmissivity information from these higher permeability zones are summarised in Table 4.4.

Table 4.4: Summary of Transmissivity Estimates for Higher Permeability Zones in the Southern Uplands Slates, Sandstones, and Granite Aquifer

Rock unit	Transmissivity (m²/day)	Source of Information
Maulin Formation	65 m ² /day	Roundwood pumping test (Wright and Woods, 2001)
Maulin Formation	130 m ² /day	Baltinglass – Tinoran (Wright and Woods, 2001)
Granites	25 m ² /day	Baltinglass-Lathaleere public supply (Wright and Woods, 2001)
Carrigmaclea Sandstones	1000 m ² /day	Thomastown public supply (refer to Chapter 13 of Volume II)

Productivity data from these aquifers can be divided into three groups, and are presented in Figures 4.2 to 4.4. No high yielding springs are recorded in these aquifers, but 'excellent' yielding wells are recorded in the Ordovician slates and the Carrigmaclea sandstones.







On the basis primarily of productivity data, the aquifers of the Southern Uplands in Kilkenny are classed as follows:

- Maulin (MN), Oaklands (OA) and Carrigmaclea (CI) Formations: locally important aquifers which are moderately productive only in local zones (Ll).
- Carricktriss (CK), Ahenny (AY and AYbr) Rathclarish (RA), South Lodge (SL), Ballylane (BY) Formations, along with the Granites (Gr) and other igneous intrusions (D, Di): poor aquifers which are generally unproductive except for local zones (Pl).

These classifications are supported by lithological and hydrological information.

4.7 Classification of the Ordovician Volcanic Aquifer (CA, CArs, KI, fv, iv)

The aquifer comprises the Campile Formation (CA) and its subdivision, the Ross Member (CArs), as well as the Kilmacthomas Formation (KI) and associated units (fv and iv). It is found in the extreme south of the county, underlying less than 1% of Kilkenny. However, it represents the northern tip of a much larger expanse which extends down into Waterford and across into Wexford. These units are considered together because they consist predominantly of volcanics. These volcanics are generally considered to break in a brittle manner along faults and folds. Experience in Waterford and Wexford has suggested that this brittle fracturing enhances fracture permeability (Hudson et al. 1998).

Hydrochemistry data have been obtained from several EPA sampling rounds at the Belview water supply in 1996 (refer to Chapter 7). The data indicate 'moderately soft' to 'slightly hard' groundwaters. No calcium, magnesium or sulphate data are available from the sample results from Belview, but data from County Waterford suggest that the hydrochemical signature is intermediate (refer to Figure 4.1), perhaps reflecting the mineralogy of the volcanic rock material and the presence of slightly longer flowpaths than is normal in Irish aquifers. Alkalinity is typically quite low and this is reflected in the slightly acidic pH values (typically around pH 6.6). Both iron and manganese were detected in excess of the EU MAC in raw water samples, and again this is likely to be a reflection of the volcanic origin of the aquifer. Based on the lithology and age of the rock formations it is possible that 'natural' water quality issues like corrosivity and high iron/manganese may be encountered in other development projects within this aquifer. Contamination by human activities is discussed in Chapter 7 of Volume II.



Where the aquifer is at or near surface, both the natural and artificial drainage densities are low. This is the case right into Waterford and Wexford. Borehole logging in south-east Co. Kilkenny (Daly, 1982) has shown that well developed fissures can occur down to 50 metres in these volcanic formations. Coupled with the low drainage density, the borehole logging data suggest that significant groundwater flows occur at depth and that groundwater flow paths are likely to be comparatively long by Irish standards, perhaps several hundred metres or even a few kilometres in the larger river valleys. This is supported by inferences from the hydrochemical data.

Transmissivities can be over 500 m²/d (Daly, 1982).

Productivity data are concentrated into classes I and II (refer to Figure 4.5). There are several excellent-yielding wells on record, but no high yielding springs. On the basis primarily of productivity and transmissivity data, the Ordovician volcanics in Kilkenny are classed as a **regionally important** fissured bedrock aquifer (**Rf**).

4.8 Classification of the Kiltorcan Sandstone Aquifer (KT and PG)

This aquifer comes to the surface intermittently across the south of Kilkenny, underlying slightly less than 10% of the county. It consists of the Kiltorcan Formation (KT) and the overlying Porter's Gate Formation (PG).

Daly (1988) described a gradual change from sandstone to shale moving upwards from the Kiltorcan and into the Portersgate Formation, which means that separate aquifer classifications for each formation cannot be made. The upper part of the Kiltorcan consists mostly of thick, clean bedded sandstones, some of which have been dolomitised (Daly, 1988). The sandstone beds thin slightly in the overlying Portersgate, and become interspersed with limestones. Moving away from the contact, low permeability shales, mudstones and siltstones are abundant at the base of the Kiltorcan and the top of the Portersgate. In fact, the shales of the upper Portersgate are regarded as a confining layer, and artesian flows have been obtained where wells have breached them to tap into the sandstones below.

The rocks have undergone at least one major phase of structural deformation. The zone of cleaner sandstones around the contact with the two formations is likely to have reacted in a more brittle manner to the deformation, allowing the development of a more dense network of fracturing and fracture permeability than in the shalier sandstones elsewhere in the aquifer. The thick, interbedded sandstones in and around the contact between the Kiltorcan and Portersgate are likely to be the main focus for fracturing and groundwater circulation in the aquifer. Faulting is believed to be far more extensive than the pattern depicted in Map 1S. Significant faults are expected to cut the aquifer every kilometre (Daly, 1988). Borehole logs have also shown regular jointing to be present, probably associated with faulting and folding (Daly, 1985).

Water level data are available from a well near Knocktopher (Figure 4.6). This hydrograph indicates an annual fluctuation of 2m and is taken from a well which lies approximately 10m to 15m higher than the nearest stream.



Hydrochemical data were compiled by Daly in 1985. Waters were 'soft' to 'moderately hard' in the sandstones and 'hard' to 'very hard' in the shales and limestones of the upper parts of the Portersgate Formation. The hydrochemical signature varied between calcium bicarbonate and calcium-magnesium bicarbonate. Daly suggests that the signature depends on the thickness of overlying subsoil, with calcium magnesium waters being associated with areas of thicker subsoil. pH ranged between 6 and 7. Levels of iron and manganese were variable, and, given the sandstone matrix of the aquifer, it is possible that iron/manganese clogging may be an issue, particularly where the pumping water level occurs below the top of the sandstones. Contamination by human activities is discussed in Chapter 7 of Volume II.

There are numerous small springs and streams across most of the area where the aquifer occurs close to the surface. In this region, Daly (1985) suggests that recharge is actively occurring, that groundwater flow paths are typically in the order of a few hundred metres, and that most discharge occurs into small streams and springs. Zones of more concentrated discharge occur into the Nore River near Thomastown and the Little Arrigle River near Ballyhale; both zones lying just upslope of the area where the aquifer becomes confined by lower permeability shaley limestones. Geophysical borehole logging data suggest that significant water movements occur at depths of over 60m where the aquifer is not confined by overlying shaley limestones. Where confined, active groundwater circulation is expected to be much more limited, but some deep flow has been inferred from mineral exploration boreholes at depths of over 200m (Daly, 1985).

Dry weather flows are available for a portion of the Nore River between Mount Juliet and Brownsbarn (Table 4.3). The Kiltorcan sandstones underlie the Nore over much of this portion. The specific dry weather flow estimated from the data are relatively high (2.8 l/sec/km²), suggesting that the aquifer is relatively effective at storing water through to the summer months.

Results of aquifer testing undertaken in the aquifer are very variable. Daly (1985) reports estimates of between 5 m²/day to 1850 m²/day, and suggests that the highest values are likely to be associated with low-lying areas close to anticlines or faults. Daly suggests that sandstone permeabilities are in the order of 0.5 to 20 m/day, increasing up to 80m/day in localised areas.

Productivity data are presented in Figure 4.7, and indicate a distinct concentration in classes I and II. Several 'excellent' yields have been recorded in the area, though no high yielding springs are known.



Primarily on the basis of productivity and transmissivity data, the Kiltorcan sandstone aquifer in Kilkenny is classed as a **regionally important** fissured bedrock aquifer (**Rf**). However, when considering large-scale groundwater development in this aquifer, the following should be noted:

• Problems with iron are likely to occur unless wells are drilled through the upper shaley parts of the Portersgate Formation and into the confined portions of the aquifer. Daly (1985) recommends that wells drilled in these locations be pumped such that water levels are not drawn down into the sandstones, in order to try to avoid the introduction of oxygen to the
aquifer near the well. If the introduction of oxygen can be avoided, the risk of iron discolouration and precipitation will be reduced.

• The balance of abstraction with recharge will require careful attention, particularly if considering portions of the aquifer which are confined and/or which occur as isolated faulted blocks.

4.9 Classification of the Lower Limestone Shale Aquifer (BV, BT)

This aquifer comes to the surface intermittently across mid and south Kilkenny, occurring on the sides of the two major synclines (see Maps 1N and 1S), comprising some 2% of the county. It consists of the Ballyvergin Formation (BV) and the overlying Ballymartin Formation (BT). The Ballyvergin formation is a maximum of 10 m thick and is only differentiated from the Ballymartin in the south Kilkenny synclines.

The Ballyvergin portion of the aquifer consists of mudstones and siltstones, while the overlying Ballymartin portion consists of thinly interbedded limestones and shales.

No hydrochemical data are available specifically for this aquifer, but Daly (1982) mentions that hydrogen sulphide and iron often reach unacceptable levels in shaley limestones.



No permeability or transmissivity data are available specifically for this aquifer.

Productivity information is limited, but available data are concentrated in classes III and IV (refer to Figure 4.8). No 'excellent' yielding wells or 'high' yielding springs are recorded for these formations.

As a consequence of the lithological characteristics and assessments made in other counties, in combination with the limited amount of productivity data available, the Lower Limestone Shale is classed as a **poor aquifer** which is **generally unproductive except for local zones (Pl)**.

4.10 Classification of the Ballysteen Limestone Aquifers (BA and BAbb)

This aquifer comes to the surface across mid and south Kilkenny (Maps 1N and 1S). It consists of the Ballysteen Formation (BA), and its subdivision, the Bullockpark Bay Member (BAbb), and underlies slightly less than 10% of the county. Although similar in age and depositional history, it is assessed separately to the lower limestone shales (described in Section 4.9), as it has cleaner limestones and less regular shale bands.

The older portions of the Ballysteen Formation consist of thick limestones, some of which are quite coarse-grained (Daly, 1992), making them more susceptible to solution and karstification. The younger portions of the aquifer are more thinly bedded and more shaley, and the bulk permeability is

therefore likely to be lower than in the older portion. The older and younger portions have not been differentiated on the bedrock maps, however, and the two are classified together.

One portion of the formation has been mapped separately; the Bullockpark Bay Member. In Kilkenny, this member has only been identified in the southern syncline (see Map 1S). It consists of clean, thickly bedded oolite (calcareous spheres) with individual beds being up to 12 m thick (Daly, 1992). The formation as a whole is between 20m and 55 m thick.

Faults and folding have affected the aquifer and, where the cleaner limestone beds are fractured, there is likely to be enhanced permeability (see Section 4.5.2).

No hydrochemical, transmissivity or permeability data are available specifically for these formations. Some data are available for dolomitised portions, and this is discussed in the context of the dolomite aquifer as a whole in Section 4.14

A comparatively large amount of productivity information is available specifically for the Ballysteen Formation (mostly from counties surrounding Kilkenny). The data are scattered across all five classes, but there is a concentration in classes III, IV and V (refer to Figure 4.9). Two 'excellent' yielding wells but no 'high' yielding springs are recorded for the undolomitised Ballysteen. The data for the Bullockpark Bay Member are more limited, but regional data from surrounding counties suggest that equivalent members may have a higher overall productivity, concentrating in classes I and II. Further more 'excellent' well yields have been recorded in this unit.



Primarily on the basis of productivity data, the Ballysteen formation in Kilkenny is classed as a **locally important aquifer** which is **moderately productive only in local zones (Ll)**.

Lithological data suggest that the Bullockpark Member (BAbb) is a 'cleaner' limestone and therefore more likely to have a generally higher productivity. The productivity data, though limited, tends to support this. Consequently, this unit is classed as a **locally important aquifer** which is **generally moderately productive (Lm)**.

Note that a dolomitised portion of the Ballysteen (BAdo) also occurs in Kilkenny. It is described and classified in conjunction with other dolomitised limestones in Section 4.14.

4.11 Classification of the Waulsortian Limestone Aquifer (WA)

The Waulsortian limestones (WA) underlie 2% of the county, occurring in the southern, mid and north-western synclines (refer to Map 1N and Map 1S). The aquifer becomes thinner towards the east, and is not believed to be present east of Stonyford. It consists of massive fine-grained clean unbedded fossiliferous limestone, but a significant portion is dolomitised in Kilkenny. This dolomitised portion (WAdo) is discussed separately, together with other dolomitised units, in Section 4.14

The massive (i.e. unbedded) nature of the Waulsortian aquifer means that bedding partings will provide less secondary permeability than in other clean limestones. Consequently, groundwater circulation will be mainly limited to fractures and a weathered zone close to the top of the rock profile.

In the north and west of the county, folding and faulting has been of a relatively low intensity. Consequently, fracture density in these areas is expected to be low. However, in the southern synclines (i.e. in the area around Kilmacow), the higher intensity folding will presumably have resulted in the development of an extensive fracture network in the Waulsortian.

The 'reliance' of Waulsortian permeability on fracturing, because of the limited amount of bedding features, and the marked contrast in fracturing between north and south Kilkenny, suggests that significantly more permeability is likely to have developed in south Kilkenny than in north Kilkenny. This is reflected by the distribution of karst features. No surface karst fractures are noted in the northern exposures, while four (3 karstic springs and one swallow hole) are noted in the Waulsortian in the southern synclines around Kilmacow. Similarly, many karst features (including Mitchesltown Caves) occur in the unit in counties to the west and south of Kilkenny.

No hydrochemical data are available for the Waulsortian in Kilkenny, but data from Poulatar (a large spring in the Waulsortian near Ardfinnan, County Tipperary) are presented in Figure 4.1. The signature is typical of clean limestones, with calcium and bicarbonate as the dominant ions, 'hard' to 'very hard' waters, and a neutral pH. Issues associated with the 'natural' chemistry of these waters may include lime-scale problems. Contamination by human activities is discussed in Chapter 7 of Volume II.

No transmissivity data are available for un-dolomitised Waulsortian limestones in County Kilkenny.

Productivity information is presented in Figure 4.10. The northern and southern Waulsortian data have been separated on the basis of inferences made from structural and karstic data. Though limited in the southern synclines, the data appears to support the separation of northern and southern Waulsortian units. Data from the north are concentrated in classes III to V, while data from the south are concerted in class I. 'Excellent' yielding wells are recorded in both the northern and southern area, but high yielding springs are recorded only in the Waulsortian of the southern synclines (e.g. Poulatar and Poulalee in Tipperary).



On the basis primarily of productivity data, along with and structural, lithological and karst data, the Waulsortian Formation is classed as follows:

- North and west Kilkenny: locally important aquifer which is moderately productive only in local zones (Ll).
- South Kilkenny (near Kilmacow): regionally important karst aquifer, with some development potential (\mathbf{Rk}^d) .

It is stressed that these classifications do not include the portion of dolomitised Waulsortian rocks (WAdo) which occur in Kilkenny, which are described and classified in conjunction with other dolomitised limestones in Section 4.14.

Note also that, when considering large-scale groundwater development in the aquifer, the balance of abstraction with recharge will require careful attention, particularly if considering portions of the aquifer which are confined and/or which occur as isolated faulted blocks

4.12 Classification of the Crosspatrick, Kilsheelan and Silverspring Aquifers (CS, SS, KS)

The Crosspatrick (CK), Silverspring (SS) and Kilsheelan (KS) Formations overlie the Waulsortian aquifer and outcrop over 2% of the county as thin bands in the southern, mid and north-western synclines. These formations are considered together because they all consist of clean, thickly bedded, cherty limestones and are all of similar ages.

Although not mapped separately, dolomitisation is reported, particularly at the base of the Crosspatrick and throughout the Silverspring Formation. This will serve to enhance the permeability of the aquifer (refer to Section 4.5.2).

As with the Waulsortian rocks, it may be that the fracture permeability in the southern formations (i.e. the Kilsheelan and Silverspring) has been enhanced by structural effects compared to their northern equivalent (i.e. the Crosspatrick Formation). However, in all three formations the bedding is better developed than in the Waulsortian (refer to Section 4.11). Consequently, it is likely that fracture densities will be generally slightly higher than in the Waulsortian.

All three formations are considered susceptible to karstification, particularly in the south. This is supported by the presence of at least two swallow holes and three caves in the Kilsheelan Formation in Tipperary (Daly et al., 1998).

The depth to rock over these formations is often greater than 3 m, so drainage density cannot be used to assess aquifer potential.

Hydrochemical data are available for the Crosspatrick Formation for county Laois (Daly, E.P., 1994). The data appear to be typical for limestone groundwaters with a calcium bicarbonate signature, 'hard' waters, and a neutral pH. Issues associated with the 'natural' chemistry of these waters may include lime-scale problems. Contamination by human activities is discussed in Chapter 7 of Volume II.

E.P. Daly (1994) suggests typical transmissivities in the order of 20 to 40 m²/day and permeabilities in the order of 0.1 to 10 m/day for the Crosspatrick Formation.

Productivity information is limited, but available data are presented in Figure 4.11. Data for the northern and southern formations have been separated on the basis of inferences made from structural and karstic data. No 'excellent' yielding wells are recorded in these units.

On the basis primarily of structural, lithological and karst data, the formations are classed as follows:

- North Kilkenny (Crosspatrick Formation): locally important aquifer which is generally moderately productive (Lm).
- South Kilkenny (Kilsheelan and Silverspring Formations): regionally important karst aquifer, with some development potential (**R**k^d).

These classifications are supported by assessments of the Silverspring Formation in South Tipperary (Daly et al., 1998) and by assessments of the Crosspatrick Formation aquifer potential as part of the GSI's Nore River Basin study (Daly, E.P., 1994).

A small portion of the Crosspatrick Formation has been mapped within the main body of the dolomite aquifer just south of Kells (Map 1). Though not specifically mapped as dolomite, this portion of the formation is assumed to be dolomitised and has been classified separately in Section 4.14.



Note that, when considering large-scale groundwater development in these aquifers, the balance of abstraction with recharge will require careful attention, particularly if considering portions of the aquifer which are confined and/or which occur as isolated faulted blocks.

4.13 Classification of the Aghmacart, Durrow and Butlersgrove Limestone Aquifer (AG, DW, BU)

This aquifer consists of the Aghmacart (AG) and Durrow (DW) Formations in the west and the Butlersgrove Formation (BU) in the east (refer to Maps 1N and 1S). It is a thick aquifer, and outcrops over slightly less than 10% of the county. It is assessed as one aquifer because all three formations consist of shaley limestones and are of similar ages. The Butlersgrove Formation is the 'Kilkenny black marble'.

The three formations are broadly equivalent in age and lithology to the 'Calp' limestone which occurs across the midlands of Ireland from Galway to Dublin. Dolomitisation has occurred extensively in these formations in the central syncline (Daly, 1993), particularly close to the contact with the dolomitised Waulsortian rocks. The dolomitised portions of the Butlersgrove and Aghmacart Formations are likely to have different aquifer properties to un-dolomitised portions, and are considered in the context of the dolomite aquifer as a whole in Section 4.14.



The aquifer outcrops on the sides of the large central syncline, which is likely to have associated faulting and fracturing. The degree of fracturing will be the main control on permeability in these formations. However, the shaley nature of these rocks means that fracturing will be, on the whole, less intense than in cleaner limestones.

Despite the shale content of the limestones in this aquifer, it contains quite a number of karst features (Figure 4.12). There are 28 features on record, most of which are springs, but there are also swallow holes and borehole features. Several of these features, however, occur very close to the contact with karst limestones (e.g. the springs used for public supply at Urlingford and Paulstown), perhaps reflecting a gradual transition across the contact from clean to shaley limestone. The Paulstown spring is so close to the contact that it is regarded, in terms of aquifer characteristics and hydrochemistry, as lying within the Ballyadams Formation (Section 4.15). Hydrochemical data are available for the aquifer from the Urlingford public supply and the Newtown-Kells group scheme. Results suggest groundwaters in this unit are 'very hard', with a neutral pH. The hydrochemical signature is calcium-bicarbonate (refer to Figure 4.1), which is typical for limestone groundwaters. In general Daly (1982) suggests that hydrogen sulphide can present problems in shaley limestones.

