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1. Introduction

1.1 General

This groundwater protection scheme was commissioned by Meath County Council and was prepared in the Groundwater Section of the Geological Survey of Ireland (GSI). The project was undertaken in two parts. Part 1 involved the mapping of the Quaternary subsoils, which was carried out by Robert Meehan of the GSI Quaternary Section from 1993 to 1996. This included compiling the Subsoils and Depth to Bedrock maps and accompanying reports. Part 2 (January 1995 to July 1996) involved compiling all the geological and hydrogeological data to produce a suite of maps (Geology, Hydrogeological Data, Aquifers, Groundwater Vulnerability and Groundwater Protection maps) and this report. Seven major groundwater sources in County Meath (Slane, Curragha, Athboy, Dunshaughlin, Dunboyne, Ballivor and Nobber) were selected for detailed investigations and source protection zones were delineated for each source. Accompanying source reports and maps have been produced for the seven sources.

1.2 Objectives and Methodology

This report briefly describes the geology, hydrogeology, aquifers, groundwater quality, and groundwater vulnerability of County Meath, and the groundwater protection scheme proposed for the county. This scheme will assist in the rational planning of future development in County Meath.

The main objective of the project was to collect, compile and assess all the data (geological and hydrogeological) available for the county. The data have been compiled on 1:25,000 scale maps and entered into a computer database. Some additional hydrogeological data were collected, mainly on water quality and aquifer coefficients. Finally a suite of environmental geology maps (1 : 63,360) were produced to accompany this report. These maps are as follows:

Primary Data Maps
- Bedrock Geology Map
- Subsoils Map
- Depth to Bedrock Map
- Hydrogeological Data Map

Derived or Interpretative Maps
- Aquifer Map
- Groundwater Vulnerability Map

Land Use Planning Map
- Groundwater Protection Map

These maps have been produced using all data available to the GSI at the beginning of 1996. Site specific investigations were not conducted for this project, thus the resulting maps are general regional maps and should not be used for site specific work, for which detailed site investigations should be conducted, as required. In areas were information was poor or not available, relevant data from adjacent counties were used.

1.3 Location

County Meath is bounded to the east by the Irish Sea and County Dublin, to the south by Counties Kildare and Offaly, to the west by County Westmeath and on the north by Counties Cavan, Monaghan and Louth. The county comprises an area of 2345 km^2.

1.4 Topography, Surface Hydrology and Land Use

The topography is generally flat to undulating with elevation generally around 60 to 100 metres above sea level, but ranging from 15 metres along the Boyne valley to around 200-300 metres along the tops of ridges (Slieve na Calliagh, north of Slane and north of Moynalty).

The surface water drainage of County Meath is dominated by the River Boyne, which drains more than half the county. The Boyne’s most important tributaries are (downstream of Navan) the Kells Blackwater, Moynalty, Mattock and Devlin rivers, and (upstream of Navan) the Enfield Blackwater, Athboy, Boycetown, Castlejordan, Clady, Deel, Kinnegad, Knightsbrook, Riverstown, Skane, Stonyford, and Yellow rivers. Other significant rivers in Meath are the Dee, Nanny, Inny, Glyde, Liffey, Tolka, Broad Meadow, and Delvin. The catchment divides are shown on Map 1. Several of the rivers also drain adjoining counties.

Agriculture is the dominant land use activity in Meath, particularly livestock farming and tillage.

1.5 Rainfall and Evapotranspiration

The average annual rainfall for Meath is 846mm, based on the 1951-1980 average monthly data provided by Met Eireann. The rainfall is lower along the coast (750mm) and increases in upland areas of the northwest to over 1000mm.

Average potential evapotranspiration (P.E.) for the nearest station, Dublin Airport, is 550mm per year. Potential evapotranspiration for County Meath was estimated from a regional Met Eireann contoured map, and ranges from 500 to 550mm/year. Actual evapotranspiration (A.E.) is estimated as a percentage (95%) of the potential evapotranspiration for the area, as 475 to 522mm/year, to allow for soil moisture deficits during the year.

The effective rainfall (rainfall minus actual evapotranspiration) is taken to be approximately 350mm per year, ranging from 230 mm along the coast to around 500mm in the west of the county.

2. The Groundwater Protection Scheme

– A Means of Preventing Contamination

2.1 Introduction

2.1.1 Groundwater Protection – A Priority Issue for Local Authorities

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

- groundwater is an important source of water supply;
- human activities are posing increasing risks to groundwater quality as there is widespread disposal of domestic, agricultural and industrial effluents to the ground and the volumes of waste are increasing;
- groundwater provides the baseflow to surface water systems, most 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 pollution must be prevented as part of sustainable groundwater quality management.

2.1.2 The Threat to Groundwater

The main threat to groundwater is posed by point contamination sources - farmyard wastes (silage effluent and soiled water mainly), septic tank effluent, sinking streams and to a lesser extent leakages, spillages, pesticides used for non-agricultural purposes and leachate from waste disposal sites (Daly, 1994). Diffuse sources such as fertilizers do not yet seem to be causing significant large-scale contamination problems and are unlikely to cause the same degree of problem in Ireland as in many European countries. However, intensive arable farming and landspreading of piggery and hatchery wastes pose a risk to groundwater in some areas.

2.1.3 Groundwater Protection through Land Use Planning

There are a number of ways of preventing contamination, such as improved well siting, design and construction and better design and management of potential contamination sources. However, one of the most effective ways is utilising groundwater protection schemes as part of the planning process.

Land-use planning, using either planning, environmental impact assessment, integrated pollution control or water pollution legislation, is the main method 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 are an essential means of enabling planning authorities to take account of both geological and hydrogeological factors in locating potentially polluting developments; consequently they are now an essential means of preventing groundwater pollution.

2.1.4 Environmental Principles

As a means of protecting the environment, the following principles are now generally recommended and are part of Irish environmental policy:

- the principle of sustainable development, which is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs";
- the precautionary approach, which means giving preference to risk-averse decisions and avoiding irreversible actions;
- the principle that environmental protection should be an integral part of the development process;
- the "polluter pays" principle, which requires that the environmental cost should be incorporated in any development proposals.

These principles provide the basic philosophy for the groundwater protection scheme proposed for County Limerick. Also, the concept of risk and the requirement to take account of the risk of contamination to groundwater from potentially polluting activities have been integrated into the groundwater protection scheme.

2.1.5 Risk and Risk Management - A Framework for Groundwater Protection Schemes

Risk can be defined as the likelihood or expected frequency of a specified adverse consequence. Applied to groundwater, it expresses the likelihood of contamination arising from potentially polluting sources or activities (called the **hazard**). A Royal Society (London) Study Group (1992) formally defined an **environmental hazard** as “an event, or continuing process, which if realised, will lead to circumstances having the potential to degrade, directly or indirectly, the quality of the environment”. Consequently, a hazard presents a risk when it is likely to affect something of value (the **target**, which in this case is groundwater). It is the combination of the probability of the hazard occurring and its consequences that is the basis of **risk assessment**.

RISK = PROBABILITY OF AN EVENT × CONSEQUENTIAL DAMAGE

There are three key stages in risk analysis: risk **estimation**, risk **evaluation** and risk **management.** These are highlighted by the following questions.

What can go wrong? *Hazard identification and identification of outcomes* How likely is it to go wrong? *Estimation of probability of these outcomes or estimation of vulnerability* What would happen if it did go wrong? *Consequence analysis*	**risk estimation**
Is the risk acceptable and can it be reduced?	**risk evaluation**
What decisions arise from risk estimation and risk evaluation? What control measures are needed to minimise the risk?	**risk management**

Protection, like risk, is a relative concept in the sense that there is an implied degree of protection (absolute protection is not possible). An increasing level of protection is equivalent to reducing the risk of damage to the protected quantity, e.g. groundwater. Moreover, choosing the appropriate level of protection, necessarily involves placing a relative value on the protected quantity.

Groundwater protection schemes are usually based on the concepts of groundwater contamination risk and risk management. In the past, these concepts were in the background, often implicit, sometimes intuitive factors. However, with the language and thought-processes associated with risk and risk assessment becoming more common, relating a groundwater protection scheme to these concepts allows consistent application of a protection policy and encourages a rigorous and systematic approach. The conventional source-pathway-target model for environmental management can be applied to groundwater risk management:

Potential source of contamination → *pathway* → **Target**

or

Hazard → *vulnerability* → **Aquifer or groundwater source**

The GSI uses the following terminology and definitions.

The **risk** of contamination of groundwater depends on three elements:
(i) the **hazard** provided by a potentially polluting activity;
(ii) the **vulnerability** of groundwater to contamination;
(iii) the potential **consequences** of a contamination event.

Risk management is based on analysis of these elements followed by a **response** to the risk. This response includes the assessment and selection of solutions and the **implementation of measures** to prevent or minimise the consequences and probability of a contamination event.

The **hazard** depends on the potential **contaminant loading**. The natural **vulnerability** of the groundwater dictates the **likelihood of contamination** if a contamination event occurs. The **consequences** to the target depend on the **value** of the groundwater, which is normally indicated by the aquifer category (regionally important, locally important or poor) and the proximity to an important groundwater abstraction source (e.g. a public supply well). **Preventive measures** may include: control of land-use practices and in particular directing developments towards lower risk areas; building codes that take account of the vulnerability and value of the groundwater; lining of landfill sites; installation of monitoring networks; specific operational practices. Consequently, assessing the risk of contamination to groundwater is complex. It encompasses geological and hydrogeological factors - (a) the vulnerability to contamination and (b) the relative importance or value of the groundwater resource, - and factors that relate to the potentially polluting activity - (a) the contaminant loading and (b) the preventive measures.

RISK TO GROUNDWATER

↙	↘
HYDROGEOLOGICAL FACTORS	**OTHER FACTORS**
⇩	⇩
(a) VULNERABILITY	**(a) CONTAMINANT LOADING**
(b) GROUNDWATER VALUE	**(b) PREVENTIVE MEASURES**

A conceptual model of the relationship between these factors is given in Figure 2.1, where septic tank effluent is taken as the hazard.

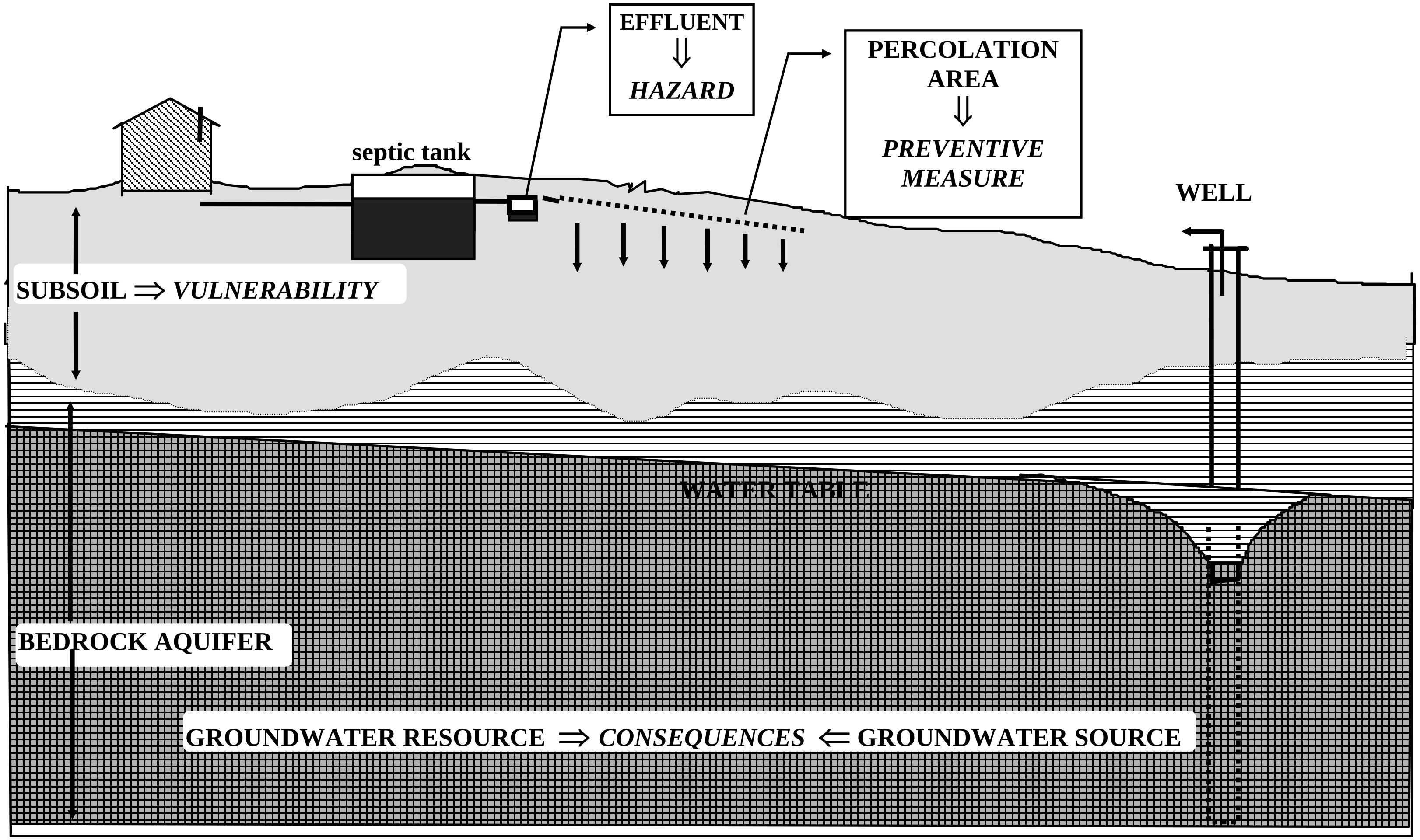


Figure 2.1 A Conceptual Model of the Elements of Risk and Risk Management

The groundwater protection scheme outlined here integrates these factors and in the process serves to focus attention on the higher risk areas and activities, and provides a logical structure within which contaminant control measures can be selected.

Exposure of groundwater to hazard can sometimes be reduced by engineering measures (such as geomembrane liners beneath landfills). However, in most cases, a significant element of the total exposure to hazard will depend on the natural geological and hydrogeological conditions, which define the vulnerability or the sensitivity of the groundwater to contamination. Engineering measures may be required in some situations to reduce the risk further.

