County Limerick
Groundwater Protection Scheme

Main Report

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1. Introduction

1.1 Objective and Scope of Groundwater Protection Scheme

This report was initiated to provide Limerick County Council with a comprehensive groundwater protection scheme. Although the main focus is on groundwater protection, the overall objective was to collect, compile and assess all readily available data on the geology, hydrogeology and groundwater quality to facilitate both groundwater resource management and public planning.

The groundwater protection scheme is the result of co-operation between Limerick County Council, the Geological Survey of Ireland and Trinity College Dublin. The original work on the protection scheme was carried out by Jenny Deakin as part fulfilment for the M.Sc. degree at the Environmental Sciences Unit, Trinity College Dublin (Deakin, 1994).

The geological and hydrogeological data for County Limerick are interpreted to enable:
(i) delineation of aquifers;
(ii) assessment of the groundwater vulnerability to contamination;
(iii) delineation of protection areas around public supply wells and springs; and
(iv) production of a groundwater protection scheme which relates the data to possible land uses in the county and to codes of practice for potentially polluting developments.

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

This study compiles, for the first time, all readily available geological and groundwater data for the county and sets in place a computerised database within the Geological Survey of Ireland (GSI), which can be accessed by the local authority and others, and which can be up-dated as new information becomes available.

A suite of environmental geology maps accompany the report. These are as follows:

(i) Primary Data or Basic Maps
- bedrock geology map
- subsoils (Quaternary) geology map
- outcrop and depth to bedrock map
- hydrogeological data map

(ii) Derived or Interpretative Maps
- aquifer map
- groundwater vulnerability map

(iii) Land-use Planning Map
- groundwater protection scheme map

These maps can be used not only to assist in groundwater development and protection, but also in decision-making on major construction projects such as pipelines and roadways.

It is important to recognise however, that detailed regional hydrogeological investigations in County Limerick are limited to a number of public supply sources and industrial sites. Consequently, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of County Limerick. However, this report provides a good basis for strategic decision-making and for site specific investigations.

The general groundwater protection scheme guidelines used by the GSI are given in Chapter 2. These are the basis for the County Limerick protection scheme and they provide the structure for this report.

1.2 Draft Limerick County Development Plan

This is the groundwater protection scheme referred to in paragraph 9.3 of the Draft Limerick County Development Plan.

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 depends 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 (a public supply well, for instance). **Preventative measures** may include, for instance: control of land-use practices and in particular directing developments towards lower risk areas; suitable 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 and factors that relate to the potentially polluting activity. The geological and hydrogeological factors are (a) the vulnerability to contamination and (b) the relative importance or value of the groundwater resource. The factors that relate to the potentially polluting activity are (a) the contaminant loading and (b) the preventative measures.

RISK TO GROUNDWATER

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

A conceptual model of the relationship between these factors is given in the Figure 2.1, where septic tank effluent is taken as the hazard. 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, particularly for drinking purposes, for the benefit of present and future generations.

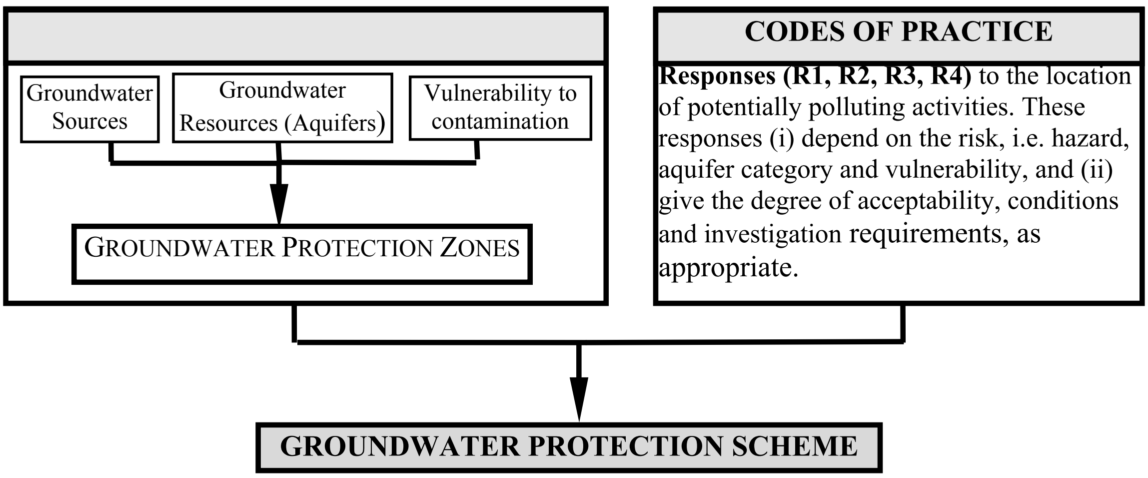
The objectives, which are interrelated, are as follows:
- to assist the statutory authorities in meeting their responsibilities for the protection and conservation of groundwater resources
- to provide geological and hydrogeological information for the planning process, so that potentially polluting 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 Groundwater Protection Scheme



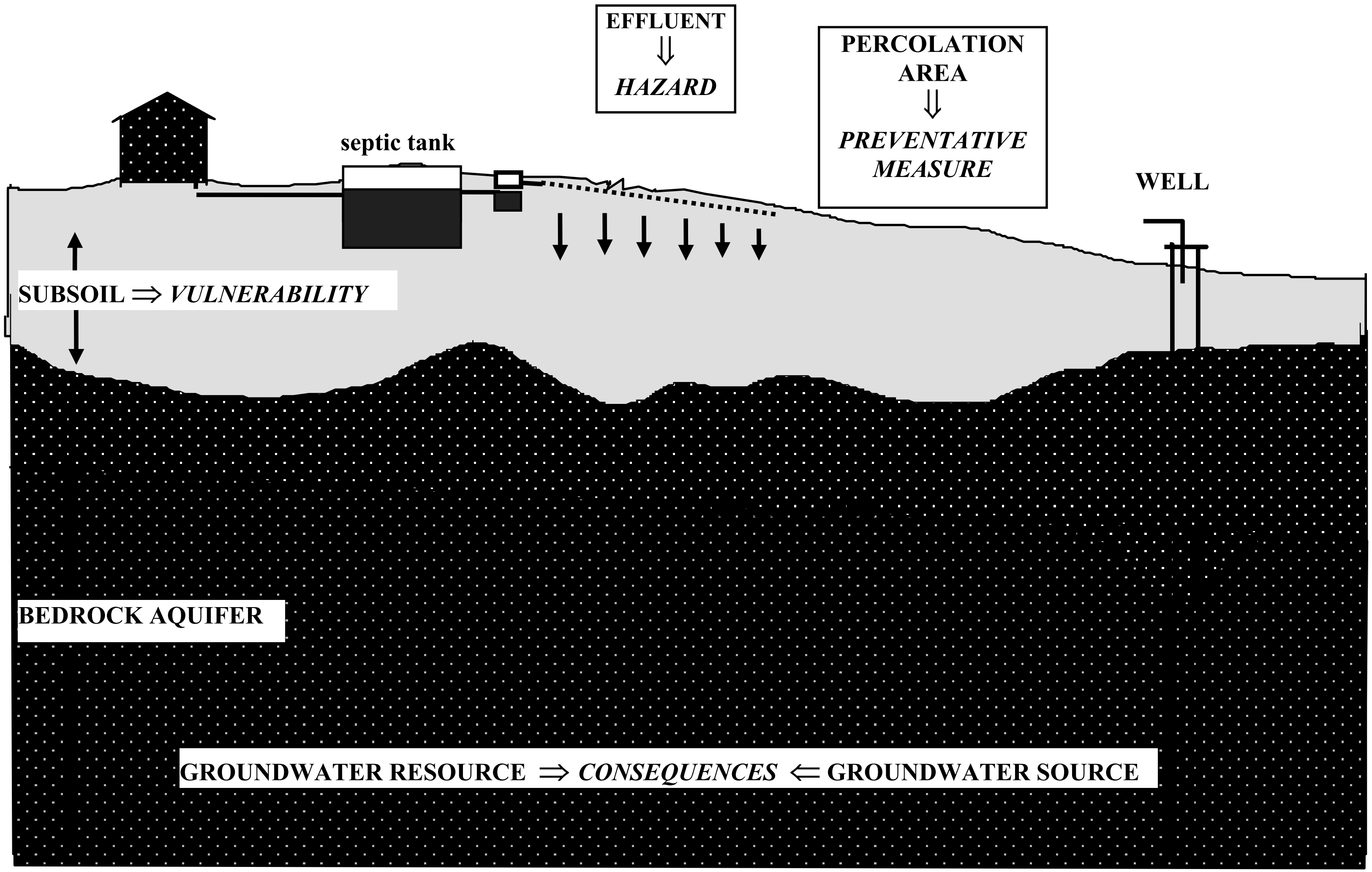


Figure 2.1 A Conceptual Model of the Elements of Risk and Risk Management

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

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

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 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.

2.3.2.3 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.

2.3.2.4 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 8 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.