No transmissivity or permeability data are available specifically for the Aghmacart, Butlersgrove or Durrow Formations.

Productivity information is limited, but available data are spread across all five classes, with a slight concentration around class III (refer to Figure 4.13). At least one 'excellent' yielding well occurs, but no 'high' yielding springs are on record (the Urlingford springs are classed as an 'intermediate' yield).



Primarily on the basis of lithological information, but supported by productivity data, the Aghmacart, Durrow and Butlersgrove Formations are classed as a **locally important aquifer** which is **moderately productive only in local zones (LI)**.

Note that, where dolomitisation is mapped (BUdo, AGdo, BUdo), the yields are generally expected to increase. Where the dolomitised portion is localised, the productivity is not expected to be as high as that which could occur where the dolomitised portion extends into adjacent dolomitised Waulsortian rocks. Thus, the dolomitised portions are classed as a **locally important aquifer** which is **generally moderately productive (Lm)**, or a **regionally important** fissured bedrock aquifer (**Rf**), depending on there proximity to other dolomitised formations. This issue is discussed further in the context of the main dolomite aquifer in Section 4.14.

4.14 Classification of the Dolomite Aquifer (BAdo, WAdo, BUdo, AGdo)

This aquifer occurs across a wide range of formations. It is visible on the geological maps (Maps 1N and 1S) as two bands, underlying slightly less than 10% of the county. The northern band runs north eastwards from Lisheen to Galmoy. The southern band extends from Callan eastwards to Goresbridge. The aquifer consists of the dolomitised portions of the Waulsortian (WAdo), the Ballysteen (BAdo), the Butlersgrove (BUdo) and the Aghmacart (AGdo) Formations.

In cross section, it becomes apparent that the two bands form the ends of a large U-bend structure (part of the central syncline of Kilkenny), which runs underneath Sieve Ardagh and the Castlecomer Plateau at depths of over 300m.

Dolomitisation of limestone generally results in an overall increase in the bulk permeability of the rock and is described in Section 4.5.2. Dolomitisation will occur preferentially in the cleaner, less shaley limestones, and along fault zones (Daly 1993). The dolomite aquifer is centred on the cleaner Waulsortian limestones and on the major fault which runs under the Nore River between Bennettsbridge and Kilkenny City (refer to Maps 1 and 5). The aquifer also extends from the Waulsortian into the shaley limestones of the older Ballysteen and younger Aghmacart/Butlersgrove formations, but the extent of the dolomitisation and overall productivity is expected to reduce moving into these formations.

The dolomitisation and associated enhanced permeability in the aquifer has been found to be greatest within 30m of the surface (Daly, 1993), but permeability and water strikes have been found at depths in excess of 100m; particularly close to the larger fault zones. Daly (1993) suggests that significant amounts of deep groundwater could occur at depths of over 200m, with some groundwaters in the north of the aquifer actively flowing underneath Sieveardagh and discharging into the Nore near the junction with the Kings River. A portion of this discharge is believed to occur via the Bausheenmore springs (2.5 km south of Bennetsbridge), which have a combined discharge in the order of approximately 10,000 m³/day to 25,000 m³/day (Daly and Boland, 1990). Additional discharge may occur directly to the Nore River, and to the group of springs just to the west of Callan (Map 4). The fact that Cappahayden spring is 'warm' (Burdon, 1983) tends to support the suggestion that deep flow is occurring within the aquifer.



In areas where the aquifer is close to the surface, the drainage density is low. This is particularly noticeable in the area between Bennetsbridge and Gowran. Dry weather flows are available for portions of the Kings River between Callan and Annamult, and the Nore River between Mount Juliet and John's Bridge (Table 4.3). The dolomites underlie most of these two portions. The specific dry weather flows estimated from the data are relatively high (1 to 2 l/sec/km²), suggesting that the aquifer is relatively effective at storing water through to the summer months.

Water level data are available from a well near Kells (Figure 4.14). This hydrograph indicates an annual fluctuation of 4 m and is taken from a well which lies 10 m higher than the Kings River.

Available hydrochemical data have been summarised in Figure 4.1. Public supplies, group schemes and large springs in this aquifer include Bennetsbridge PWS, Bausheenmore springs, Cuffesgrange GWS, Ballymack GWS, Kilree-Stoneyford GWS and Ahenure GWS. Typically, the waters are 'very hard', with calcium and bicarbonate as the dominant ions. This reflects the fact that the sources sampled extract waters from the unconfined, shallow part of the aquifer, where groundwater circulation and recharge is active. Daly (1993) suggests that the groundwaters in the aquifer are characterised by a higher magnesium : calcium ratio than most limestone groundwaters, reflecting the

mineralogy of dolomite. Daly also suggests that sodium may dominate over calcium in the deep, confined part of the aquifer. Contamination by human activities is discussed in Chapter 7 of Volume II.

Aquifer tests undertaken and compiled by the GSI as part of the Nore River Basin Study suggest that bulk permeabilities in the more dolomitised parts of the aquifer are in the order of 0.5 m/day to 10 m/day with transmissivities ranging from approximately 50 m²/day to 500 m²/day (Daly, 1993).



Productivity data are presented in Figure 4.15. There is a spread across all five classes, with a concentration in classes I and II. Several 'excellent' yielding wells and one 'high' yielding spring (Bausheenmore) occur on record.

On the basis of transmissivity, productivity, lithological and hydrological data, the dolomite aquifer is classed as a **regionally important** fissured bedrock aquifer (**Rf**). Highest yields are generally more likely near major fault zones in the dolomitised Waulsortian portion of the aquifer.

Note that this classification does not apply to all portions where dolomitisation is mapped in the Ballysteen, Aghmacart and Butlersgrove Formations. Where dolomitisation is localised and apparently 'isolated' from the main body of the dolomite aquifer, these portions are classed as **locally important aquifers** which are **generally moderately productive (Lm)**.

In summary, the Waulsortian, Ballysteen, Aghmacart and Butlersgrove Formations can each have one of three aquifer classifications, depending on the degree and location of dolomitisation:

Formation	Classification where dolomite not mapped	Classification where dolomite mapped in localised areas	Classification within the body of the main dolomite aquifer
Ballysteen	Ll	Lm	Rf
Waulsortian	Ll	Rf	Rf
Butlersgrove	Ll	Lm	Rf
Aghmacart	Ll	Lm	Rf

The distribution of these classifications is best illustrated by a comparison of Maps 1 (geology) and 5 (aquifers). The basis for the classification of the areas where dolomites are not mapped in the Waulsortian, Ballysteen, Aghmacart and Butlersgrove Formations is presented in Sections 4.10, 4.11, and 4.13.

4.15 Classification of the Karst Limestone Aquifer (BM, BMdo, CL)

This aquifer consists of the Ballyadams (BM) and Clogrennan (CL) Formations and outcrops throughout the northern half of the county. It is one of the most extensive aquifers in Kilkenny, underlying approximately 15% of the county. Both formations in the aquifer are of similar ages and

consist of thick-bedded clean limestones, with beds getting slightly thinner and somewhat cherty in the Clogrennan Formation.



The rocks occur in the central syncline and have undergone at least one major period of folding. The clean nature of the limestone means that this deformation will probably have resulted in extensive brittle fracturing.

The clean nature of the limestone will also mean that the rocks will have been susceptible to dissolution. Coupled with the probability of extensive fracturing, this means that the aquifer is likely to be karstified. This is supported by the presence of a large number of karst features on record (refer to Figure 4.16). Fieldwork undertaken in the Freshford area in the summer of 1999 identified eight new karst features, and a patchy development of limestone pavement similar to that found in the Burren (Buckley, 1999). In one field alone, three dolines were found. In fact, a whole range of features are present, including a large number of swallow holes, suggesting that the karst network is well-developed. In karstic areas, groundwater flow velocities are typically tens of metres per hour. In the Freshford portion of the aquifer, limited dye tracing has ascertained that a karst network with velocities of 58 - 172 m/hr exists (Burke, *pers. comm.*). Some portio for the BM formation are dolomitised (BMdo), which is likely to enhance the development of karst.

Though the groundwater flow system is karstic, Cawley, 1990's study of 43 wells in the aquifer showed that a continuous watertable does exist, indicating that flow in the aquifer may be through a diffuse network of conduits.

Karstification is predominantly a near-surface phenomenon (refer to Section 4.5.2), and is likely to concentrate within 20 m of the top of the rock in this formation (Cawley, 1990). Thus, most groundwater flow is likely to be concentrated in this upper zone, and E.P. Daly (1994) has estimated that the maximum saturated and permeable part of the aquifer is 75 m thick. Where the aquifer is protected from dissolution by the presence of the Namurian shale aquifer above it, significant karstification and permeability is not believed to exist (Daly, E.P., 1994). Similarly, where the Namurian has been eroded away in only recent geological times, karstification and permeability are likely to be limited. Ball (1972) suggest that this effect may be evident along the contact between the Ballyadams and the Namurian strata to the north west of Callan.

Due to the predominance of conduit flow in karst systems, large fluctuations in watertable levels are expected, particularly in areas of elevated topography. An example is provided in Figure 4.17. This hydrograph represents an annual fluctuation of 20m and is taken from a well which lies some 30m to 40m higher than the nearest surface water. Elsewhere in the aquifer, annual fluctuations of up to 30 m have been observed (Cawley, 1990). These very high annual fluctuations are considered indicative of a relatively low groundwater storage potential. It may be interesting to compare Figure 4.17 with hydrographs from non-karstic aquifers in Kilkenny (Figures 4.6, 4.14 and 4.20).



Where the aquifer occurs close to the surface, stream densities are low. In fact, surface water sinks underground in many areas where the aquifer is at surface. Examples include:

- Swallow holes near Shellumsrath (3 km south-west of Kilkenny City). These occur where streams, flowing off areas of thicker subsoil to the west, meet an area where the karst aquifer comes very close to the surface (Map 4).
- Sinking streams in the Borrismore and Nuenna catchments, near Freshford. Cawley (1990) found that the upper portions of the main channels frequently go dry in the summer months.
- Sinking streams have been observed near Paulstown spring (refer to Chapter 11 of Volume II).

Dry weather flows are available for the portion of the Nore River between Ballyragget and John's Bridge (Table 4.3). The karst aquifer and the Nore gravels are likely to supply most dry weather flows over this portion of the river. The specific dry weather flow estimated from the data is relatively high (2 l/sec/km²), suggesting that the aquifer, where it combines with the overlying gravel aquifer, is relatively effective at storing water through to the summer months.

Public and group scheme water supplies and springs in this aquifer include Paulstown PWS (spring), Barna GWS, Tubbrid GWS, Graine/Craddockstown GWS, Balief/Clomantagh GWS, 'Clomantagh Boiling Well', and Clara GWS. Hydrochemical data are presented in Figure 4.1. Waters are typically 'hard' to 'very hard', with a neutral pH and with calcium and bicarbonate as the dominant ions. This signature is thought to reflect the generally shallow nature of flows within the karst aquifer. Contamination by human activities is discussed in Chapter 7 of Volume II.

As with most karstic systems, permeability and transmissivity data are very variable. Daly (1994) cites a range in permeability of 0.1 m/day to 100 m/day, and a range in transmissivity of 5 m²/day to 3000 m²/day.

A large amount of productivity information is available for this aquifer (refer to Figure 4.18). As is typical for karstic systems, the data are very variable. Nevertheless, a significant number of wells occur in class I. In addition, several excellent yielding wells are on record, along with at least one high yielding spring (Paulstown).

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



When considering large-scale groundwater development in the aquifer, note the following:

- Permeability and productivity within the aquifer will be highly variable. Lowest permeabilities will occur away from fracture zones, in areas close to the contact with Namurian sediments, and in areas where the aquifer is confined by Namurian sediments.
- High flow rates and point recharge mean that the aquifer will be more susceptible to contamination events than some of the other regionally important aquifers in Kilkenny.
- The balance of abstraction with recharge will require careful attention, particularly if considering portions of the aquifer which are confined and/or which occur as isolated faulted blocks

4.16 Classification of the Namurian and Westphalian Shale Aquifer (LS, KN, KNcf, BE, MC, CQ, LF, LFgc)

This aquifer consists of the Luggacurren (LS), Killeshin Siltstone (KN), Bregaun (BE), Moyadd Coal (MC), Coolbaun (CQ) and Lickfinn Coal (LF) Formations, along with the Carlow Flagstone (KNcf) and Glengoole Coal (LFgc) subdivisions. It occurs in the Slieveardagh and the Castlecomer Hills and underlies approximately 21% of the county. The formations are considered together because they all consist of shales, siltstones and sandstones, and because they are all of a similar geological age. The Killeshin and Bregaun Formations both contain more siltstones than the other formations.

The formations all occur towards the centre of a major syncline, and there is evidence of faulting on the geological map (Map 1N). However, the shale content is such that the rocks are not expected to have deformed in a brittle manner and fracture density is expected to be comparatively low.

No hydrochemical data are available. However, it is likely that waters will be 'moderately hard' to 'soft', particularly in areas where subsoils are thin. Daly (1982) identifies frequent iron and manganese problems in this aquifer.

In areas where the rock is exposed at the surface, the land is 'rushy', small springs are frequent at breaks-in-slope and drainage densities are high.

No permeability or transmissivity data are available.

Available productivity data (Figure 4.19) are restricted to classes IV and V. No excellent well yields or high yielding springs are on record. Further, of the seven 'good' yielding wells on record, six are in



the Killeshin Siltstones.

Primarily on the basis of productivity data, supported by lithological and hydrological data, this aquifer is classed as follows:

- Killeshin Formation (KN), Carlow Flagstone Member (KNcf) and Bregaun Formation (BE): poor aquifer which is generally unproductive except for local zones (Pl).
- Luggacurren (LS), Moyadd Coal (MC), Coolbaun (CQ) and Lickfinn Coal (LF) Formations, plus the Glengoole Coal (LFgc): **poor aquifers** which are **generally unproductive (Pu)**.

4.17 Classification of the Swan and Clay Gall Sandstone Aquifers (CQss and CG)

This aquifer occurs on the Castelcomer Plateau, underlying approximately 1% of County Kilkenny.

Both formations consist mainly of sandstone and are of a similar geological age. They lie within the sequence of shales, siltstones and sandstones that make up the Namurian and Westphalian Shale aquifer (refer to Section 4.16). The Swan Sandstone does not occur everywhere within this sequence but can be up to 28 m thick. The Clay Gall Sandstone ranges from 2m to 58m in thickness.

The rocks occur within the syncline that makes up the Castelcomer Plateau and have been subjected to at least one major phase of structural deformation. This deformation has caused considerable fracturing within the two sandstone formations (Misstear et al. 1980), which will have reacted to the tectonic pressures in a more brittle manner than the surrounding shales.

The configuration of the aquifer within the syncline is such that it outcrops around the rim of the plateau, but dips down to depths of over 246 m below ground in the centre of the plateau. It seems likely, therefore, that waters away from the main recharge-outcrop area will be confined by the low permeability Westphalian shales. This is supported by the presence of artesian pressures in some wells drilled closer to the centre of the plateau (e.g. the Swan public supply in County Laois).

Hydrochemical data are available from the Swan public supply well in Laois and from sampling undertaken by the GSI as part of the Nore River Basin study (Figure 4.1). Waters close to the recharge-outcrop area have a calcium-bicarbonate signature which is typical of actively-flowing, young groundwaters. Waters in the deeper, confined parts of the aquifer have a sodium bicarbonate signature, which is thought to be a result of ion exchange processes. The main significance of ion exchange in this context is that it indicates long groundwater residence times which, in turn, provide further evidence to suggest that deep flow can occur within the aquifer and that waters the deeper parts of the aquifer are of considerable age. In general, waters are 'moderately soft' to 'moderately hard' and iron and manganese may present a problem in certain parts of the aquifer. Contamination by human activities is discussed in Chapter 7 of Volume II.

Dry weather flows are available for the portion of the Dinin River upstream of Castlecomer (Table 4.3). The aquifer outcrops at the river in the vicinity of Castelcomer and it is likely that, in conjunction with gravel deposits in the Dinin valley, it will supply most dry weather flows over this portion of the river. The specific dry weather flow estimated from the data is relatively low (0.7 l/sec/km²), suggesting that the aquifer, even where it combines with the overlying gravel aquifer, is not particularly effective at storing water through to the summer months.

Well testing undertaken by Misstear et al. in 1980 suggest transmissivities in the order of $10m^2/day$ (range of $1m^2/day$ to 500 m²/day) and permeabilities in the order of 0.1 m/day (range of 0.01 m/day to 50 m/day).

Available productivity data cluster in classes II and III (refer to Figure 4.20). Two excellent yielding wells are on record in this formation, but no high yielding springs are known.



Primarily on the basis of productivity data, the Swan and Coolbaun sandstones are classed as **locally important aquifers** which are **generally moderately productive (Lm)**.

4.18 Classification of the Sand and Gravel Aquifers

4.18.1 Introduction

Kilkenny has some extensive developments of sand and gravel, the largest of which is associated with the River Nore (Maps 2 and 5). Around the Nore, the Nuenna, the Dinin, and the Kilmanagh Rivers these deposits are likely to be 'clean' enough (in terms of the content of silt and clay) and extensive enough to be aquifers.

Most of the aquifers identified in the Section 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.

4.18.2 Kilmanagh River Gravels

These coarse sands and gravels occur in the western half of the county, along the Kilmanagh River and it's confluence with the Munster and King's rivers. The aerial extent of the portions of the aquifer which are generally over 5 m in thickness is approximately 30 km². The sands and gravels of this aquifer are believed to be outwash material associated with a phase of ice retreat (Naughton, 1978). They are regarded as having high permeability, with a low content of silt and clay material (refer to Section 5.3.4). Transmissivities of 200 m²/day to 250 m²/day and permeabilities of 30 m/day to 60 m/day were estimated from two pump tests carried out in the deposit (Naughton, 1978). The aquifer can be considered in two parts, the area from Tullaroan to Kilmanagh which covers 10 km², and the area from Kilmanagh to Callan which covers 20 km².



In the Tullaroan to Kilmanagh portion, the aquifer is believed to generally be 5 to 10 m in thickness, and overlain by a layer of finer sediments, which represents a later reworking of the original glacial outwash material. Between Tullaroan and Kilmanagh, this layer consists of well sorted sands and silts, and is not thought to impede drainage (Naughton, 1978). Consequently, the aquifer is considered to be generally unconfined in this area. North of Tullaroan, however, this upper layer is more silty and is thought to contain a perched watertable.

The portion of the aquifer from Kilmanagh to Callan is believed to be confined by the presence of a till cap (Map 2). Further, the deposit in this area is believed to be interspersed with clays and silts (Daly, 1994). The thickness of the aquifer is believed to be up to 15 m, with the overlying till generally 3m to 4m in thickness. Note that the distribution of clays and silts within this portion of the aquifer is not well defined.

Regionally, most discharge from the aquifer is believed to occur to the Kilmanagh River, to a group of springs near Callan (including the Callan public water supply) and to the Kings River near Callan.

Recharge to the confined portion is expected to be mainly supplied by cross-flow from the unconfined portion, and by up-flow from the deep dolomite aquifer (refer to Section 4.14).

Recharge in the unconfined portion is both via rainfall and, at times of low groundwater levels, via sinking surface streams. An example hydrograph is provided in Figure 4.20. This hydrograph demonstrates an effect whereby water levels, which normally fluctuate by less than 1m, drop by an additional 1m at the end of certain summers. These summers correspond with years when the Kilmanagh river has dried-up. It seems likely, therefore, that the river, when flowing, helps to maintain summer water levels within the aquifer. In the winter, it is likely that flows are reversed and the aquifer discharges into the river. Thus, there appears to be a very active link between groundwater

and surface water in the unconfined portion of the aquifer. The hydrograph also suggests that the saturated thickness in the central part of the aquifer will remain just above 5m even at times of lowest water levels. In the confined part of the aquifer, Ball (1972) indicates that winter water levels within the gravels are very close to surface, or are under artesian pressures.