2.1.6 Objectives of the Groundwater Protection Scheme

The overall aim of the groundwater protection scheme is to preserve the quality of groundwater, particulary for drinking purposes, 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 provide a logical structure within which contamination control measures can be selected

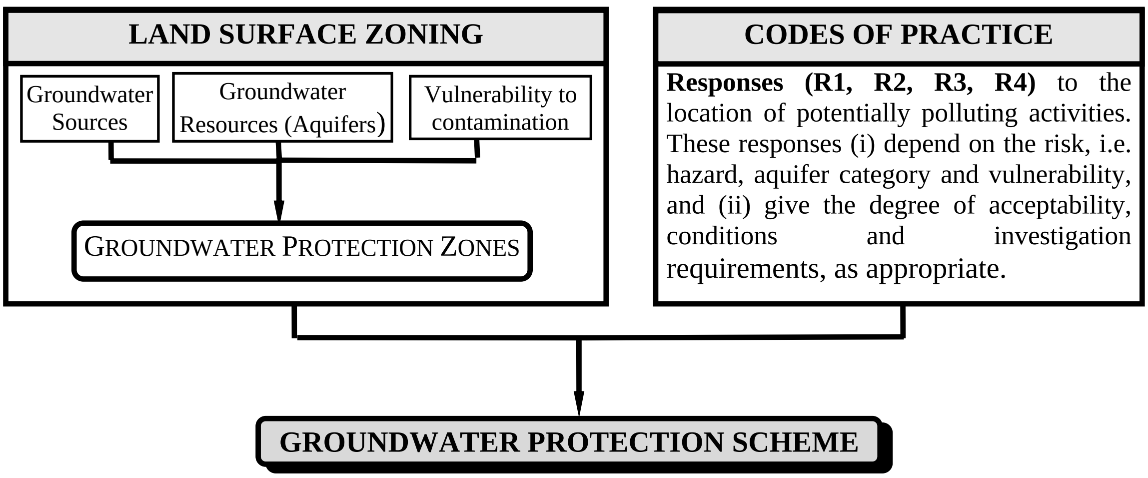
The scheme is not intended to have any statutory authority now or in the future; rather it should provide a framework for decision-making and guidelines for the statutory authorities in carrying out their functions. As groundwater protection decisions are often complex, sometimes requiring detailed geological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

2.2 How A Groundwater Protection Scheme Works

There are **two main components** of the groundwater protection scheme (Figure 2.2):

- **Land surface zoning**, which encompasses the hydrogeological elements of risk**.**
- **Codes of practice for potentially polluting activities** which encompasses both the contaminant loading element of risk and planning/preventative measures as a response to the risk**.**

Figure 2.2. Summary of Components of a Groundwater Protection Scheme



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. The quality and level of sophistication of the land surface zoning map usually depends on the data and resources (time, money and staff) available, and on the degree of hydrogeological analysis used. Delineation of protection zones based on adequate hydrogeological information and analysis is recommended as a defensible basis for planning decisions.

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.
- Delineation of **areas surrounding** individual **groundwater sources** (usually public supply sources); these are termed source protection areas.
- Delineation of areas according to the value of the groundwater resources or **aquifer category**; these are termed resource protection areas.

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

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **code of practice** 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 – maps showing the zones and the control measures – are different, they are incorporated together and closely interlinked in the scheme.

2.3 Land Surface Zoning for Groundwater Protection

2.3.1 Groundwater 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 the time of travel of infiltrating water (and contaminants), on the relative quantity of contaminants that can reach the groundwater and on 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 recharge type - 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 in 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 by the GSI - **extreme**, **high**, **moderate** and **low**. The hydrogeological basis for these categories is summarised in Table 2.1 and further details can be obtained from the GSI. The ratings are not scientifically precise; they are based on pragmatic judgements, experience and limited technical and scientific information. However, provided the limitations are appreciated, vulnerability assessments are an essential element 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 applied below this zone, often at depths of at least 1m.

Table 2.1. Vulnerability Mapping Guidelines

Vulnerability Rating	**Hydrogeological Requirements**				
	Subsoil Permeability (Type) and Thickness			**Unsaturated Zone**	**Recharge Type**
	high permeability (*sand/gravel*)	moderate permeability (*sandy till*)	low permeability (*clayey till, clay, peat*)	(*sand & gravel* aquifers only)	
Extreme	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m	point (<30 m radius)
High	>3.0 m	3.0 - 10.0 m	3.0 - 5.0 m	>3.0 m	diffuse
Moderate	N/A	>10.0 m	5.0 - 10.0	N/A	diffuse
Low	N/A	N/A	>10.0 m	N/A	diffuse

Notes: i) N/A = not applicable.
ii) Precise permeability values cannot be given at present.
iii) Release point of contaminants is assumed to be 1-2 m below ground surface.

(from Daly and Warren, 1997)

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

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 and 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 have not been taken into account.

2.3.2 Groundwater Source Protection Zones

Groundwater sources, particularly public, group scheme and industrial supplies, are of critical importance in any region. Consequently, the objective of source protection zones is to provide an additional element of 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.

2.3.2.1 Delineation of Source Protection Areas

Three source protection areas are recommended for delineation:
- Source Site (**SS**)
- Inner Protection Area (**SI**)
- Outer Protection Area (**SO**), encompassing the source catchment area or zone of contribution.

The orientation, shape and size of the Source Site is based on practical, non-technical considerations.

In delineating the Inner and Outer 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 zone of contribution. Also, the lack of a scientific basis reduces its defensibility as a method.

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

(i) calculated fixed radius
(ii) analytical methods
(iii) hydrogeological mapping
(iv) numerical modelling, using FLOWPATH.

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 <u>guide</u> for decision-making, which can be reappraised in the light of new knowledge or changed circumstances.

2.3.2.2 Source Site (SS)

This is the innermost protection area, which includes the source and usually the operational activities associated with water supply. It should be under the ownership and control of the local authority. The area should be fenced off and the boundaries should be at least 10m from the source. All potentially polluting activities not directly related to the production of drinking water should be prohibited and care should be taken that the operational activities do not cause contamination (e.g. runoff from paved areas, storage of fuel and chemicals).

2.3.2.3 Inner Protection Area (SI)

This zone 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 where conduit flow is dominant, the TOT approach is not applicable, as there are large variations in permeability, high flow velocities and a low level of predictability.

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

2.3.2.4 Outer Protection Area (SO)

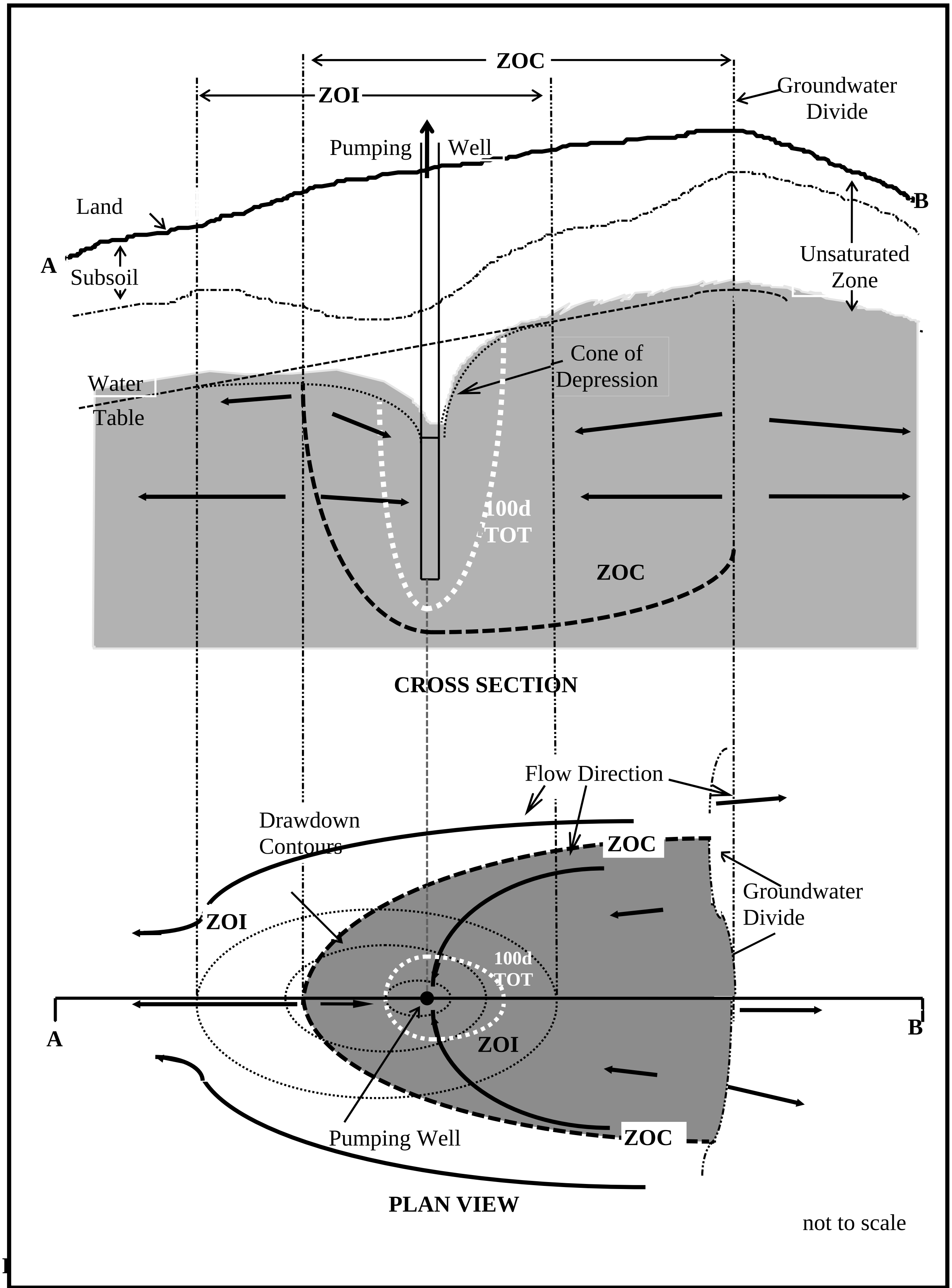
This zone covers the zone of contribution (ZOC) (or complete catchment area) of the groundwater source. It is defined as the area needed to support an abstraction from long-term groundwater recharge (the proportion of effective rainfall that infiltrates to the water table). The abstraction rate used in delineating the zone will depend on the views of the source owner. The GSI currently increases the maximum daily abstraction rate 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 20° variation in the flow direction is frequently included as a safety margin in delineating the ZOC. A conceptual model of the ZOC (or outer protection area) and the 100-day TOT boundary (or inner protection area) is given in Figure 2.3.

If the arbitrary fixed radius method is used, a distance of 1000m is chosen 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 (SI), 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.

2.3.2.5 Delineation of Source Protection Zones

The matrix in Table 2.2 below gives the result of integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 12 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. All of the hydrogeological settings represented by the zones may not be present around each local authority source.



I

Influence (ZOI)

(adapted from U.S. EPA, 1987)

Table 2.2. Matrix of Source Protection Zones

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

2.3.3 Groundwater Resource Protection Zones

For any region, the area outside the source protection areas can be subdivided, based on the value of the resource and the hydrogeological characteristics, into eight resource protection areas.

Regionally Important (R) Aquifers

(i) Karstified aquifers (where conduit flow is dominant) (**Rc**)
(ii) Fissured bedrock aquifers (**Rf**)
(iii) Extensive sand/gravel **(Rg)**

Locally Important (L) Aquifers

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

Poor (P) Aquifers

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

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

The matrix in Table 2.3 below 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.

Table 2.3. Matrix of Groundwater Resource Protection Zones

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

2.4 Groundwater Protection Response Matrices

The **Groundwater Protection Response Matrices** set out the recommended response to a certain type of development. The level of response depends on the different elements of risk - the vulnerability, the value of the groundwater (with sources being more valuable then 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 response matrices do not necessarily restrict development, but are a means of ensuring that good environmental practices are followed.

Four levels of response (**R**) to the risk of a potentially polluting activity are recommended for the Irish situation:

R1 Acceptable subject to normal good practice.

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

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

R4 Not acceptable

2.5 Integration of Groundwater Protection Zones and Response Matrices

The integration of the groundwater protection zones and the response matrix is the final stage in the production of the groundwater protection scheme. The approach is illustrated for a hypothetical potentially polluting activity in the matrix in Table 2.4 below:

Table 2.4. Groundwater Protection Scheme Matrix for Activity X

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

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

The matrix encompasses both the geological/hydrogeological and the contaminant loading aspects of risk assessment. In general, the arrows (→ ↓) indicate directions of decreasing risk, with the ↓ arrow showing the decreasing **likelihood of contamination** and the → arrow 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.

In deciding on the response decision, it is useful to differentiate between potentially polluting developments that already exist prior to implementation of a groundwater protection scheme and proposed new activities. For existing developments, the first step is to carry out a survey of the area and prepare an inventory. This is followed by site inspections in high risk situations, and monitoring and operational modifications, perhaps even closure, as deemed necessary. New potential sources of contamination can be controlled at the planning stage. In all cases the control measures and response category depend on the potential contaminant loading, the groundwater vulnerability and the groundwater value.

Decisions on the response category and the code of practice for potentially polluting developments are the responsibility of the statutory authorities, in particular, the local authorities and the EPA; although it is advisable that the decisions should follow from a multi-disciplinary assessment process involving hydrogeologists.

At present, codes of practice have not been completed for any potentially polluting activity. Draft codes have been produced for landfills, septic tank systems and landspreading of agricultural wastes; only the landfill code of practice is readily available (from the EPA). Preparation of codes of practice requires the involvement and, in most instances, the agreement of the local authority. As a means of illustrating the use of the scheme and the relationship between the groundwater protection zones and the codes of practice, draft codes of practice are given in the following sectioins

2.6 Draft Response Matrix for Landfills

Table 2.5 gives a Response Matrix for landfills (from EPA, 1996) and this is followed by the specific responses to the proposed location of a landfill in each groundwater protection zone.

Table 2.5. Groundwater Protection Scheme Matrix for Landfills

VULNERABILITY RATING	SOURCE PROTECTION			RESOURCE PROTECTION						
				Regionally Imp.		Locally Imp.		Poor Aquifers		
	Site	*Inner*	*Outer*	*Rc*	*Rf/Rg*	*Lm/Lg*	*Ll*	*Pl*	*Pu*	
Extreme (E)	R4	R4	R4	R4	R4	R4	R2[4]	R2[4]	R2[2]	↓
High (H)	R4	R4	R4	R4	R4	R3[2]	R2[4]	R2[4]	R2[2]	↓
Moderate (M)	R4	R4	R4	R4	R3[2]	R2[5]	R2[3]	R2[3]	R2[1]	↓
Low (L)	R4	R4	R3[1]	R3[1]	R3[1]	R2[1]	R2[1]	R2[1]	R2[1]	↓
	→	→	→	→	→	→	→	→	→	

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

- To reduce the risk to groundwater, it is recommended that landfills taking domestic/municipal waste be located in, or as near as possible, to the zone in the bottom right hand corner of the matrix.
- The engineering measures used must be consistent with the requirements of the national licensing authority (EPA).
- Landfills will normally only be permitted as outlined below.

R2[1] Acceptable.
Engineering measures may be necessary to provide adequate containment.
Engineering measures are likely to be necessary in order to protect surface water.

R2[2] Acceptable.
Engineering measures are likely to be necessary to provide adequate containment.
There may not be a sufficient thickness of subsoil on-site for cover material and bunds.

$R2^{3}$ Acceptable.
Engineering measures are likely to be necessary to provide adequate containment.
Special attention should be given to checking for the presence of high permeability zones.

$R2^{4}$ Acceptable.
Engineering measures are likely to be necessary to provide adequate containment.
Special attention should be given to checking for the presence of high permeability zones. If such zones are present, the landfill should not be allowed unless special precautions are taken to minimise the risk of leachate movement in the zones and unless the risk of contamination of existing sources is low. Also, the location of future wells down-gradient of the site in these zones should be discouraged.
There may not be a sufficient thickness of subsoil on-site for cover material and bunds.

$R2^{5}$ Acceptable.
Engineering measures are likely to be necessary to provide adequate containment.
Special attention should be given to existing wells down-gradient of the site and of the projected future development of the aquifer.

$R3^{1}$ Not generally acceptable, unless it can be shown that:
(i) the groundwater in the aquifer is confined, or
(ii) it is not practicable to find a site in a lower risk area.

$R3^{2}$ Not generally acceptable, unless it is not practicable to find a site in a lower risk area.

R4 Not acceptable.

Landfills on or near regionally important (major) aquifers should only be considered where no reasonable alternative can be found, and in the following instances:
- ♦ Where the hydraulic gradient (relative to the leachate level at the base of the landfill) is upwards for a substantial proportion of each year (confined aquifer situation).
- ♦ Where a map showing a regionally important (major) aquifer includes low permeability zones or units which cannot be delineated using existing geological and hydrogeological information but which can be found by site investigations. Location of a landfill site on such a unit may be acceptable provided leakage to the permeable zones or units is insignificant.
- ♦ Where the waste is classified as inert and waste acceptance procedures are employed in accordance with the proposal for an EU Directive on Landfill of Waste.