Table 2.2. Matrix of Source Protection Zones

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

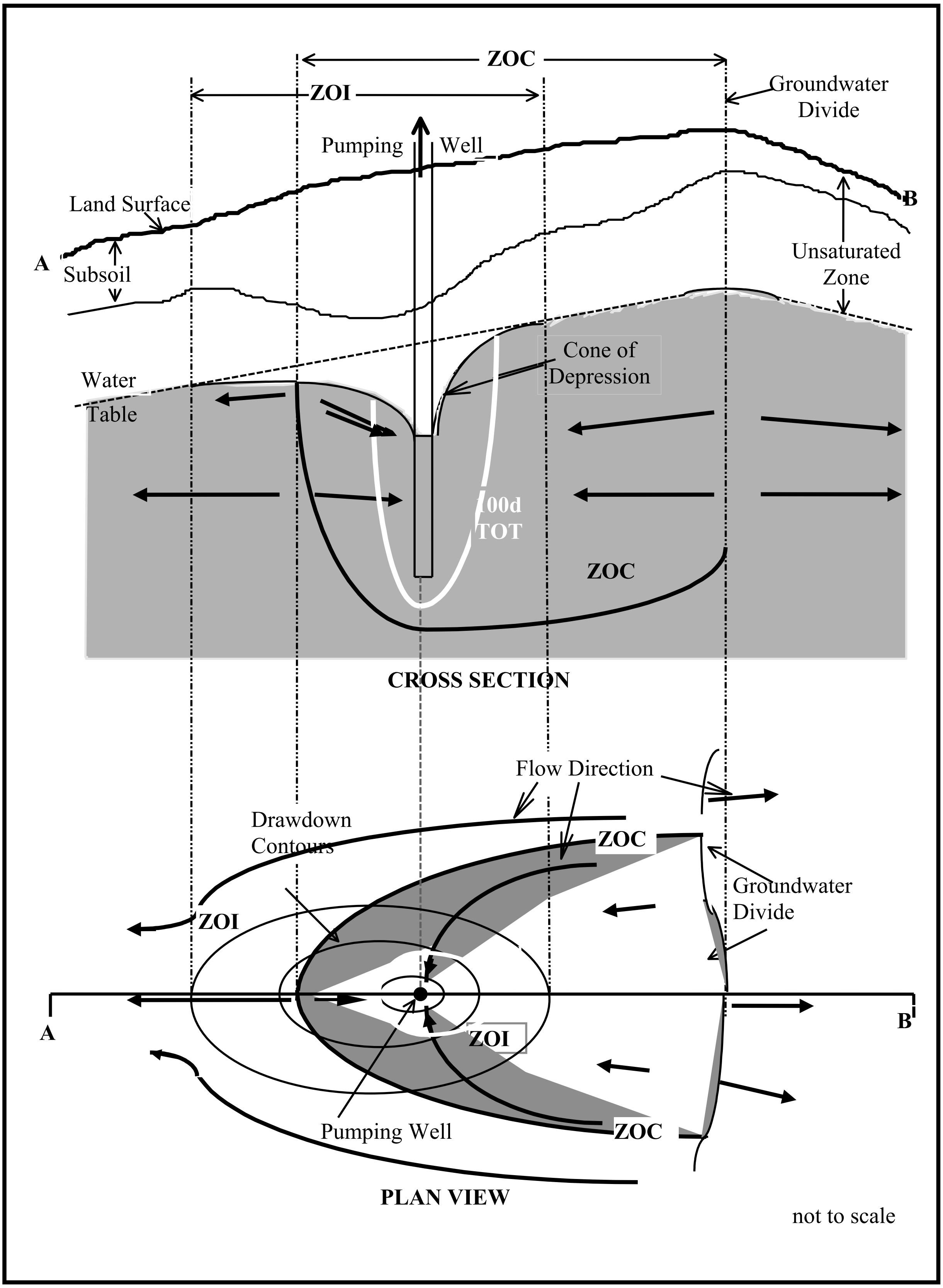


Figure 2.3 Conceptual Model of the Zone of Contribution (ZOC) and the Zone of Influence (ZOI) at a Pumping Well (adapted from U.S. EPA, 1987)

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 (**Rk**)
(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)	
	Rk	Rf/Rg	Lm/Lg	Ll	Pl	Pu
Extreme (E)	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	Pu/E
High (H)	Rk/H	Rf/H	Lm/H	Ll/H	Pl/H	Pu/H
Moderate (M)	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	Pu/M
Low (L)	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	Pu/L

2.4 Codes of Practice

The Codes of Practice contain a series of **Response Matrices**, each setting 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 in a Code of Practice, 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 codes of practice are not necessarily a restriction on 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 Codes of Practice

The integration of the groundwater protection zones and the code of practice 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		
	Inner	*Outer*	*Rk*	*Rf/Rg*	*Lm/Lg*	*Ll*	*Pl*	*Pu*	
Extreme (E)	R4	R4	R4	R4	R3^{m}	R2^{d}	R2^{c}	R2^{b}	↓
High (H)	R4	R4	R4	R3^{m}	R3^{n}	R2^{c}	R2^{b}	R2^{a}	↓
Moderate (M)	R4	R3^{m}	R3^{m}	R2^{d}	R2^{c}	R2^{b}	R2^{a}	R1	↓
Low (L)	R3^{m}	R3^{o}	R2^{d}	R2^{c}	R2^{b}	R2^{a}	R1	R1	↓
	→	→	→	→	→	→	→	→	

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

The 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 organic wastes; only the landfill and landspreading codes of practice are readily available (from the EPA). As a means of illustrating the use of the scheme and the relationship between the groundwater protection zones and the codes of practice, the draft codes of practice for landfills is given in the following section.

2.6 Draft Code of Practice 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		
	Inner	*Outer*	*Rk*	*Rf/Rg*	*Lm/L*	*Ll*	*Pl*	*Pu*	
Extreme (E)	R4	R4	R4	R4	R4	R2^{4}	R2^{4}	R2^{2}	↓
High (H)	R4	R4	R4	R4	R3^{2}	R2^{4}	R2^{4}	R2^{2}	↓
Moderate (M)	R4	R4	R4	R3^{2}	R2^{5}	R2^{3}	R2^{3}	R2^{1}	↓
Low (L)	R4	R3^{1}	R3^{1}	R3^{1}	R2^{1}	R2^{1}	R2^{1}	R2^{1}	↓
	→	→	→	→	→	→	→	→	

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

- ♦ From the point of view of reducing 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.

With regard to the possible siting of landfills on or near regionally important (major) aquifers and where no reasonable alternative can be found, such siting should only be considered 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 or non-hazardous and the waste acceptance procedures employed are in accordance with the criteria published by the Environmental Protection Agency.

2.7 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.

Similarly, the **source protection zone maps** result from combining **vulnerability** and **source protection area maps**. The **source protection areas** are based largely on assessments of **hydrogeological data**, 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

2.8 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. In certain cases the scheme may not provide sufficient information for site specific decisions and it may be necessary to carry out further site investigations before arriving at a definite decision. 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 their responsibility for preventing groundwater contamination in a practical and reasonable manner.

2.9 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 sustainable 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.

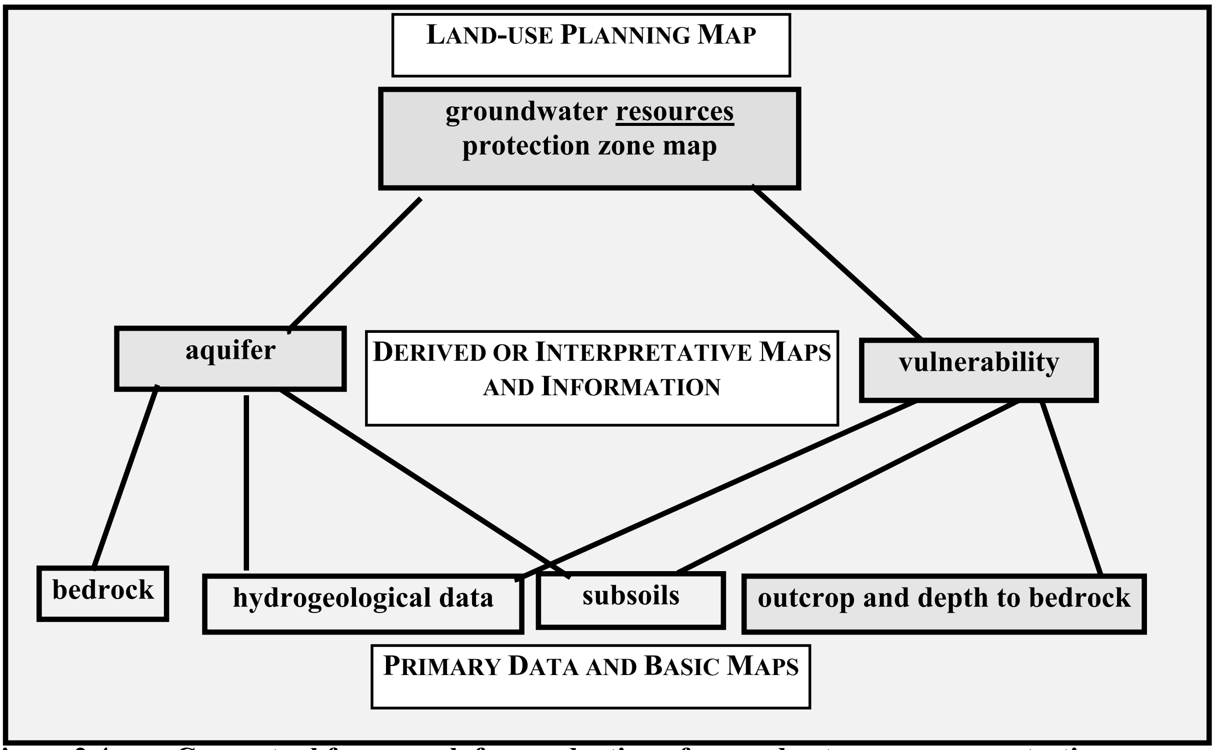


Figure 2.4 Conceptual framework for production of groundwater <u>resource</u> protection zones, indicating information needs and links.