The aquifer is an important source of water in the area, feeding both the Callan public supply and the Ballycallan/Kilmanagh group scheme. Hydrochemical data are available from both these sources and are presented in Figure 4.1. The groundwaters appear to be 'hard' to 'very hard' and the dominant ions are calcium and bicarbonate. These characteristics probably reflect the limestone mineralogy of the gravel deposits, and the active nature of groundwater circulation in the unconfined area. Contamination by human activities is discussed in Chapter 7 of Volume II.

Productivity information is presented in Figure 4.21. The data are clustered around classes I and II, and several excellent yielding wells are on record. The Callan spring flow is classed as 'intermediate'. Note that all but one data point are from the unconfined portion of the aquifer near Kilmanagh.



Primarily on the basis of our current understanding of the extent, thickness and grain size distribution of the deposit, the Kilmanagh gravels are classed as a **Regionally important** gravel aquifer (**Rg**).

Note that the productivity data are derived from the unconfined portion of the aquifer. In the confined interval is a provided will be more variable and are likely to be generally lower, given the increased urrence of clays and silts in this portion of the aquifer.

4.18.3 Nore Gravels

This large development of sand and gravel extends along almost the entire length of the Nore, from north of Ballyragget to south of Thomastown. Where they are generally over 5 m in thickness, they have an aerial extent of 80 km^2 .

The sand and gravel deposits associated with the Nore are believed to be fluvio-glacial in origin, being deposited by the large quantities of meltwater associated with ice-retreat. This means that coarse sands and gravels are likely to predominate. Though permeability testing data are limited, productivity, borehole logging and quarry data tend to support the suggestion that coarse material predominates and that the permeability of the aquifer is high (refer to Section 5.3.4). Much of the area has a characteristic hummocky terrain, which is typical of water-lain sand and gravels, although some more poorly sorted lenses have also been encountered, particularly in the north (Daly, 1978).

The gravels are considered in three major portions (see Map 5).

- North of Ballyragget to just east of Freshford: gravels in this portion are generally greater than 10 m in thickness over 13 km². Lenses of finer material occur, and some parts are overlain by till.
- *Threecastles to Kilkenny City*: gravels in this portion are generally greater than 10 m in thickness over an area of 27 km². The portion contains the cleanest, best sorted and deepest sands and gravels in the county; sometimes in excess of 30 m thickness. Note that topography

is quite irregular in this area, and it is likely that wells drilled in some of the higher, more isolated hills will be dry. This feature can be seen in the gravel quarries which occur to the south east of Kilkenny City. Most of these quarries have excavated down to bedrock without the need for dewatering.

• *South of Kilkenny City:* The Nore valley narrows considerably and the lateral extent of the gravels decreases to a thin strip along the river. As such, the potential catchment area for rainfall recharge is significantly reduced compared to the portion of the gravel aquifer to the north. Nevertheless, the saturated thickness is generally in excess of 5m and, in boreholes and infiltration galleries located close to the Nore, river recharge is expected to compensate for the reduced potential for rainfall recharge. Note that infiltration galleries in Bennettsbridge and Thomastown have successfully exploited river recharge in this portion of the gravel aquifer in the past, and the public supply borehole at Bennetsbridge is also thought to derive much of its supply by inducing river recharge (refer to Chapter 8 of Volume II).

The gravels are generally unconfined. However, in certain areas (e.g. near Ballyragget), considerable thicknesses of clay-rich till have been found overlying the aquifer, and these appear to have reduced the percolation into the aquifer, creating ponding at the surface (Cullen, 1983).

River flow analysis carried out by E.P. Daly (1994) showed that the aquifer is likely to contribute to base-flow in the Nore, it also showed that over some stretches of the aquifer, particularly in the northern portion, the Nore can be influent into the sand and gravels. An examination of the water level data for the aquifer show that static water levels can fluctuate from 2 m below ground level to 20 m below ground level. At some points it also comes to the surface, as in Kilkenny City, where a high yielding spring is found. This suggests that the saturated thickness of the aquifer is likely to vary both spatially and temporally.

The aquifer has not been widely developed. Users include Glanbia (Ballyragget), the Dunmore sand and gravel quarry and Kilkenny Mart. Hydrochemical data are available for Dunmore quarry and Kilkenny Mart, and is summarised in Figure 4.1. Waters appear to be typically 'hard' to 'very hard', with a calcium-bicarbonate signature, reflecting the limestone mineralogy of much of the gravel deposit. Available data indicate pH values of between 7 and 8. Contamination by human activities is discussed in Chapter 7 of Volume II.

Only one productivity data point is available for the aquifer, and this falls into class 'II'. Several excellent yielding wells are on record, along with at least one high yielding spring (Kilkenny City).

Based primarily on the dimensions of the aquifer and productivity/yield data, the Nore gravels between Ballyragget and Kilkenny City are classed as a **Regionally important** gravel aquifer (**Rg**), while those between Kilkenny City and Thomastown are classed as a **Locally Important** gravel aquifer (**Lg**).

4.18.4 Nuenna Gravels

This sand and gravel body extends along the Nuenna River, west of Freshford. It is generally more than 5 m in thickness over an area of approximately 4 km^2 .

The Nuenna gravels are typical products of a fluvio-glacial regime, consisting of a chaotic mix of gravels and coarse sands. As discussed in Section 5.3.4, this aquifer is regarded as having high permeability. Much of the area is relatively flat and low-lying, with only occasional ridges of gravel. Reworking of the top of the deposit has resulted in a predominantly finer-grained upper layer. The aquifer is considered to be between 5 and 10 m thick, but along a very narrow strip by the river it is likely to be up to 20 m thick (Cawley, 1990).

The area along the Nuenna River is recognised as a discharge zone for groundwater (Cawley, 1990). A whole series of springs discharge along the length of the river, which occupies a narrow valley flanked by hills. The underlying bedrock is the karst limestone aquifer (refer to Section 4.15) and the springs are likely to be associated with groundwater flow in both the gravels and the karst network. Cawley

(1990) found the static water level to be a maximum of 5 m below ground level, and that the annual fluctuation was no more than 5 m.

No productivity data are available for the aquifer, and no 'excellent' yielding wells are on record.

On the basis of the dimensions of the aquifer, and indirect evidence of permeability, the Nuenna gravels are classed as a **locally important** gravel aquifer (**Lg**).

4.18.5 Dinin Gravels

This aquifer extends along the Dinin River in the north east of Kilkenny. Though it is thickest and widest where it meets the Nore gravels near Dunmore, there are uncertainties in relation to the saturated thickness further upstream. Examination of quarry exposures indicate that the sands and gravels have a generally high permeability (refer to Section 5.3.4), but that the deposit is generally dry in the hills which stand above the level of the valley floor. An examination of certain exposures close to the Dinin River has suggested that the sand and gravel deposits also extend underneath the level of the valley floor but are less than 5m thick in certain places and are underlain by clay-rich tills. It is likely, therefore, that yields from these gravels will be highly variable, and that wells drilled in the hills which stand proud of the valley floor will be dry. Nevertheless, the Dinin gavels have been classified as a *potential* **locally important** gravel aquifer (**Lg**) on the basis of the following information:

- Geophysical studies (Daly and Misstear, 1976) have detected the presence of over 10m of saturated sand and gravel under the valley floor close to the Dinin River.
- Daly and Misstear (1976) noted a large increase in flow in the Dinin River downstream of Castelcomer and attributed this increase to discharge from a gravel aquifer.
- An infiltration gallery in the gravels close to the river is used to supply the town of Castelcomer.

Note that no productivity data are currently available for the aquifer and no 'excellent' yielding wells are on record.

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) the vulnerability depends on the type, permeability and thickness of the subsoils. Each subsoil type described in Chapter 3 is assessed here in terms of its permeability. The vulnerability map is then derived by 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.

	Hydrogeological Requirements						
Subsoil	Diffuse recharge			Point	Unsaturated		
Thickness	Subs	oil permeability an	Recharge	Zone			
	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	Extreme		
				(30 m radius)			
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. 							

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

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 (\mathbf{E}), high (\mathbf{H}), moderate (\mathbf{M}) and low (\mathbf{L}), based on the geological and hydrogeological characteristics.

Note that the vulnerability map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1–2 m below the ground surface. The map is intended as a guide to the likelihood of contamination of groundwater if a contamination event occurs. It does not replace the need for site investigation. The characteristics of individual contaminants are not considered.

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. Peats, and lake clays are usually low permeability. 'Clean' gravels are usually high permeability. Tills and 'dirty' gravels are usually moderate or low permeability.
- Depth to bedrock map, compiled by the Quaternary 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 mid Kilkenny (Conry, 1974). This gave additional, indirect information on subsoil permeability in the areas mapped by Quaternary Section as 'till'. This map is re-produced in Appendix II.
- 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 included:
 - Description of the engineering properties of exposed subsoils using techniques based on BS5930:1999 (British Standards Institution, 1999).
 - Collection of subsoil samples for laboratory particle size analyses.

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

Details on analytical methodologies are presented in section 5.3.1.

- 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 of the Subsoils

5.3.1 Methodology

The permeability categories, and resulting vulnerability categories depicted on the vulnerability map (Maps 6N and 6S) 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 Kilkenny, these characteristics also determine the engineering behaviour of the materials (Swartz, 1999) as described using the subsoil description and classification method, derived from BS5930:1999 (British Standards Institution, 1999). This method is therefore used to assess the

permeability of the subsoils at each exposure, supported by recharge and drainage observations in the surrounding area.

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 Kilkenny, have established the following relationships: i) samples with moderate permeability secondary indicators usually have greater than 50% silt and clay. ii) samples with moderate permeability secondary indicators usually have greater 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).
- 5. Soils map. No soils map exists for the whole of Co. Kilkenny. In it's absence, work carried out in the 1970's by Michael Conry of Teagasc was consulted. This work has been summarised in the paper "Kilkenny's Golden Vein: it's Soils, Land-use and Agriculture" (reproduced in Appendix II). The original 1:10,560 scale maps used in the field mapping were obtained, and field interviews were carried out on site with Michael Conry. This data was used to assess drainage characteristics where specific site recharge observations were not available. Poorly drained soils such as surface water gleys 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 the moderate to high boundary is estimated to be in the region of 10⁻⁴ m/s (O'Suilleabhain, 2000). However,

permeability measurements are highly scale dependent: laboratory values, for example, are often up to two orders of magnitude 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.

In any one area, as many of these factors as possible were considered together in order to try to obtain a balanced, defensible permeability decision. In order to allow extrapolation from point data to an areal assessments, the county was divided into permeability units, usually on the basis of similar bedrock, subsoil and/or soil characteristics. It is intended that the assessments will allow a broad overview of relative permeabilities across the county, in order to help focus field investigations for future development projects on areas of interest. In mapping an area the size of County Kilkenny, the process cannot be comprehensive 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 5.3.2 to 5.3.5. Vulnerability maps are presented on Maps 6N and 6S. Details of the supporting data for each permeability decision can be found in Appendixes II and III.

5.3.2 Low Permeability

In Kilkenny, the deposits which have low permeabilities are clayey glacial tills, lacustrine clays and peat. Clayey tills are the most common of these low permeability deposits. A small area of lacustrine clay occurs to the north west of Slieveroe and a slightly larger area of peat occurs west of Urlingford.

Permeability Unit 1: The Castlecomer Plateau

The plateau is situated in the north-east of the county and is predominantly underlain by Namurian and Westphalian shales and shaley sandstones. It is a poorly drained area with rushy gley soils underlain by fine-grained glacial tills and peats. The particle size analyses, the subsoil descriptions, widespread surface water gley soils, rushy slopes and shaley bedrock all suggest generally low permeability subsoils (Appendix III). Note that sands and gravels that are found close to the Dinin River and are assessed separately as part of Units 6 and 16.

Permeability Unit 4: The North Western Peat

This small unit situated west of Urlingford, is the eastern-most extent of a large development of midlands raised bog. The area is flat and boggy, with widespread heather, moss and rushes. Where thick, the peat in conjunction with its underlying layer of fine lacustrine deposits, is likely to be of low permeability (Appendix III).

Permeability Unit 7a: The Slieveardagh Plateau

This plateau is situated in the north-west of the county. The dominant rock-types are Namurian and Westphalian shales and siltstones and the subsoils are tills. The particle size analyses and subsoils descriptions, along with inferences from the vegetation and drainage all strongly suggest generally low permeability subsoils (Appendix III). Some areas appear better drained, but this can usually be explained by the presence of shallow rock. Note that the sands and gravels that are found close to the Nuena River are assessed separately as part of Unit 3.

Permeability Unit 8c: The Western Kilkenny Lowlands, South of Callan

This Unit occurs in a low-lying area in the west of the county, underlain by tills and shaley limestones. It is distinguished from the Central Lowlands to the east of Callan by the widespread presence of gley soils, and from the lowlands to the north of Callan by the absence of mapped sand and gravel deposits. Although not clear-cut, the balance of available soils, particle size, and drainage data suggests generally low permeability subsoils (Appendix III). Note that some areas of good pasture land and even some tillage can be seen, but these correlate with ridges of shallow rock.

Permeability Unit 9: The Ordovician Central Uplands

This is an upland area of glacial till occurring in the east of the county with a patchy distribution from Ballyhale to Slieveroe. It occupies small valleys underlain by tills and Ordovician slates and Devonian sandstones. The particle size analyses and subsoil descriptions, and the artificial drainage density, suggest generally low permeability subsoils (Appendix III).

Permeability Unit 10: The Granite Uplands

This is a small Unit of glacial till overlying granite bedrock, occupying two long, steep sided valleys in the east of the county; one near Graiguenamanagh, the other near Tullagher. Both valleys are poorly drained, contain up to 10 m of till, and have rushes and ditches on their sides. Insufficient data are available for the particle size and subsoil descriptions, and the soil, subsoil and rock types are inconclusive. However, the drainage density suggest generally low permeability subsoils. (Appendix III).

Permeability Unit 12: The Slievenaman Uplands

This is a small, poorly-drained upland Unit of glacial till underlain by Silurian slates and surrounded by rocky hills. It situated to the south of Windgap. Although limited particle size data are available, the subsoil descriptions and the vegetation and drainage patterns generally suggest low permeability subsoils (Appendix III).

Permeability Unit 14: The South Kilkenny Lowlands

This is a large, predominantly low-lying area in the south of the county, stretching from Owning in the west to Kilmacow in the east. It is underlain by a mix of clean and dirty limestones and also some sandstones. The main subsoil types are glacial tills, with one small area of lacustrine clays. The vegetation and drainage density are not indicative of low permeability. However, the particle size data set and subsoil descriptions both suggest generally low permeability subsoils. On balance, therefore, a classification of low permeability has been assigned (Appendix III). Further, the particle size data set indicates that there will be pockets where the subsoil permeability is higher than the average for the Unit. There is no clear correlation between the location of these pockets and rock type variations, or depth to bedrock variations, and these pockets have not been mapped separately.

5.3.3 Moderate Permeability

In Kilkenny, the deposits which have moderate permeabilities are silty and sandy glacial tills, alluvium, and poorly sorted sand and gravel deposits. Silty tills are the most widespread of these moderate permeability deposits, occupying much of the central Kilkenny lowlands. Sandy tills occur in the north-west of the county, in the Galmoy area. There are only limited developments of alluvium along rivers, the most extensive of these being along the Nore and Suir. Occasional patches of poorly sorted, fines-rich gravels occur throughout the county.

Permeability Unit 2: The North Western Tills

This is a flat plain of intermediate elevation, underlain by dolomitised limestones, and situated in the north-west of Kilkenny. Tills are the main subsoil. They are very sandy, probably due to the sandy weathered texture of the dolomitised Waulsortian limestone which underlies much of the area. The particle size data and subsoil descriptions suggest generally moderate permeability subsoils. This is supported by the free-draining soil-type (Conry, *pers. comm*), the widespread tillage farming, the low drainage density and the presence of dolomitic bedrock (Appendix III).

Permeability Unit 7b: The Slieveardagh Slope-Sides

This area covers the steep slope sides rimming the Slieveardagh Plateau in the north-west of the county. It is underlain by siltstones, shales and limestones and the main subsoil types are till and gravel. The particle size data and low drainage density both suggest generally 'moderate' permeability subsoils (Appendix III). Note that the field descriptions from exposures indicate that there may be pockets of lower permeability material.

Permeability Unit 8a: The Central Kilkenny Lowlands

This is a low-lying plain in central Kilkenny, underlain by predominantly clean limestones and bordered by the Castlecomer Plateau to the north, and the slopes of Slieveardagh to the west. The main subsoil type is glacial till derived from the clean limestone bedrock. Soils maps are available, and the main soil is mapped as medium-heavy grey brown podzolic with only occasional pockets of gley in hollows. The particle size and subsoils descriptions suggest that permeabilities will be variable but generally close to the moderate/low permeability boundary. However, on balance, the soils mapping information, together with the limited occurrence of field drains, suggest that the subsoils permeability will be generally moderate (Appendix III). Note that the Nore sand and gravels aquifer, which runs through the middle of this Unit, is discussed separately as Permeability Unit 5.

Permeability Unit 8b: The Western Kilkenny Lowlands, North of Callan

A particularly flat and low-lying area in the west of the county, this Unit is underlain by till and clean limestones. It is distinguished from the rest of the Central Lowlands by the widespread presence of sand and gravel deposits, both adjacent to and underlying the tills of the unit. The main soil-type is gley. This is a particularly difficult area to assess. The particle size analyses suggest moderate permeability, while the subsoils descriptions (including those from boreholes), soil type and drainage density all suggest low permeability. As with the lowlands to the east of Callan (Permeability Unit 8a), it is likely, therefore, that permeabilities will be close to the moderate/low boundary. On balance, the area is considered to be generally moderate permeability, mainly on the basis of the grain size data (Appendix III). In this Unit, the gley soils and high drainage densities are explained by the presence of a high water table. This high water table was identified by Ball (1972) and is thought to be due to a combination of:

- a) Low-lying topography at the base of steeper slopes (Slieveardagh Hills).
- b) The orientation of bedrock dip in the opposite direction from regional groundwater flow. Gravity will therefore tend to drive groundwater up-dip to the surface. This effect is depicted schematically in Figure 9.1 of Volume II.
- c) Generally lower bedrock permeability where the karst aquifer lies adjacent to Slieveardagh (refer to Section 4.15).

Numerous sand and gravel bodies are mapped in this region, washed down from melting ice in the Slieveardagh Hills (Naughton 1978). This slightly coarser depositional environment is thought to be the reason why subsoils in this Unit generally have a higher permeability than subsoils in the lowlands to the south of Callan (Unit 8c).

Permeability Unit 11: Alluvial Deposits

These deposits are found in narrow strips along streams and rivers throughout the county. Although they are underlain by a wide range of rock-types and occur within most of the other permeability regions, they generally consist of a range of fine-grained water sorted sands, silts and clays. However, they are usually quite narrow and thin deposits in Kilkenny and have not generally influenced vulnerability classifications. They are generally considered to be of moderate permeability (Appendix III).

Permeability Unit 16: Dirty Fluvio-glacial Sands and Gravels

These deposits are found throughout the county and generally consist of small pods of poorly sorted sands and gravels. They are neither clean enough nor large enough to contain quarries, and, unlike many sand and gravel deposits (e.g. the Nore valley gravel aquifer) do not have a hummocky surface expression. They are frequently found on the southern side of upland areas and are likely to have developed when meltwater from stationary glaciers on these uplands reworked material downslope. Some of the deposits formed sub-glacially, forming small eskers on the southern edge of the Castlecomer Plateau. When surrounded by low permeability deposits, they are distinguished by their well drained appearance. Where county-specific soils mapping is available, the areas are classified as medium textured grey brown podzolics. They frequently support tillage. Although limited, the subsoil description data, coupled with the particle size analyses suggests that these deposits have a moderate permeability (Appendix III).

5.3.4 High Permeability

In Kilkenny, the deposits which have high permeabilities are well-sorted sand and gravel deposits, often associated with large rivers, such as the Nore.