2.7 Draft Response Matrix for Septic Tank Systems

Table 2.6 gives a draft Response Matrix for septic tank systems and Table 2.7 gives the specific responses to the proposed location of a septic tank system in each groundwater protection zone.

Table 2.6. Draft Groundwater Protection Scheme Matrix for Septic Tank Systems

VULNERABILITY RATING	SOURCE PROTECTION			RESOURCE PROTECTION						
				Regionally Imp		Locally Imp.		Poor Aquifers		
	Site	*Inner*	*Outer*	*Rc*	*Rf/Rg*	*Lm/Lg*	*Ll*	*Pl*	*Pu*	
Extreme (E)	**R4**	**$R3^{1}$**	**$R3^{3}$**	**$R3^{3}$**	**$R2^{2}$**	**$R2^{2}$**	**$R2^{1}$**	**$R2^{1}$**	**$R2^{1}$**	↓
High (H)	**R4**	**$R3^{2}$**	**$R2^{7}$**	**$R2^{4}$**	**R1**	**R1**	**R1**	**R1**	**R1**	↓
Moderate (M)	**R4**	**$R2^{9}$**	**$R2^{6}$**	**$R2^{3}$**	**R1**	**R1**	**R1**	**R1**	**R1**	↓
Low (L)	**R4**	**$R2^{8}$**	**$R2^{5}$**	**$R2^{3}$**	**R1**	**R1**	**R1**	**R1**	**R1**	↓
	→	→	→	→	→	→	→	→	→	

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

2.8 Information and Mapping Requirements for Land Surface Zoning

The **groundwater resources protection zone map** is the regional land-use planning map, and therefore is the critical and most useful map for the County Council. It is the ultimate or final map as it is obtained by combining the **aquifer** and **vulnerability maps.** The **aquifer map** boundaries, in turn, are based on the **bedrock map** boundaries and the **aquifer categories** are obtained from an assessment of the available **hydrogeological data**. The **vulnerability map** is based on the **subsoils map**, together with an assessment of relevant **hydrogeological data**, in particular indications of permeability and karstification. This is illustrated in Figure 2.4.

Similarily, the **source protection zone maps** result from combining **vulnerability** and **source protection area maps**. The **source protection areas** are based largely on assessments of **hydrogeological data**, but are usually influenced by the **geolog**y. This is illustrated in Figure 2.5.

The conceptual frameworks for groundwater resource and source protection shown in Figures 2.4 and 2.5 provide the structure for the remainder of this report:
- ♦ Chapter 3 Bedrock geology
- ♦ Chapter 4 Subsoils geology
- ♦ Chapter 5 Hydrogeology and aquifer classification
- ♦ Chapter 6 Hydrochemistry and water quality
- ♦ Chapter 7 Groundwater vulnerability
- ♦ Chapter 8 Groundwater protection

2.9 Flexibility, Limitations and Uncertainty

The Groundwater Protection Scheme is only as good as the information which is used in its compilation - geological mapping, hydrogeological assessment, etc. - and these are subject to revision as new information is produced. Therefore the scheme must be flexible and allow for regular revision.

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Also, where site specific data received by the County Council in the future are at variance with the maps, this does not undermine the scheme, but rather provides an opportunity to improve the scheme. In essence a Groundwater Protection Scheme is a tool which helps Council officials to respond to relevant development proposals and is a means of showing that the County Council is undertaking its responsibility for preventing groundwater contamination in a practical and reasonable manner.

2.10 Conclusions

- ♦ Groundwater protection schemes are an essential means of enabling local authorities 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, they are now an essential means of preventing groundwater contamination.

- ♦ If planning decisions based on a groundwater protection scheme are to be readily defensible, it is important that the scheme should be founded on hydrogeological concepts and on a sufficient degree of geological and hydrogeological information.

- ♦ Groundwater protection schemes should not be seen as a panacea for solving all groundwater contamination problems. In practice their use needs a realistic and flexible approach. The maps have limitations because they generalise (with the degree of generalisation depending on data availability) variable and complex geological and hydrogeological conditions. Consequently, the proposed scheme is not prescriptive and needs to be qualified by site-specific considerations and investigations. 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 scheme has the following benefits and uses:

- it provides a hierarchy of levels of risk and, in the process, assists in setting priorities for technical resources and investigations;
- it contributes to the search for a balance of interests between groundwater protection issues and other special and economic factors;
- it can be adapted to include risk to surface water;
- 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;
- by controlling developments and enabling the location of certain potentially hazardous activities in lower risk areas, it helps ensure that the pollution acts are not contravened;
- it can be used in preparing Emergency Plans, assessing environmental impact statements and the implications of EU directives, planning and undertaking groundwater monitoring networks and in locating water supplies.

♦ The groundwater protection scheme outlined in this report will be a valuable tool and a practical means in helping to achieve the objective of <u>sustainable</u> water quality management, as required by national and EU policies. Effective use of the scheme achieves this objective because it provides:

- geological and hydrogeological information and knowledge as a basis for decision-making and land-use planning;
- a framework and policy which enables groundwater to be protected from the impacts of human activities;
- codes of practice for the location and control of potentially polluting activities.

Table 2.7. Responses to the Proposed Location of a Septic Tank System

(draft, subject to change)

Response Code	Acceptability, Conditions or Exceptions
R1	**Acceptable**, subject to normal good practice (i.e. compliance with S.R.6 : 1991).
$R2^1$	**Probably acceptable**, subject to compliance with S.R.6:1991. Particular attention should be given to the depth of subsoil in situations where there are nearby wells and springs.
$R2^2$	**Probably acceptable**, subject to compliance with S.R.6:1991. Special attention should be given to the depth of subsoil over bedrock and to the thickness of the unsaturated zone in free-draining areas.
$R2^3$	**Probably acceptable**, subject to compliance with S.R.6:1991. Special attention should be give to the location of karst features, such as swallow holes and collapse features. Percolation areas should not be located within 15 m of such features.
$R2^4$	**Probably acceptable**, subject to compliance with S.R.6:1991. Particular attention should be given to (i) the depth of subsoil over bedrock, (ii) in free-draining areas, the thickness of the unsaturated zone, (iii) Percolation areas should not be located within 15 m of karst features.
$R2^5$	**Probably acceptable**, subject to: (i) compliance with S.R.6:1991, and (ii) provision of evidence *(e.g. from nearby wells)* on the type and depth of subsoil to confirm that the site is not in a higher risk zone that precludes the location of septic tank systems.
$R2^6$	**Probably acceptable**, subject to: (i) compliance with S.R.6:1991; (ii) provision of evidence *(e.g. from nearby wells)* on the type and depth of subsoil to confirm that the site is not in a higher risk zone; (iii) taking account of the number of existing houses so that the problem of significant contamination by nitrate does not arise.
$R2^7$	**Probably acceptable**, subject to: (i) compliance with S.R.6:1991; (ii) provision of evidence *(e.g. from nearby wells)* on the type and depth of subsoil to confirm that the site is not in a higher risk zone; (iii) taking account of the number of existing houses so that the problem of significant contamination by nitrate does not arise. Engineered preventive measures, such as on-site treatment systems, may be advisable to reduce the risks in some situations (*for instance, where the site is close to the limits of the zone – close to extreme vulnerability or the SI zone boundary*).
$R2^8$	**Probably acceptable**, subject to: (i) compliance with S.R.6:1991; (ii) provision of evidence *(e.g. from nearby wells)* on the type and depth of subsoil to confirm that the site is not in a higher risk zone; (iii) that surface ponding of effluent and/or shallow contaminated groundwater does not pose a significant risk to the source (*this would apply particularly where the site is up-gradient of the source and/or the well casing has not been grouted and sealed*).
$R2^9$	**Probably acceptable**, subject to: (i) compliance with S.R.6:1991; (ii) provision of evidence *(e.g. from nearby wells)* on the type and depth of subsoil to confirm that the site is not in a higher risk zone; (iii) taking account of the number of existing houses so that the problem of significant contamination by nitrate does not arise; (iv) an assessment that surface ponding of effluent and/or shallow contaminated groundwater does not pose a significant risk to the source (*this would apply particularly where the site is up-gradient of the source and/or the well casing has not been grouted and sealed*).
$R3^1$	**Not generally acceptable**, unless it is shown by investigation and assessment that the risk to groundwater is reduced by the hydrogeological situation at the site (e.g. *if the site is in a lower risk zone where septic tank systems are acceptable subject to compliance with S.R.6:1991). (On-site treatment systems should not be seen as an alternative.)*
$R3^2$	**Not generally acceptable**, unless it is shown by investigation and assessment that the risk to groundwater is reduced by the hydrogeological situation at the site *(e.g. if the site is in a lower risk zone or the subsoil thickness is substantially greater than 3 m or, in the case of sands/gravels, the unsaturated zone is substantially greater than 3 m*) or alternatively can be significantly reduced by the use of engineered preventive measures, such as on-site treatment systems. Compliance with S.R.6:1991 or appropriate Agrement Certificate is essential.
$R3^3$	**Not generally acceptable**, unless it is shown by investigation and assessment that the risk to groundwater is reduced by the hydrogeological situation at the site *(e.g. if the site is in a lower risk zone*) or alternatively can be significantly reduced by the use of engineered preventive measures, such as on-site treatment systems. Compliance with S.R.6:1991 or appropriate Agrement Certificate is essential.
R4	Not acceptable

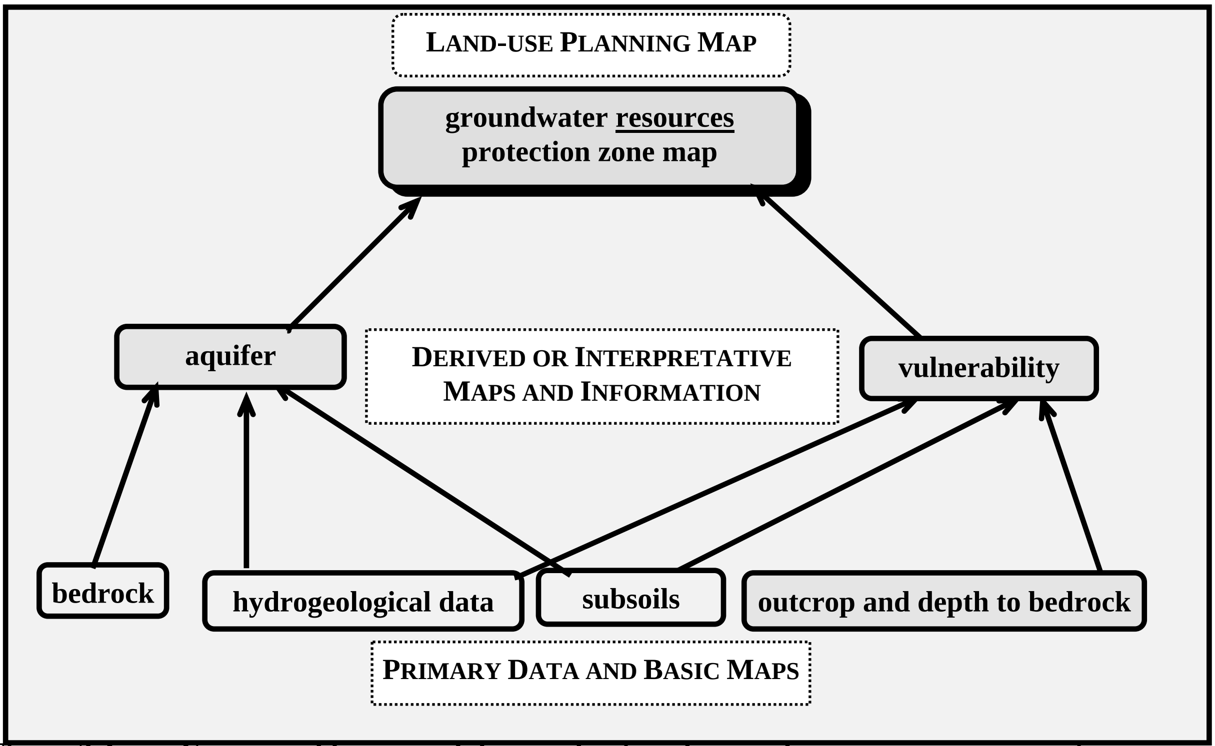


Figure 2.4 Conceptual framework for production of groundwater resource protection zones

(indicating information needs and links)

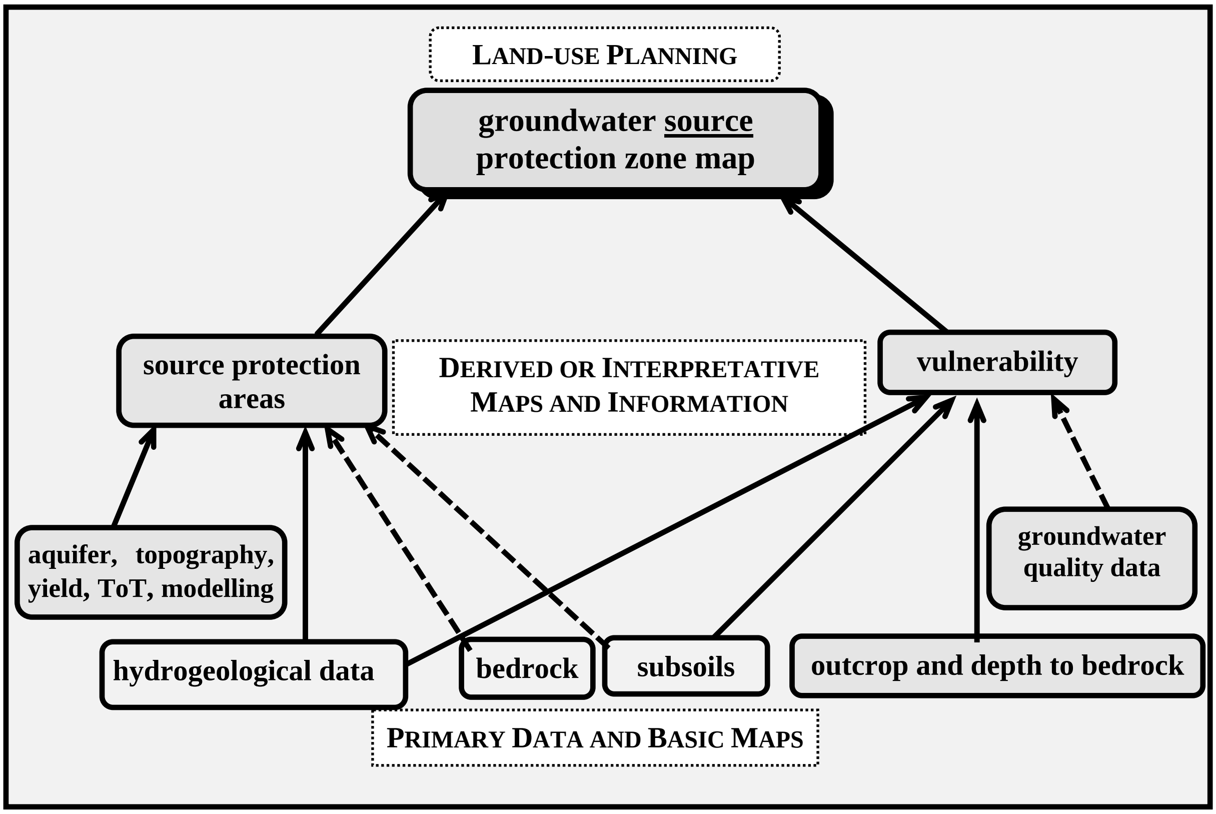


Figure 2.5 Conceptual framework for production of groundwater source protection zones

(indicating information needs and links)

3. Bedrock Geology

3.1 Introduction

The bedrock geology of County Meath is comprised of rocks that range in age from the Lower Palaeozoic to the Mesozoic (500 to 205 million years old). The rocks can be divided into four main groups: Ordovician and Silurian shales, greywackes and volcanics; Lower Carboniferous limestones and shales; Upper Carboniferous (Namurian) sandstones and shales; and Permian/Triassic sandstones.