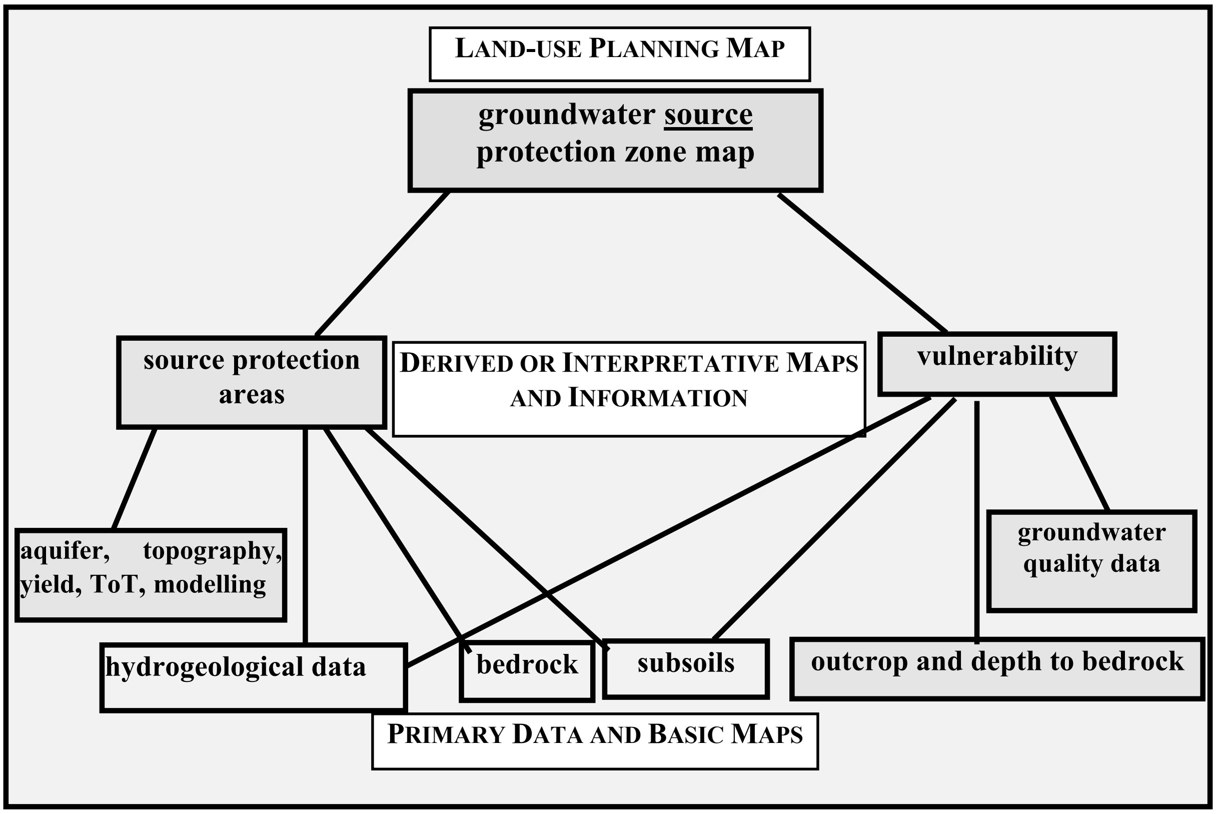


Figure 2.5 Conceptual framework for production of groundwater <u>source</u> protection zones, indicating information needs and links.

3. Bedrock Geology

3.1 Introduction

The objective of this chapter is to present a brief description of the elements of the bedrock geology that are relevant to the hydrogeology. The hydrogeology of the bedrock of County Limerick depends largely on the rock composition (lithology) and on the rock deformation that occurred during the long geological history of the county.

The bedrock geology of Co. Limerick comprises a series of rocks ranging in age from Silurian (438 million years old) to the Westphalian of the Upper Carboniferous (300 million years old). The rocks deposited in this period consist of both sedimentary – limestones, sandstones and shales – and igneous (volcanic) rocks.

The landscape of Co. Limerick reflects the varied underlying geology. The mountains to the north-east and south-east of the county are composed largely of the resistant Old Red Sandstone with older, less competent Silurian rocks in the core, while the younger, softer and soluble Carboniferous limestones underlie an extensive low lying plain, which is interrupted by three narrow ridges of folded Old Red Sandstone. The limestone plain passes westwards to a steep escarpment (west of Newcastlewest), which marks the upland areas of the younger Upper Carboniferous sandstones and shales. The volcanic rocks are also well defined in the east around Herbertstown and Pallasgrean.

These rocks were folded and faulted throughout the county. However, the intensity of rock deformation decreases moving northwards.

The geology of the county is complex with both temporal and lateral changes in rock composition. However, only a brief description of the different rock units and their inter-relationships is given in this report; a more detailed description is given in Deakin (1994). The rocks are described in groups, according to their age and starting with the oldest:
(i) Silurian Rocks;
(ii) Devonian Rocks;
(iii) Lower Carboniferous Rocks;
(iv) Upper Carboniferous Rocks.

The bedrock geology of the area is shown on Map 1. (Formal rock unit names are used in this chapter, together with their letter code which is shown on the maps.) This map was compiled by Deakin (1994) from existing sources. The geology of Limerick is currently being up-dated by the Bedrock Section of the GSI; when all the relevant maps are published, this map can be re-done.

3.2 Silurian Rocks

The oldest rocks to crop out in Co. Limerick are of Upper Silurian age and they are visible in both the north-east and south-east upland regions, forming the Slieve Felim Hills and the Galty Mountains respectively. The rocks may be generally described as a series of muddy sandstones (greywackes) with interbedded mudstones and siltstones of varying colours from pale grey through green to purple. Two rock units are present in the Galty Mountains – the Inchacoomb Formation (1600 m thick) and the overlying Ballygeana Formation (1275 m thick). At Slieve Felim, one rock unit is present – the Hollyford Formation.

3.2.1 Inchacoomb Formation (IB)

The Inchacoomb Formation is described as a sequence of thickly bedded, mid-grey turbidites with occasional interbedded siltstones, mudstones, sandstones and shales. It is further subdivided into two members: the upper Assaroola member (Ibaa; 600 m thick) consisting mainly of fine grained, grey calcareous siltstones, and the lower Inchacoomb member ((Ibib; 1000 m thick) which is predominantly thick, greenish grey greywackes.

3.2.2 Ballygeana Formation (BN)

The Ballygeana Formation comprises a series of darker, siltier greywackes with a larger proportion of interbedded siltstones, mudstones and shales than the Inchacoomb Formation.

3.2.3 Hollyford Formation (HF)

This consists of a repetitive series of dark, grey-blue muddy sandstones (greywackes) (60%), dark mudstones (25%) and well bedded, grey-green siltstones (15%), which are interbedded. The Hollyford Formation is more than 100 m thick. It is generally finer grained than the rocks in the Galty mountains.

3.3 Devonian Rocks

Rocks of Devonian age, the Old Red Sandstone (ORS), vary somewhat in lithology in different parts of County Limerick. Brief descriptions of the different rock units and their locations are given in Table 3.1.

Table 3.1. Devonian Rock Units in County Limerick.

Rock Formation	Thickness (m)	Lithology	Location
Cappaghwhite (CA)	300	Coarse conglomerates overlain by red sandstones and interbedded black mudstones	Slieve Felim
Kiltorcan Sandstone (KT)	300	Thickly bedded, yellow and white, coarse grained sandstones, red to yellow fine grained sandstones and occasional purple, red and green mudstones	Ballingarry, Coronogher
Red Sandstones (rb)	up to 1955	Purple, red and grey sandstones, siltstones and conglomerates with interbedded mudstones	Ballingarry, Corronoher
Ardane (AE)	*c.* 70	Thickly bedded coarse grained sandstones and pebble conglomerates	Galty Mountains
Ballydavid Sst. (BD)	*c.* 470	Fine to medium grained red sandstones with few mudrocks and rare thin conglomerates	Galty Mountains
Slievenamuck (SM)	*c.* 600	Conglomerates and purple coarse grained conglomeratic sandstones. Gradual decrease in mudrock component moving upwards	Galty Mountains
Slievereagh (SR)	*c.* 125	Thickly bedded purple conglomerates	Galty Mountains
Lough Muskry (LM)	*c.* 330	Interbedded purple-red siltstones with sandstones and some conglomerates. Characterised by the presence of purple mudrocks up to 2 m thick	Galty Mountains
Galtymore Sst. (GS)	*c.* 200	Thickly bedded, fine to medium grained, pale red sandstones	Galty Mountains
Pigeon Rock (PR)	*c.* 160	Poorly bedded conglomerates and breccias in beds 0.5–5 m thick. Sporadic sandstone beds in thin discontinuous wedges	Galty Mountains

3.4 Lower Carboniferous Rocks

These rocks are the most widespread in Co. Limerick. The Carboniferous was a period of marine deposition of a wide range of sediments, including sandstones, shales, muddy limestones and pure limestones. The limestones underlie the extensive low-lying plain in central Limerick and are bounded to the west by an upland area of Upper Carboniferous sandstones and shales rising some 150 m above the limestones. There was also a period of volcanism in east Limerick at this time.