Permeability Unit 3: Nuenna River Sand and Gravel Deposit

This is a large area of well-sorted sand and gravel, underlain by clean karstified limestones, and situated along the Nuenna River in north-west Kilkenny. It bisects the Slieveardagh Plateau. It is bordered on it's western side by the north-western tills, and on it's eastern side by the Nore Gravels. In some places along the sides of the Nuenna, the deposit forms ridges crossing the valley sides, and may be sub-glacial in origin. The lack of fines may be due to the influence of the underlying karst at the time of deposition; the karst may have allowed the meltwater to drain away, carrying the fines fraction with it (Hegarty, *pers. comm.*). Although the particle size analyses is inconclusive, the subsoil descriptions, the subsoil type, and the abundance of gravel pits all suggest high permeability subsoils (Appendix III).

Permeability Unit 5: Nore River Sand and Gravel Deposit

This is a large area of well-sorted sand and gravel, predominantly underlain by clean karstified limestones, and situated along the Nore River in central Kilkenny, stretching from Ballyragget in the north to Thomastown in the south. It divides the Slieveardagh Plateau from the Castlecomer Plateau, and splits the Central Kilkenny Lowlands in half. It contains at least 23 gravel pits, some quite large. The area has the characteristic hummocky gravel topography and a mix of light textured and medium heavy grey brown podzolics. Although no particle size data is available, the subsoil descriptions, the subsoil type, and the abundance of gravel pits all suggest high permeability subsoils (Appendix III).

Permeability Unit 6: Dinin River Sand and Gravel Deposit

This is an area of well-sorted sand and gravel, predominantly underlain by fines-rich Namurian and Westphalian sandstones, siltstones and shales. It is situated along the Dinin River in north-east Kilkenny, where it divides the Castlecomer Plateau in two. The presence of numerous sand and gravel pits, where the sediments are generally quite coarse, and the low density of artificial drainage suggest high permeability subsoils (Appendix III).

Permeability Unit 15: Tullaroan Sand and Gravel Deposit

This is a small area of well-sorted sand and gravel, underlain by fines-rich Namurian siltstones, and situated on the southern slope of the Slieveardagh Plateau in north-west. It is distinguished from the surrounding region by its hummocky topography and it's well-drained appearance. The presence of a gravel pit and the low density of artificial drainage suggests generally high permeability subsoils (Appendix III).

Permeability Unit 17: Unconfined Kilmanagh Sand and Gravel Deposit

Situated just south of Tullaroan and extending to south of Kilmanagh, this unit straddles the border between the slopes of the Slieveardagh Plateau and the lowlands to the north of Callan. The area has been identified as high permeability from permeability testing and particle size data collected by the Geological Survey of Ireland in the 1970's (Naughton, 1978). The boundary of the region is not apparent in the subsoils map of Kilkenny (Map 2N and 2S) because it is covered in places by till deposits which are typically 1 m to 2 m in thickness. This till becomes thicker and more widespread south of Kilmanagh, and this area is discussed separately as Permeability Unit 8b. Note that the particle size data suggests that the permeability, though generally high, will be variable in places. Unit 17 encompasses the unconfined portion of the Kilmanagh sand and gravel deposits described in Section 4.18.2.

5.3.5 Areas where rock is close to the surface

These are areas where the depth to bedrock is generally less than 1m and consequently where the subsoil deposits are too thin to be of consequence for groundwater protection. They most commonly occur in upland areas throughout the county, and often the bedrock can be seen exposed at the surface (e.g. on Brandon Hill). They are referred to as Permeability Unit 13, and are shown on Maps 3N and 3S.

5.3.6 Made Ground

Galmoy and Castlecomer contain large areas of made ground, with the tailings pond in Galmoy, and the slag-heaps from coal mining in Castlecomer. The tailings pond in Galmoy is treated as surface water and is not given a vulnerability classification. The slag-heaps in Castlecomer stand proud of the landscape and are not considered to influence the vulnerability classification of the area.

5.4 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 Kilkenny, the water table is thought to be generally more than 3 m deep. Thinner unsaturated zones are expected very close to major rivers, but gravels in these areas are generally overlain by alluvium. This alluvium will increase the travel time of percolating groundwaters 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 the major rivers is not considered to significantly influence the overall vulnerability in Kilkenny. One exception to this is the stretch of the Kilmanagh River from Kilmanagh itself to the northern boundary of the Kilmanagh sand and gravel aquifer. Groundwater in the gravel aquifer close to this stretch of the river is considered to be extremely vulnerable for three main reasons:

- Alluvium has not been mapped over most of this stretch.
- The stream is known to sink underground over most of this stretch during certain summers.
- Water levels from a borehole hydrograph near Oldtown (refer to Figure 4.20) are generally 1m to 2m below ground and provide evidence of a very close connection between groundwater and surface water. This borehole lies within 100m of the river.

Note that the thickness of the unsaturated zone will increase moving away from the Kilmanagh River, and the zone of extreme vulnerability is not thought to extend more than 100m on either side of the River.

5.5 Depth to Bedrock

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

5.6 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.

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

The large areas of extreme vulnerability where rock is generally at or close to 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 (refer to section 6.4). Similarly, many small pockets of deeper subsoil are likely to exist even within areas where rock outcrop is common. This is particularly likely over karst limestone areas.

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.

6 Groundwater Protection Zones and Responses

6.1 Introduction

The general groundwater protection scheme guidelines were outlined in Chapter 1, and in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice for potentially polluting activities – was described (see also Appendix I). Subsequent chapters described the different geological and hydrogeological land surface zoning elements as applied to County Kilkenny. This chapter draws these together to give the ultimate elements of land surface zoning – the groundwater protection scheme map and the source protection maps. It is emphasised that these maps are not intended as 'stand alone' elements, but must be considered and used in conjunction with the groundwater protection responses for potentially polluting activities. Three 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 Kilkenny; those which are present are given in Table 6.1.

	RESOURCE PROTECTION ZONES						
VULNERABILITY RATING	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		

 Table 6.1 Matrix of Groundwater Resource Protection Zones

6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around eight public water supply sources in Co. Kilkenny: Bennettsbridge, Callan, Glenmore, Paulstown, Piltown, Thomastown, Urlingford-Johnstown, and Graiguenamanagh. These have been produced as separate chapters in Volume II (see Chapters 8 to 15). The accompanying maps are Maps 8, 9 and 10.

6.4 Integration of Groundwater Protection Zones and Responses

The integration of the groundwater protection zones and the groundwater protection responses is the final stage in the production of a groundwater protection scheme. The 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 Kilkenny with respect to groundwater contamination.

Activity*	Percentage of Kilkenny Occurring within Each Response Level					
	Least restrictive	Intermediate response levels: ('R2' and 'R3')	Most restrictive			
	response level		response level ('R4')			
	('R1')		· · ·			
	Risk to groundwater	Higher risk to groundwater. In order to manage the risk, additional	Additional requirements will			
	can be managed using	requirements over and above normal good practice are	not reduce the risk to			
	normal good practice	conditions construction operation and the number of existing	groundwater to acceptable			
	guidennes.	developments in the area.	10 0013.			
		1				
		If the required site-specific ground conditions do not occur at a				
		particular site, or if the density of existing developments is too nign, the activity would be regarded as 'unacceptable'				
Londfill	20/	670/	30%			
	570	0770	5070			
IDC	200/	600/	7 0/			
IPC Landannooding**	3070	0070	270			
Landspreading						
A •		(70/				
On-site	55%	0/%	-			
Treatment						
Systems						

Fable	6.2	Rest	onse	Levels	in	Kilkenny	
	0.4	IVCS	JUHSC	LUCIUS	111	INIIKCIIII Y	

* 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 Kilkenny 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 Kilkenny 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. Kilkenny 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 Kilkenny 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 from: 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

Appendix I

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

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.
	Hydrogeological Conditions								
Vulnerability	Subsoil Per	meability (Type)	and Thickness	Unsaturated	Karst				
Rating			Zone	Features					
	high	moderate	low permeability	(sand/gravel	(<30 m				
	permeability	permeability	(e.g. <i>clayey</i>	aquifers	radius)				
	(sand/gravel)	(e.g. sandy subsoil)	<u>only</u>)						
Extreme (E)	e (E) 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	ii) Precise permeability values cannot be given at present.								
iii) Relea	se point of contain	minants is assumed	to be 1-2 m below	ground surface.					

Table A.1 Vulnerability Mapping Guidelines

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

Source Protection Zones

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

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

Areas surrounding individual groundwater sources; these are termed source protection areas (SPAs). Division of the SPAs on the basis of the vulnerability of the underlying groundwater to contamination.

These elements are integrated to give the source protection zones.

Delineation of Source Protection Areas

Two source protection areas are recommended for delineation: Inner Protection Area (SI); Outer Protection Area (SO), encompassing the remainder of the source catchment area or ZOC.

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

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires little technical expertise. However, it can both over- and under-protect. It usually over-protects on the

downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

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

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

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

Inner Protection Area (SI)

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

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

Outer Protection Area (SO)

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

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

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

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



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

Delineation of Source Protection Zones

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

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

Resource Protection Zones

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

Regionally Important (R) Aquifers

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

Locally Important (L) Aquifers

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

Poor (P) Aquifers

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



Source Protection Zones

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

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

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

Table A.3 Matrix of Groundwater Resource Protection Zones

are a means of ensuring that good environmental practices are followed.

Four levels of response (**R**) to the risk of a potentially polluting activity are proposed: **R1** Acceptable subject to normal good practice.

 $\mathbf{R2}^{a,b,c,\dots}$ 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).

 $\mathbf{R3}^{m,n,o,\dots}$ 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 $(\rightarrow \downarrow)$ indicate directions of decreasing risk, with \downarrow showing the decreasing likelihood of contamination and \rightarrow showing the direction of decreasing consequence. The contaminant loading aspect of risk is indicated by the activity type in the table title.

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

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

	SOU	RCE	RESOURCE PROTECTION						
VULNERABILITY	PROTE	PROTECTION		Regionally Imp. Locally		y Imp.	Poor Aquifers		
RATING	Inner	Outer	Rk	Rf/Rg		Ll	Pl	Pu	
					Lm/L				
					g				
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°	R2 ^d	R2 ^c	R2 ^b	R2 ^a	R1	R1	↓
$ \rightarrow \rightarrow$									

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

(Arrows ($\rightarrow \psi$) indicate directions of decreasing risk)

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 decisionmaking on the basis that the best available data are being used. The onus is then on a developer to provide new information which would enable the zonation to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

Use of a Scheme

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

Appendix II: Paper by Michael Conry: Kilkenny's 'Golden Vein': it's Soils, Land-use and Agriculture (Conry, 1974).

KILKENNY'S 'GOLDEN VEIN': IT'S SOILS, LAND-USE AND AGRICULTURE

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Introduction

The Suir valley in Co. Kilkenny, with its fertile soils and mild climate, is noted both for agricultural and horticultural production, and particularly for its quality apple growing. It could be called 'the Golden Vale of Kilkenny.' Although it is a distinct geographical unit, its area is rather small. On the other hand, soil survey investigations show that the large central portion of the county possesses a very high proportion of first-class soils and is one of the most prosperous farming areas in the country. For this reason, it can be justifiably called the 'Golden Vein' of Kilkenny. Unlike the traditional Golden Vale of Munster, Kilkenny's Golden Vein is geographically well defined and it occurs in the central portion of the county (covering an area of 221 square miles) enclosed on the north by the coal-bearing Castlecomer Plateau and Slieveardagh Hills and on the south by the range of hills stretching from Slievenamon (Co. Tipperary) to Brandon Hill (Fig. I).

The purpose of the present paper is to outline the factors of soil formation which are responsible for soil differences within the area, and to discuss the properties and land-use range of the various soils and general farming pattern in the area.

Factors of Soil Formation

Variations in soil properties in any area are primarily due to the interaction of the factors of climate, relief and vegetation which act over a period of time on soil parent material. To these may be added man's modifying influence on soil profile characteristics. However, few of the soil differences in the study-area can be attributed to climate, vegetation, time or human interference. The climate is uniform throughout the areaand is rather mild and moist with an average annual rainfall of 800 -1000 mm. The only effects attributable to human activity are cultivation of the surface horizon and the addition of large quantities of burnt lime during the nineteenth century. The only difference attributable to time M. CONRY



is the lack of horizonation of the few recent free draining alluvial soils in the area as compared with the well-defined horizons of the remaining relatively mature soils. The major soil differences in the area can therefore be attributed to differences in parent material and relief (Table I).

20

KILKENNY'S GOLDEN VEIN

TABLE 1

PARENT MATERIAL AND THE EXTENT OF THE SOILS IN THE GOLDEN VEIN

		Taterial Great Soil Mapping Unit		A	rea	Percentage	
Parent Material		Great Soil Group	(Fig. 2)	Acres	Śą. mls.	total area	
	Glacial till composed of		Medium heavy textured G.B.P.	83,152	129.9	58.8	
tt	limestone, shale and sandstone	Grey Brown Podzolics	Medium textured G.B.P.	8,699	13.6	6.2	
ial Dri	Fluvio-glacial gravels		Light textured G.B.P.	5,997	9.4	4.2	
Glac	Glacial till composed of	Clove	Imperfectly drained Gley	4,823	7.5	3.4	
	shale and sandstone	Gieys	Poorly drained Gley	37,637	58,8	26.6	
F	liver Alluvium	Regosols	Alluvium	1,132	1.8	0.8	

Parent material

.

Although the basic rock formations consist almost completely of limestone with varying concentrations of dolomite, the parent material of the soil, which consists of a mantle of glacial drift, shows considerable variation in geological composition, physical constitution and thickness. This mantle of drift consists of (a) till which was deposited by advancing ice during the Weichsel glaciation and (b) fluvioglacial eskery gravels deposited by melt-waters from the retreating ice front. The limit of the Weichsel General Glaciation coincides almost everywhere with the southern boundary of the area (Fig. 1). The variation in geological composition is due mainly to the influence of the coal-bearing hills to the north of the region.

The vast majority of the soils in the region owe their medium-heavy texture and great depth of profile to the influence of the earthy Upper Limestone and Upper Carboniferous deposits. The influence of the latter is not so extensive in the east of the region because the last ice-sheet did not cross the Castlecomer Plateau. The more extensive distribution of heavy textured wet soils in the extreme west of the region indicates that the last ice sheet actually crossed over the Slieveardagh Hills and hence the Coal Measure shales, grits and flagstones made a greater contribution to the drift composition. The presence of somewhat lighter-textured shallower soils (Soil 2, Fig. 2) found chiefly in the vicinity of the River

21

M. CONRY

Nore is attributed to the higher calcium and magnesium carbonate content in the Lower Limestone deposits. The light textured soils (Soil 3, Fig. 2) which are found chiefly in the vicinity of the rivers Barrow and Nore are derived from coarse textured gravels and sands.



Figure 2.

Relief

Despite the fact that the study-area has a fairly uniform, gently undulating topography, with an elevation ranging from 60 metres to approximately 150 metres (the greater part of the area lies between 60 and 75 metres), relief is an important factor in accounting for soil differences within the region. Poorly drained gleys occur on lower ground while the freely drained soils are found on more favourable slopes. Alluvial soils occur in the flat areas adjacent to streams and rivers.

Poorly drained gleys, however, occur on rolling topography particularly in the west of the area where the parent material is rather dense and impermeable due to the presence of a substantial proportion of the coalbearing shales, grits and flagstones. The interaction of these soil-forming factors gives rise to six major soils belonging to three Great Soil Groups, namely, Grey Brown Podzolics, Gleys and Regosols (Alluvial soils).

I. GREY BROWN PODZOLICS

Grey Brown Podzolic soils, which are generally some of the best soils in Ireland, are derived from calcareous glacial drift deposits. The dominant soil-forming process is the accumulation of finely divided clay in the B horizon which is known as a textural B or Bt horizon. The soil profile normally consists of a deep brown to dark brown friable AI horizon overlying a thick, fairly compact brownish, more heavy textured Bt horizon, which in turn overlies calcareous drift material. When leaching is more intensive a bleached horizon (A2) develops above the B2t.

The lighter textured members of the Grey Brown Podzolics are good all-purpose soils and when adequately manured and managed are very productive under most agricultural enterprises. Because these soils are easily cultivated a high percentage are tilled annually. The heavier textured Grey Brown Podzolics are also highly productive under most agricultural enterprises but owing to their heavier texture they are better for grass production than the lighter textured soils.

The Grey Brown Podzolics are by far the most important soils in the region and can be divided into three textural groups.

A. Medium-heavy textured Grey Brown Podzolics

These soils (Soil I, Fig. 2) occur extensively on gently rolling topography between 200-400 feet. They comprise 58.8 per cent of the total area and are chiefly responsible for the Golden Vein's reputation. They are deep, well-drained soils derived from calcareous drift composed mainly of limestone with smaller proportions of Coal Measures shales and sandstone. The profile consists of a dark-brown, friable heavy loam Ar horizon (20-25 per cent clay and 35-45 per cent silt) over a bleached, sometimes indurated A2 horizon which in turn overlies a thick fairly compact clay loam to clay B2t horizon (35-50 per cent clay).

These soils have a wide use range. Although they are inherently some of the most fertile soils in the country, they respond well to fertiliser application. They are excellent grassland soils being capable of very high levels of production over a long grazing season under high levels of fertiliser application and good management. Despite their somewhat heavy texture, they are very suitable for the production of a wide range of farm fruit and vegetable crops. Cereals, sugar beet, turnips, peas, French beans, carrots and other root crops are grown extensively. They are reputedly

M. CONRY

less suitable for malting barley but it is nevertheless grown widely on these soils. Horticultural crops grown successfully include apples, raspberries, blackcurrants, strawberries and hops. This deep, free-draining medium-heavy textured soil with its excellent moisture holding capacity is especially suitable for blackcurrant production. However, the installation of a sprinkler system to reduce the risk of frost damage is desirable if not essential but it does increase production costs considerably.

B. Medium textured Grey Brown Podzolics

These soils (Soil 2, Fig. 2) occur in the Nore valley and in a few other isolated areas. They are very similar to the medium heavy textured Grey Brown Podzolic except that their somewhat lighter texture (19-21 per cent clay) and shallower depth is attributed to a higher portion of purer limestone in the underlying bedrock and till. They have the same wide land-use range, but their greater amenability for tillage cropping is counterbalanced by hazards associated with small portions of outcropping rock and their hummocky topography. These soils occupy 6.2 per cent of the area.

C. Light textured Grey Brown Podzolics

These light textured (15-18 per cent clay) Grey Brown Podzolics (Soil 3, Fig. 2) occupy only 4.2 per cent of the total area. They occur principally at the lower elevations (60-75 metres) in the immediate vicinity of the River Nore and to a smaller extent associated with the River Barrow (Fig. 2). They are derived from calcareous gravels deposited by the retreating ice-front of the Weichsel Glaciation. They are, therefore, identical with the Athy Complex mapped in Counties Carlow and Kildare. The principal soil in the complex is a light textured moderately deep Grey Brown Podzolic consisting of a deep dark-brown, friable sandy loam surface horizon over a bleached A2 horizon and a heavier textured B2t horizon. Shallow stony soils on hillocks and some imperfectly drained Gleys in local depressions occupy a smaller proportion of the complex.

These soils have a wide use-range, and are capable of producing a wide range of tillage crops. Uneven ripening, due to variation in soil depth and moisture holding capacity, even in the same field, can be a serious limiting factor especially for peas, French beans and cereal growing. They are also good grassland soils but drought can be an important limiting factor in dry periods.

2. GLEYS

Gleys are soils in which the effects of drainage impedence dominate and which have developed under conditions of permanent or intermittent

24...



Plate 1. Sheep are most common in the central and eastern part of the Golden Vein, but beef production is a major enterprise throughout the whole area.



Plate 2. Thoroughbred breeding is an important enterprise particularly on the well-drained soils in the central and eastern part of the Golden Vein.

KILKENNY'S GOLDEN VEIN

water-logging. As a result of the water-logging the mineral horizons of the Gleys are usually grey, with distinct ochreous mottling.

A. Poorly drained Gleys

These soils occupy 26.6 per cent of the area and occur principally in the extreme west of the area (Soil 5, Fig. 2). Their poor drainage is due to a combination of heavy texture and rather flattish to gently undulating topography. The heavy texture is attributed to the influence of the shales and grits of the Slieveardagh Hills and the Castlecomer Plateau (Fig. 1). Some of the soils in this group occur in rather low positions and therefore the poor drainage is also due to high ground-water level.