South Meath consists of an accumulation of Lower Carboniferous deep water muddy limestones, an extension of the Dublin Basin. This basin is bounded to the north by older Lower Palaeozoic rocks of the Longford-Down Inlier and to the east by the Balbriggan Inlier. Shallow water clean limestones of equivalent age are found south of Drogheda and around Lough Sheelin.

In the north of Meath, the Kingscourt Outlier is a smaller Basin/Platform consisting of Lower Carboniferous shallow water limestones and clastic rocks. The Kingcourt Outlier, like the Dublin Basin, rests unconformably on the surrounding Lower Palaeozoic rocks. Upper Carboniferous rocks of Namurian age are found overlying these limestones south of Kingscourt, around Summerhill, Trim and Slane.

The youngest rocks in Meath are Permian and Triassic sandstones, which are found around Kingscourt and rest unconformably on the Namurian.

As a result of limited bedrock outcrop in many areas, the geological boundaries are uncertain, in particular the boundary between the Lower Palaeozoic and the Carboniferous rocks. The orientations of many of the faults are also speculative/conceptual and this must be remembered when interpreting the Geology and Aquifer maps.

The bedrock geology is presented in Map 2 (E & W). A brief summary of the bedrock geology is given below, in conventional geological order, i.e. beginning with the oldest rocks. The formal geological formation names have been used, to facilitate comparison with the GSI bedrock maps (Sheets 13 and 16).

3.2 Lower Palaeozoic Rocks

The oldest rocks in Co. Meath are Ordovician and Silurian in age (500 - 410 million years) and belong to the Lower Palaeozoic era. These rocks occur in the Longford-Down Inlier, northeast from Slane - Newtown, Navan - Castletown, and in the northwest around Kells, Slieve na Calliagh, Moynalty and to the west of Kilmainhamwood. The second main area is to the east, the Balbriggan Inlier around Gormanstown, Bellewstown and Ardcath.

The Lower Palaeozoic rocks represent a complex geological history and comprise a wide range of rock types including greywackes (turbidites), volcaniclastic sediments, lavas, shales, mudstones and cherts. During the Ordovician the Iapetus Ocean began to close and volcanoes formed adjacent to the continental margins, giving rise to a complex suite of volcanic and deep water sediments. During the Devonian to early Carboniferous periods the two continents collided and the accumulated sediments were squeezed up to form a chain of mountains (Caledonian Orogeny). The Navan-Silvermines Fault is thought to represent the Iapetus Suture along which the two continents collided.

These rocks are highly folded and faulted by several phases of deformation. The rocks have also been metamorphosed on a regional scale transforming the original shales and sandstones and giving the rocks their pervasive fabric or cleavage which allows these rocks to be instantly recognisable.

The Lower Palaeozoic rocks in northwest Meath have not been comprehensively mapped since the last century. They are predominantly grey to green, thin bedded to massive greywackes and shales and are undifferentiated on the Geology map.

The Lower Palaeozoic rocks of the Longford-Down Inlier have been divided into several blocks or tracts (Vaughan 1991), usually separated by faults. The Silurian blocks are Clontail Tract, Salterstown Tract and Rathkenny Tract north of the suture and the Clogherhead Tract south of the suture. The Ordovician is divided into 3 groups, Mellifont Abbey Group, Grangegeeth Group and Slane Group.

In the Balbriggan Inlier (Murphy 1984) the Silurian in the northern sector is divided into 3 formations: Kennetstown Formation, Clatterstown Formation and Denhamstown Formation.

The Ordovician rocks are classified into three formations in the north: Carnes Formation, Hilltown Formation, Prioryland Formation, and three in the southern sector: Clashford House Formation, Herbertstown Formation and Fourknocks Formation.

Table 1 gives brief descriptions of the Ordovician, Silurian and Devonian rocks, taken from PhD. theses by Vaughan (1991) and Murphy (1984).

3.3 Lower Carboniferous

During the Lower Carboniferous there occurred a transgression of the sea which resulted in the deposition of limestones. These rocks lie unconformably upon the Lower Palaeozoic rocks. Deposition was very complex with local variations whose lack of lateral continuity has resulted in many local stratigraphical units.

3.3.1 Basal Clastics (Red Beds)

The Lower Palaeozoic rocks on the northern side of Slieve na Calliagh are unconformably overlain by a variable thickness (0-5m) of Red Beds. These consist of red sandstones, siltstones and mudstones with conglomerates. On the Geology Map these rocks are not differentiated from the Navan Beds except near Slieve na Calliagh.

3.3.2 Navan Group

The Navan Group comprises: the Red Beds, the Mixed Beds, the Pale Beds and the Shaly Pales (Philcox 1984), which are not differentiated on the Geology Map.

The Red Beds (fluviatile or alluvial plain) form the basal unit (up to 45m) consisting of red clastics which fine upwards from coarse grits and conglomerates to laminated sandstones and siltstones.

The Mixed Beds comprise the Laminated Beds (dark laminated siltstones, mudstones and shales, which are partially marine) and the Muddy Limestone (dark fine grained, well bedded argillaceous and crinoidal limestone, indicating a rapid transition from periodically clastic to fully marine carbonate sedimentation.)

The Pale Beds (200m) comprised pale to grey argillaceous carbonate-cemented sandstones, silts and shales with pelletal, oolitic and bioclastic calcarenites. The Stackallan Member (60-100m), a pale to dark grey, generally massive fine grained micritic limestone, defines the base of the Pale Beds. The uppermost 0-8m of the unit is often dolomitised and recrystallised.

The Shaly Pales (100-110m) consist of bioclastic sandstones, shales and siltstones; grey sandstones and calcarenites and dark shales.

In the Kingscourt area the Rockfield Sandstone Member (maximum 70m thick) occurs at the base of the Shaly Pales, and is a fairly uniform medium to coarse grained sandstone with some muddy sandstone with thin shales. Above the Rockfield Sandstone are sandy bioclastic limestones.

3.3.3 Argillaceous Bioclastic Limestone (ABL)

The ABL (250-280m) comprises dark grey, well bedded, strongly crinoidal shaly limestones and mudstones, which become increasingly crinoidal and paler upwards.

3.3.4 Waulsortian Reef Limestone

The Waulsortian Limestone (50-200m) comprises massive pale grey biomicrites formed as mounds of calcareous mud in deep to moderate water depths.

In northwest Meath near Oldcastle the limestone sequence is much thinner (Brand & Emo 1985) and the Waulsortian is absent.

In the Kingscourt area the equivalent to the Waulsortian is the Kilbride Limestone which is thickly bedded, coarse grained crinoidal limestone with thin shale partings. On the Geology Map the Kilbride Limestone is included in the ABL.

At Navan the ABL and the Waulsortian are absent due to erosion. Overlying the erosion surface is a Boulder Conglomerate 50m thick at the base of the Calp. The Tobercolleen Limestone is also absent from the Navan area.

3.3.5 Tobercolleen Limestone

The Tobercolleen (or lower Calp basin limestone) is deep basinal, (85m thick) predominantly (>90%) black, terrigenous mudstone and calcareous shales and often bioturbated.

3.3.6 Calp Limestone

These are basinal sediments consisting of dark grey, fine grained, graded limestones (bioclastic calcarenites), interbedded with black calcareous mudstones and shales. The thickness of the limestone beds, grain size, colour and the proportion of shale vary widely. Towards the top of the Calp the basinal limestones are often interbedded with shallower water oolites or graded crinoidal calcarenites and calcirudites of turbiditic origin, which become more frequent towards the basin margins. Occasional thin sandy limestones can also be encountered. Lateral variations occur within the Calp Limestone between basin-edge successions and its finer-grained basin-centre equivalents.

3.3.7 Derravaragh Limestone

These limestones are a lithological variation of the Calp Limestone and are silicified thick bedded limestones, with chert nodules and shaly layers. South of Slieve na Calliagh the Calp Limestone is overlain by or passes into the Derravaragh Limestone (Personal Communication, D. Smith, GSI).

3.3.8 Shallow Water Limestone

Shelves of clean limestone occur in the extreme north (Kingscourt) and east (Lower Boyne Valley and Naul) areas. North of Slieve na Calliagh shallower and coarser, cleaner, turbiditic limestones also occur. These shallow water limestones are laterally equivalent to the deep water Calp Limestone.

These platform limestones are over 850 m thick and comprise four formations (not differentiated on the Geology Map):

The Crufty Formation (maximum 60m thick) includes intertidal and shallow subtidal micrites, sandstones shales and peloidal packstones. In some places it is extensively dolomitised.

The Holmpatrick Formation (maximum 480m thick) is dominated by coarse grained crinoidal limestones and is heavily dolomitised.

The Mullaghfin Formation (maximum 80m thick) is similar to the Holmpatrick Formation but has horizons of micritic limestone and mudbanks. Evidence exists for some palaeokarstic features *(Bridge Farm quarry, Nobber and Barley Hill quarry, Ardagh).*

The Deer Park Formation (maximum 100m thick) consists of medium grey, thickly bedded crinoidal limestones, dark grey to black, cherty thinly bedded argillaceous wackestone and packstones and massive pale grey, crinoidal limestones (P. Strogen *et al* 1995).

These limestones also occur south of Drogheda (Pickard *et al* 1992 & 1994) and platform sedimentation occurred across the lower Boyne Valley. They are overlain by basinal limestones and shales of the Calp. The basal part of the Calp consists of coarse conglomerates and graded calcarenites which fine upwards, to be succeeded by shale-dominated limestones.

3.3.9 Edenderry Limestone

These limestones are a lithological variation of the platform limestones which formed on high energy shallow water shelves. They are poorly bedded, medium to coarse grained oolitic (spherical grains) limestones. Some of the oolites appear to have been transported away from the shelf edge, which may explain their occurrence within the Calp at Castlerickard Bridge, near Longwood.

3.4 Namurian

The conformable Namurian shales and sandstones (Pro-Delta environment) occur around Summerhill, SE of Slane, near Trim and in the Kingscourt area. There is an almost complete succession of Namurian rocks in the Kingscourt Outlier, but the younger sandstones are not preserved elsewhere in Meath.

The Summerhill Syncline (Nevill, 1957) is divided into the Lower Shale Series (600 m of alternating dark thinly bedded shales and black argillaceous limestones, some graded greywackes and occasional thin sandstone beds), the Upper Black Shale Series (approximately 75 m of soft black shales) and the Moynalvy Sandstone Beds (approximately 90 m of fine grained olive green sandstones occurring around Garadice, Moynalvy and Woodtown). These are not differentiated on the Geology Map.

South of Slane the Namurian is dominated by shales.

In the Kingscourt area the Namurian consists of up to 500m of alternating, thick shale-dominated units, and thick sandstone-dominated units, each named and dated (Jackson 1965) which are not differentiated on the Geology Map:

The Ardagh Shale (80 metres of black shales with clay ironstone nodules) and the Ardagh Sandstone, (70 metres of massive micaceous sandstones with sandy shales). These sandstones are seen in two swallow holes (near Barley Hill House) at the junction with the underlying shales and Visean limestone).

The Barley Hill Grits include the Carrickleck Sandstone (60 metres of buff coloured and often pebbly sandstone, highly weathered and friable; the sandstone thins northwards), and the Carrickleck Shale (85 metres). Above the Carrickleck Shale are two more sandstones separated by shale (25metres in all) with a dolerite sill (Barley Hill Sill, 3 metres thick) near the base.

The Rathe Sandstones, Clontrain Grit (generally white in colour) the Corratober Grits and Shales, Corratober Brick-Shale, Corrybracken Sandstones and the Cabra Sandstones and Shales all have alternating sequences of white, grey and red sandstones or siltstones, with grey to black shales, carbonaceous shales, clay ironstone bands and thin traces of coal seams (Jackson 1965).

3.5 Permian

These rocks are limited to the Kingscourt area and lie unconformably upon the Upper Carboniferous. These terrestrial desert sediments are generally red due to iron oxidation under tropical conditions. The basal Permian rocks are latterly impersistent and typically 90 metres thick. The Upper Permian rocks of the Kingscourt Gypsum Formation (Visscher 1971) consist of:

Basal Conglomerate Member, (absent in the east), 0-18m thick, with a gypsum matrix

Lower Mudstone Member, 2-25m of grey mudstones, shales and laminated siltstones occasionally calcareous

Lower Gypsum Member, 20-35m of shales and evaporites including Gypsum; the gypsum is white or grey and forms massive beds near the top of the sequence

Middle Mudstone Member, 6-12m of micaceous red shales

Upper Gypsum Member, 6-10m of red mudstones with massive pink gypsum beds and red siltstones

Upper Mudstone Member, 26-35m of red mudstones and clays with gypsum lenses over a metre thick at the top

3.6 Triassic

The Permian rocks are succeeded conformably by at least 500 metres of Triassic red bed sequences of the Kingscourt Sandstone Formation (Visscher 1971) which is comprised of four Members: the basal Siltstone Member (80-100m) with alternating siltstones and fine sandstones, and the Lower (70-100m), Middle (2-30m),and Upper (>270m) sandstone members of fine red sandstones with laminations. In all members red is the dominant colour although green and grey bands occur, and individual sandstone beds are thick. The sandstones are uniform in grain size with only occasional coarser or shaly units. The four members are not differentiated on the Geology Map.

4. Quaternary (Subsoils) Geology

4.1 The Quaternary Period

The Quaternary Period is the most recent period of geological time, generally taken to cover the last 1.65 million years. It is subdivided into two epochs which are the Pleistocene (1.65 million to 10,000 years ago) and the Holocene (10,000 years ago to the present). The Holocene, in Ireland, is the post-glacial period. Most of the subsoil sediments in Ireland were deposited during the last 130,000 years.

Quaternary sediments differ from earlier sediments in being generally unlithified. Most Quaternary sediments owe their genesis in one way or another to the action or melting of ice. Ireland was covered by ice for long periods in the last 130,000 years, just as many high latitude regions are nowadays. The last glaciation occurred between 63,000 years ago and 10,000 years ago, and had a huge influence on both the landscape and the underlying geology of the country. Since 10,000 years ago the action of modern rivers and the infilling of lakes, along with the formation of peat bogs, have been the main natural processes affecting both our landscape and geology.

4.2 Glaciation In Ireland

There is direct evidence in Ireland of no more than two glacial periods. There may have been others, but the destructive power of ice sheets has removed any earlier evidence. Ireland has, though, a very rich legacy of glacial deposits and landforms relating to the most recent glaciation. Over 90% of Ireland is covered by deposits from this period.

The most recent glaciation lasted for about 63,000 years and ended only 10,000 years ago, when our climate warmed again. The maximum extent of the ice occurred sometime between 20,000 and 22,000 years ago, when it covered the whole country apart from a limited area in the southwest around west Limerick and north Kerry. In other areas only the highest mountain peaks stuck up above the ice. This ice was moving all the time, under its own weight, rather like wet concrete.