At times during the Carboniferous, the depositional environment varied across the county and therefore rocks of a similar age have different compositions. So, for instance the Waulsortian rocks (Section 3.4.4) are overlain by a variety of rock units. As muddy limestones were being deposited in deep water in the vicinity of the Shannon (the Shannon Trough), pure limestones were being deposited in a shallow sea further south. These lateral variations are usually gradational; therefore the geology of Limerick is complex. The lateral variations are indicated on the legends of Maps 1E and 1W; they are not described further in this report.

3.4.1 Mellon House Formation (MH)

The Mellon House Formation (40 m thick) incorporates the transition from terrestrial to marine sediments, and comprises fine grained sandstones, dark-grey laminated siltstones, and calcareous shale with some limestone. Deep borehole logs suggest that there is an increase in limestones within the formation moving from west to east across the county.

3.4.2 Ringmoylan Shale Formation (RM)

The Ringmoylan Shale Formation (20–30 m) is dominated by thinly bedded, dark-grey to black calcareous shales, which are interbedded with thin bands of fossiliferous limestones and scattered thin siltstone bands.

The Ringmoylan Shales are very poorly exposed and their probable presence is often indicated by a persistent strip of low lying marshy ground. Separation of this formation from the underlying Mellon House Beds on the geology maps (Maps 1E and 1W) was estimated on the basis of average thicknesses only.

3.4.3 Ballysteen Limestone (BA)

The Ballysteen Limestone includes four units: the Ballyvergin Mudstone, the Ballymartin Limestone, the middle unit and the upper unit.

The Ballyvergin Mudstone Formation is a thin 5 m horizon of grey-green, non-calcareous mudstone with thin siltstone bands. This serves as a regional marker bed throughout south-west Ireland.

The Ballymartin Formation (35–45 m) is composed of thinly bedded, pale-grey, muddy fossiliferous limestones which alternate in equal proportions with dark calcareous shales.

The middle unit is approximately 140 m thick and is a well bedded, relatively pure, dark blue-black, fossiliferous limestones with little shale. These clean limestones pass gradationally upwards into the upper unit, a 50 m thick, poorly fossiliferous muddy limestone, with increasing shale content moving upwards.

There is a distinct thickening of the upper parts of the Ballysteen moving south-eastwards from the Shannon Estuary, accompanied by a decrease in shale content.

3.4.4 Waulsortian Limestone Formation (WA)

This is a pale-grey, poorly-bedded, fine grained limestone containing frequent fossils. It is also called "Waulsortian Reef" and "Mudmound" limestone. It was deposited as interfingering mounds of fine organic, probably mainly algal, material in a sea where the sediment input from land was minimal. Original cavities are now filled with calcite and may form a significant proportion of the total volume of the rock. It is one of the most extensive limestone units in Co. Limerick. Topographically, it is often expressed as rounded hills, some replicating the originally deposited mounds.

3.4.5 Muddy Shelf Limestones (msl)

The succession to the west of the county, south of the Shannon Estuary, comprises primarily muddy limestones and mudstones. The sequence is equivalent to what is known as the Calp in eastern Ireland successions and is largely undifferentiated in Limerick. At the western edge of the Shannon trough, these limestones have been differentiated into four units: Rathkeale Limestone, Durnish Limestone, Shanagolden Limestone, and Parsonage Limestone.

3.4.6 Rathkeale Limestones (RC)

This unit consists of dark muddy limestones and shaly mudstones.

3.4.7 Durnish Limestones (DU)

This is a thick (300 m) sequence of blue black fossiliferous limestones, with bands of chert nodules parallel to bedding.

3.4.8 Shanagolden Limestones (SG)

These are black, well bedded limestones similar to the Durnish Limestones except that chert is uncommon.

3.4.9 Parsonage Beds (pa)

These are pale to dark grey calcitic mudstones.

3.4.10 Clean Shelf Limestones (csl)

Moving towards the margins of the Shannon Trough, a shallower series of oolitic limestones with lenses of bedded cherts are present. These limestones are interbedded on occasion with thin shales but may generally be described as clean.

In south-east Limerick, relatively clean limestones (Kilsheelin Limestone, Croane Limestone and Rathronan Limestone) with occasional chert and shales were deposited. These are steeply dipping and appear as thin bands on Map 1E.

In south Limerick, the limestones of similar age are called the Aghmacart Limestone and the Ballyadams Limestone.

3.4.11 Kilsheelan Limestone (KS)

This is a clean to slightly muddy limestone unit, with occasional chert nodules, and is about 600 m thick.

3.4.12 Croane Limestone (CR)

This is at thinly bedded dark fine grained limestone unit with shales and cherts, and is about 300 m thick.

3.4.13 Rathronan Limestone (RR)

This is a poorly bedded pale grey clean limestone unit with thinly bedded cherts, and is about 300 m thick.

3.4.14 Aghmacart Limestone (AG)

This is a dark-grey, generally fine grained limestone with thin shales and with frequent chert bands towards the bottom.

3.4.15 Ballyadams Limestone (BM)

This is a pale-grey, thickly bedded, coarse grained, fossiliferous limestone with clay wayboards.

3.4.16 Knockroe Volcanic Formation (KRf/KRt)

These rocks are primarily basaltic in composition and include lavas, intermediate to basic tuffs (ashes) and coarse agglomerates. The thickness of the sequence varies at different points around the syncline from 250 m to nearly 550 m. The areas of greater thickness are close to eruptive centres. The formation commences with a coarse purple agglomerate at the vents which grades outwards to fine tuffs. This is followed by basalt flows, calcareous tuffs and finally intrusive rocks. Many of the lavas have brecciated bases.

3.4.17 Herbertstown Limestone Formation (HB)

These limestones are clean, pale-blue, thickly bedded, well sorted, medium to coarse, oolitic and skeletal grainstones.

This limestone unit is interfingered with and laterally equivalent to both the upper and lower volcanic sequences. Thickness varies laterally from 150 m thick to the south-east, elsewhere reaching as much as 500 m thick.

3.4.18 Knockseefin Volcanic Formation (KVf/KVt)

The sequence consists of basic lava flows and basic tuffs which were sourced from the south-east in a second period of volcanism. Lateral thickness changes range from 500 m in the east to zero in the west and north-west where the Herbertstown Limestones are dominant.

3.4.19 Dromkeen Limestone Formation (DK)

The Dromkeen Formation consists of clean, pale grey, well bedded, fine grained limestones. The rocks are very similar to the Herbertstown Limestones although they are typically finer grained, lighter in colour, much more poorly sorted, have a lesser degree of cementation and are almost completely post volcanic (Strogen, 1988). Volcanic detritus and muddy material is absent but thin sporadic shale bands of a few centimetres in thickness do occur.

3.5 The Upper Carboniferous Rocks

The Upper Carboniferous rocks are sub-divided by age into older Namurian rocks and younger Westphalian rocks. Namurian rocks are present in west, south and east-central areas of Limerick. Westphalian rocks are present in west Limerick only.

In west Limerick, the following rock units (in order of increasing age) are present:

- Upper Namurian Beds (NAMu)
- Cummer Flagstones (CF)
- Clare Shales (CS).

In south-west Limerick, the Upper Namurian Beds are sub-divided into a five cycles of alternating sandstones, siltstones and shales:

- Knockaclarig Cyclothem (kc), including the Mountcollins Sandstone (ms);
- Cleanglass Cyclothem (cc), including the Breanagh Sandstone (bs);
- Mileen Cyclothem, including the Mileen Beds (mc) and the Rockchapel Sandstone (rs);
- Tournafulla Cyclothem, including the Tournafulla Beds (tc) and the Tournafulla Sandstone (ts);

- Foiladaun Cyclothem, including the Meentinny Flagstone (mf) and the Newcastle Siltstone (ns).

In south-east Limerick, along the border with Cork, a small area of Namurian rocks, called the Giants Grave Mudstones (GG), is present. Similar rocks, called the Lackentadane Mudstones, are present in a narrow band coming across the Tipperary border.

In the area surrounded by volcanic rocks in east-central Limerick, the Longstone Formation is present. This is sub-divided into three rock units (in order of increasing age):
- Caherconreafy Sandstone Member (LOcc);
- Longstone Flagstone Member (LOfg);
- Longstone Shale Member (LOsh).

The youngest rocks in Co. Limerick are Westphalian in age (300 million years), and they are called the Cratloe Flagstone Formation (CT).

3.5.1 Clare Shales (CS)

This formation primarily comprises a series of soft, pyritic, olive and black, fossiliferous shales. The shales crop out at the base of the escarpment near Newcastlewest in a thin band and in a small outcrop to the extreme north-west of the county. The whole formation thins out in a southerly direction over the county from its thickest (92 m) at Foynes, approximately the centre of the Shannon Trough, to zero in south Co. Limerick.

3.5.2 Cummer Flagstones (CF)

The Cummer Flagstones (230 m) overlies the Clare Shales and crops out on the steep face of the escarpment, broadening out slightly to form a plateau north-west of Ardagh. The rocks consist of alternations of bedded, muddy, coarse siltstones and mudstones overlain by an upper unit of more massive (up to 9 m thick) fine grained quartzitic, muddy sandstones or coarse siltstones with alternating mudstones.

3.5.3 Upper Namurian Beds (NAMu)

The remaining Namurian beds comprise a series of alternating sandstones, siltstones and shales in varying thicknesses. To the north on Foynes Island, the sediments appear quite sandy and a particular unit of sandstones (45 m) overlying the Cummer Formation is identified there as the Foynes Sandstone, but is not shown on Map 1W.