The land-use range of these soils is rather limited. Due to their poor physical properties they are unsuitable for arable cropping particularly in wet seasons. Large areas of these soils have been artificially drained and reclaimed in recent years. Despite these improvements they are still mainly unsuitable for tillage farming.

Although this soil is reputedly unsuitable for apple growing, a large Golden Delicious orchard planted in 1971 on a carefully drained area near Callan shows promising returns. These soils are best suited to grassland production but again they have major limitations when compared with their well drained counterparts; the grazing season is curtailed in spring and autumn and a large portion of the grass must be conserved for winter feeding.

B. Imperfectly drained Gleys

These soils (Soil 4, Fig. 1) are rather similar to the above soils but because they occur on slightly higher portions of the topography they are not subject to the same degree of drainage impedence. Their properties and use range are, therefore, intermediate between the well drained medium-heavy textured Grey Brown Podzolics and the poorly drained Gleys. The profile consists of a heavy textured surface horizon over strongly mottled heavy textured A2 and B2t horizons.

Due to their heavy texture and poor structure they are generally unsuitable for arable cropping. Cultivation and harvesting problems manifest themselves particularly in unfavourable seasons. Autumn ploughing alleviates spring cultivation problems to a large degree and good crops of cereals, potatoes, vegetables and root crops can be obtained in favourable years. Reasonably good crops of strawberries and blackcurrants have also been obtained on these soils. The soils are most suitable for grass production but again because of heavy texture and poor structure a high standard of management is essential for efficient production and utilisation of sward. Due to poaching hazard the grazing season must be curtailed

M. CONRY

both in spring and autumn and a high proportion of the sward must be conserved for winter feeding.

3. REGOSOLS

These soils are derived from fresh-water river alluvial deposits and occupy only 0.8 per cent of the area. They are young immature soils and show little or no profile development.

The only considerable expanses of alluvium within the area are the alluvial flats which occur adjacent to the rivers Nore and Barrow (Soil 6, Fig. 2). These free-draining soils are subject to flooding. Consequently they are best suited to grass production, but good crops of cereals and root crops have also been obtained on these soils.

Smaller areas of poorly drained alluvium which occur along the Nore and smaller rivers (i.e. the Kings, Glory and Powerstown rivers) and streams are only suitable for grazing because they are regularly flooded in winter-time.

Agriculture

Kilkenny's Golden Vein is a typical mixed farming area. The major enterprises include cattle and sheep, milk production, mixed tillage farming and an increasing acreage under horticultural crops.

The chief reasons for its mixed farming pattern are (i) a very high proportion (70 per cent) of deep fertile soils which are adaptable to the production of a wide range of crops. If the poorly drained soils on the western part of the county are excluded, over 90 per cent of the soils in the remaining part of the Golden Vein are highly productive. (ii) A high proportion of medium-sized and large holdings without too much fragmentation. Farm-size ranges from 20 to 500 acres with an average of 60 to 70 acres. (iii) A moderate annual rainfall of 800-1000 mm.

Dry stock based mainly on grass and silage production is a major enterprise. Lee & Diamond (private communication) calculate that this area with 80 livestock units per 100 acres has one of the highest stock densities in Ireland. This is not surprising seeing that 90 per cent of the soils in the central and eastern part of the area consist of first class grassland soils. With N application of 206 lb/acre the extremely high stock carrying potential of 110 L.U. per 100 acres is feasible.

The production of milk is considerable with a number of smaller creameries supplying milk to larger central creameries. A high proportion of the milk is sent to the Avonmore plant for the manufacture of milk products. Cow herds generally range from 20 to 50 with over 90 per cent of the farmers using milking machines.

M. CONRY

ment is very high, excellent returns on capital can be obtained. Not only are cone yields high but the resin quality compares with anything produced in England or the Continent. The mild moist climate does not present any serious management problems and it seems that an expansion of the hop acreage in Ireland is economically feasible and socially desirable. The production of apples in the past has been confined mainly to a few Bramley orchards where levels of production and quality have been good. Recent plantings of Golden Delicious on dwarf rooting stock are proving exceptionally promising on the medium heavy and medium textured Grey Brown Podzolic soils.

Conclusion

The central Kilkenny area covering a total area of 221 square miles can be justifiably described as Kilkenny's Golden Vein. It provides one of the best examples of a typical mixed farming area in Ireland. This is mainly due to the exceptionally high proportion (70 per cent) of first class soils and the very high proportion of medium-sized and large farms. The range of enterprises covers all aspects of livestock production and tillage crops together with a wide range of viable horticultural enterprises.

REFERENCE

J. LEE and S. DIAMOND

1972 The potential of Irish land for livestock production, An Foras Talúntais, Dublin.

ACKNOWLEDGMENTS

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Appendix III: Permeability Regions in County Kilkenny.

Summary of Permeability Data and Analyses for Permeability Unit 1 - Castlecomer Plateau .

Description of unit location:	Upland plateau underlain by Namurian and Westphalian shales, siltstones and sandstones, continuing north and east into Laois and Carlow and bordered by River Nore gravels to west
	and Central Kilkenny Lowlands to the south. Partially split by Dinin gravels (permeability region 6)
Why is this a single K unit?	Relatively uniform topography, bedrock, subsoils, soils and land use
1. General Permeability Indica	ators and Region Characteristics
Rock type	Shales, Silts and Sandstones. Aquifer category ranges from locally important to poor. Formation codes are: KN, BE, MC, GC and CQ
Depth to bedrock	Predominantly <3m, can achieve 5-10m in places
Subsoil type	Predominantly glacial tills, commonly <3m to rock. Occasional small pockets of Peat (in north and east) and sand and gravel (in south and west)
Soil type	Predominantly Association 22 which is 75% gleys (Irish soils map)
Vegetation and land use	Rough grazing predominant, rushes common.
Artificial drainage density	High. Steep ditches on higher ground, French drains common in valley floors
Natural drainage density	High.
Topography and altitude	Upland plateau, typically 250m to 300m. Valley floors drop to 170m.
Ave. effective rainfall (mm)	600

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.



5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as generally 'low'. The PSA analysis is not conclusively low, but none of the samples have less than 35% fines. The glacial history of the plateau suggests that ice trapped on the plateau repeatedly ground down the clay-rich bedrock, producing a fine-grained glacial till with few clasts. Solifluction on the plateau flanks moved material down into the limestone valleys. During subsequent ice advance, the plateau stood above the glaciers, which swept along it's sides dragging the fine-grained material further on to the limestone valleys to the east and south. This is why the southern extent of this region extends up to 4km on to the limestone.

Summary of Permeability Data and Analyses for Permeability Unit 2 - North-Western Tills .

	le la						
Description of unit location:	Flat area predominantly underlain b	y dolomitised limestone and bordered to the east and south by t	the alluvium along	the River Goul (perme	eability region 11) and to the west by worked		
	peat (permeability region 4). This region continues to the north into Laois.						
Thy is this a single K unit? Relatively uniform topography, bedrock, subsoils, soils and land-use.							
1. General Permeability Indica	ators and Region Characteristic	S					
Rock type	Limestone. Aquifer category range	s from dolomitised and regionally important to poor. Formatic	on codes are AG, C	S, WAdo and BA			
Depth to bedrock	Predominantly <3m. In the north, i	t thickens to 3-10m.					
Subsoil type	Mapped as glacial tills, regarded as	a poorly consolodated, sandy till.					
Soil type	Soil Association 34, which is 70%	minimal grey brown podzolics. Michael Conry of Teagasc (per	rs. Comm.) describe	d them as permeable	soils which can suffer drought.		
Vegetation and land use	Abundant tillage.						
Artificial drainage density	Low, no drainage ditches seen.						
Natural drainage density	Low.						
Topography and altitude	Flat plain of intermediate elevation	Altitiude genarally 120-130m, rising to 160m towards the nor	th.				
Ave. effective rainfall (mm)	450						
2. Summary of Particle Size Ai	nalysis and Field Descriptions o	f Subsoil Samples.					
NB Particle distributions adjusted to discount	t particles greater than 20mm. Graphs only de	pict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m i	in exposures, AND 2) loc	cations not at permeability	boundaries.		
Summary of particle size data:	proportion of clay fraction in each	Summary of particle size data: proportion of total fines fract	tion in	Field description	of samples: range in principal subsoil types		
10 ¬		each sample		de	escribed using BS5930:1999		
Clay % generally indicates moderate or high K subsoils in	Clay % is Clay % generally indicates low K inconclusive subsoils	Fines % generally Fines % generally Fines % generally Fines % is Fines % indicates high K Fines % generally Fines % is indicates mod K	s % generally	2			
		16 - subsoils. subsoils. subsoils.	subsoils.	0			
l o l o l o l o l o l o l o l o l o l o			lanb	6			
			- Free	4			
2				0			
0				SAND &	SILT SILT/CLAY CLAY		
<9% 9% to <12% 12 Banges	2% to 14% >14% to 17% >17%	<8% 8% to <35% 35% to 50%	>50%	GRAVEI			
Kanges	in clay content	Ranges in total fines content (clay & silt)	2070	Borehole samples	Exposure samples or sand & gravel quarries		
3. Data from Permeability Test	ts.						
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	sults Range Values Typical value Pump tests # Results Range V	alues Typical value	Lab tests # Results	Range Values Typical value		
min/25mm	tests (m/sec):	(m/sec):		(m/sec):			
4. Summary and Analysis							
Criteria	Comments		Implica	tions of each criterio	on for assessment of subsoil permeability		
Quaternary / subsoil origin	Tills with a predominantly sandy m	atrix, likely source, weathered dolomites.		>>>	moderate		
Particle size data	Clay <9% in all 3 samples. Fines 89	% to <35% in 2/3 of samples (mod K)		>>>	moderate to high		
Field description data	Exposure samples			>>>	moderate		
	Borehole samples			>>>	-		
Soil type	Minimal grey brown podzolics whi	ch are free draining.		>>>	moderate		
Artificial drainage density	Low.			>>>	moderate to high		
Natural drainage density	Low.			>>>	moderate to high		
Permeability test data	No reliable data			>>>	-		
Rock type	Mainly dolomitised limestones. The	eir sandy weathered texture strongly influences the till matrix.		>>>	moderate		
Land use	Tillage widespread, no evidence of	rushes.		>>>	moderate to high		
			Overall conclusio	n >>>	MODERATE		
5 COMMENTEL							

5. COMMENTS: The unusual sandiness of the tills is probably due to the extensive presence of dolomitised Waulsortian limestone, both beneath the region and also to the north, in Laois. The weathered product of this clean dolomitic rock is a red sand, which can be see incorporated into the tills. The data for this area strongly suggests a moderate permeability. The drainage and vegetation data could even suggest a high permeability. However, the silt percentages and the BS data suggest moderate.

Summary of Permeability Data and Analyses for Permeability Unit 3 - Nuenna SAG.

	Summary of	I CI incability Data and Analyses i	for refineability Unit 5 - I	ucina SAU.			
Description of unit location:	A large area of well-sorted sand and	gravel situated along the Nuenna River in	north-west Kilkenny, dividing the	e Slieve Ardagh Plateau in	two (Permeability Regions 7a & 7b). It is		
	bordered on it's western side by the north-western tills (Permeability Region 2), and on it's eastern side by the Nore Gravels (Permeability Region 5).						
Why is this a single K unit?	Relatively uniform topography, subs	oils, soils, land use.					
1. General Permeability Indica	ators and Region Characteristics						
Rock type	Predominantly karstified regionally	mportant limestone (BM and CL), some cl	ay-rich poor limestone in the wes	st (DW)			
Depth to bedrock	Variable. 0 to 10m, most commonly	<u>3 to 5m.</u>					
Subsoil type	Clean, well-sorted, water-lain sand a	nd gravels.		200/ 1 100/1	4		
Soil type	No county-specific data, soils map o	I Ireland mappes it as Association 34: 70%	minimal grey brown podzolics, 2	20% gleys, 10% brown ear	ths.		
Vegetation and land use	Abundant tillage and poppies. Small	, locally used gravel pits common.					
Artificial drainage density	Low, no drainage ditches seen.						
Natural drainage density	Low.						
Topography and altitude	hummocky plain of intermediate ele	/ation. Altitude genarally 120-130m OD,	rising to 160m OD towards the n	orth-west.			
Ave. effective rainfall (mm)	450						
2. Summary of Particle Size A	nalysis and Field Descriptions of	Subsoil Samples.					
<i>NB Particle distributions adjusted to discoun</i>	it particles greater than 20mm. Graphs only dep	ict samples taken from 1) a known depth exceeding 1.	.5m in boreholes or 1m in exposures, ANI	D 2) locations not at permeability	boundaries.		
Summary of particle size data:	proportion of clay fraction in each	Summary of particle size data: proportion	rtion of total fines fraction in	Field description	of samples: range in principal subsoil types		
10 T Class & comments in diserter state	mple	20 7 E ach samp!	le	d	lescribed using BS5930:1999		
8 moderate or high K subsoils i	inconclusive subsoils	18 - Fines % generally indicates high K - Fines % generally indicates mod K	Fines % is Fines % generally inconclusive indicates low K	12			
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l neu							
		10		<u><u>u</u><u>4</u></u>			
2		6					
0 +	,			SAND &	SILT SILT/CLAY CLAY		
<9% 9% to <12% 1	2% to 14% >14% to 17% >17%		250/ 4 500/	GRAVEL	SIET SIET/CEAT CEAT		
Ranges	in clay content	<8% 8% 10 <35% Ranges in total fines co	ass% to 50% >50% ntent (clay & silt)	Borehole samples	s ■Exposure samples or sand & gravel quarries		
L 3 Data from Permeability Tes				1			
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Rest	Its Range Values Typical value Pump te	sts # Results Range Values Typical	value Lab tests # Results	Range Values Typical value		
min/25mm	tests (m/sec):	(m/se	c):	(m/sec):	Tunge values Typical value		
4. Summary and Analysis			<u></u>				
Criteria	Comments		In	nplications of each criteri	on for assessment of subsoil permeability		
Quaternary / subsoil origin	Well sorted fluvio-glacial sands and	gravels		>>>	high		
Particle size data	Fines <35% in all samples.			>>>	high or moderate		
Field description data	Exposure samples			>>>	high		
-	Borehole samples			>>>	-		
Soil type	Minimal grey brown podzolics whic	h are free draining.		>>>	high or moderate		
Artificial drainage density	Few drains	C C		>>>	high or moderate		
Natural drainage density	Low density			>>>	high or moderate		
Permeability test data	No reliable data			>>>	-		
Rock type	Clean, karstified limestones			>>>	high or moderate		
Land use	Tillage common. No evidence of rus	hes. Small sand and gravel pits		>>>	high		
		inest strike suite and graver pro-	Overall con	clusion >>>	HIGH		

5. COMMENTS: Where the gravel deposits are thick along the sides of the Nuenna, they form ridges crossing the valley sides, and may be sub-glacial in origin (SH reference). The lack of fines may be due to the effect of the underlying karst at the time of deposition - it may have drained the meltwater away, carrying the fines fraction with it. Although the PSD analysis, soil, drainage density and rock type are inconclusive between high and moderate, the BS descriptions, the subsoil type, and the abundance of gravel pits (at least 7) all support a decision of high permeability.

Summary of Permeability Data and Analyses for Permeability Unit 4 - north-western peat .

Description of unit location:	Low-lying area underlain by limest	one and bordered by the north-w	estern tills to the north east and so	outh (permeability	region 2) These ne	eatlands are the eastern-most extent of a large			
Description of unit rotation.	development of midlands basin pea	levelopment of midlands basin peat which extend into Tipperary North Riding, and which are commercially worked.							
Why is this a single K unit?	Uniform topography, bedrock, subs	Iniform topography, bedrock, subsoils, soils and land use.							
1. General Permeability Indica	ators and Region Characteristic	<u> </u>							
Rock type	Limestone. Aquifer category range	s from dolomiitsed and regionally	y important to poor. Formation cod	les are: BA, WA,	WAdo, CS and AG	ſ			
Depth to bedrock	Generally 3m to 10m. Thins down	to 1m to 3m at edges.			,				
Subsoil type	Basin peat. This peat is likely to be	sitting on top of lake clays and s	ilts. Two small patches of sand and	d gravel occur wit	thin the peat.				
Soil type	Soil Association 44: Basin Peat (rat	ised bog)	-						
Vegetation and land use	Heather, moss and rushes. Where p	beat is thick enough, Bord na Mo	na industrial harvesting is carried	out.					
Artificial drainage density	High. On worked areas of peat, dra	inage is extensive to allow entry	for machinery.						
Natural drainage density	Moderate. The bog can store a grea	t deal of the recharge.							
Topography and altitude	Flat plain of intermediate elevation	. Altitiude genarally 120-130m.							
Ave. effective rainfall (mm)	450								
2. Summary of Particle Size A	nalysis and Field Descriptions o	f Subsoil Samples.							
NB Particle distributions adjusted to discoun	t particles greater than 20mm. Graphs only de	pict samples taken from 1) a known dept	th exceeding 1.5m in boreholes or 1m in exp	posures, AND 2) locat	tions not at permeability	boundaries.			
Summary of particle size data:	proportion of clay fraction in each	Summary of particle size	e data: proportion of total fines fraction i each sample	in	Field description	of samples: range in principal subsoil types escribed using BS5930:1999			
10 Clay % generally indicates	Clay % is Clay % generally indicates low K	$\begin{bmatrix} 20\\ 18 \end{bmatrix}$ Fines % generally $$ Fines %	generally Fines % is Fines % ge	nerally 14					
8 moderate or high K subsoils is	inconclusive	16 indicates high K indicate	es mod K inconclusive indicates	low K 12 $table K$					
9 6			sous						
nb 4		at 10		6 -					
^E 2		6		¹ 2 -					
2		4		0 -					
$0 + \frac{1}{2}$	2% to $14%$ >14% to $17%$ >17%	ō 		P	SAND &	SILT SILT/CLAY CLAY			
Ranges	in clay content	<8% 8% to Ranges in	<pre><35% 35% to 50% >50 total fines content (clay & silt)</pre>	%	Borehole samples	Exposure samples or sand & gravel quarries			
2 Data from Dormoability Too	ta								
J. Data If offit Fermicability Test	# Tests T>50 Variable head # Rev	sults Range Values Typical value	Pump tests # Results Range Value	s Typical value	Lab tests # Results	Range Values Typical value			
min/25mm	tests (m/sec):	and range values Typical value	(m/sec):	s Typical value	(m/sec):	Range values Typical value			
4. Summary and Analysis				1					
Criteria	Comments			Implicati	ons of each criterio	on for assessment of subsoil permeability			
Quaternary / subsoil origin	Peat			•	>>>	low			
Particle size data	For the material beneath. Raised bo	gs generally consist of peat over	lake deposits.		>>>	moderate to low			
Field description data	-		*		>>>	-			
	-				>>>	-			
Soil type	Basin Peat (raised bog)				>>>	low			
Artificial drainage density	High				>>>	low			
Natural drainage density	Intermediate				>>>	moderate to low			
Permeability test data	-				>>>	-			
Rock type	A range of limestones from clean V	Vaulsortian to dirty Aghmacart.			>>>	moderate			
Land use	turf-cutting				>>>	low			
	C C		Ov	erall conclusion	>>>	LOW			
5 COMMENTS: D 11									

5. COMMENTS: Raised bogs consist of a build-up of organic matter in water-logged conditions. They developed in the warmer and wetter post glacial period and are infilled lakes. Because of their lake origin, they are lined by lacustrine clays and silts which isolate them from the rock below. This means that they are generally fed by surface water alone. Apart from the less compacted upper layers, peat has a relatively low permeability. The small ammount of raised basin peat in Kilkenny is at the edge of a much larger development. This means that it is likely to be thinner than in the centre of the bog's development, and also that the underlying lacustrine deposits may be thin or even absent. In this case, the peat may be lying directly on glacial deposits or even bedrock. Data is sparse for the kilkenny peat, but it seems likely that the overall depth to bedrock is 5 to 10m. Where extensively cut and drained this will, of course have an effect on the depth and the permeability.

Summary of Permeability Data and Analyses for Permeability Unit 5 - Nore SAG.