As ice moves, pieces of rock and soil over which it flows become attached to its base, and may become incorporated into the lower layers of the ice, making the base of the ice very abrasive. It can then rapidly erode the underlying material. In this way the substrate is eroded, picked up and transported by the ice. When the ice melts, the material is deposited as one of the many landforms caused by glacial ice. Thus rocks can be carried far away from their source and left as ‘erratics’, either at the surface or incorporated into the subsoil.

4.3 Glacial Deposits in County Meath

Many of the Quaternary deposits in County Meath were laid down during the last glaciation affecting Ireland. County Meath was completely smothered by the ice sheet, which moved in a general southeasterly direction. The deposits remaining from this glaciation are varied in their sedimentology and their landforms. County Meath has a very varied suite of landforms which, together with their sedimentology, gives hints as to the events which took place during the last glaciation in the county.

Eight main genetic types of sediment were recognised during the Quaternary mapping:

- tills
- esker sands and gravels
- alluvium
- head
- glacio-fluvial sands and gravels
- glacio-lacustrine deposits
- peat
- marine deposits

Bedrock at or close to the surface, was also mapped.

Till (commonly 'Boulder Clay') is sediment deposited by or from glacier ice, which is the principal depositional agent, but gravity and, in some cases, water, also play a part. Tills are often overconsolidated, or tightly packed, unsorted, unbedded, include many different particle and clast (stone) sizes, and commonly have sharp, angular clasts. On the GSI's 1:25,000 maps tills are categorised according to their dominant lithological component, e.g. Lower Carboniferous limestone till or Lower Palaeozoic shale till. The texture of the till must be taken into account, as this determines its permeability. Thus tills may be described as gravelly, sandy, silty or clayey till.

Within different till types, a wide variety of permeabilities are possible. In this project, generalisations were made to classify the tills as stony, bouldery, gravelly, sandy, silty, clayey, etc. On the maps fourteen different till textures have been recorded. Those examined in the field only, *i.e.* that were not sampled and sieved, were classified according to the dominant particle size observed (surrounding drainage was also taken into account). Most were recorded as stony, gravelly, sandy, silty or clayey, and only in cases where a bi-modal particle size distribution was extremely obvious were they given a dual label *i.e.* stony sandy till, gravelly clayey till. Where exposure was exceptionally poor the till was classified as 'undifferentiated'. Those labelled in the field and those that were sampled and sieved were classified thus:

- Undifferentiated: Applied to deposits observed only in the field, as sieving always resulted in a particle size classification.
- Clayey: >30% silt/clay **or** >20% silt/clay and <30% sand (clasts <50%); in both cases where field observations recorded the till as **clayey**.
- Silty: >30% silt/clay **or** >20% silt/clay and <30% sand (clasts <50%); in both cases where field observations recorded the till as **silty**.
- Sandy: >40% sand **or** >30% sand and <20% silt/clay; in both cases where field observations recorded the till as **sandy**.
- Gravelly/Stony >55% clasts **and** <45% sand, silt and clay (with none dominant), where field observations recorded the till as gravelly/stony. (In the case of gravelly and stony tills, field observations are very important.)
- Sandy Gravelly: >50% clasts **and** >30% sand. (Field observations again important.)
- Silty Gravelly: >50% clasts **and** >30% silt/clay, where the matrix was recorded in the field as silt.
- Sandy Silty: >30% sand **and** >30% silt/clay, where the matrix was recorded in the field as very silty.
- Gravelly Clayey: >50% clasts **and** >25% silt/clay, where the matrix was recorded in the field as clayey and the till 'gravelly'.
- Stony Sandy: >50% clasts **and** >30% sand, where the till was recorded in the field as 'stony'.
- Clayey Stony: >50% clasts **and** >25% silt/clay, where the matrix was recorded in the field as clayey and the till 'stony'.
- Stony Silty: >50% clasts **and** >25% silt/clay, where the matrix was recorded in the field as silty and the till 'stony'.
- Bouldery: >55% clasts **and** where the till was recorded in the field as 'bouldery'.

Till is the most extensive Quaternary deposit occurring within the county. Seven till types occur:

Till derived from Lower Palaeozoic rocks is found in two major areas in the county: (i) to the north of Navan, (i) in the Bellewstown/Gormanston area. This till is generally orange/brown in colour, matrix-dominated and clayey, resulting in relatively poor drainage characteristics.

Till derived from Lower Carboniferous limestone is the most dominant till type found within the county, cropping out over the majority of the area south of Navan, and in a southwest-northeast trending strip northeast of Kells. The till is usually matrix dominated, but may be very stony in the areas of Calp limestone in the south of the county. Generally the deposit has a brown colour, and enjoys better drainage than the till derived from Lower Palaeozoic rocks, despite the wide range of textures seen.

Till derived from Upper Carboniferous (Namurian) rocks is found in relatively small areas throughout the county, the largest three being (i) northeast of Nobber, (ii) southwest of Donore and (iii) southwest of Warrenstown. This till is generally dark brown in colour, matrix-dominated and clayey, with quite poor drainage characteristics. A limited area of till derived from weathered Namurian sandstone occurs in the extreme north of the county around Ardagh, where it is sandy and quite well drained.

Till derived from chert occurs in two small areas: (i) to the south of Drumone, on the ridges immediately north of Lough Bane; and (ii) southwest of Trim, north of the confluence of the Boyne and Deel rivers. These tills are stony, with varying matrix textures, and quite well drained.

Till derived from Triassic sandstone occupies an area of less than two square kilometres in the extreme north of the county just east of Kingscourt. This till is red in colour, and is quite clayey despite being derived chiefly from sandstone. This is due to the influence of the surrounding (clayey) Lower Palaeozoic tills.

Till derived from Basic Igneous rocks occurs southeast of the Carrickdexter Escarpment just west of Slane. This till is quite stony, and is well drained due to its shallow depth.

Irish Sea Till is found east of a line joining Drogheda and Duleek. This till is very clayey and its colour varies across the area. South of this area the outwash gravels around Bettystown/Gormanston are underlain by the same till between 5m depth and bedrock.

Glacio-fluvial sands and gravels are different from tills in that they are deposited by running water only. The gravels are usually stratified (layered) and pebbles are usually rounded. Glacio-fluvial deposits are usually loosely packed. Due to the huge amounts of water produced by the melting of the ice sheet which covered most of Ireland at the end of the last glacial period, these deposits are very common in Ireland. They represent the stagnation and decay of the ice sheets. On the maps they are represented as 'sands and gravels' and are also categorised according to their dominant rock type *e.g.* Lower Carboniferous limestone sands and gravels. They give rise to a variety of different landforms, including 'kames', 'moraines' and, in some cases, 'drumlins'.

Sands and gravels are quite widespread across the county, and abundant in many of the hummocky areas below 120m altitude. The largest expanses of gravel occur along the Blackwater and Boyne Valleys, around Castletown, west of Drumone, west of Summerhill and north of Gormanston.

Esker sands and gravels are laid down by glacial meltwaters in tunnels and crevasses in stationary or retreating ice sheets, and are seen on land as long, narrow, sinuous ridges. They commonly include rounded boulders and cobbles. Clasts are usually much larger overall than in other glacio-fluvial deposits. Sand may or may not be present. The esker alignment usually corresponds closely with the ice flow direction. The gravels are usually bedded, the beds often slumping towards the flank of the esker, indicating collapse as the confining ice walls melted.

Esker sands and gravels are quite common, especially in the southern two-thirds of the county. The most extensive esker systems occur around Murrens, west of Kells, in Castletown and in the Trim/Summerhill region.

Glacio-lacustrine deposits were deposited into a large number of meltwater-fed lakes during and shortly after deglaciation. Deposits consist of sorted gravel, sand, silt and clay. They are found normally in wide flat plains, or in small depressions in the landscape. The deposits have different permeabilities depending on the dominant grain size. Deltas, which are formed as sediment is deposited at a river mouth on entry into a glacial lake, usually contain interbedded sands and gravels which dip lakeward. These are left as gravel and sand hills when the ice disappears and the lake drains away. Lacustrine basins, which are distal parts of the lake system, usually contain finer sediments, such as clays and silts. The differentiation of the dominant grain sizes within lacustrine sediments is imperative as such a wide variety of grain size combinations is possible, each resulting in a different permeability.

Glacio-lacustrine silts and clays are usually found around and beneath the county's most extensive peat bogs, and are also common in the interdrumlin hollows in the north of the county.

Alluvium is a post-glacial deposit and may consist of gravel, sand, silt or clay in a variety of mixes and usually includes a fairly high percentage of organic material (10%-30%). Alluvium is mapped only on modern river floodplains. The alluvial deposits are usually bedded, consisting of many complex strata of waterlain material left both by the flooding of rivers over their floodplains and the meandering of rivers across their valleys.

Alluvium is present along most of the major rivers in the county (Boyne, Blackwater, Nanny, Dee, Tolka, Deel, Stonyford, Athboy, Moynalty, Kilmainham, Upper Inny) albeit discontinuously.

Peat is also a post-glacial deposit, consisting mostly of partially decomposed vegetation which has accumulated and compacted in marshes, ponds and lakes carved out and left by Quaternary ice sheets. In Ireland, peat usually overlies badly drained glacio-lacustrine silts and clays. In the last few centuries, much of the peat has been cut away for fuel. Both cutover and intact bog were mapped, provided that the peat in all cases attains a thickness of at least one metre.

The most extensive peat bogs occur west of Ballivor, south of Athboy, south of Kinnegad, at Fletcherstown and at Tullaghanstown west of Navan.

Head is a sediment deposited during the severe cold climate (similar to present-day tundra) which occurred during and shortly after deglaciation. In these conditions, the frozen ground thaws in spring and becomes very mobile and a slow flow of shattered fragments of rock, also resulting from the intensely cold conditions, occurs from higher to lower ground. Head deposits are most common where the bedrock is very friable, for example in areas underlain by shale. The deposit varies in texture from being very flaky to very muddy, depending on the lithology of the local bedrock.

Head is found on the slopes of the Lower Palaeozoic ridges to the north and east of the county, and on the ridges cored by Namurian rocks to the south of the county (*e.g.* Warrenstown).

Marine deposits are found along the coast and usually take the form of beaches, spits and bars. These deposits are continually reworked by the sea today. Beach sands and gravels are the most common deposits *e.g.* at Bettystown.

Bedrock at or close to (within 1 metre of) the surface was also mapped, according to the type and lithology of the rock. The most extensive bedrock outcrops in the county occur on the crests and flanks of the Lower Palaeozoic ridges to the north of the county *e.g.* Slieve na Calliagh.

5. Hydrogeology & Aquifer Classification

5.1 Introduction

Groundwater is a very important resource and provides about 20% of the public water supply in County Meath. 28% is taken from major rivers and 17% from lakes. The remaining 35% is obtained from other local Authorities: Drogheda Corporation (which extracts from the River Boyne to supply east Meath), Dublin County Council (extracts from the River Liffey at Lexlip), Westmeath County Council and Cavan County Council.

Meath County Council operates 14 major groundwater supplies and 51 minor groundwater supplies, some of which supply only a few houses each. Groundwater from all the major supplies and 17 minor supplies (Table 5.1) were sampled for chemical and bacteriological analyses. The following minor supplies were not sampled due to their very small demand:

Table 5.1 Minor County Council Supplies

Minor County Council boreholes (*A)		Minor County Council Supplies (*B)	
Anneville	Donore	Ballinabrackey	Moylough
Balfeaghan	Julianstown	Baltrasna	Mullaghroy
Ballymacad	Knockmark	Baxter	Mullaghteelin
Bective	Leggagh	Belper	Rathkeenan
Carnaross	Moat	Collestown	Ross Road
Castlepole	Oakley Park	Crowpark	Ross
Clonlyon	Ross	Croboy	Toberultan
Cookstown		Danestown	
Crossdrum		Dean Hill	
Cross Guns		Mitchelstown	

The locations of the minor sources listed (A) in the above table, have been verified and these wells are still in operation. The sources listed in (B) have not been verified.

There are also many private abstractions of groundwater for industrial, domestic and farming purposes. Well data have been compiled from a variety of sources including GSI surveys, water well drillers, consultants' reports and the Council. The data are unevenly dispersed throughout the county and vary in quality from very poor to good.

Many wells have not been adequately tested to obtain reliable information on the specific aquifer characteristics. The well records are incomplete, and many private wells are not recorded. Some of the data are out of date, especially where boreholes have now replaced old shallow dug wells.

5.2 Aquifer Classification

The rocks in Co. Meath have been classified into three main bedrock aquifer categories, with each category being sub-divided into two or three sub-classes:

1. **Regionally Important Aquifers**
   (i) Groundwater flow mainly in Karst conduits (enlarged by solution) (**Rk**)
   (i) Groundwater flow mainly in fissures/fractures in the rock (**Rf**)
2. **Locally Important Aquifers**
   (i) Generally moderately productive (**Lm**)
   (i) Moderately productive only in local zones (**Ll**)
3. **Poor Aquifers**
   (i) Generally unproductive except for local zones (**Pl**)
   (i) Generally unproductive (**Pu**)

The Quaternary deposits of sands and gravels are classified as aquifers where they are sufficiently extensive (greater than 1km^2) and have a saturated thickness of at least 5m. Sand and gravel aquifers are classified into Regionally or Locally important:

1. **Regionally Important Aquifers:** Greater than 10km^2 in extent (**Rg**)
2. **Locally Important Aquifers:** Less than 10km^2 in extent (**Lg**)

5.3 Regionally Important Aquifers

The Shallow Water Limestones are the only rocks in Co. Meath which fall into the regionally important category and are classified as having both karst flow dominant (Rk on the map) and fissure flow dominant (Rf on the map) in different areas. These rocks are found in the east just south of Drogheda, in the north from around Ardagh to Nobber, and in the west around Lough Sheelin.

These limestones are pale grey, thickly bedded, fine to coarse grained limestones with abundant fragments of crinoids and coral fossils. The lower part of the rock succession is often dolomitised and karstified, which can be seen where drift cover is absent. These limestones have a moderate to good secondary permeability and the development of joints and fissures by solutional processes and the dolomitisation and decalcification have increased the available storage of the limestones. The greater the degree of solution within the limestones, the greater the likelihood of karstic features and thus karstic groundwater flow patterns. The permeability of the resulting solution features may have been reduced by later (Quaternary) infilling with sands, silts and clays.

5.3.1 Regionally Important Aquifers - karst flow dominant (Rk)

The shallow water limestones in the Kingscourt Outlier around Ardagh to Nobber are classified as having karst flow dominant (Rk on the map). This classification is based on evidence from County Monaghan, where there is extensive karstification of this limestone unit; swallow holes, caves, collapse features and springs have been observed (Personal Communication, M. Burke). These limestones in County Meath have been extensively covered by Quaternary subsoils and karst features have not been located except for two swallow holes which were noted by John Jackson (1955) just south of Barley Hill House, Ardagh, where dark grey micaceous shales overlie dolomitised clean limestones. Evidence for some palaeokarstic features are also reported at Bridge Farm quarry, Nobber and Barley Hill quarry, Ardagh.

The well records show two locations with “excellent” well yields in excess of 1000m^3/d (at Meath Hill and Rolagh). The Meath Hill well was artesian with an overflow rate of 600m^3/d, and the specific capacity was 550m^3/d/m. A third “good” well was located north of Nobber (270m^3/d) and the specific capacity was 38m^3/d/m, while the apparent transmissivity was 50-60 m^2/d.

Based on the geology, evidence for karstication and the occurrence of high yielding wells, these shallow water limestones are classified as a Regionally Important Aquifer - karst flow dominant (Rk on the map).

5.3.2 Regionally Important Aquifers - fissure flow dominant (Rf)

The remainder of the shallow water limestones which are found in east Meath, just south of Drogheda, and in the west around Lough Sheelin, are classified as having fissure flow dominant (Rf on the map), as the evidence available at present does not indicate extensive development of karst.