In the south-west, the sediments were deposited in five cycles, each comprising, in ascending order, some or all of the following rock types: shale, siltstone, flaggy sandstone, massive sandstone, seat earth and coal. The sandstones and siltstones are the dominant rock type throughout the cyclothemic succession. The sandstones are generally well bedded, massive and dark grey in colour although the Rockchapel sandstone is pale grey to white with dark carbonaceous specks. The coals are either a rich carbonaceous shale or anthracite, often pyritic and both these and the seat earths are thin and localised.

3.5.4 Giants Grave Formation (GG)

This consists of dark mudstones with siltstones and sandstones.

3.5.5 Lackentadane Group (LA)

Rocks of the Lackentadane Group, which lie to the east of Duntryleague, are a series of finely micaceous, olive green, flaggy mudstones, shaly mudstones, siltstones and fine grained sandstones, and are typical of Namurian strata. Deposits of the lower Clare Shale type are absent from the succession in this area and the first beds to be laid down are equivalent to the Cummer Formation of the west.

3.5.6 The Longstone Formation (LO)

The formation totals 190 m in thickness and may be generally described as a sequence of basal laminated mudstones and shales, and thin sandstones, with a decrease in shale content moving upwards, culminating in thickly bedded sandstones towards the top.

Longstone Shale Member: 75–80 m of predominantly olive, but buff-weathering, flaggy mudstones and shales. Dark shales occur near the base, becoming more silty and internally laminated moving upwards. Scarce fine grained graded sandstones occur towards the top of the member.

Longstone Flagstone Member: 105 m thick succession showing rapid increase in siltstone proportion and a decrease in shale. Flagstone beds are 5–15 cm thick with internal laminations emphasised by white mica.

Caherconreafy Sandstone Member: 6 m unit of thickly bedded, well sorted, medium grained, ferruginous and calcareous sandstone.

3.5.7 Crataloe Flagstone Formation (Coal Measures)

The outcrop area of this unit is small and is situated to the west of the county at the Crataloe Coal Field. The formation is composed of alternating beds of sandstones, shales and mudstones.

The succession begins with a heavy shale content, blue-black and very fossiliferous for the first 6 m, moving up into a 40 m thick mudstone dominated section with some thin layers of fine grained pale sandstone. Overlying the mudstone is the coal seam (anthracite) which was formerly mined in shallow pits, and this in turn is overlain by 15 m of unexposed strata which are taken to be muddy. A deeply weathered 50 m thick pale felspathic, medium and coarse grained sandstone succeeds upwards with layers of pseudo-conglomerate composed of 'clay-galls' enclosed in coarse sand. The uppermost beds in the succession are shales and fine grained sandstones of a maximum thickness of 15 m (Nevill, 1958).

3.6 Structural History

The structural geology of the county has caused varying degrees of rock deformation. Bedrock permeability is influenced by this deformation. Rocks deform mainly by folding and faulting; both of which are associated with fracturing and permeability development.

Two orogenies (mountain-building events), called the Caledonian and Variscan, have affected Limerick. As a consequence, gentle east-west trending anticlines (folds) and synclines dominate with numerous cross faults.

The Caledonian Orogeny tightly folded and cleaved the Silurian rocks in a north-east-south-west direction and this trend is reflected in the later Variscan orogenic deformation. The effects of the latter are preserved in the Devonian and Carboniferous strata. The intensity of deformation under both orogenys increases with proximity to the orogenic fronts, both of which lay to the south of the county. Faulting was also an important component of these deformation events and this has occurred both parallel and perpendicular to strike.

The strike parallel faults are more prominent in south Limerick closer to the Munster Basin where they tend to fault out the shalier formations – e.g. south of the Galty Mountains where the Kiltorcan Sandstone is in contact with the lower parts of the Ballysteen Formation, separated by 'rotten' greenish shales interpreted as fault gouge (Shearley, 1988). The cross faults trend 10–30^{o} NW and are a series of long straight vertical fractures with both strike slip and normal dip slip motion. The faulting gives rise to a pattern of compartmentalised blocks, each having its own structural style, creating isolated blocks of different stratigraphical horizons at the surface. This may be an explanation for the fault pattern south of Bruree. Reverse thrust faults are also common, particularly again to the south, at the northern margin of the Munster Basin. Jointing is generally in a north-south direction and is steeply dipping, although there is also a subordinate set trending east-west.

In general, the jointing caused by the Variscan folding and faulting is greatest in south Limerick and is likely to decrease northwards towards the Shannon. The impact is likely to be least in north-eastern Limerick.

4. Subsoils (Quaternary) Geology

4.1 Introduction

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

During the Pleistocene the glaciers and ice sheets laid down a wide range of deposits, which differ in thickness, extent and lithology. Material for the deposits originated from bedrock and was subjected to different processes within, beneath and around the ice. Some were deposited randomly and so are unsorted and have varying grain sizes, while others were deposited by water in and around the ice sheets and are relatively well sorted and coarse grained.

4.2 Subsoil Types

There are eight subsoil types identified in Co. Limerick and shown on Maps 2E and 2W:

- till
- sands and gravels
- till-with-gravel
- slope deposits (also known as head)
- lake sediments
- alluvium
- peat
- marine deposits.

Areas where bedrock comes within 1 m of the surface are also shown on the maps.

4.3 Till

Till (often referred to as boulder clay) is the most widespread subsoil in Limerick. On Maps 2E and 2W, it is classified on the basis of the dominant clast lithology and the matrix composition (texture).

The dominant clast type (lithology) is the principle basis for classifying the tills in Limerick. Five categories are shown on Maps 2E and 2W: limestone till, sandstone till, Silurian till, volcanic till and Namurian till. Tills in Co. Limerick are generally well defined lithologically.

The subdivision of tills based on matrix composition depends on the proportions of different sized particles present in the matrix. There are five broad categories; clayey tills, silty tills, sandy tills, gravelly tills and stony tills. The methods of determining the categories is by visual assessment and particle size analysis. A clayey till, for example, will have a high percentage of clay particles present, a silty till will have a high percentage of silt in its matrix and so on. The main confusion which may arise lies in distinguishing between a gravelly and a stony till. A gravelly till has a sandy gravelly make-up and the clasts within it will be subrounded to rounded. (Distinguishing between this and a dirty gravel comes solely from a genetic interpretation.) A stony till, on the other hand, can have any sort of matrix composition and is often clay rich. The stones and boulders within it are also more angular in nature (Warren, W. P., pers. comm.).

Boundaries based on till texture are not shown on the subsoils maps; however, symbols indicate the texture at specific locations. Also, a limited number – 21 – particle size analyses were carried out to help assess the till texture.

4.3.1 Limestone Tills

The dominant till type is limestone till and it is generally found throughout Limerick, reflecting the dominance of the Carboniferous limestone bedrock from which it is derived. A distinct line swings across the county in an east-west direction separating areas of mainly gravelly till to the north from the more typical clayey deposits to the south. The limestone clasts have a tendency to weather out in places.

4.3.2 Sandstone Tills

Sandstone tills are found in the north-east and south-east of the county, associated with Old Red Sandstone bedrock, and are typically a reddish colour with stone counts of 60–70% sandstone and <30% limestone. The southerly deposit has a varied matrix composition and can be either sandy and gravelly or clayey. The tills are largely undifferentiated in the north and are considered to be more sandy and gravelly than limestone tills.

4.3.3 Silurian Tills

Silurian tills are found to the south-east of the county where the Silurian bedrock (greywackes and shales) crops out. (They are termed Silurian tills due to the lithology of their dominant clasts, not because they are Silurian in age.) The till matrix is clayey where differentiated due to the high percentage of shale in the parent material.

4.3.4 Volcanic Tills

The volcanic tills are very site specific and are located to the south-south-east of the volcanic outcrops. This is due to carry-over of volcanic material in the ice which moved in that direction. The deposit matrix is generally stony and is clayey in places.

4.3.5 Namurian Tills

The Namurian tills are present in the west of the county on the Namurian uplands (shales and sandstones). This rock type tends to produce more matrix material than the slightly more competent Silurian rocks (Warren, W. P., pers. comm.). The matrix is usually clayey.

4.4 Sands and gravels

Deposition of sands and gravels takes place mainly when the glaciers are melting. This gives rise to large volumes of meltwaters with great erosive and transporting power. The subsoils deposited in this environment are primarily well rounded gravels with sand, with the finer fractions of clay and silt washed out. Outwash deposits take the form of fans of stream debris dropped at the glacier front via drainage channels. Deltaic deposits are similar but form deltas where the drainage channels discharge into a standing body of water. Deposits remaining in the drainage channels form eskers, similar to a river drainage system in arrangement with tributaries converging downstream.

The presence of sand and gravel is often reflected in the topography as ridges (eskers), hummocks and hollows (kames and kettle holes) or in large fan shaped deposits (outwash, deltas).

Where the dominant clast lithology is known, the gravels are differentiated into two main types – limestone and sandstone – with the former being the most common.

The sands/gravels in north-east Limerick and in central and south Limerick are generally better sorted with less clay and silt than the more poorly sorted deposits in south-east Limerick on the northern flank of the Galty mountains. All the sand/gravel deposits will contain some till, with the proportion higher in the south-east.

4.5 Till-with-gravel

Till-with-gravel is an intermediate deposit type and it is used to describe subsoils which contain intermixed tills and gravels to such an extent that they were not mapped out individually, usually due to the complexity of the deposits. The matrix composition is extremely variable and will depend on the proportion of till present. Generally speaking it can be expected to be gravelly although the south-easterly deposit does have a clayey component.