Description of unit location:	A large area of well-sorted sand and gravel situated along the Nore River in central Kilkenny, stretching from Ballyragget in the north to Thomastown in the south. It divides the				
	Slieve Ardagh Plateau from the Castlecomer Plateau (Permeability (K) Regions 7b & 1), and splits the central Kilkenny lowlands in half (K Region 7a).				
Why is this a single K unit?	Relatively uniform topography, subsoils, soils, land use.				
1. General Permeability Indica	tors and Region Characteristics				
Rock type	Predominantly regionally important karstified limestone (BM & CL), some clay-rich locally important and poor limestones (BU & DW) & even some shales (LS & KN)				
Depth to bedrock	Variable. 3 to >10m, most commonly >10m.				
Subsoil type	Clean, well-sorted, water-lain sand and gravels.				
Soil type	Mapped by MC: 50:50 light and medium textured grey brown podzolics.				
Vegetation and land use	Abundant tillage and poppies. Gravel pits common - some quite large (e.g. SH6 just south of Kilkenny city).				
Artificial drainage density	Low, no drainage ditches seen.				
Natural drainage density	Low.				
Topography and altitude	Low-lying, hummocky plain. Altitude typically 70 mOD to 90mOD.				
Ave. effective rainfall (mm)	340				
. 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.

J					
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		Implication	s of each criterio	n for assessment of subsoil permeability
Quaternary / subsoil origin	Well sorted fluvio-glacial sands and gravels			>>>	high
Particle size data	No data			>>>	-
Field description data	Exposure samples			>>>	high
	Borehole samples			>>>	-
Soil type	Free draining light and medium textured grey brown podzolics.			>>>	high or moderate
Artificial drainage density	Few drains			>>>	high or moderate
Natural drainage density	Low density			>>>	high or moderate
Permeability test data	No reliable data			>>>	-
Rock type	Mainly clean karstified limestones, also some fines-rich shales and	siltstones.		>>>	high or moderate
Land use	Tillage common. No evidence of rushes. Sand and gravel pits			>>>	high
		Ove	rall conclusion	>>>	HIGH

5. COMMENTS: This is an extensive and thick deposit of well sorted sand and gravels associated with the River Nore. It contains at least 23 gravel pits, some quite large. The area has the characteristic hummocky gravel topography. Although no PSD analysis is available, and the soil, drainage density and rock types are inconclusive, the BS descriptions, the subsoil type, and the abundance of gravel pits all support a decision of high permeability.

Summary of Permeability Data and Analyses for Permeability Unit 7a - Slieve Ardagh Plateau .

Description of unit location:	Upland areas underlain by siltstones	s and shales. They are bounded	to the west and split through	the midle by sa	nd and gravels (pr	remeability region 3).	On their eastern ar	nd south
	eastern sides they are bounded by slope-side tills (permeability region /b)							
Why is this a single K unit?	Uniform topography, bedrock, subsoils and land-use.							
1. General Permeability Indica	tors and Region Characteristics	8						
Rock type	Siltstones and shales. Aquifer categories	gory is uniformally poor. Format	ion codes are KN, BE and L	F				
Depth to bedrock	Generally shallow (0-3m) Increase	s to 3-5m in a thin rim around the	e edge, rising to 10m on the s	south-eastern ed	ge.			
Subsoil type	Glacial tills.							
Soil type	Mainly soil associations 10 and 19	which contain a range of soil type	es, but predominantly grey b	rown podzolics	and acid brown ea	rths. M. Conry, "gleys	&brown earths"	
Vegetation and land use	Rough grazing, well drianed on sha	llow rocky hilltops but rushy and	prone to poaching in lower	ground.				
Artificial drainage density	High, abundant ditches.							
Natural drainage density	Inconclusive, field observations sug	gest a flashy stream flow regime	, such streams are unlikely t	to be recorded of	n OS maps.			
Topography and altitude	Relatively flat-topped plateau. Alti	tude generally 180-250m, rising t	to 340m in the north.					
Ave. effective rainfall (mm)	580							
2. Summary of Particle Size An	nalysis and Field Descriptions of	f Subsoil Samples.						
<i>NB Particle distributions adjusted to discount</i>	t particles greater than 20mm. Graphs only de	pict samples taken from 1) a known depth I	h exceeding 1.5m in boreholes or 1m	n in exposures, ANL	2) locations not at pe	rmeability boundaries.		
Summary of particle size data: p	proportion of clay fraction in each	Summary of particle size	data: proportion of total fines fra each sample	oction in	Field d	escription of samples: rang described using B	ge in principal subsoil \$5930:1999	l types
10 Clay % generally indicates	Clay % is Clay % generally indicates low K	20 Fines % generally Fines % g	generally Fines % is Fi	nes % generally	14			
8 — moderate or high K subsoils in	nconclusive	16 indicates high K indicates	s mod K inconclusive in	ndicates low K				
9 6		14 - subsolis subsolis.	oils.	subsoils.	8			
nb. 4		<u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u><u></u></u>			6			
<u>۲</u>		6			2			
2		4			0 +			
$0 + \frac{9\%}{9\%} = \frac{9\%}{12\%} = \frac{12}{12\%} = $	2% to $14% > 14%$ to $17% > 17%$			ļļ	SAND GRAVE	& SILT	SILT/CLAY	CLAY
Ranges	in clay content	<8% 8% to Ranges in t	<35% 35% to 50% total fines content (clay & silt)	>50%	Boreho	le samples Exposure sam	ples or sand & gravel of	quarries
3. Data from Permeability Test	ts.							
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	ults Range Values Typical value	Pump tests # Results Range	Values Typical v	Alue Lab tests	# Results Range Values	Typical value	
min/25mm	tests (m/sec):		(m/sec):		(m/sec):			
4. Summary and Analysis	Comments			I				
Criteria Oustomomy (subsoil origin	Clasical tills			Im	iplications of each	n criterion for assessin	lent of subsoli pe	rmeability
Quaternary / subsoir origin Derticle size date	Clay $>14\%$ in both samples (law K)	Einer 50% in $1/2$ (low K)				moderate to	low	
Faille Size data	Clay >14% in both samples (low K)). Fines $> 30/6$ in 1/2 (low K)			~~~	linuerate to	IOW	
Field description data	Exposure samples					IOW		
Solit terror					~~~~	-	1	
Soli type	Inconclusive.				>>>	moderate to	IOW	
Artificial drainage density	Hign.				>>>	IOW	1	
Natural drainage density	Inconclusive.				>>>	moderate to	low	
Permeability test data	Fines rich siltetenes and shales. I a	anllas deniared tille suill been on ab			>>>	-		
	Fines-fich suisiones and shales. Lo	cany derived this will have an ab	bundant source of low K mat	enal.	>>>	IOW		
Land use	Kougn grazing, rushes common.			0	>>>	low		
5 COMMENTS. TI I I				Overall conc	iusion >>>	LOW		

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as 'low'. Although the subsoil type is inconclusive, and insufficient data is available for the soils to be an influencing factor, the BS and PSD analysis suggest low. This is backed up by land use and artificial drainage density.

Summary of Permeability Data and Analyses for Permeability Unit 6 - Dinin SAG.

	Summary	of I clineability Data and	mary ses for T er meabin	eg enne e bh				
Description of unit location:	An area of mainly well-sorted sand	and gravel situated along the Dir	nin River in north-eastern Kilke	enny, stretching f	from just north of Castle	ecomer to the River Nore to the south-west. It		
	runs through the middle of the Cast	ans through the middle of the Castlecomer Plateau (Permeability (K) Region 1).						
Why is this a single K unit?	Relatively uniform topography, sub	telatively uniform topography, subsoils, soils, land use.						
1. General Permeability Indica	tors and Region Characteristics	5						
Rock type	predominantly underlain by fines-ri	ch Namurian and Westphalian sa	andstones, siltstones and shales	, all poor aquifers	s (KN, BE, MC, CG, C	Q)		
Depth to bedrock	Variable. 3 to 10m, most commonly	/ 5-10m.						
Subsoil type	A mix of clean, well-sorted, water-l	ain sand and gravels, and slightly	y finer silts.					
Soil type	Not distinguished from the gleys of	the Castlecomer Plateau						
Vegetation and land use	Mainly grazing but also some tillag	e, rushes only in the low-lying ar	reas next to the river. Overgrow	vn sand pits seen.				
Artificial drainage density	No drains seen on hummocky portion	ons of deposit, some seen along f	flat river bank.					
Natural drainage density	High - many streams coming off the	e low permeability till-clad hilsid	les.					
Topography and altitude	River valley at intermediate elevation	ons. Altitude varies from 120 mC	OD in the upper stratches of the	river, to 80 mOI	O near the Nore.			
Ave. effective rainfall (mm)	600							
2. Summary of Particle Size Ar	nalysis and Field Descriptions of	f Subsoil Samples.						
NB Particle distributions adjusted to discount	t particles greater than 20mm. Graphs only de	pict samples taken from 1) a known dept	h exceeding 1.5m in boreholes or 1m i	n exposures, AND 2)	locations not at permeability	boundaries.		
Summary of particle size data: 1	proportion of clay fraction in each	Summary of particle size	data: proportion of total fines fract	ion in	Field description	of samples: range in principal subsoil types		
10sai	mple	20	each sample		d	lescribed using BS5930:1999		
Clay % generally indicates	Clay % is Clay % generally indicates low K nconclusive subsoils	18 Fines % generally Fines % generally	generally Fines% is Fines	% generally	14			
		16 - subsoils. subs	soils s	subsoils.	210			
6 6					8			
b 4								
2		~ <u>6</u>						
		4 2 -						
<9% 9% to $<12%$ 1'	2% to $14%$ >14% to $17%$ >17%	0 +		Į	SAND &	SILT SILT/CLAY CLAY		
Ranges	in clay content	<8% 8% to Ranges in	<pre><35% 35% to 50% total fines content (clay & silt)</pre>	>50%	Borehole samples	s Exposure samples or sand & gravel quarries		
					L			
3. Data from Permeability Test	ts.							
T' tests: # Results # Tests 1<1	# lests 1>50 Variable head # Res	ults Range Values Typical value	Pump tests # Results Range V	alues Typical value	e Lab tests # Results	Range Values Typical value		
A Summary and Analysis	tests (m/sec).		(m/sec).		(m/sec).			
4. Summary and Analysis Criterie	Comments			Imali	actions of each aritari	on for accomment of subseil normachility		
Quaternary / subsoil origin	Mainly well sorted fluvio glacial sa	nds and gravels		Impu		high		
Particle size data	Only one data point indicating high	or moderate K			>>>	high or moderate		
Field description data	Exposure samples	of moderate K			~~~	high		
rield description data	Borehole samples				~~~	lingii		
Soil time	Not distinguished from Castleaome	r Distant			~~~	- high or moderate		
Artificial drainage dangity	Some draing	I Flateau			~~~	high or moderate		
Netural drainage density	Juich density				~~~	high or moderate		
Natural dramage density	Na raliable data				~~~	lingh of moderate		
Poole tumo	Finas rich siltatones and shales				~~~~	- high or moderate		
Lond use	Some tillage Duckes only store rive	or Small and and group! to			~~~	high of modelate		
Land USC	some unage. Rusnes only along fiv	er. Sinan sand and graver pits.		Overall	:	<u>ingn</u> IUCU		
5 COMMENTS. This is a demonstrate	fmainly well control and and grouple	d with the Diver Divin The area has the	aharaatariatia hummaalay ara1 +	overall conclus	number of overgroup1	nite The DC and the limited DCD both suggest high		

5. COMMENTS: This is a deposit of mainly well sorted sand and gravels associated with the River Dinin. The area has the characteristic hummocky gravel topography and contains a number of overgrown gravel pits. The BS and the limited PSD both suggest high permeability, and this is supported by the well-drained nature of the ridges.

Summary of Permeability Data and Analyses for Permeability Unit 7b - Slieve Ardagh slope sides .

Description of unit location:	Slope-sides underlain by siltstones, shales and limestones. In the north they are bounded by gravel deposits to the north, east and south (permeability regions 3 & 5) and by the Slieve									
	Ardagh Platau to the west (region 7a	Ardagh Platau to the west (region 7a). In the south, the Slieve Ardagh Plateau is to the north and west and the central lowlands to the east and south (permeability area 8a).								
Why is this a single K unit?	Relatively uniform topography, subs	oils and land-use.								
1. General Permeability Indica	ators and Region Characteristics									
Rock type	Northern area: karsified limestone, s	outhern area: siltstones and shales. Limestones regionally important aquifers,	siltstones and shales poor. Formation codes: BM, CL, KN and BE.							
Depth to bedrock	Variable, <3m towards the top of the	s slopes, increasing to $>10m$ at the base. Mainly 5-10m.								
Subsoil type	Commonly glacial tills, but also freq	uent areas of sand and gravel.								
Soil type	"Gleys and brown earths of the Sliev	"Gleys and brown earths of the Slieve Ardagh Hills" (Michael Conry). Soil associations 10, 19 and 34.								
Vegetation and land use	Mainly grazing but also some tillage	, rushes rare.								
Artificial drainage density	Low, infrequent ditches.									
Natural drainage density	High, numerous streams receive prec	pitation from the plateau.								
Topography and altitude	Often steep slope sides of intermedia	te elevation. Altitude ranges from 180 down to 130m, but in the north it dror	ps right down to 80m.							
Ave. effective rainfall (mm)	430									
2. Summary of Particle Size A	nalysis and Field Descriptions of	Subsoil Samples.								
NB Particle distributions adjusted to discour	it particles greater than 20mm. Graphs only dep	ict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, AND	2) locations not at permeability boundaries.							
Summary of particle size data:	Summary of particle size data: proportion of clay fraction in each Summary of particle size data: proportion of total fines fraction in Field description of samples: range in principal subsoil types									



3. Data from Permeability Tests.

T' tests: # Results # Te	ests 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 Analysi	is										
Criteria		Comments						Implicatio	ons of each criterio	on for assessn	nent of subsoil permeability
Quaternary / subsoil origin		Tills and grave	els. Borehole records sugg	gest gravels o	ften underlie th	ne tills, poss. altering th	e overall K.		>>>	moderate to	low
Particle size data		Clay <14% in	5 out of 6 samples. Fine	s >35-50% in	n 1/2 the sample	es (inconclusive K), bu	t <35% in 3/8		>>>	moderate	
Field description data		Exposure sam	ples						>>>	moderate to	low
		Borehole samp	ples						>>>	low	
Soil type		Inconclusive.							>>>	moderate to	low
Artificial drainage density		Low.							>>>	moderate to	high
Natural drainage density		High.							>>>	low	
Permeability test data		No reliable da	ta						>>>	-	
Rock type		Mainly siltston	nes and shales.						>>>	low	
Land use		Some tillage, f	few rushes.						>>>	moderate	
		-					Over	rall conclusion	>>>	MODERAT	Ē

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as generally 'moderate'. The field descriptions from exposures provide the most important data set to question this. However, the presence of sand and gravel, both at the surface and beneath the till, is likely to increase the overall permeability, even if the till by itself may be low K. If this is the case, it explains why low K deposits can be found in both sections and boreholes, while the predominant permeability is moderate. The PSA and vegetation strongly suggest that this is the case.

Summary of Permeability Data and Analyses for Permeability Unit 8a - Central Kilkenny Lowlands .

Description of unit location:	Low-lying areas underlain by limestone and bordered by Castlecomer plateau to north, lowland gley soils to west, Windgap / Slievenamon hills to south, and Carlow county boundary
	to east. Split in centre by River Nore gravels (permeability region 5).
Why is this a single K unit?	Low-lying areas underlain by limestone and bordered by Castlecomer plateau to north, lowland gley soils to west, Windgap / Sli
1. General Permeability Indica	tors and Region Characteristics
Rock type	Limestone. Aquifer category ranges from karstified and regionally important to locally important. Formation codes are: CL, BM, DW, AG, BU, CS, WA, BA
Depth to bedrock	Variable: 0m to 20m+. Typically 3m to 5m.
Subsoil type	Dominantly glacial tills. Occasional gravel pockets to west of Nore. Frequent pockets of areas where rock is close to surface.
Soil type	Dominantly medium heavy grey-brown podzolics. Occasional small pockets of gleys and light grey-brown podzolics.
Vegetation and land use	Farmland dominant. Tillage common.
Artificial drainage density	Low. Typically less than 25% of field boundaries have drainage ditches.
Natural drainage density	Low
Topography and altitude	Low-lying, generally flat plain. Altitude typically 70 mOD to 90mOD.
Ave. effective rainfall (mm)	340

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 Ty	ypical 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 criterio	n for assessment of subsoil permeability
Quaternary / subsoil origin	Generally tills		>>>	moderate to low
Particle size data	Clay <9% in 1/2, <14% in 1/2. Fines >50% in only 1 out of 9.		>>>	moderate
Field description data	Exposure samples		>>>	low
	Borehole samples		>>>	moderate to low
Soil type	Medium heavy grey-brown podzolics		>>>	moderate
Artificial drainage density	Few drains		>>>	moderate
Natural drainage density	Low density		>>>	moderate
Permeability test data	No reliable data		>>>	-
Rock type	Generally cleaner limestones. Locally derived tills should generally	have relatively low clay contents	>>>	moderate
Land use	Tillage common. No evidence of rushes		>>>	moderate to high
		Overall	conclusion >>>	MODERATE

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as generally 'moderate'. The field descriptions from exposures provide the most important data set to question this. However, in till areas, exposures are most commonly found in field drains. Thus, the exposures data set may be 'biased' in that they will tend to be found mostly frequently in parts of the region where artificial drainage occurs. The overall data set suggests that there will be pockets where the subsoil permeability is higher or lower than the average for the region. There is no clear correlation between the location of these pockets and rock type variations, or depth to bedrock variations.

Summary of Permeability Data and Analyses for Permeability Unit 8b - lowland lst. gleys .

Description of unit location:	Low-lying area underlain by limest	one and bordered to north and west by Slieve Ardagh slope si	des (permeability	region 7b), to the east b	y the central Kilkenny lowlands (permeability							
1	region 8a) and to the south by the w	vestern Kilkenny lowlands (permeability region 8c).	a i	0 //								
Why is this a single K unit?	Relatively uniform topography, bed	rock, subsoils, soils and land use.										
1. General Permeability Indicat	ors and Region Characteristic	5										
Rock type	Limestone. Aquifer category ranges	from karstified and regionally important to poor. Formation	codes are: WA, C	S, AG, DW, BM, and C	Ľ.							
Depth to bedrock	Variable: 0m to >10m. Typically >3	3m to 10m.										
Subsoil type	ommonly glacial tills, but also frequent areas of sand and gravel.											
Soil type	redominantly poorly drained gleys. Occasional small pockets of medium heavy grey-brown podzolics.											
Vegetation and land use	orestry common, also flat pasture land, some tillage. Rushes common.											
Artificial drainage density	High, abundant ditches.	ligh, abundant ditches.										
Natural drainage density	High.											
Topography and altitude	Low-lying, generally flat plain. Alti	tude typically 70mOD to 80mOD. In north of area, rises to 20	00mOD in one are	a.								
Ave. effective rainfall (mm)	450											
2. Summary of Particle Size Ana	alysis and Field Descriptions o	f Subsoil Samples.										
NB Particle distributions adjusted to discount	particles greater than 20mm. Graphs only de	pict samples taken from 1) a known depth exceeding 1.5m in boreholes or 11	n in exposures, AND 2,) locations not at permeabilit	y boundaries.							
Summary of particle size data: pi	roportion of clay fraction in each	Summary of particle size data: proportion of total fines fra	action in	Field descriptio	n of samples: range in principal subsoil types described using BS5930:1999							
10 Clay % generally indicates	ny % is Clay % generally indicates low K	20 Fines % generally Fines % generally Fines % is F	ines % generally	14								
8 + moderate or high K subsoits incom	nciusive subsoils _	$16 - \frac{18}{16} - \frac{16}{16} -$	indicates low K	12 310								
9 6		$\frac{14}{212}$ = subsous.	subsolls.	8								
b 4				56								
2				2								
				0 +								
$0 + \frac{1}{2} + $	2% to $14%$ >14% to $17%$ >17%		P []	SAND &	SILT SILT/CLAY CLAY							
Ranges in	n clay content	<8% 8% to <35% 35% to 50% Ranges in total fines content (clay & silt)	>50%	Borehole sar	nples Exposure samples or sand & gravel quarries							
3. Data from Permeability Tests	S.	1										
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	ults Range Values Typical value Pump tests # Results Range	Values Typical value	ue Lab tests # Results	Range Values Typical value							
min/25mm	tests (m/sec):	(m/sec):		(m/sec):								
4. Summary and Analysis												
Criteria	Comments		Impl	lications of each criter	ion for assessment of subsoil permeability							
Quaternary / subsoil origin	Tills and gravels. Borehole records	suggest gravels often underlie the tills, poss. altering the over	all K.	>>>	moderate to low							
Particle size data	Clay <14% in all samples, <12% in	just one (mod K). Fines <50% in all 8 samples, <35% in 1/3		>>>	moderate							
Field description data	Exposure samples			>>>	moderate to low							
	Borehole samples			>>>	low							
Soil type	Poorly drained gleys, only occasion	al pockets of better drained land.		>>>	low							
Artificial drainage density	High.			>>>	low							
Natural drainage density	High.			>>>	low							
Permeability test data	No reliable data			>>>	-							
Rock type	Generally cleaner limestones. Local	ly derived tills should generally have relatively low clay cont	tents	>>>	moderate							
Land use	Coniferous forestry common, abund	lant rushes		>>>	low							
			Overall conclu	sion >>>	MODERATE							

5. COMMENTS: This is a particularly borderline area. The PSD analysis suggests moderate, while the borehole BS analysis, soil type, land use and drainage density all strongly suggest 'low'. The exposure BS analysis could be either. The ice-flow direction suggests that material from the clay-rich rocks of the Slieve Ardagh Hills to the north was dragged across the area. However, this is a particularly low-lying area where the watertable is likely to be close to the surface, meaning that the gleys could be groundwater gleys and the vegetation and drainage could reflect water-logging. This hypothesis is backed up by the presence of better drained pockets of land on higher ground. The presence of sand and gravel, both at the surface and beneath the till, is likely to increase the overall permeability, even if the till by itself may be low K. If this is the case, it explains why low K deposits can be found in both sections and boreholes, while the dominant permeability is 'moderate'.