The presence of fissuring within these limestones at Drogheda is shown in boreholes at Drybridge, Co. Louth, (drilled as part of the investigation by the North East Regional Development Organisation (NERDO) in 1981), where 8m out of the 16m of borehole which was calliper logged had a diameter greater than the drill bit size. Trial wells at Mell, County Louth also showed cavities up to 10% of the total rock penetrated. The porosity is estimated at 5% at Mell Quarries and 10% at Platin Quarry (NERDO 1981).

Recent borehole records from the site investigation for the Northern Motorway in these limestones have recorded cavities/fissures with a vertical depth up to 3m (BMA 1995). Evidence from the Platin Quarries in Co. Meath also suggests karstic solution of fissures has developed within this limestone.

The GSI manuscript maps record karstic features at Ross Quarry, near Lough Sheelin, Co. Meath. George Du Noyer illustrates deep hollows and trenches in the surface of the limestone at Ross Quarry, which were later infilled with stiff brown clay and overlain by a gravelly limestone till. This illustration (on the cover of this report) may represent a buried or infilled karst system, which is no longer in operation.

From the well records six locations indicate well yields in excess of $100m^3/d$. The highest yield was at Platin Quarry, with a present pumping rate of $3,600m^3/d$. A sand filled fissure was encountered in Production Well No.2 between -17m O.D, and -19m O.D. The specific capacity at the end of the pumping test was $230m^3/d/m$, while the transmissivity ranged from 80-150 m^2/d.

Based on the geology, evidence for fissure flow and the presence of ‘good’ wells, these shallow water limestones are classified as a Regionally Important Aquifer - fissure flow dominant (Rf on the map).

5.4 Locally Important Aquifers

Locally important aquifers cover approximately half of Meath and are mainly located in the south.

5.4.1 Locally Important Aquifers - generally moderately productive (Lm)

5.4.1.1 Permian & Triassic

These rocks outcrop within the Kingscourt Outlier in the north of Co. Meath. The Permian and Triassic are a very significant aquifer in Northern Ireland due to the high yields. As a result of their small areal extent ($<25Km^2$) in the Republic they are classified as only “Locally important and generally moderately productive” (Lm on the map).

They generally consist of red shales, siltstones and sandstones. There is little hydrogeological information available for these rocks in Co. Meath. An investigation at Knocknacran Mine, Co. Monaghan by Geoffrey Walton (1982) indicated transmissivities in the range of $20\text{-}200m^2/d$.

The North East Regional Development Organisation (NERDO) drilled at Mullantra, Kingscourt in 1981 to investigate the potential of the Triassic sandstone. The sandstone was very friable and liable to collapse. The well yielded $915m^3/d$ with a specific capacity of $23\text{-}33m^3/d/m$. Transmissivity was calculated at $48m^2/d$. The aquifer is locally confined by 48 metres of till at this location. Recent drilling (1994-1996) east of Kingscourt in Countries Cavan, (Corgarry) Monaghan (Descart) and Meath for the Kingscourt water supply, indicated estimated yields between <10 to $>1000m^3/d$. The high yielding wells which were tested indicated specific capacities of $110m^3/d/m$. One of the wells encountered a grey to white rock unit which may be gypsum (calcium sulphate). The Triassic sandstones also contain very muddy and silty units which can give very poor yielding supplies. During the pumping tests, steady state conditions were not obtained (Personal Communication, K. O'Dwyer, K.T. Cullen & Co.).

The highly weathered Permian and Triassic sandstones are capable of transmitting large volumes of groundwater, although the interbedded mudstones can act as barriers to groundwater movement. Karstic features have been developed in the gypsum units (revealed by mining) and can transmit groundwater. The quality of water from the gypsum units could be unacceptable for drinking as a result of the very high sulphate concentrations that would be expected.

Based upon the lithologies and hydrogeological data available the Permian and Triassic rocks have been classified as "Locally important aquifers - generally moderately productive" (Lm on the Map).

5.4.1.2 Namurian Sandstone

The Namurian succession found in the Kingscourt Outlier is younger than the successions found elsewhere in Meath and is composed of thick alternating sequences of sandstones with shales. These sandstones are poorly cemented and often very weathered which increases their permeabilities.

Recent drilling (1994-1996) in the Namurian east of Kingscourt in County Meath, for the Kingscourt water supply, encountered yields estimated between 200 to 800m^3/d from four trial wells. These high yielding wells indicate the potential of these sandstones for groundwater development. The pumping tests which were conducted on these trial wells provided specific capacities from 40 - 85m^3/d/m. During the pumping tests, steady state conditions were not obtained (Personal Communication, K. O'Dwyer, K.T. Cullen & Co.).

The Council well at Kilmainham provided a discharge of 240m^3/d with a transmissivity in the order of 15-30m^2/d and a specific capacity of 6m^3/d/m.

The results of the drilling have established the potential of these rocks as an aquifer and on this basis the Namurian rocks of the Kingscourt Outlier have been classified as "Locally important aquifers - generally moderately productive" (Lm on the Map).

5.4.1.3 Calp Limestone

The Calp limestone occur over much of the county, particularly in the south. They are composed of dark grey to black, fine grained, well bedded limestones and shales.

The base of the Calp succession consists of coarse grained, cleaner limestones with occasional thin shale bands and often sandstone units are present. Where these variations are encountered especially where secondary permeability is well developed due to the faulting of the rocks, well yields are often much higher than would be expected for the Calp limestones. The lower Calp limestone may also be dolomitised in certain areas.

The base of the Calp limestone succession is more productive than the top but not enough geological information is available to divide the Calp limestone. Basal Calp limestone is found for example at Curragha, and at Kilmoon where the underlying Lower Palaeozoic rocks were encountered.

The upper Calp limestone are deeper basinal limestones and are dominantly fine grained black shales with limestones. The higher shale content ensures a much lower permeability and results in a lower yield. The cleaner limestone units are also found closer to the basin margins where they have slumped into the deeper water sediments.

In Co. Dublin, the proposed Powerstown Landfill site (County Fingal), located on Calp limestone was classified as "Locally important aquifer, moderately productive only in local zones" (Ll) by the consultant to An Bord Pleanala. The site investigations undertaken are site specific and cannot be applied to the entire Calp limestones of Counties Dublin and Meath. This classification of the Calp (Ll) concurs with the GSI's views for the Calp limestones in County Dublin.

In County Offaly the hydrogeological data has also resulted in the Calp limestones being classified as a "Locally important aquifer moderately productive only in local zones" (Ll). There are areas of higher productivity which would be classified as a "Locally important aquifer - generally moderately productive" (Lm). The data are insufficient to delineate these areas and the Ll classification has been retained for the entire Calp in Offaly (Personal Communication D. Daly).

The well records for County Meath show 33 sites with wells in Calp yielding greater than 100m^3/d. 22 are classified as "good" wells and the remaining 11 as "excellent" wells (>400m^3/d). There are also many "moderate" and "poor" wells located within the Calp limestone. Yields are often as low as 10m^3/d. These wells are often domestic supplies and occasionally council supplies but generally have not been tested to establish their potential output. Examples of Council wells drilled with estimated moderate and low yields are as follows:

Location	Depth (metres)	Lithology	Yield (m^3/d)
Hill of Tara	73	Limestone	44
Dunshaughlin (Tower)	300	Black limestone & shales	50
Curragha (Ballymack)	122	Black limestone & shales	55
Athboy	122	Black limestone & shales	30

Typical specific capacities range 5 - 150m^3/d/m and transmissivities range 20-1000m^2/d.

The seven largest County Council groundwater supplies (Slane, Curragha, Athboy, Dunshaughlin, Dunboyne, Ballivor and Nobber) all abstract from the Calp Limestone. These sources were subjected to 12 hour pumping test and short recovery tests and the results are given in Table 5.2 below.

Table 5.2 Pumping Test Results in Co. Meath

Location	Pumping Rate m^3/d	Specific Capacity m^3/d/m	Transmissivity m^2/d	Specific Yield
Slane	PWNo.1 = 780 PWNo.2 = 1640	60 - 65 130 - 135	70 - 130 150 - 200	0.002
Curragha	PWNo.2 = 1320	130	60 - 130	0.002
Athboy	1080	800 - 980	100 - 1000	0.075
Dunshaughlin	810	40 - 47	100-300	0.0004
Dunboyne	PWNo.1 = 115 PWNo.2 = 175 PWNo.3 = 335 PWNo.4 = 535	10 - 15 5 - 10 80 30 - 35	10 - 50 10 - 50 60 - 150 30 - 100	0.001 - 0.04
Ballivor	PWNo.2 = 265	8 - 15	10 - 200	0.01 - 0.02
Nobber	175	20 - 30	20-40	0.002

High yielding wells have also been located at Enfield, Longwood, Summerhill, Kilmoon, Batterstown, Ballivor (NEC), Ballivor (Kilmurry), Ratoath, and Nobber (College Proteins).

In Meath the high number of "excellent" and "good" wells, which includes many of the Council's major groundwater supplies, has led to the conclusion that the Calp Limestone is an important aquifer and it has been classified as "Locally important aquifer - generally moderately productive" (Lm on the map). The general hydrogeological data indicates a lot of local variation including the variability in the well yields and aquifer coefficients which depend on the groundwater flow paths through the fractures and fissures. The aquifer coefficients vary depending on the depth below ground level. In general higher values are obtained in the zone close to the surface and decrease with depth. The main groundwater flows are concentrated in the upper fractured and weathered zone and along fracture/fault lines.

The overlying Quaternary deposits often consist of thick limestone tills which can act as a confining layer thus producing artesian supplies, for example at Kilmoon, Dunshaughlin and Longwood. The present data is insufficient to delineate possible zones of confinement.

5.4.1.4 Derravaragh Limestone

The Derravaragh Limestone are silicified limestones and is a lithological variation within the Calp Limestone. These limestones are located in west County Meath south of Oldcastle. There are no hydrogeological data available except for the large spring located in gravels at Lough Bane pump house. This spring has a discharge of approximately 2,500m^3/d.

The Derravaragh Limestones are classified with the Calp Limestone as a “Locally important aquifer - generally moderately productive” (Lm on the map).

5.4.1.5 Edenderry Limestone

The Edenderry Limestones are oolitic limestones which are a lithological variation within the Shallow Water Limestones. These limestones are located in southwest Meath south of Kinnegad. There are no hydrogeological data available for these limestones in Meath. In Offaly they are classified as locally important (Lm) and this is being applied in Co. Meath.

5.4.2 Locally Important Aquifers - moderately productive only in local zones (Ll)

These aquifers in general have a low permeability, but they have the potential to provide high yields where favourable geological conditions occur.

5.4.2.1 Navan Group

The Navan Beds consist of a range of lithologies including basal conglomerates, sandstones, siltstones, shales, muddy limestones and cleaner limestones.

Within the Navan Beds some of the lithologies are occasionally dolomitised and fractured. The coarse grained limestones (Meath Formation or Pale Beds) are often dolomitised and recrystallised. The dolomite is often associated with fracturing and void creation. Indicators of primary palaeokarst can occur in the Micrite Unit of the Pale beds (M. Fleming 1996). Several boreholes in Co. Meath {1439-2 Athboy, 1439-4 Athboy, 91-3347-1 Woodtown, Kil-1 Kilallon, CK-2 Crossakeel, and in the J-Series (NW of Navan) J-58, J-60, J-56, J-83 (6.8m cavity), J-27, J-68, and J-30} indicate alteration due to dolomitisation. The Meath Formation or Pale Beds are the most likely to have cavity systems, voids and fractures developed (M. Fleming 1996).

Karstification and sub-aerial erosion occurred at the end of the Courceyan. This is shown by an unconformity at Navan, where a channel over 100m deep and probably over a kilometre wide has been cut into the underlying limestones. This allowed karstification to varying depths in particular of the Navan beds.

Three “excellent” wells (550-1650m3/d) are located within the Navan beds: at Moynalty, Castletown and Mountainstown. Specific capacities range from 45-200m^3/d/m. Tara Mine (Navan) is located on Navan Beds and hydrogeological information from the dewatering of the mine indicates very low transmissivities and yields in this area. Despite the presence of high yielding wells the Navan Beds are thus classified as only “Locally important aquifers - moderately productive only in local zones” (Ll on the map). This is the result of the very variable lithologies within the Navan Beds which produce the very variable yields.

5.4.2.2 Waulsortian Limestone

The Waulsortian bank or reef limestones are comprised of almost unbedded pale grey, very fine grained limestones which formed as massive mounds of lime mud. These limestones originally had very open structures with a large cavity volume. These cavities may or may not have been later infilled with calcite. Clean limestones such as the Waulsortian are highly susceptible to dissolution and karstification which involves the enlargement of the primary openings.

The Waulsortian can also be extensively dolomitised which is often joint or fault controlled. Dolomitisation increases the porosity of limestones by up to 15%. Dolomitisation and karstification are usually local and unpredictable, which gives the limestones a greater potential to provide high yielding wells, but frequently gives very low yields (<20m^3/d).

There is very limited evidence of dolomitisation and karstification within the Waulsortian of Co. Meath, other than the warm springs. Two warm springs in particular are located in the south near Longwood: St Gorman's Spring and Ardanew Spring.

The Geothermal Project undertaken by Minerex Ltd. in 1983 found that Waulsortian reef limestones tended to have groundwater circulation, whether it was cold or warm water. As part of the Geothermal Project two boreholes were drilled adjacent to St Gorman's Spring to a depth of 13m. The first borehole, 2m from the spring encountered very broken Waulsortian limestone and a cavity which was connected to the spring. The second borehole, 12m from the spring also encountered fractured limestone. Both boreholes responded rapidly to the abstraction of water from the spring and to fluctuation in the pumping rate (1300-1800m^3/d). The temperature ranged from 20.9-21.3^{o}C and the conductivity from 570-585µS/cm.

The well records indicate seven "good" wells (100-400m^3/d) which are all located around the Longwood and Summerhill areas. Specific capacities range from 5-140m^3/d/m and transmissivities from 30 to 40 m^2/d.

The Waulsortian has the potential of being highly dolomitised and karstified, but with the lack of good evidence it is classified as a "Locally important aquifer - moderately productive only in local zones" (Ll on the map).

5.5 Poor Aquifers

These aquifers are characterised by very low permeabilities and transmissivities and are therefore generally very low yielding. Consequently groundwater movement is relatively slow and is often restricted to shallow flow paths near the surface, along fracture zones or through slightly more permeable units. The water table is usually close to ground level and closely mirrors the topography. Well yields are often very low (<40m^3/d), though sufficient for domestic usage, and occasional high yields may be encountered.

5.5.1 Poor Aquifers - generally unproductive except for local zones (Pl)

5.5.1.1 Namurian Shale

The Namurian rocks in north Meath have been classified as locally important aquifers (section 4.3.1.2), while the remainder of the Namurian successions in the south are classified as poor aquifers. These rocks are predominantly composed of siltstones, mudstones and shales with only occasional sandstones. The sandstones possess slightly higher permeabilities and yields, owing to their greater ability to fracture than the shaly units.

Wells are in generally very low yielding, although higher yields have been recorded from Warrenstown and Summerhill with 545m^3/d and 110m^3/d respectively.

The Namurian successions in south Meath are classified as a "Poor aquifer - generally unproductive except for local zones" (Pl on the map).

5.5.1.2 Argillaceous Bioclastic Limestone

This succession is dominated by fine grained argillaceous or muddy limestones and shales. These rocks contain substantial amounts of clayey material and are thus not susceptible to solution or karstification. There is no primary permeability and limited secondary permeability which restricts groundwater storage and movement.