4.6 Slope Deposits (Head)

Slope deposits are accumulations of rock waste derived from underlying bedrock. They are primarily found on hill and mountain slopes where they are often associated with outcropping rock, thin tills and peat. The deposits are extremely variable and are very much dependent on the parent rock type. Clasts are angular and interstices may be filled with a variable matrix. These deposits are also known as hillwash and rubble. Deposits in Limerick are classified on the basis of the dominant clast lithology and there are consequently three types: sandstone head, Silurian head and Namurian head.

4.7 Lake Bottom Deposits

Small areas of post-glacial lake clays and silts are scattered over the low lying limestone plain in small, often isolated, hollows.

4.8 Alluvial Deposits

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

Alluvial deposits may be subdivided into gravels, sands and silts. However, there was insufficient information for Limerick to enable this subdivision to be shown on the subsoils map. Alluvial sediments are expected to be primarily silty deposits with some clay in the large flood plains of the Mulkear, Deel and Maigue, where flow velocities are relatively low. They are likely to be more sandy where flow velocities are faster – on and close to the hills and mountains. Alluvial gravels are also present in places.

4.9 Peat

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

The largest areas of peat in Co. Limerick are the blanket peats on the higher ground in the west on the poorly drained Namurian shales and sandstones, in the mountainous areas of the Galtys and the Slieve Felims, and in north Limerick in the area around Castleconnell. Basin peats are found in the low-lying areas of the central plain and are often associated with alluvium, lake clays and marls. These two peat types are not differentiated on Maps 2E and 2W.

4.10 Marine Deposits

Marine deposits in Limerick are also post glacial in age and are deposited by the actions of the present day Shannon estuary. They occur on the northern coast of the county in the Shannon estuary and do not encroach inland to any large degree. They may be subdivided in the same manner as alluvial deposits into beach gravels, sands and estuarine silts and muds. Limerick marine deposits are very small and site specific and so have not been differentiated on the maps.

4.11 Subsoil Thicknesses

The thickness of the subsoil (the depth to bedrock) is a critical factor in determining groundwater vulnerability.

Subsoil thicknesses vary considerably over the county, from very thin cover where rock is close to the surface, to depths of more than 80 m. The direction of ice movement, being generally towards the south, has spatially influenced the thicknesses of the deposits. Those on the northern flanks of rock features are usually thicker than those on the leeward side.

Depth-to-rock maps (Maps 3E and 3W) have been prepared from the Geological Survey databases. These maps show areas where rock crops out at surface and depth-to-rock data from borehole records. There are three groups of borehole records, which are colour coded according to the degree of locational accuracy. Data coloured red are plotted to within an accuracy of 50 m, the green data are less accurately located and are correct to within 100–500 m, while the blue borehole data are only referenced by the townland in which they were drilled and accuracies to within 1 km are to be expected.

Generally speaking, the thickest deposits are tills and till-with-gravel, and they are found in the morainic ridges which lie around the edges of the limestone plain, banked up against the upland areas of the Galtys and the Namurian scarp. Deposits reach up to 80 m thick in the south-east of the county, to the north of the Galtys, while in the region south of Newcastlewest, thicknesses of more than 40 m are recorded. The other bedrock ridges also have thick deposits on their northern flanks and depths of 20–40 m are common.

Gravel deposits are usually less than 10 m thick although there are 11 deposits throughout the county which may reach greater thicknesses (refer to Chapter 5). Head deposits are usually thin as they occur on mountain slopes and would normally vary from less than 1 m up to 6–7 m thick. Thicknesses of lake and alluvial deposits are unknown but it is unlikely that they are more than 10 m thick. The greatest thickness of peat occurs on Slieve Felim and in the valley further north where deposits range from 3–4.5 m in depth. Elsewhere thicknesses of just over 1 m are the norm with maximum depths of up to 2.5 m.

5. Hydrogeology and Aquifer Classification

5.1 Introduction

This chapter summarises the relevant and available hydrogeological and groundwater information for County Limerick. A brief description of the hydrogeology of each rock unit is given, followed by aquifer category based on the GSI aquifer classification scheme. The hydrogeological data for the county are summarised on Maps 4E and 4W and the aquifers are shown on Maps 5E and 5W.

5.2 Data Availability

All the groundwater data in the GSI and County Council files were compiled and all existing well records (3000) were entered into a computer database in the GSI.

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

- Groundwater abstraction rates for local authority (Table 4.1) and group schemes sources, and for a limited number of other high yielding private wells
- Information from approximately 3,000 well records in the GSI
- Specific capacity data for some wells, mainly local authority owned. (Specific capacity is the rate of abstraction per unit drawdown; the unit used is $m^3/d/m$.)
- Pumping tests carried out on 14 public supplies as part of this project (see summary of results in Table 5.2)
- Information on large springs
- Reports by engineering and hydrogeological consultants
- General hydrogeological experience of the GSI, including work carried out in adjacent counties and a review of groundwater in the south Munster region (Wright, 1997).

5.3 Rainfall and Evapotranspiration

Mean annual rainfall in Limerick for the period 1951–1980 varied from 860 mm in the lower topographic areas of mid-Limerick to over 1400 mm in the mountainous areas (Meteorological Service data). Higher rainfall occurs in the upland areas, in particular the Galty Mountains, Slieve Felim Mountains and west Limerick.

There are no Meteorological Service evapotranspiration stations in Co. Limerick and the closest one is that at Shannon Airport where the long term mean annual potential evapotranspiration is calculated as 534 mm (Meteorological Service data). The mean annual potential evapotranspiration for Co. Limerick is estimated, from summary countrywide contoured Meteorological Service data, to vary from approximately 475 to 550 mm. Actual evapotranspiration is estimated to be about 90 to 95% of the potential evapotranspiration. The mean annual potential recharge (rainfall minus actual evapotranspiration) values are therefore estimated to be in the range 370 to >800 mm, with the lowest levels in the low-lying areas and the highest in the mountains.

5.4 Groundwater Usage

There are 123 public and private group water schemes in Co. Limerick, of which almost 80% are from groundwater supplies. In total these groundwater schemes abstract almost 15,300 m^3/d (based on figures from ERU, 1991), which constitutes approximately 45% of total water consumption in the County Council area (i.e. not including the area supplied by Limerick Corporation). The County

Council public supplies are summarised in Table 5.1. Areas not served by the County Council or Group Water Schemes generally rely on individual private wells as the main source of water supply.

Table 5.1. Summary of Co. Council Public Supplies (compiled from Co. Council data)

SCHEME	ABSTRACTION (approx.)	SOURCE
Annacotty Area		
Montpelier	68 m^3/d	Bore
Murroe	682 m^3/d	Spring
Cappamore	227 m^3/d	Springs, river
Doon	509 m^3/d	Bores, spring
Oola	336 m^3/d	Spring
Pallasgrean Moymore	409 m^3/d	Spring
Caherconlish	436 m^3/d	Spring
Rathkeale Area		
Fedamore	64 m^3/d	Bore
Banoge	11 m^3/d	Bore
Croom/Carrigeen	500 m^3/d	Bore / Dug well
Ballingarry	409 m^3/d	Dug well/spring
Kilcoleman/Clouncagh	2432 m^3/d	4 Springs, Bore / Bore
Ballyhahill	41 m^3/d	Bore
Loughill	32 m^3/d	Bore
Newcastlewest Area		
Glin	227 m^3/d	Bore
Carrigkerry	55 m^3/d	Bore
Ardagh	273 m^3/d	Dug well/spring
Athea	114 m^3/d	Dug well/spring
Mountcollins	114 m^3/d	Bore
Tournafulla	50 m^3/d	Bore, Dug well, Spring
Broadford	173 m^3/d	Bore
South West Region	1640 m^3/d	4 Springs
Castlemahon	59 m^3/d	Dug well/spring
Kilmallock Area		
Herbertstown	268 m^3/d	Bore
Kilteely	145 m^3/d	Bore
Hospital	505 m^3/d	Bore
Bruff	427 m^3/d	Bore
Athlacca	14 m^3/d	Bore
Knocklong/Scarteen	286 m^3/d	Bore
Galbally	182 m^3/d	Bore
Anglesborough	11 m^3/d	Bore
Kilbehenny	41 m^3/d	Dug well/spring
Ballylanders	168 m^3/d	Bore
Mortlestown/Glenosheen	791 m^3/d	Bore
Bruree	195 m^3/d	Bore
Castletown/Ballyagran	218 m^3/d	Bore
Jamestown	570 m^3/d	Springs, Bore
TOTAL	12682 m^3/d	

Table 5.2. Summary of the project pumping tests.