Summary of Permeability Data and Analyses for Permeability Unit 8c - Western Kilkenny Lowlands .

Description of unit location:	Low-lying area underlain by limestone	and bordered to north by the	central lowland gleys (perr	meability area 8b)	to the east by the centra	al Kilkenny lowlands (permeability region 8a), to
	the south by the Slievenaman uplands	(permeability region 12). The	e lowlands continue to the v	west into County T	ipperary.	
why is this a single K unit?	Relatively uniform topography, bedroc	:K, subsolls, solls and land use.	•			
1. General Permeability Indica	tors and Region Characteristics				1. 1. 1. 1.	
Rock type	Mainly dirty limestone, some sandston	ie in south. Aquifer category p	predominantly poor, region	ally important san	dstone in south. Forma	tion codes are: BA, KT and PG.
Depth to bedrock	Ranges from 0m to 21m, mainly 3-5m	·				
Subsoil type	Predominantly tills.			1 1 1'	1 1 1 1	
Soil type	Predominantly poorly drained gleys.	some small pockets of better di	rained Medium heavy grey	y brown podzolics	where subsoils are thin	l.
Vegetation and land use	Forestry common, also flat pasture land	d, some tillage. Rushes comm	10n.			
Artificial drainage density	High, abundant ditches.					
Natural drainage density	High.			150 00 5 1	3737 1	
Topography and altitude	Low-lying, generally flat plain. Altituc	le typically /0mOD to 80mOL	D. In south of area, rises to	150mOD. Total ar	ea: XX square km.	
Ave. effective rainfall (mm)						
2. Summary of Particle Size Ar	alysis and Field Descriptions of S	ubsoil Samples.		1	2) 1	
NB Particle distributions adjusted to discount	particles greater than 20mm. Graphs only depict	samples taken from 1) a known depth	h exceeding 1.5m in boreholes or	Im in exposures, AND	2) locations not at permeabi	lity boundaries.
Summary of particle size data: p	proportion of clay fraction in each	Summary of particle size	data: proportion of total fines f each sample	fraction in	Field descript	tion of samples: range in principal subsoil types described using BS5930:1999
Clay % generally indicates moderate or high K subsoils in 6 4 2 0 <9% 9% to <12% 12 Ranges 3. Data from Permeability Test	Clay % is Clay % generally indicates low K subsoils subsoils % to 14% >14% to 17% >17% in clay content	20 18 16 16 112 12 10 10 10 10 10 10 10 10 10 10 10 10 10	zenerally Fines % is inconclusive inconclusive inconclusive states and the second states	Fines % generally	14 12 20 96 2 0 SAND & GRAVEL Borehole samp	SILT SILT/CLAY CLAY ples Exposure samples or sand & gravel quarries
T' tests: # Results # Tests T<1 min/25mm	# Tests T>50 Variable head # Results tests (m/sec):	Range Values Typical value	Pump tests # Results Rang (m/sec):	ge Values Typical va	alue Lab tests # Resul (m/sec):	lts Range Values Typical value
4. Summary and Analysis						
Criteria	Comments			Im	olications of each crite	erion for assessment of subsoil permeability
Quaternary / subsoil origin	Predominantly tills, no apparent influe	nce from gravels. Abundant av	vailability of clay-rich mate	erial.	>>>	moderate to low
Particle size data	Clay >14% in $3/5$ of samples. Fines >	50% in $1/2$ of samples.			>>>	low
Field description data	Exposure samples	-			>>>	moderate to low
*	Borehole samples				>>>	moderate to low
Soil type	Gleys.				>>>	low
Artificial drainage density	High.				>>>	low
Natural drainage density	High.				>>>	low
Permeability test data	No reliable data				>>>	-
Rock type	Mainly clay-rich limestones.				>>>	low
Land use	Coniferous forestry common, abundan	t rushes. Some good pasture la	and and tillage on shallow i	rock areas	>>>	low
		- ·	-	Overall concl	usion >>>	LOW
5 COMMENTS.						

5. COMMENTS: In contrast to Region 8b immediately to the north, this area appears to be low permeability. The PSD data is just over 1/2 low, and the BS data just under 1/2 low. The soil type, land use and drainage density all strongly indicate 'low'. The suggestion is not that the till in 8c has a different permeability to the till in 8b, rather, that the till throughout is low K but in 8b it is affected by the widespread presence of sand and gravel, both at the surface and beneath the till. These sand and gravel bodies are not seen in 8c and it appears that the low K till is the dominant factor. This is backed up by the widespread development of poorly drained gley soils across the area. Medium heavy grey brown podzolics (MH-GBP's) are also seen, but are in close association with shallow rock areas where the potential for drainage is increased. These shallow rock areas are often seen as long, low, well-drained ridges crossing the area. The draining influence of the rock seems to extend outwards considerably, with MH-GBP's only giving way to imperfectly drained gleys at subsoil thicknesses of up to 3m.

Summary of Permeability Data and Analyses for Permeability Unit 9-Ordovician Uplands .

Description of unit location:	Upland area in east Kilkenny, extending from east of Thomastown to Ballyhale and down to Slieveroe. Underlain by Ordovician slates in the north, east and south and Devonian ssts. in the west. Four main areas occur, the eastern and central ones being split by areas of rock close, while the northern one is bounded by region 8a and the southern one is bounded by region 14.
Why is this a single K unit?	Although it is scattered in its distribution, it has relatively uniform topography, bedrock, subsoils and land use.
1. General Permeability Indica	ntors and Region Characteristics
Rock type	A mix of slates, volcanics and dirty sandstones. Mainly poor and locally important, regionally important in the south. Formation codes: MN, OA, BY, CA and CI
Depth to bedrock	Quite variable, mainly between 1 and 5m, achieves thicknesses of 10m in southern area.
Subsoil type	Glacial tills. Some thin strips of alluvium along Blackwater and Pollanasa Rivers. Area is divided up by areas of thin subsoil.
Soil type	No data specific to Kilkenny - soils map of Ireland has a range of soil associations, probably not terribly useful.
Vegetation and land use	Predominantly rough grazing with occasional rushes on slopes.
Artificial drainage density	Variable, in parts of the W and E 1/4 of boundaries are ditches.
Natural drainage density	Moderate
Topography and altitude	Steep-sided valleys ranging from 50m to 140m, southern area is lower lying (20-60m)
Ave. effective rainfall (mm)	570

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 An	nalysis										
Criteria		Comments						Implicatio	ns of each criterio	n for assessment of	subsoil permeability
Quaternary / subsoil or	igin	Generally tills	, plentiful supply of low j	permeability	rocks.				>>>	low	
Particle size data		4/7 of samples	s > 14% clay. $4/5$ of sample	les have fines	s indicating inc	onclusive K, but 1/5 in	ndicate low K		>>>	low	
Field description data		Exposure sam	ples						>>>	low	
		Borehole samp	ples						>>>	-	
Soil type		Variable							>>>	moderate or low	
Artificial drainage dens	sity	Frequent ditch	nes						>>>	low	
Natural drainage densit	ty	Moderate							>>>	moderate or low	
Permeability test data		No reliable da	ta						>>>	-	
Rock type		Generally clay	rich slates and dirty sand	dstones. Clea	aner volcanics	in extreme south.			>>>	moderate or low	
Land use		Grazing, rushe	es.						>>>	low	
		_					Over	all conclusion	>>>	LOW	

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as generally 'low'. Although the rock and subsoil types are inconclusive, and insufficient data is available for the soils to be an influencing factor, the PSA and BS analysis suggest low. This is backed up by land use and artificial drainage density.

Summary of Permeability Data and Analyses for Permeability Unit 10 - Granite Uplands.

Description of unit location:	This is a small unit located only on granita badroak and accumuing no me	v	t north of Graiguana	managh in aget Kilkanny, while the other							
Description of unit location.	area occurs just west of Tullagher Both are entirely surrounded by shallo	we rock unlands and are located along the floor	s of long thin valley	managn in east Kirkenny, while the other							
Why is this a single K unit?	Both areas have the same rock-typs, till genesis and land-usage.	in four aplands and are found atong the floor		<u>.</u>							
1. General Permeability Indicat	ors and Region Characteristics										
Rock type	Granite.										
Depth to bedrock	Typically 3-5m, in the centre of the Tullagher area thicknesses of >10m a	are achieved in a long narrow strip.									
Subsoil type	Glacial till.	<u> </u>									
Soil type	No data specific to Kilkenny - on the soils map of Ireland it is Soil Assoc	iation 14: 75% acid brown earths, 15% gleys,	10% brown podzolic	S.							
Vegetation and land use	Grazing land on steep valley sides with some rushes. Due to their low, fl	at topography, the valley floors are poorly-drait	ned.								
Artificial drainage density	/4 field boundaries are ditches.										
Natural drainage density	High.										
Topography and altitude	Steep-sided, narrow valleys at intermediate elevations, typically 80m on t	the valley floor, rising to between 100m and 12	20m on the valley sid	les.							
Ave. effective rainfall (mm)	570										
2. Summary of Particle Size An	lysis and Field Descriptions of Subsoil Samples.										
NB Particle distributions adjusted to discount	articles greater than 20mm. Graphs only depict samples taken from 1) a known depth exce	eding 1.5m in boreholes or 1m in exposures, AND 2) locat	ions not at permeability b	oundaries.							
Summary of particle size data: p	oportion of clay fraction in each Summary of particle size data:	proportion of total fines fraction in	Field description of	of samples: range in principal subsoil types							
10 Clay % generally indicates	ay % is Clay % generally indicates low K 20 Fines % generally Fines % generally	by Fines % is Fines % generally 14									
8 — moderate or high K subsoils ind	nclusive	inconclusive indicates low K									
Ω 6	14 - subsoils.										
	Bilo	51 51 4									
占 2											
		0									
$0 + \frac{0}{120} + \frac{0}{120} + \frac{1}{120} + $		_┦_┏━┓_┦┦║	SAND &	SILT SILT/CLAY CLAY							
-9% 00 -12% 12 Ranges i	clay content <8%	2 35% to 50% >50% lines content (clay & silt)	Borehole samples	Exposure samples or sand & gravel quarries							
3. Data from Permeability Test											
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Results Range Values Typical value Pr	ump 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	Implicati	ons of each criterio	n for assessment of subsoil permeability							
Quaternary / subsoil origin	Glacial till with a high proportion of granite clasts and mica flakes preser	nt.	>>>	moderate or low							
Particle size data	insufficient data. The one clay % is inconclusive. One fines % suggests n	noderate, the other mod. or low.	>>>	moderate or low							
Field description data	Exposure samples		>>>	moderate or low							
	Borehole samples		>>>	-							
Soil type	Variable		>>>	moderate or low							
Artificial drainage density	Frequent ditches		>>>	low							
Natural drainage density	High		>>>	low							
Permeability test data	No reliable data		>>>	-							
Rock type	Granites with a high mica (clay) content, but also a high quartz content, v	which can readily weather to sand	>>>	moderate or low							
Land use	Grazing, occasional rushes	-	>>>	moderate or low							
		Overall conclusion	>>>	LOW							
5. COMMENTS: The general weight	f evidence suggests the overall permeability of the subsoils in this region could be classifie	d as 'low' or 'moderate'. Although the rock, subsoil and so	il types are inconclusive,	and insufficient data is available for the PSA and BS							

analysis, the land use and drainage regime suggest low.

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

	Summary	of I et medsiney Duta and I maryses for I et meas									
Description of unit location:	These deposits are found in narrow	strips along streams and rivers throughout the county. The la	rgest developments	of alluvium occur a	long the Nore, Suir and Barrow rivers, with						
	thinner developments along the Nue	enna, Dinin, Kings and Blackwater rivers, and occasional wis	ps along a variety o	of smaller streams.							
Why is this a single K unit?	They are all fine-grained water-lain	deposits found on the banks and flood-plains of rivers.									
1. General Permeability Indic	ators and Region Characteristics	<u>S</u>									
Rock type	Variable. Ranges from Ordovician	slates right up to Westphalian sandstones.									
Depth to bedrock	Variable, generally 3m to 10m, >10	Im in places along the Nore. The alluvium generally overlies	gravels or tills so th	e alluvium itself car	often be far thinner.						
Subsoil type	Interbedded, predominantly fine-grained, sandy, silty and clayey water-lain alluvial deposits.										
Soil type	Variable. A high watertable alongsi	de the river generally results in the development of a strip of	groundwater gley.								
Vegetation and land use	Immediately next to the rivers, the l	and is commonly water-logged and rushy. Where the alluviu	m is extensive, it m	ay be tilled or graze	d.						
Artificial drainage density	High, reflecting the proximity of the	e watertable to the surface.									
Natural drainage density	High.										
Topography and altitude	Occupies valley floors, the elevation	n of which can vary from 140m along the Dinin in the north,	to 5m along the Sui	r in the south. Gene	rally found at ~60m						
Ave. effective rainfall (mm)	340 to 600										
2. Summary of Particle Size A	Analysis and Field Descriptions of	f Subsoil Samples.									
NB Particle distributions adjusted to discou	int particles greater than 20mm. Graphs only de	pict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1	m in exposures, AND 2)	locations not at permeab	ility boundaries.						
Summary of particle size data:	proportion of clay fraction in each	Summary of particle size data: proportion of total fines fr	action in	Field descrip	tion of samples: range in principal subsoil types						
$10 \pm Class \%$ comoughly indicates \mathbf{S}	ample	20 - each sample		14	described using BS5930:1999						
8 moderate or high K subsoils	inconclusive subsoils	18 - Fines % generally - Fines % is - Fines % is 18 - indicates high K - indicates mod K - inconclusive	ines % generally	14							
cò		16 - subsoils. subsoils.	subsoils.	210							
l lneu											
55 4 -				<u><u><u>u</u></u> 4</u>							
2				2							
0	, ļ , ļ , J			SAND &	SILT SILT/CLAY CLAY						
<9% 9% to <12%	12% to 14% _ >14% to 17% >17%	$0 + \frac{1}{2} + $	>509/	GRAVEL							
Kange	es in clay content	Ranges in total fines content (clay & silt)	~30%	Borehole sam	ples Exposure samples or sand & gravel quarries						
3 Data from Permeability Te	ste										
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	sults Range Values Typical value Pump tests # Results Range	Values Typical value	e Lab tests # Resu	lts Range Values Typical value						
min/25mm	tests (m/sec):	(m/sec):	, fundos i ppicar fund	(m/sec):	no range values ryprearvalue						
4. Summary and Analysis											
Criteria	Comments		Impli	cations of each crit	erion for assessment of subsoil permeability						
Quaternary / subsoil origin	interbedded sands, silts and clays		ľ	>>>	high, moderate or low						
Particle size data	Only one sample available, with fin	es between 8 and 35%		>>>	moderate						
Field description data	Exposure samples			>>>	moderate						
P 2000	Borehole samples			>>>	moderate						
Soil type	Often glev			>>>	low						
Artificial drainage density	High			>>>	low						
Natural drainage density	High			>>>	low						
Permeability test data	No reliable data			>>>	-						
Rock type	variable			>>>	high, moderate or low						
Land use	Some tillage and grazing where land	d is not water-logged		>>>	high, moderate or low						
			Overall conclus	ion >>>	MODERATE						
5 COMMENTS											

5. COMMENTS: Although these alluvial deposits are found throughout the county, at a range of elevations and underlain by a wide variety of rock-types, they all share a common origin and the BS exposure and borehole descriptions show that they all consist of a mix of sands, silts and clays. This makes it most likely that they will have a moderate permeability (supported by the one PSD value). It must be remembered that they are quite recent deposits that are likely to be underlain by the subsoil type abutting them. Only along the largest rivers are they likely to be thicker than two or three meters. Despite this, along all but the smallest of streams they are likely to have an influence on the overall permeability. Unfortunately, the inaccessibility of river banks to drilling means that the actual depths of the alluvium has not been widely established. One borehole along the Kings River showed alluvial thicknesses of up to 3m.

Summary of Permeability Data and Analyses for Permeability Unit 12 - Slievenaman Uplands .

Description of unit location:	Upland areas underlain by Silurian slate	es and minor tuffs. Bounded by Kilkenny central lowlands to the north (permeabilit	y region 8), Mullinavat upland area to east (permeability (K) region 9), Slievename									
_	to the west (Tipperary) and South Kilke	nny lowlands to the south (K region14). The areas are quite small and are surround	led by rock close (region 13).									
Why is this a single K unit?	Relatively uniform topography, bed	rock, subsoils and landuse.										
1. General Permeability Indica	tors and Region Characteristics	i										
Rock type	Silurian slates and minor tuffs and v	olcanics. The rocks are all poor aquifers. Formation code is AY.										
Depth to bedrock	Mainly 1-3m, in west of area, thickens to 10m.											
Subsoil type	Glacial till.											
Soil type	Association 6 and 9 both of which h	ave 80% brown podzolics, 15% gleys and 5% podzols.										
Vegetation and land use	Predominantly rough grazing with v	videspread rushes.										
Artificial drainage density	High. Steep sided ditches common.	·										
Natural drainage density	High in west of area where thicknes	ses are greater.										
Topography and altitude	Hilly, steep topography. Quite varia	able altitude - up to 250m in east of area, down to 100m in the steep-sided v	valleys.									
Ave. effective rainfall (mm)	580											
2. Summary of Particle Size Ar	alysis and Field Descriptions of	i Subsoil Samples.										
NB Particle distributions adjusted to discount	t particles greater than 20mm. Graphs only de	pict samples taken from 1) a known depth exceeding 1.5m in boreholes or 1m in exposures, Al	ND 2) locations not at permeability boundaries.									
Summary of particle size data: p	proportion of clay fraction in each	Summary of particle size data: proportion of total fines fraction in	Field description of samples: range in principal subsoil types									
10 Clay % generally indicates	lay % is Clay % generally indicates low K	20 Fines % generally Fines % generally Fines % is Fines % generally	14									
8 - moderate or high K subsoils incl	onclusive subsoils	$\begin{bmatrix} 18 \\ 16 \end{bmatrix}$ indicates high K indicates mod K inconclusive indicates low K indicates low K										
6	I	s.14 - subsoils										
nb 4 -												
王 2												
			SAND & SILT SILT/CLAY CLAY									
<9% 9% to <12% 12 Ranges	in clay content	<8% 8% to <35% 35% to 50% >50% Ranges in total fines content (clay & silt)	Borehole samples Exposure samples or sand & gravel quarries									
3. Data from Permeability Test	IS.											
T' tests: # Results # Tests 1<1 min/25mm	# Tests 1>50 Variable head # Rest tests (m/sec):	uits Range Values Typical value Pump tests # Results Range Values Typica (m/sec):	Il value Lab tests # Results Range Values Typical value (m/sec):									
4. Summary and Analysis												
Criteria	Comments	Ι	mplications of each criterion for assessment of subsoil permeability									
Quaternary / subsoil origin	All tills		>>> moderate to low									
Particle size data	Only two data sets, both inconclusiv	e K fines contents, one clay % moderate, one inconclusive	>>> moderate to low									
Field description data	Exposure samples		>>> low									
,	Borehole samples		»»» -									
Soil type	There are gleys among the soil asso	ciations, the land is considered suitable for grazing, rather than tillage	>>> moderate to low									
Artificial drainage density	High	,	>>> low									
Natural drainage density	High		>>> low									
Permeability test data	No reliable data		>>>> -									
Rock type	Generally clay-rich slates only minc	or quantities of cleaner volcanics, locally derived tills should reflect this.	>>> low									
Land use	Rushy grazing	1 2 2	>>> low									
	50 0	Overall co	nclusion LOW									
5 COMMENTS, The summal surface												

5. COMMENTS: The general weight of evidence suggests the overall permeability of the subsoils in this region should be classified as generally 'low'. Although the subsoil and soil types as well as the PSA analysis are inconclusive, the BS descriptions and the vegetation and drainage patterns all strongly suggest low.