Well yields are typically low (10-40m^3/d), with occasional higher yields up to 100m^3/d. These limestones are classified as a “Poor aquifer - generally unproductive except for local zones” (Pl on the map).

5.5.1.3 Lower Palaeozoic Rocks

The Lower Palaeozoic Rocks consist of greywackes, sandstones, siltstones, and mudstones with interbedded volcanic rocks. These rocks are generally fine grained and have been intensively folded, faulted and altered. This complex geological history has resulted in these lithologies having a very low permeability. Groundwater is restricted to the shallow weathered zone at the surface or along fault and fracture zones.

Within these rocks five high yielding wells have been located of which two are termed “excellent” (over 400m^3/d). The highest yielding well (610m^3/d) is located near Kilmainham. The transmissivity is 20-40m^2/d and the specific capacity 16m^3/d/m. This unusually high yield is possibly related to the close proximity to the major Kingscourt fault zone.

Two high yielding wells have been located in the Slane succession, just to the north of Slane village, which consists of basaltic lavas, tuffs and sandstones. The high yields are probably related to the presence of the volcanic units and fractures.

Other units in which “good” wells have been located are the Rathkenny succession (northeast of Slane village) and Clatterstown succession (south of Bellewstown). Again these higher than normal yields are likely to be associated with faults.

The units which can be distinguished as having the potential for higher yields are Grangegeeth, Canes, Hilltown, Clashford House and Herbertstown together with Slane, Rathkenny and Clatterstown and the zone along the Kingscourt fault These are classified as “Poor aquifers - generally unproductive except for local zones” (Pl on the map).

The remainder of the Lower Palaeozoic rocks are classified as “Poor aquifers - generally unproductive” (Pu on the map, see section 4.5.2.2).

5.5.2 Poor Aquifers - generally unproductive (Pu).

5.5.2.1 Tobercolleen Limestone

The Tobercolleen consists entirely of thinly bedded mudstones and as a result this lithology has a very low permeability.

Well data for this unit are very poor and yields are generally less than 40m^3/d. These rocks are classified as a “Poor aquifer - generally unproductive” (Pu on the map).

5.5.2.2 Lower Palaeozoic Rocks

These Lower Palaeozoic Rocks (Contail, Salterstown, Clogherhead, Kennetstown, Denhamstown, Mellifont Abbey, Prioryland and Fourknocks successions) generally consist of siltstones and mudstones with minor greywackes and sandstones. These rocks are very fine grained, have been intensively folded, faulted and altered and have a very low permeability. Groundwater is restricted to the shallow weathered zone at the surface or along fault and fracture zones.

Well data for these geological units are very poor and yields are generally less than 40m^3/d and are classified as a “Poor aquifer - generally unproductive” (Pu on the map).

5.5.2.3 Igneous Rocks

There are small outcrops of Pre-Carboniferous intrusive igneous rocks and Carboniferous volcanics. No hydrogeological data are available for these rocks, but they are classified on the basis of their lithology as “Poor aquifers - generally unproductive” (Pu on the map)

5.6 Sand & Gravel Aquifers

Nine areas have been designated as locally important sand & gravel aquifers in Meath. Seven of these are termed “potential” local aquifers as there are no known water supplies currently developed in them and their confirmation must await further investigation. The sand & gravel aquifers are unconfined and are assumed to be in hydraulic continuity with the underlying bedrock aquifer.

Table 5.3 Sand & Gravel Aquifers in Co. Meath

Deposit	Description	Estimated thickness
Known Sand & Gravel Aquifers		
Mosney/Balloy Gravels	Interbedded outwash gravels	10 - 20m
Meath Hill Gravels	Clean, coarse morainic gravels	15 - 20m
Potential Sand & Gravel Aquifers		
Ballinter	Clean, coarse morainic & outwash gravels	8 - 15m
Summerhill	Clean, coarse morainic & esker gravels	10m
Tobertynan	Very clean delta gravels & sand	11m
Longwood	Clean, coarse morainic & outwash gravels	10m
Drumone	Clean, coarse esker & fan gravels	5 - 15m
Blackwater/Inny Valley	Clean, coarse outwash & fan gravels & sand	10 - 12m
Kingscourt Valley	Clean, coarse outwash gravels	5 - 12m

Drilling investigations in the Mosney/Balloy gravels indicated an average yield of 250-300m^3/d with a specific capacity of 28m^3/d/m. The estimated transmissivity is around 40m^2/d, which is rather low and may be due to the very complex sequence of interbedded clays, sands and gravels which vary latterally in this area.

A private group scheme well at Meath Hill yields 1000m^3/d from clean sands & gravels and the top 6m of the underlying shallow water limestones.

The sand & gravel aquifers are classified as “Locally important” (**Lg** on the map), since none of the deposits has an areal extent greater than 10 Km^2.

Table 5.4 High Yielding Wells & Specific Capacities in Co. Meath.

Rock Unit	Well Number (>400m³/d)			Well Number (100-400m³/d)			
		Yield	**Specific Capacity**		**Yield**	**Specific Capacity**	**Aquifer Category**
Triassic	-			-			**Lm**
Permian	-			-			**Lm**
Namurian	2629SE064	850	32	2629SE068	c200		
	2629SE065	1000	110				
	2629SE066	900					**Lm**
	2629SE067	900					
	2629SE069	650					
Namurian	2629SE024	1850		2629SE012	240		
	2925SW357	545		2629SE052			
	2629SE064	1000		2627NE059	240	7	**Pl**
				2627NE020	330		
				2623NE144	110		
Calp	2925SW101-103	c1850	60-160	2925SE003	110		
Limestone	2925SW364	490	23,7	2925SW139	105		
	2923NW388-	125-655	10 - 230	2925SW394	260	13	
	390,404			2923NW447	195		
	2925SW098,105	c700	38,24,48	2923NW385	110		
	355			2923NW276	220		
	2625NW001	1360	185, 980	2923NW484	350	12	
	2625SW013,014	575	30, 100	2923NW257	130		
	2625SW036	545	68	2923NW038	130		
	2625SW010	545	68	2925SW395	110	22	
	2623NW022	1000	28	2925SW122	195		
	2623NE108	1745	100	2925SW136	140		**Lm**
	2927SW012-015	1000	70-200	2623NE100	240	11	
				2625NE046	220		
				2627NE055-056	175	35	
				2625SW085-	245	5	
				086	110		
				2625SW090	110		
				2625SW088	180		
				2625SW011	240	30	
				2625SW012	230	12	
				2627NE067	230	10	
				2627NE123	270	40	
					330		
Shallow	2627NE126	1600		2627NE042	270	34	
Water	2629SE053	1000					**Rk**
Limestones	2927SE047-048	3600		2925NW043	130		
				2925NW045	140		
				2925NW070	110		**Rf**
				2925NW071	100		
				2927SE039	160		
Waulsortian				2623NE087	110		
				2623NE259	110		
				2623NE096	370	40	
				2623NE101	130	5	**Ll**
				2623NE102	195	12	
				2623NE291	110		
				2623NW023	245	140	
Navan Beds	2627NW001	980	220				
	2627SE058-059	220,550	44,55				**Ll**
	2627NE057	1650	95				
Lower	2627NE060	610	17	2927SW031	115	8	
Palaeozoics	2927SW037	430		2927SW046	130		**Pl**
				2925NE075	220		
Gravels	2629SE053	1000		2925NE005	295	30	**Lg**

6. Hydrochemistry & Groundwater Quality

6.1 Introduction

"Hydrochemistry" refers to the chemical composition of the water and "groundwater quality" refers to the chemical, physical and microbiological characteristics, relative to a standard. The standard used for groundwater is the drinking water standard required by the EC (Quality of Water Intended for Human Consumption) Regulations S.I. No. 81 of 1988. These regulations give formal effect in Irish law to the 1980 EC Directive on Quality of Water for Human Consumption (80/778/EEC) and apply to all water intended for human consumption or used in food production (except mineral waters), whether in their natural state or after treatment. The Irish standards (Appendix BII) are used here, although there are some differences from the EC standards

Groundwater analyses were collected and compiled to determine the general hydrochemistry and overall water quality currently occurring in County Meath. Groundwater analyses were available for a variety of sources over the past number of years, resulting from sampling by the County Council. These analyses were not used in this study as the samples were of treated water, rather than raw water and often the samples were from combined surface and groundwater sources, rather than individual groundwater supplies.

A regular groundwater sampling programme was established. A total of 99 raw water samples were collected during 1995 and 1996 from groundwater supplies throughout the county. The sampling programme was conducted approximately every three months (March, June, September 1995 and January 1996) which allowed seasonal variations in the hydrochemistry and water quality to be assessed. A full chemical analysis including all major cations, anions and important metals was carried out by the State Laboratory on all the samples. Bacteriological analyses (Coliforms and *E.coli*) were conducted by the County Council Laboratory staff in Liscarton, Navan. The samples were delivered to Liscarton within six hours from the time of sampling. The results of the analyses are tabulated in Appendix BI.

Duplicate samples were taken from several wells, during each sampling period, to ensure quality control. The differences between duplicate analyses were generally within acceptable ranges.

In order to verify the quality of the data obtained, major ion balances have been calculated:

$$\text{Balance (\%)} = \frac{\Sigma\text{ (Cations, meq/l)} - \Sigma\text{(Anions, meq/l)}}{\Sigma\text{(Cations, meq/l)} + \Sigma\text{(Anions, meq/l)}} \times 100$$

A charge balance error of ±5% is usually taken as acceptable. There were five samples with an error outside this range, of which four were within ±10% and were considered reasonable. One sample (ME953006) from Dunshaughlin has an ionic balance of 21.8% which is not acceptable.

6.2 Hydrochemistry

The groundwater in County Meath is predominantly a calcium bicarbonate water, a direct result of the predominant rock type, limestone and the overlying limestone tills.

Groundwater in County Meath is generally hard (251-350mg/l $CaCO_3$) to very hard (>350mg/l $CaCO_3$). Softer waters occur in areas where the underlying bedrock is not limestone, such as the Namurian shales and sandstones and the Lower Palaeozoic shales and grits.

6.2.1 Seasonal changes in hydrochemistry

In the majority of the sources sampled, the total hardness, calcium, conductivity, nitrate and total dissolved solids (TDS) were higher during the winter sampling periods and the total alkalinity was often lower. This may be explained by the naturally higher amounts of recharge entering the aquifers in the winter, resulting in greater amounts of dissolution of the limestone. The higher water tables may also influence this process which also implies fairly slow groundwater movement to allow the dissolution to occur. However during the winter groundwater flow rates may be very rapid, due to the higher quantities of recharge, which would allow greater amounts of dilution of the above parameters. The higher level of nitrate may be a direct result of runoff from farmyards and fields during heavy rainfall.

Where the total hardness is less than the total alkalinity, cation exchange may be occurring, with the replacement of Ca^{2+} and Mg^{2+} ions by Na^{+} ions, thus reducing the hardness of the groundwater. This may be occurring at Lobinstown and Enfield. Further analyses would be required to confirm this.

The magnesium/calcium ratio in limestone waters can be used to indicate possible dolomitisation where calcium ions have been replaced by magnesium ions. A ratio greater than 0.3 (when the parameters are expressed as meq/l) indicates this or it may indicate contamination. Waters from the Lower Palaeozoic and Namurian rocks often have a high Mg/Ca ratio due to the naturally low concentration of calcium ions in these rocks. Two limestone sources indicate high ratios (Ballair and Ballivor), but there is no other evidence to confirm dolomitisation at these locations.

6.3 Groundwater Quality

During the groundwater monitoring programme, raw water samples were collected from 34 sites: 16 major County Council boreholes, 14 minor County Council boreholes and the springs at Lough Bane. The major supplies were sampled four times, (every three months) and the minor supplies were sampled twice (March and September 1995). Three additional sites were only sampled once (March 1995). The boreholes which were sampled are listed in Table 6.1.

Table 6.1 Wells Sampled in County Meath

Major County Council Boreholes	Minor County Council Boreholes	Additional Minor Sites
Dunboyne PW1, PW2, PW3. & PW6	Batterstown	Carrickleck
Dunshaughlin PW1 & *PW2	Dunsany	Yellow Furze
Slane: combined sample PW1 + PW2	Castletown	Balloy
Curragha PW2	Lobinstown	
Athboy	Newtown	
Nobber	Bellewstown	
Kilmainhamwood	Deanhill	
Moynalty	Ballair	
Trim	Carnacross	
Ballivor	Clonard	
Enfield	Clonycavan	
Summerhill	Robinstown	
Longwood	Rathmoylan	
Kilmessan	Agher	

*PW2 at Dunshaughlin is located at the County Council Offices

Parameters such as E. *coli*, potassium (K), chloride (Cl), nitrate ($N0_3$) and ammonia (NH_3) are good contamination indicators. The potassium/sodium (K/Na) ratio is also a useful indicator of local contamination by vegetative organic matter.

Background levels for potassium, chloride and nitrate (as $N0_3$) in Meath are 1, 10 and 2 mg/l respectively. It has been shown elsewhere in Ireland that concentrations of these parameters of 3-4 times their background level indicate significant contamination. Thus the threshold levels are: potassium (3-4mg/l), chloride (30-40mg/l) and nitrate (6-8mg/l as $N0_3$). Samples which have parameters above the threshold may also have abnormal levels of some other parameters such as total hardness, total dissolved solids, manganese, etc. and frequently contain E. *coli* (Daly & Woods 1994).

These threshold levels of the above parameters can be used to distinguish between uncontaminated groundwaters and those showing some chemical evidence of contamination, indicating significant human influence on the groundwater quality. Groundwater with one or more parameters exceeding the MAC can be classified as polluted, unless the elevated parameters are naturally occurring. In County Meath high levels of iron and manganese, sometimes above the MAC, occur naturally in the groundwater. These groundwaters are not classified as polluted but require treatment to reduce their levels below the MAC for use as drinking water.

The sources sampled in Meath have been classified depending on their water quality.

Class 1 Sources showing no evidence of contamination, which includes groundwaters which have naturally high levels of some parameters (eg. iron and manganese).

Class 2 Sources which show elevated levels of chloride, potassium or nitrate indicating significant contamination, or parameters above the recommended guide levels.

Class 3 Sources in which one or more parameters exceed the MAC.

27 % of the samples are classified as Class 1, 32% as Class 2 and the remaining 41% of samples as Class 3.

Approximately half of the samples show elevated levels of iron and manganese, which occur under natural conditions.

Eight of the wells sampled indicated contamination with E. *coli*, and six of these sources also showed chemical indications of contamination. A further 14 sites contained background coliforms. A total of 21 sources indicated some contamination in the form of elevated indicator parameters, although only seven were above the MAC.

The large number of sources which indicate contamination highlight the need for the protection of all the sources.

Eight sites (Newtown, Deanhill, Ballair, Clonycavan, Robinstown, Lough Bane, Dunboyne gallery and Trim) contained E. *coli* which indicates contamination by human or animal wastes. Robinstown also showed high potassium and manganese, the K/Na ratio is >0.4 and thus indicates contamination by plant organic matter such as farmyards.

Several sources have shown occasional high levels of particular parameters. Clonard has high ammonia together with high iron and manganese. High ammonia usually indicates a nearby waste source and/or vulnerable conditions. Rathmoylan and Nobber showed high levels of lead, Kilmessan indicated high nitrite, Clonycavan high zinc and Agher high fluoride. Further sampling is required at these sites to determine if these occasional high values are a major problem or just anomalies.

The remainder of the samples which have concentrations of iron and manganese above the MAC are the result of natural groundwater conditions. These sources are as follows: Kilmainham and Deanhill (Namurian), Clonycavan, Robinstown and Agher (Waulsortian), Curragha, Dunshaughlin, Ballivor, Longwood, Summerhill, Enfield, Clonard, Batterstown and Dunboyne (Calp Limestones).