Public Supply	*GSI no.*	*Grid ref.*	*Depth (m)*	*Aquifer*	*DTB[a] (m)*	*SWL[b] (m)*	*s[c] (m)*	*Q[d] test (m^3/d)*	*Q normal (m^3/d)*	*Hrs/d pumped*	*Q/s[e] 10 hrs (m^3/d/m)*	*Q/s 1 week (m^3/d/m)*	*KD[f] (m^2/d)*	*[Range]*
Ballinvreena	1713NWW093	17014 12643	60 ?	ORS/thrust fault	24 ?	12	6.68	1595	–	–	239	222	146	[110–487]
Ballyagran	1411NWW035	14701 12808	35.4	Kiltorcan/gravel	~16	8.26	10.8	1073	450	10	99	91	105	[94–196]
Ballylanders	1711NWW038	17779 12368	58.5	Silurian	10.4	14.98	7.5	396	159	10	53	35	32	[23–64]
Broadford	1111NEW068	13327 12181	66	Muddy Shelf Lst	3	33.9	5.99	250	264	24	42	40	80	[20–92]
Bruree	1413SWW094	15467 13051	90	Fault/ORS	3	2.1	9.27	413	441	~ 21	44.5	39	132	[54–151]
Clouncagh	1113SEW153	13708 13448	45	Mellon Hse. Beds	15	4.7	8.8	534	590	24	63	57	68	[41–150]
Croom	1413NWW201	15080 14118	45	Waulsortian Lst.	18	8.8	4.5	789	527	16	175	127	120	[95–145]
Doon Carrigmore	1713NWW080	18318 14707	45	Ballysteen/fault	0.9	18.6	4.02	289	70	6	72	45	36	[27–212]
Fedamore	1413NEW140	15929 14453	80.7	Waulsortian Lst.	10.2	13.62	9.6	191	123	9	20	20	34	[23–41]
Glin	1113NWW197	11421 14619	85.3	Namurian/gravel ?	?	<16.66	>16.1	400	406	24	<25	<18	12	[10–20]
Herbertstown	1413NEW138	16819 14087	65.4	Herbertstown/volcs	0.9	14.49	3.1	306	273	23	98	83	102	[74–117]
Hospital (Inner)	1713SWW042	17060 13630	51.8	Ballysteen	4.9	6.8	5.7	–	251	24	–	44	–	–
Hospital (Castle.)	1713SWW043	17051 13636	45	Ballysteen	4.9	7.05	1.62	366	366	24	226	165	140	[60–392]
Kilcoleman	1113SEW150	13574 13661	42.9	Kiltorcan	27	0	11.5	973	1000	variable	85	81	154	[111–197]
Mortlestown	1411NEW101	16600 12178	62.4	ORS	10	16.1	17.3	414	364	21	24	22	53	[6–63]
Pallasgrean New	1713NWW078	17722 14673	102	Herbertstown	< 2 ?	2.6	44.4	370	–	–	8	–	26	[2–36]

Notes:

a) Depth-to-bedrock below ground level

b) Static water level below ground level

c) Drawdown during 10 hour test

d) Discharge (*Q test* refers to the rate of pumping during the pumping test. *Q normal* indicates the quantity of water abstracted daily.)

e) Specific capacity (*Q/s 10 hrs* is the specific capacity calculated from the pumping test data. *Q/s 1 week* is extrapolated from the pumping test data.)

f) Transmissivity

5.5 General Aquifer Classification

5.5.1 Aquifer Categories

According to the aquifer classification used by the GSI (Daly, D. 1995), there are three main aquifer categories, with each category sub-divided into two or three classes:

Regionally Important (**R**) (or Major) **Aquifers**

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

Locally Important (**L**) (or Minor) **Aquifers**

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

Poor (**P**) **Aquifers**

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

These aquifer categories take account of the following factors:

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

Aquifers are defined on the basis of:

- Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water. For instance, pure limestones and clean sandstones are more permeable than muddy limestones and clayey sandstone, respectively. Areas where strong folding and faulting has produced strong joint systems tend to have increased permeability.
- Hydrological indications of groundwater storage and movement. For example, the presence of large springs can indicate a good aquifer; the absence of surface drainage suggests high permeability; high groundwater base flows in rivers indicates good aquifer potential, etc.
- Information from boreholes, such as high permeabilities from pumping tests, specific capacities (pumping rate per unit drawdown), and well yields.

5.5.2 Karstification

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

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

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

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

5.5.3 Use of Well Yields in Defining Aquifers

Although the main type of information available for aquifer classification in County Limerick is well yields, many other sources of information have been used (for example bedrock lithology, structural deformation, test pumping and surface drainage). It should be remembered that the aquifer delineation is a generalisation which reflects the overall resource potential, and that because of the complex and variable nature of Irish hydrogeology, there will often be exceptionally low or high yields which do not detract from the overall category given to any particular rock unit. It is also important to remember that the top few metres of all the bedrock types are likely to be relatively permeable.

The rock units in County Limerick are listed in Table 5.3, together with a summary of the useful well data and karst features for each formation, and the aquifer category. The wells (a total of 174) were categorised as “excellent”, “good”, “moderate” and “poor” for each rock unit. Any available specific capacity data are given. (In assessing the well data in Table 5.3, it should be noted that there will be a bias towards higher yielding wells, as only these wells are used by the County Council and group schemes. The remaining wells (>2000) in the GSI database are mainly privately owned and are shown to have ‘moderate’ or ‘poor’ yields; however, these wells have not been tested properly and the yields given may not be the maximum possible. Therefore, these data are not used in assessing aquifer categories; they are used mainly to give depths to rock and water levels)

Use of Well Yields in Defining Aquifers

Well yields should never be used on their own as the basis for categorising a rock unit as a particular aquifer category. However they are often the main type of data available and they allow the three main aquifer categories to be conceptualised. Regionally important (**R**) aquifers would have (or be capable of having) a large number of wells yielding in excess of approx. 400 m^3/d (4000 gph); locally important (**L**) aquifers are capable of moderate well yields 100-400 m^3/d (1000-4000 gph); and poor (**P**) aquifers would generally have low yielding wells - less than 100 m^3/d.

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

5.6 Silurian Rocks

Well records for the rocks of Silurian age in the south-east of the county indicate eight 'good' wells (including the Ballylanders public supply) in the Inchacoomb Member and 3 in the Ballygeana Formation. A specific capacity of 35 m^3/d/m was calculated for the public supply in Ballylanders. The transmissivity from a ten hour pumping test was determined as being of the order of 32 m^2/d [23–64 m^2/d]. The only information available for the Hollyford rock unit in the Slieve Felim mountains is the site investigation undertaken for the proposed landfill. In four boreholes, permeabilities in the top 30 m of rock ranged from 4.2 x 10^{-9} m/s to 8.8 x 10^{-5} m/s (3.6 x 10^{-4} to 7.6 x 10^{-1} m/d). A zone of higher permeability (with measured permeabilities in a fifth borehole of 1.2 x 10^{-4} to 1.1 x 10^{-5} m/s), 150-200 m wide, 12-14 m deep and 2.2 km long was delineated on the site. The transmissivity estimated for this zone was 27-82 m^2/d.

In general, the permeability of Silurian rocks is relatively low. However, permeabilities in the upper few metres are often high although they decrease rapidly with depth. Local zones of higher permeability will be present, usually due to faulting. It is likely that the rocks in south-eastern Limerick will be somewhat more jointed than in the Slieve Felim mountains as they have undergone a greater degree of structural deformation. Evidence of the relatively low permeabilities is provided by the drainage density and flashy runoff response to rainfall in areas underlain by Silurian rocks.

Examination of data in the GSI well database shows that water levels in Silurian rocks are shallow, usually less than 15 m below surface, although within the Inchacoomb Member they are a somewhat deeper. This may be attributed to higher permeabilities in this rock unit but may also be a reflection of topography; the Inchacoomb Formation, being the oldest rocks to crop out in the Galty anticline, are generally topographically higher than the rest of the formation.

While groundwater in these rocks is usually unconfined, clayey till and peat sometimes confine the groundwater and artesian flowing boreholes can be encountered in low lying areas.

The Silurian rocks in south-eastern Limerick i.e. the Inchacoomb Formation and the Ballygeana Formation, are classed as **locally important aquifers which are moderately productive only in local zones (Ll)**.

The rocks of the Hollyford Formation in the north-east of the county are classed as a **poor aquifer which is locally productive (Pl)**.

5.7 Old Red Sandstone (ORS)

This hydrogeological unit includes all Old Red Sandstone formations with the exception of the Upper Devonian Kiltorcan Sandstone Formation.

There are 13 records of wells providing supplies in excess of 100 m^3/d, five of which give more than 400 m^3/d. Mortlestown Public Supply (abstraction rate 364 m^3/d) draws its water from this aquifer. A ten hour pumping test at this site gave a transmissivity of 53 m^2/d [range 6–63 m^2/d], with a relatively low specific capacity of 22 m^3/d/m. Three other large supplies – the Bruree and Montpelier public supplies and the new Group Water Scheme at Ballinvreena near Kilfinnane – are also bored into this rock unit, although they may not be representative of the general aquifer characteristics. Analysis of a ten hour pumping test at Bruree (abstraction rate of 440 m^3/d) together with water temperature

Table 5.3. Well Yield Categories and Karst Features

Rock Unit	Well Yield Categories (specific capacities in brackets)					Karst and Dolomite Features	Aquifer Category
	Excellent (>400m³/d)	Good (100-400m³/d)	Moderate (40-100 m³/d)	Poor (<40m³/d)	Failed		
Sands/gravels		1 (>1000)					**Lg**
Crataloe Flagstones							**Lm**
Upper Namurian & Cummer Flagstone		7	3	3 (3)	1		**Pl**
Clare Shales & Longstone Shales			1 (3)		3		**Pu**
Herbertstown & Dromkeen Limestones		1 (8)			1	dolomite	**Rf**
Volcanics	2	6 (83)					**Lm**
Ballyadams Limestone	1	4				1 swallow hole	**Rf**
Kilsheelan, Croane and Rathronan Limestones							**Rk**[d]
Northern Clean Shelf Limestones	1 (43)	3 (5)				2 swallow holes dolomite	**Lm**
Aghmacart Limestone		1		1 (5)		dolomite	**Ll**
Muddy Shelf Limestones incl. Rathkeale, Durnish, Shanagolden and Parsonage	1	7 (40)	4 (1, 1, 42, 71)	2		2 swallow holes, 1 turlough, 1 cave dolomite	**Ll**
Waulsortian Limestone	13 (5, 10, 173)	23 (8, 15, 20, 24, 36, 64)	6 (2, 3, 23, 55, 72)	2 (3, 7)	1	numerous at Aughinish. Also, 9 caves, 8 turloughs, 1 swallow hole dolomite	**Rk**[c] in Askeaton area **Rf** in rest of county
Ballysteen Limestone	2 (30)	13 (3, 4, 44, 64 72, 97, 165)	6 (1, 3, 10, 11, 15, 40)	6 (0.2, 1, 2, 4, 5, 6)	1	1 collapse feature	**Ll**
Ringmoylan Shale							**Pu**
Mellon House Beds	1?	2 (4)					**Ll**
Kiltorcan Sandstone	8 (9?) (23, 77, 99, 229)	2 (7, 85)			1		**Rf**
Old Red Sandstone	6 (238, 44)	7 (24)	4 (21, 41, 73)	3 (1, 3)	1		**Ll**
Silurian Rocks		13 (35)					**Ll** in south **Pl** in north

Notes:

(1) These statistics are skewed towards higher yielding sources – mainly Co. Co. and group scheme supplies.