Description of unit location:									
Why is this a single K unit?									
1. General Permeability Indicat	tors and Region Characteristics	و			. <u> </u>				
Rock type									
Depth to bedrock									
Subsoil type									
Soil type									
Vegetation and land use	 								
Artificial drainage density									
Natural drainage density									
Topography and altitude	 								
Ave. effective rainfall (mm)	 								
2. Summary of Particle Size Ana	alysis and Field Descriptions of	Subsoil Samples.							
NB Particle distributions adjusted to discount p	particles greater than 20mm. Graphs only dep	pict samples taken from 1) a known depth	h exceeding 1.5m in boreholes (or 1m in exposures, ANI	D 2) locati	ons not at permeabil	ity boundaries.		
Summary of particle size data: pr	roportion of clay fraction in each	Summary of particle size	data: proportion of total fine	es fraction in		Field descripti	on of samples: ra	nge in principal subs	soil types
10 Clay % generally indicates	a ble Clay % is Clay % generally indicates low K	20 T Fines % generally Fines %	each sample	Eines 9/ conorally	14 -		described using	BS5930:1999	
8 moderate or high K subsoils inco	conclusive	18 indicates high K indicates	enerally rines % is	indicates low K	12 -				·
5 6	ĮĮ'	14 subsoils. subso	oils.	subsoils.					
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2	/			(] '	0 +				
			/	<u>ا</u> ا		SAND &	SILT	SILT/CLAY	CLAY
<9% 9% to <12% 12% 12% Ranges ir	% to 14% >14% to 17% >17%	<8% 8% to Ranges in	<35% 35% to 50%	>50%		GRAVEL	es 🗖 Exposure sa	mples or sand & grav	el quarries
	!		Jotal lines content (clay & sin)	<u>, </u>		Borenoie sump.		hiples of sand & grun	erquarres
3. Data from Permeability Tests	š								
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	ults Range Values Typical value	Pump tests # Results R/	ange Values Typical v	value	Lab tests # Result	s Range Values	Typical value	
min/25mm	tests (m/sec):		(m/sec):			(m/sec):			
4. Summary and Analysis				_					
Criteria	Comments			Im	nplicatio	ons of each crite	rion for assess	ment of subsoil	permeability
Quaternary / subsoil origin						>>>			
Particle size data						>>>			
Field description data						>>>			ļ
						>>>			
Soil type						>>>			
Artificial drainage density						>>>			
Natural drainage density						>>>			
Permeability test data						>>>			
Rock type						>>>			
Land use				0 "		>>>			-
				Overall conc	<u>lusion</u>	>>>			
5. COMMENTS:									

Summary of Permeability Data and Analyses for Permeability Unit 14 - South Kilkenny Lowlands .

Description of unit location:	Low-lying area underlain by limestones in the centre and sandstones round the perimeter. Bounded by lower palaeozoic uplands to the north and east (permeability (K) regions 13 and 9				
	respectively) and the River Suir to the south and west.				
Why is this a single K unit?	Relatively uniform topography, subsoils and landuse.				
1. General Permeability Indicators and Region Characteristics					
Rock type	Aquifer category ranges from regionally important limestones and sandstones to poor dirty limestones. Formation codes are: CI, KT, PG, BV, BT, BA, WA, SS, KS				
Depth to bedrock	Variable, approx. 1/3 <3m, typically >5m				
Subsoil type	Predominantly glacial tills, with one expanse of lacustrine clays. Area of sand and gravel in NW (K region 16), Strips of alluvium along the Suir and the Blackwater (K region 11).				
Soil type	Mainly Association 13 - 70% Acid Brown Earths, 15% Grey Brown Podzolics, 15% Gleys.				
Vegetation and land use	Farmland dominant, mainly grazing with some tillage. Rushes on flatlying ground, none on slopes.				
Artificial drainage density	Ditches on lowlying ground, better drained on slopes.				
Natural drainage density	High.				
Topography and altitude	Flat low ground in centre, more undulating around edges. Typical altitude 20m in centre, rising to 80m in north.				
Ave. effective rainfall (mm)	470				

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<	# Tests T>50 Variable head # Results Range Value	es Typical value Pump tests # Results Range Value	ues Typical value Lab tests # Re	sults Range Values Typical value		
min/25mm	tests (m/sec):	(m/sec):	(m/sec):	Sand Tallige Calabo Typical Calab		
4 Summary and Analysis						
Criteria	Comments		Implications of each cr	iterion for assessment of subsoil permeability		
Quaternary / subsoil origin	Generally tills, prob derived from northern mix of	clean Devonian sandstones and clay rich Sillurian	rocks >>>	moderate to low		
Particle size data	3/4 of samples >14% clay, just one sample <12%.	2/3 of samples >50% fines.	>>>	low		
Field description data	Exposure samples	-	>>>	low		
-	Borehole samples		>>>	-		
Soil type	Mainly acid brown earths (free draining with good	moisture-holding capacity)	>>>	moderate to low		
Artificial drainage density	Drains on low ground		>>>	moderate to low		
Natural drainage density	High density		>>>	low		
Permeability test data	No reliable data		>>>	-		
Rock type	Around 50:50 clean limestones and more clay rich	rock types.	>>>	moderate to low		
Land use	Grazing common, rushes in low ground.		>>>	moderate to low		
	-	0	Overall conclusion >>>	LOW		

5. COMMENTS: Although quite a number of criterion are inconclusive, the PSA and BS descriptions both strongly suggest low. And, as none of the criterion suggest moderate alone, it can be concluded that the area is mainly "low". The overall data set suggests that there will be pockets where the subsoil permeability is higher than the average for the region. No clear correlation has been found between the location of these pockets and rock type variations, or depth to bedrock variations.
Summary of Permeability Data and Analyses for Permeability Unit 15 - Tullaroan SAG.

Description of unit location:	Situated just to the north-east of Tullaroan and straddling the border between the Slieve Ardagh Plateau (Permeability Region 7a) and the southern slope sides (Permeability Region 7b).							
Why is this a single K unit?	This is a small area of sand and gravel with a distinctive tonogramy							
1. General Permeability Indicat	tors and Region Characteristics	s						
Rock type	Fines-rich Killeshin Siltstone Formation (KN), a low permeability poor aquifer.							
Depth to bedrock	5m to >10m	5m to >10m						
Subsoil type	Water-lain sand and gravels.	Water-lain sand and gravels.						
Soil type	Not differentiated from the "Gleys and brown earths of the Slieve Ardagh Hills" (Michael Conry). Soil associations 10, 19 and 34.							
Vegetation and land use	Tillage and grazing, some sand and gravel quarries.							
Artificial drainage density	Low.	Low.						
Natural drainage density	Low.							
Topography and altitude	Upland area with gentle hills of sand and gravel at between 260m and 150mOD.							
Ave. effective rainfall (mm)	580							
2. Summary of Particle Size An	alysis and Field Descriptions of	<i>i</i> Subsoil Samples.						
NB Particle distributions adjusted to discount	particles greater than 20mm. Graphs only dep	pict samples taken from 1) a known dept	h exceeding 1.5m in boreholes or 1m in exposures, AN	ND 2) locations not at permeabil	lity boundaries.			
Summary of particle size data: proportion of clay fraction in each		Summary of particle size	data: proportion of total fines fraction in	Field descript	Field description of samples: range in principal subsoil types described using BSS930:1999			
10 Clay % generally indicates	Clay % is Clay % generally indicates low K	20 Fines % generally Fines %	generally Fines % is Fines % generally	14				
8 - moderate or high K subsoils inc	conclusive	18 indicates high K indicate	s mod K inconclusive indicates low K					
99 6			oils	8	· · · · · · · · · · · · · · · · · · ·			
1 4								
<u>ت</u>]							
		4						
$0 + \frac{9\%}{12\%} = 0.00\%$	10/100 > 1.00/100 = 1.00/100 >			SAND &	SILT SILT/CLAY CLAY			
~7/0 7/0 10 ~12/0 12 Ranges i	in clay content	<8% 8% to Ranges in	<35% 35% to 50% >50% total fines content (clay & silt)	Borehole samp	bles Exposure samples or sand & gravel quarries			
3. Data from Permeability Test:	s							
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Rest	ults Range Values Typical value	Pump tests # Results Range Values Typical	l value Lab tests # Resul	ts Range Values Typical value			
min/25mm	tests (m/sec):		(m/sec):	(m/sec):				
4. Summary and Analysis								
Criteria	Comments		I	mplications of each crite	rion for assessment of subsoil permeability			
Quaternary / subsoil origin	Well sorted fluvio-glacial sands and	gravels		>>>	high			
Particle size data	Limited data available. Fines % indi	icate moderate		>>>	moderate			
Field description data	Exposure samples			>>>	high			
	borehole samples			>>>	-			
Soil type	Inconclusive			>>>	-			
Artificial drainage density	Few drains			>>>	moderate or high			
Natural drainage density	Low density			>>>	moderate or high			
Permeability test data	No reliable data			>>>	-			
Rock type	Fines-rich siltstones and shales.			>>>	low			
Land use	Tillage common. No evidence of rus	shes. Small sand and gravel pits		>>>	high			
			Overall con	nclusion >>>	HIGH			
5. COMMENTS: Although the availa	ble PSD information suggests moderate perm	eability, the BS exposure classifications.	along with the free-draining hummocky nature of the	land and the presence of a grav	el pit, all indicate that in general it is high permeability.			

Summary of Permeability Data and Analyses for Permeability Unit 16 - dirty fluvioglacial SAG.

Description of unit location:	These deposits are found throughout the county and generally consist of small pods of poorly sorted sands and gravels. They generally have a very small aerial extent, ranging from							
Why is this a single V unit?	<1km2 to 2km2. They are frequently found on the southern side of upland areas and are likely to have developed from glacial meltwater. Relatively uniform to compare the option of the southern side of upland areas and are likely to have developed from glacial meltwater.							
1 Conoral Dormonbility Indiant	Relatively uniform topography, sub-							
1. General Fermeability indicate Rock type	Variable Panges from Ordovisian	slates to Westnhalian sandstones						
Depth to bedrock	Variable. Kanges from Ordovician states to westphanan sandstones.							
Subsoil type	Variable. 1-10m Dirty sand and gravels of fluvio glacial origin							
Soil type	Dirty sand and gravers of nuvio-gravitationing is available, the areas are classified as medium textured grey brown podzolics							
Vegetation and land use	Farmland dominant. Tillage common							
Artificial drainage density	Low Typically less than 25% of field boundaries have drainage ditches							
Natural drainage density	Low							
Topography and altitude	Generally located on intermediate or low lying plains at elevations of 120 to 30m OD							
Ave. effective rainfall (mm)	340 to 600							
2. Summary of Particle Size Ana	alysis and Field Descriptions of	f Subsoil Samples.						
NB Particle distributions adjusted to discount p	particles greater than 20mm. Graphs only dep	pict samples taken from 1) a known depth	h exceeding 1.5m in boreholes or 1m in exp	posures, AND 2) locati	ions not at permeability i	boundaries.		
Summary of particle size data: proportion of clay fraction in each		Summary of particle size data: proportion of total fines fraction in			Field description of samples: range in principal subsoil types			
10 Clay % generally indicates	aple Iay % is Clay % generally indicates low K	20 T Fines % generally	each sample		de	escribed using BS5930:1999		
8 moderate or high K subsoils inco	conclusive	18 - indicates high K indicates	generally Fines % is Fines % generally g	low K 12 -				
б н		14 - subsoils subso	oils subsoin	ls				
		§ 12 § 10		- 6 dee				
Er L				上 4 - 2 -				
2		4		0 -				
0 + + + + + + + + + + + + + + + + + + +					SAND &	SILT SILT/CLAY CLAY		
<9% 9% to <12% 129 Ranges in	% to 14% >14% to 17% >17% n clay content	<8% 8% to Ranges in t	<35% 35% to 50% >50 total fines content (clay & silt)	%	GRAVEL Borehole samples	Exposure samples or sand & gravel quarries		
		5						
3. Data from Permeability Tests	S		D			D U 1 U 1 1		
T' tests: # Results # Tests 1<1	# lests 1>50 Variable head # Resu	ults Range Values Typical value	Pump tests # Results Range Values	s Typical value	Lab tests # Results	Range Values Typical value		
A Summary and Analysis	tests (m/sec).		(m/sec).		(111/800).			
4. Summary and Analysis Criteria	Comments			Implicatio	ons of each criterio	on for assessment of subsoil permeability		
Quaternary / subsoil origin	Fluvio-glacial Sands and Gravels, al	lso two sub-glacial esker deposits	s on the southern edge of Castleco	mer	>>>	moderate to high		
Particle size data	Fines <50% in all 3 samples, but eve	enly split between low or modera	ate, moderate and high		>>>	moderate to high		
Field description data	Exposure samples	2	, C		>>>	moderate		
*	Borehole samples				>>>	-		
Soil type	Varied, some medium grey brown p	oodzolics			>>>	moderate		
Artificial drainage density	Few drains				>>>	moderate		
Natural drainage density	Low density				>>>	moderate		
Permeability test data	No reliable data				>>>	-		
Rock type	variable				>>>	high, moderate or low		
Land use	Tillage common. No evidence of rus	shes			>>>	moderate to high		
			Ov	erall conclusion	>>>	MODERATE		

5. COMMENTS: Although these sand and gravel deposits are found throughout the county, at a range of elevations and underlain by a wide variety of rock-types, they are all small, poorly sorted, waterlain deposits, with a high fines content. They are commonly found on the southern side of the upland areas in Kilkenny, making it likely that they were deposited by meltwater from stationary ice sheets on the hills. Some of the deposits formed sub-glacially, forming small eskers on the southern edge of the Castlecomer Plateau (Permeability Region 1). Although limited, the BS exposures data, coupled with the PSD analysis suggests that these deposits have a moderate permeability. This is supported by the soils data (where available), the drainage and the land use.

Summary of Permeability Data and Analyses for Permeability Unit 17 - Kilmanagh SAG.

			1. dl. in and 11. mid at a 1.11. m	41 - 1 1 - 1	1	(1, 0, 1) $(1, 0, 1)$ $(1, 0, 1)$ $(1, 0, 1)$ $(1, 0, 1)$ $(1, 0, 1)$	
Description of unit location:	Situated just south of Tullaroan and	extending to south of Kilmanag	in, this small unit straddles	the border between t	ne southern slope sldes	of the Slieve Ardagh Plateau (Permeability	
Why is this a single K unit?	Region 7b) and the western Kilkenny lowlands, north of Callan (Permeability Region 8b).						
1 General Permeability Indica	ators and Region Characteristics						
Rock type	Fines-rich Killeshin Siltstone Form	ation (KN), a low permeability p	oor aquifer				
Depth to bedrock	$\frac{1 \text{ mics-field Kinesing Single Formation (KN), a low permeability pool aquiter.}}{1 \text{ mics-field ministry Smith}}$						
Subsoil type	JUCULOUK IIII ID / 10111, IIIaIIII J JIII ID 10111. type Water-lain sand and gravels, overlain in places with up to 3m of glacial till. In the south the till becomes thicker and the patchy sands and gravels become part of 0h.						
Soil type	water-tain satu and gravers, overlain in places with up to 511 of gravita inf. in the south the full decomes infeker and the pattern satus and gravers become part of 80.						
Vegetation and land use	Mainly grazing some rushy flat land with water-logging close to river						
Artificial drainage density	ty Ditches on lowlying ground, better drained on slones						
Natural drainage density	High - deposit occurs along the floo	or of a valley					
Topography and altitude	Valley floor at intermediate elevations of 150m to 100m OD						
Ave. effective rainfall (mm)	430						
2. Summary of Particle Size A	nalysis and Field Descriptions of	f Subsoil Samples.					
NB Particle distributions adjusted to discour	nt particles greater than 20mm. Graphs only de	pict samples taken from 1) a known dept	th exceeding 1.5m in boreholes or	1m in exposures, AND 2)	locations not at permeabilit	y boundaries.	
Summary of particle size data:	proportion of alow frontion in each	Summary of particle size	e data: proportion of total fines f	fraction in	Field description	n of samples: range in principal subsoil types	
10 - Sammar y or particle size data.	mmle	Summary of particle size	each sample	iraction in	r iciu ueser ipuo	described using BS5930:1999	
Clay % generally indicates	Clay % is Clay % generally indicates low K	18 Fines % generally Fines % g	enerally Fines % is	Fines % generally	14		
		16 - <i>subsoils. indicates</i>	s mod K inconclusive pils.	indicates low K subsoils.	310		
9 6					8		
हुन् 4							
		6			2		
2					0		
				Į	SAND &	SILT SILT/CLAY CLAY	
<9% 9% to <12% 1 Ranges	s in clay content	<8% 8% to Ranges in	<35% 35% to 50%	>50%	GRAVEL Borehole sa	nples Exposure samples or sand & gravel quarries	
		Tunges in					
3. Data from Permeability Tes	its.		1				
T' tests: # Results # Tests T<1	# Tests T>50 Variable head # Res	ults Range Values Typical value	Pump tests # Results Ran	ge Values Typical valu	Lab tests # Results	Range Values Typical value	
Min/25mm	tests (m/sec):		(m/sec): 2 3x1	0-3 - /x10-3 5x10-3	(m/sec):		
4. Summary and Analysis Critoria	Commonts			Impl	inations of each aritar	ion for assassment of subseil normaphility	
Quaternary / subsoil origin	Fluvio-glacial sands and gravels			mpi		high	
Particle size data	Both samples have $<8\%$ fines				>>>	high or moderate	
Field description data	Exposure samples				>>>	high	
i leid desemption data	Borehole samples				>>>	high	
Soil type	Inconclusive				>>>	-	
Artificial drainage density	Drains on low ground				~~~	- moderate or low	
Natural drainage density	High				>>>	low	
Pormashility tost data	Tuglia from numn tost rosults				~~~	high	
Pools type	Fines rich hadroak				~~~	lingii	
Landuse	Grazing some rushes				~~~	moderate or low	
	Grazing, some rusites.			Quanell constant	sion >>>		
				Overall conclus		шып	

5. COMMENTS: This area has been identified as high permeability from the PSD and from exposure and borehole BS descriptions. It does not have the characteristic hummocky terrain, nor is it particularly well drained, situated as it is along a valley floor. But, it is a important source of water in the area, feeding the Ballycallan Group Scheme as well as private houses. The pump test available for this sand and gravel aquifer indicates that it has a high permeability. The presence of rushes and waterlogged land can be explained by a high watertable and also by the presence of thin till overlying much of the sand and gravel. This till becomes thicker and more widespread south of Kilmanagh, and this is why the southern extent is included with Permeability Region 8b rather than being distinguished as separate sand and gravel. This till presence in the area north of Kilmanagh explains why some of the PSD's suggest moderate permeability rather than high.