6.3.1 Iron & Manganese

Iron and manganese are very abundant elements, but are usually only found in low concentration in groundwater. When found in excessive quantities, they can form precipitates which can clog wells, screens, pumps and rock fractures, thus reducing the yield of the well.

The problem of high iron and manganese is common throughout Ireland. Dark, fine grained, pyritic shaly rocks such as the Calp Limestone are the most likely to have naturally reducing conditions. These lithologies are also rich in organic matter, iron, manganese and sulphate. The high concentrations of iron and manganese in the groundwater occur mainly through the chemical process of ion exchange under reducing conditions. (Deakin 1995).

The pumping of groundwater from a borehole allows oxygen to be introduced into the aquifer, allowing iron and manganese to be precipitated from solution. Wells with high iron and manganese levels should be pumped at lower pumping rates to keep the drawdown as small as possible, reducing the potential for oxidation. Contamination of the groundwater, for example by silage effluent or nitrate, which tends to produce reducing conditions, can also increase the amount of iron and manganese entering into solution.

6.4 Conclusions

Groundwater pollution is not a major problem in County Meath, although some contamination has been indicated at some sources. Often the boreholes are located too close to potential pollution sources such as septic tanks or farmyards, or streams in which the water quality is poor.

The main concerns are the presence of bacteria (Total Coliforms and E. *coli*) in several of the sources sampled. E. *coli* is used to indicate contamination by human or animal waste. It is recommended that all the groundwater sources be sampled regularly and the sources which are frequently contaminated with bacteria be investigated to determine the actual source of pollution.

7. Groundwater Vulnerability

7.1 Introduction

Groundwater Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater resources may be contaminated by human activities at a given location (Daly and Warren 1994).

The Vulnerability Map (Maps 5(E) & 5(W)) shows the vulnerability to contamination of the underlying groundwater and not of the aquifer or of a particular groundwater source. The vulnerability rating is irrespective of the possible type and concentration of human pollutants, which is dealt with by the groundwater protection matrices.

The Vulnerability Map thus delineates areas with approximately the same natural protection from potential pollution sources. The maps are interpretative and should not be used for site specific studies; actual vulnerability at any given site should be confirmed by field investigations.

7.2 Vulnerability Classification

The vulnerability classification scheme for County Meath is outlined in Table 7.1.

Table 7.1 Vulnerability Classification Scheme.

Vulnerability Rating	**Hydrogeological Setting**
Extreme	Locations where rock is at the ground surface. Locations where the subsoil is known to be <3m thick from sections or borehole records. In the vicinity of karst features.
Probably Extreme	Areas interpreted to have < 3m of subsoil overlying bedrock.
High	Locations where high permeability subsoil is known to be >3m thick from sections or borehole records. Locations where intermediate permeability subsoil is known to be 3-10m thick from sections or borehole records. Locations where low permeability subsoil is known to be 3-5m thick from sections or borehole records.
Probably High	Areas of high permeability subsoil interpreted to be >3m thick. Areas of intermediate permeability subsoil interpreted to be 3-10m thick. Areas of low permeability subsoil interpreted to be 3-5m thick.
Moderate	Locations where intermediate permeability subsoil is known to be >10m thick from sections or borehole records. Locations where low permeability subsoil is known to be 5-10m thick from sections or borehole records.
Probably Moderate	Areas of intermediate permeability subsoil interpreted to be >10m thick. Areas of low permeability subsoil interpreted to be 5-10m thick.
Low	Locations where low permeability subsoil is known to be >10m thick from sections or borehole records.
Probably Low	Areas of low permeability subsoil interpreted to be >10m thick.

7.3 Vulnerability Assessment

The Vulnerability Maps are compiled from point sources of data, which were then extrapolated over the land surface to provide areal characterisation. The thickness, composition and permeability of the natural subsoil deposits are very variable, even over short distances. For the purpose of this scheme the vulnerability mapping involves a large degree of generalisation: areas being classified, for example, as areas of moderate vulnerability, could include small areas with either a higher or lower vulnerability rating. The vulnerability ratings are denoted as 'probable' except close to actual data points, and are shown on the map with symbols.

The main characteristics controlling vulnerability are:

- the type and permeability of the subsoil
- the thickness of the subsoil and the unsaturated zone
- the attenuation capacity of the subsoil
- the hydrogeology

The information available on the topsoils and their attenuation capacity is not detailed enough to aid in the vulnerability assessment. The attenuation capacity of the topsoils depends on the type of pollutant and is not used to assess the vulnerability rating.

There is relatively detailed subsoil information for County Meath due to the reconnaissance mapping, drilling, trial pitting, augering and grain size analyses. This has allowed the vulnerability to be compiled at the scale of 1:25,000.

7.3.1 Subsoils

The type and thickness of the subsoils are very important in determining the vulnerability of groundwater to pollution. The higher the clay content, the lower the permeability and the thicker the deposit, the lower the resulting vulnerability. The subsoils have been classified depending on their general permeability:

- Limestone-derived tills are considered to be of intermediate permeability due to their gravelly nature.
- The Permian and Triassic sandstone-derived tills also have an intermediate permeability due to their sandy texture.
- All Lower Palaeozoic-derived tills are assumed to have a high clay content and therefore a low permeability.
- The Namurian-derived till is considered to have a low permeability, although there are areas which are sandy.
- All sand & gravel deposits are assumed to have high permeability.
- Till-with-gravel is assumed to have intermediate permeability.
- All lake deposits are assumed to be thin and the permeability of the underlying deposit is taken into account.
- Alluvial deposits are very variable in terms of permeability and are considered to have a high permeability.
- Peat deposits in Meath are all classified as raised bogs and are considered to have a low permeability.
- Marine deposits are classed as intermediate to high permeability.

The depth to bedrock map was contoured using 3m, 5m, and 10m contours to assist compilation of the vulnerability map. Data points plotted with a locational accuracy of +/-100m were used in the actual contouring and less accurate data points were used within their limitations to assess the general thickness over an area.

7.3.2 Groundwater Vulnerability in County Meath

The county has been classified into four main categories; probably extreme, probably high, probably moderate, and probably low. Within these areas, points of known vulnerability are denoted using symbols.

A large proportion of the county is classed as either probably high or probably moderate, with smaller areas of probably extreme and probably low The large areas of probably extreme vulnerability are generally a direct result of bedrock being exposed at or close to the ground surface and are commonly found in the upland areas of the county. The large areas of probably moderate vulnerability are due to the relatively thick cover of low to intermediate permeability tills.

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. A combination of detailed mapping of the subsoils, assessment of surface drainage and permeability measurements would reduce the area of high vulnerability and would probably reduce the area of extreme vulnerability. However, the vulnerability maps are a good basis for decision-making in the short and medium term.

8. Groundwater Protection Zones

8.1 Groundwater Resource Protection

The Groundwater Protection Map (Maps 8(E) and 8(W)) deals with protection of the aquifers based on their resource potential and vulnerability. The county is delineated into protection zones (24 for bedrock aquifers, with an additional zone for sand & gravel aquifers) with decreasing risk and protection measures, ranging from regionally important aquifers with karst flow with extreme vulnerability (Rk/E), which requires the highest degree of protection, to poor aquifers of low vulnerability (Pu/L), which need the least protection measures. The zones are presented in Table 8.1

Table 8.1 Groundwater Resource Protection Zones

AQUIFER		VULNERABILITY	PROTECTION ZONE
Regionally Important	karst flow	Extreme	Rk/E
		High	Rk/H
		Moderate	Rk/M
		Low	Rk/L
	fissure flow	Extreme	Rf/E
		High	Rf/H
		Moderate	Rf/M
		Low	Rf/L
Locally Important	generally moderately productive	Extreme	Lm/E
		High	Lm/H
		Moderate	Lm/M
		Low	Lm/L
	moderately productive only in local zones	Extreme	Ll/E
		High	Ll/H
		Moderate	Ll/M
		Low	Ll/L
Poor	generally unproductive except for local zones	Extreme	Pl/E
		High	Pl/H
		Moderate	Pl/M
		Low	Pl/L
	generally unproductive	Extreme	Pu/E
		High	Pu/H
		Moderate	Pu/M
		Low	Pu/L
Unconsolidated Aquifers			
locally important	sand & gravel	High	Lg/H

8.2 Groundwater Source Protection

The source protection areas are designed to protect groundwater abstractions by employing varying levels of restrictions on human activities. Three zones are delineated for each source (Slane, Curragha, Athboy, Dunshaughlin, Dunboyne, Ballivor and Nobber):

- the Source Site (SS)
- the Inner Protection area (SI)
- the Outer Protection area (SO)

The Source Site is the area immediately around the source. It should have a minimum radius of 10 metres, which should be owned by the Council and fenced off to ensure complete protection.

The Inner Protection Area (SI) is the area defined by a 100 day time of travel to the and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

The Outer Protection Area (SO) includes the remainder of the complete catchment area to the source, i.e. the zone of contribution (ZOC), and it is delineated as the area required to support an abstraction from long-term recharge.

The matrix in Table 8.2 gives the results of integrating the three elements of land zoning (vulnerability categories, source protection areas and resource protection areas, a total of 12 and 24 zones respectively). Each zone is represented by a code e.g. **SO/M** which represents an outer source protection area, where the groundwater is moderately vulnerable to contamination.

Table 8.2 Matrix of Groundwater Protection Zones

VULNERABILITY RATING	SOURCE PROTECTION			RESOURCE PROTECTION					
				Regionally Important		Locally Important		Poor Aquifers	
	Site	Inner	Outer	Rk	Rf / Rg	Lm / Lg	ll	Pl	Pu
Extreme (E)	SS/E	SI/E	SO/E	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	Pu/E
High (H)	SS/H	SI/H	SO/H	Rk/H	Rf/H	Lm/H	Ll/H	Pl/H	Pu/H
Moderate (M)	SS/M	SI/M	SO/M	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	Pu/M
Low (L)	SS/L	SI/L	SO/L	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	Pu/L

8.3 Groundwater Protection Response Matrix

The control of groundwater contamination sources is by the use of a response matrix which lists the degree of acceptability of potentially polluting activities for each zone and describes the recommended controls for both existing and new activities. It is shown by a level of response or restriction, which is applied to each activity. The control measures are divided into four levels of response based upon the likely acceptability:

R1 Acceptable subject to statutory regulations and normal good practice.
$R2^{a,b,c,...}$ Acceptable in principle, subject to conditions in note a,b,c, etc.
$R3^{m,n,o,...}$ Not acceptable in principle; some exception may be allowed subject to conditions in note m,n,o, etc.
R4 Not acceptable.

These levels of response can be applied to specific activities or to groups of activities (D. Daly 1995).

The final step in the groundwater protection scheme is to integrate the protection zones and the response matrix. The matrix combines both the geological/hydrogeological and the contaminant loading aspects of risk assessment. A response category is given for each zone.

The response matrices are being drawn up by the Environmental Protection Agency, Geological Survey of Ireland and the Department of the Environment and Local Government, for use in conjunction with the groundwater protection maps.

Thegroundwater protection maps were compiled on a regional scale and are very complex. These maps should not be used as a substitute for site investigations, which will still often be necessary in order to make decisions on specific sites.

8.4 Groundwater Source Protection Reports and Maps

The techniques used to delineate source protection zones (section 2.3.2) have been applied to seven public supply wells in County Meath: Slane, Curragha, Athboy, Dunshaughlin, Dunboyne, Ballivor and Nobber. These have been produced as separate source reports.

9. Conclusions

Groundwater is an important resource in Co. Meath, providing 20% of the total public water supply used by the county. In addition to this many private houses, farms and companies also use groundwater from either their own wells or private group scheme boreholes. The aquifers of Meath are not fully developed, providing the potential for future groundwater development as the need for water continues to increases. Even at present the supply of public water does not met the requirements, especially during the summer months when water rationing measures are in force, particularly in east Meath.

The groundwater quality in Co. Meath is generally considered to be good with few parameters exceeding the MAC (Maximum admissible concentration) set by the EU for drinking water. The groundwater can be classed as a calcium bicarbonate water, which is typically regarded as very hard. Approximately half of the sources sampled showed elevated levels of iron and manganese, often above the MAC. These high levels occur naturally in the groundwater and this is a common problem throughout Ireland. The high concentrations of iron and manganese are directly related to the geology and generally found in groundwaters from the Calp Limestone. These groundwaters are not regarded as polluted but do require treatment to reduce the levels below the MAC before use as drinking water.

Groundwater pollution at present is not a major problem in County Meath, although there are some groundwater sources which have indicated some contamination. Often these groundwater sources are located too close to potential pollution sources such as septic tanks, farmyards or streams in which the water quality is poor.

The vulnerability of groundwater to pollution is determined by the subsoil type and its thickness. A significant proportion of Meath is regarded as extreme or highly vulnerable as a direct result of thin subsoils or the presence of highly permeable deposits and the water quality is related to the vulnerability of the area.

The Groundwater Protection Map and the associated Groundwater Protection Response Matrices, currently under development by the GSI, EPA and DoELG, will help the Council to make better informed decisions on planning applications. Specific site investigations should be used to determine that no adverse effects to the groundwater will occur as a result of a given proposed development.

This report and the accompanying maps should also assist the Council:

- in seeking additional sources of groundwater which will be least vulnerable to contamination
- in managing its water resources
- in planning for emergency responses to pollution incidents
- in responding to unusual water shortages (droughts)
- in outline geotechnical appraisals, e.g. for new roads or sewerage schemes

10. Recommendations

- The preparation of this scheme involved the compilation of raw data from a variety of sources. In some cases the raw data was very sparse and of very poor quality, which resulted in problems in devising the proposed scheme for Meath. The Council should ensure that in future data is collected and recorded in a standard format, which would be easily accessible for future county projects. This would also help in future revisions of the groundwater protection scheme. All geotechnical reports, consultancy reports, drilling logs with location maps and all hydrochemical analyses should be sent to the Groundwater Section of the GSI. This data can then be entered into the national database.

- Regular monitoring of all the groundwater sources should be conducted on the raw water as well as on the treated water. The groundwater should be analysed using indicator parameters for contamination, and any sources which are frequently contaminated with bacteria should be investigated to determine the actual source of pollution. This sampling programme can also be used to monitor the effects of potentially polluting activities and any changes in the water quality can be recorded.

  The minimum parameters to be analysed for are: Coliforms and E. *coli*, nitrate, potassium, chloride and conductivity levels and these should be conducted on a regular basis, while a complete analysis should be conducted at least twice a year. The monthly monitoring of conductivity levels should be maintained as a first indication of any water quality problems. The data collected from all the wells are showing an increase in the conductivity levels. Further monitoring of these wells is required to establish the causes and control the results.

- It is recommended that the Council control and monitor potentially polluting activities being carried out on the delineated groundwater source protection zones.

- The production wells and adjacent observation wells should all be adequately secured from the public and from potential vandalism. These wells should be securely fenced off and the area around each well should be properly maintained. Any trial wells which will not be used should be infilled and plugged with cement to prevent the entry of contaminants into the aquifer.

- The completion of well heads below ground level is not recommended unless necessary due to particular site conditions. Wells completed below ground level should be contained in a sealed manhole which will prevent the entry of surface water.

- Further investigation work should be conducted at each major source to establish the amount of recharge which is induced from the adjacent river, in order to refine the protection zones. The groundwater quality is often dependant on the river water quality as they are hydraulically connected, thus the catchment to the rivers should be delineated and all potential polluting activities within the river catchment should be monitored, particularly farmyard activities upgradient from the well and all industrial and commercial developments.

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