(2) The values in brackets are the only specific capacity data available. The units are m³/d/m. Where no specific capacity information is available for a well included in the statistics, the yield category indicates the maximum yield.

(3) While there are >3000 well records for Co. Limerick, most have neither drawdown data to enable the specific capacities to be calculated nor maximum yield information.

measurements taken during the test indicated that a significant proportion of the supply is being contributed by the river and this accounts for the relatively high calculated transmissivity of 132 m^2/d [range 54–151 m^2/d]. At the Montpelier Public supply, the ORS is overlain by a large gravel deposit, which may be contributing to the well. The new Ballinvreena supply is bored close to a major thrust fault, and the fracturing associated with this fault is more likely to be responsible for the large yield (1600 m^3/d), high transmissivity (146 m^2/d [range 110–487 m^2/d]) and the very high specific capacity (222 m^3/d/m) obtained from a three day pumping test. Information on four wells in the Glenstal/Muroe area provided by Mr. John Lynch (a Limerick based well driller) showed a wide variation in well yields, with 'excellent', 'good', 'moderate' and 'poor' wells in close proximity.

Water levels within the unit are generally less than 15 m below ground surface with an average of approximately 12 m although this varies depending on topography. There are no records of any artesian water but aquifers may be confined in places beneath less permeable mudstones and siltstones. Generally speaking however, these rocks crop out at high elevations on the flanks of hills and are unconfined.

The Old Red Sandstone unit is classed as a **locally important aquifer** which is **moderately productive only in local zones (Ll)**. Larger supplies may be developed where storage is increased by overlying gravels or where the borehole is sited close to a major fault zone.

While the **Ll** classification for the ORS in south and mid-Limerick can be justified on the basis of lithological, structural geology and hydrogeological information, assigning an aquifer classification to the Cappaghwhite Sandstone in north-eastern Limerick is problematical. North of this area, for instance in Slieve Bloom (Daly *et al*., 1997), the ORS is regarded as a poor aquifer. However, the Cappaghwhite sandstone has some lithological similarity with the Kiltorcan Sandstone, in particular, it contains beds of white/yellow/grey sandstone. The Kiltorcan Sandstone is classed as a regionally important aquifer. It was decided not to give the Cappaghwhite Sandstone this classification as it appears to contain less of the white/yellow/grey beds than the Kiltorcan Sandstone and as it is not supported by sufficient hydrogeological data. On balance an **Ll** classification is regarded as reasonable, although future work may cause it to be reclassified as **Rf** or **Pl**. The optimum area for wells is likely to be in the vicinity of the boundary with the overlying Mellon House Beds.

5.8 Kiltorcan Sandstone

There are four 'excellent' groundwater sources in this rock unit including the public supplies at Kilcoleman and Ballyagran and the undeveloped flowing artesian well at Pullagh. The Kilcoleman supply comprises a number of large springs and a reserve borehole. The total output from the springs, which are located at the boundary between this formation and the overlying Mellon House Beds, is 1820 m^3/d. A transmissivity value of 154 m^2/d was calculated from a ten hour pumping test on the borehole at Kilcoleman. The Ballyagran public supply well is high yielding (1073 m^3/d), with a specific capacity of 90 m^3/d/m.

The thickly bedded, often coarse, sandstones of this formation are extensively jointed and fractured. Permeabilities are higher in the upper part of the formation, as there are higher percentages of sandstones present, and along fault zones.

Water levels vary depending on topography, ranging from near surface to depths of over 20 m. Artesian supplies may be obtained where boreholes penetrate the aquifer through the confining shaly beds of the overlying formations and particularly on the northern flanks of hilly areas where Quaternary deposits are thick. The anticlinal and synclinal folding of the formation renders the aquifer both confined and unconfined. Confined groundwater circulating at depth discharges to the surface via large faults although impermeable fault zones may also retard circulation by isolating all or part of an aquifer block from another or by isolating the recharge area from the deepest parts of the formation.

Extensive work carried out on this aquifer in the Nore River Basin indicates that transmissivities of up to 500 m^2/d are common. Specific yield is normally about 2% although near the surface it can be as high as 5% (Daly, E. P., 1988). Tests on wells from the Clonaslee Sandstone (a similar sandstone) in Laois show the aquifer potential there to be somewhat less (Daly *et al*., 1997). This may be explained by the fact that Laois is farther from the Munster Basin than Limerick and hence the degree of fracturing will be less.

The Kiltorcan Sandstone is classed as a **regionally important fissured aquifer (Rf).**

5.9 Mellon House Beds (MH)

Well records confirm one excellent supply (Cloncagh Public Supply, 590 m^3/d) and three other 'good' sources in excess of 100 m^3/d. However, the well at Cloncagh may be penetrating the top of the Kiltorcan Sandstone and one of the 'good' wells may have supplementary storage due in overlying gravels. A ten hour pumping test was carried out at Clouncagh. The transmissivity value of 68 m^2/d [41–150 m^2/d] and a specific capacity of 57 m^3/d/m are indicative of a good supply. Data on aquifer characteristics are otherwise lacking.

The lithologies of the Mellon House Beds are variable both in shale content and thickness, giving rise to equally variable transmissivities. The coarser, thicker sandstone units are likely to have a greater degree of fracturing than the more plastic interbedded shales.

Water levels are variable but are usually less than 15 m below ground surface. There is some evidence of artesian water from boreholes drilled through this formation but it may be that they have also penetrated the underlying confined Kiltorcan rock unit. The aquifer is generally unconfined although it does yield supplies under confined conditions beneath the Ballymartin and Ringmoylan Shale Formations. The interbedded shale beds may also isolate individual aquifer beds and groundwater flow is likely to be complex with movement primarily along fault zones.

The lower part of this rock unit is likely to be the most productive, and in the Nore Basin and in Tipperary it is grouped with the underlying Kiltorcan Sandstone (Daly, E. P. (1988) and Keegan (1993)). This grouping is to facilitate optimum well development.

The Mellon House Beds are classed as a **locally important aquifer** which is **moderately productive only in local zones (Ll)**.

5.10 Ringmoylan Shales (RM)

There is no available hydrogeological information for this rock unit. However, the shaly nature suggests that permeabilities will be low. It is classed as a **poor aquifer which is generally unproductive (Pu)**.

5.11 Ballysteen Limestone (BA)

The twenty eight well records with adequate data (Table 5.3) show a wide variation in well yields and specific capacities. Specific capacities are often low (<10 m^3/d/m). Exceptions include the two public supply wells at Hospital (44 m^3/d/m and 165 m^3/d/m) and the well at Doon Carrigmore (45 m^3/d/m).

A ten hour pumping test with an observation well carried out at Hospital gave a transmissivity range of 60–392 m^2/d. The higher transmissivity values were characteristic of the first 15 minutes of both the pumping test and the recovery. Thereafter the groundwater flow rate into the well is reduced giving the more representative transmissivity value of 140 m^2/d. This suggests the presence of a thin, upper, high permeability zone which is probably providing a significant proportion of the supply. Once the water level drops below this zone to the lower permeability rocks, the rate of drawdown in the well increases. This is supported by the fact that the well dries up substantially in dry summers when the water table drops below the upper zone.

A ten hour pumping test was also carried out at Doon Carrigmore. This borehole gave a lower transmissivity of 36 m^2/d [27–212 m^2/d] although the specific capacity is similar (45 m^3/d/m). The borehole is located close to a major fault which is likely to be providing a zone of increased permeability.

The two Bruff public supply wells are currently supplying over 420 m^3/d, although they are capable of giving a higher yield. Numerical modelling to delineate the source protection areas suggested that the permeability of the limestone is 0.6 m/d.

Water levels are often shallow, less than 5 m below ground surface, although there are records of deeper water levels of up to 20 m which are related to variations in topography. The depth to water level in boreholes is often less than the depth-to-rock. As the overlying Quaternary deposits are primarily low permeability limestone tills, this means that groundwater is confined in places. In particular there are a number of artesian supplies to the north of the Ballingarry inlier where groundwater has been confined by a thick overlying deposit of limestone till.

Insufficient geological information prevented the separation of the four units which are grouped together as the Ballysteen Limestone – Ballyvergin Mudstone, Ballymartin Limestone, middle unit and upper unit (see Section 3.4.3) – into distinct mappable units on the Bedrock Geology map (Maps 1E and 1W). The relatively pure middle unit is likely to be far more permeable than the other more shaly units. The public supply wells at Bruff are thought to be in this unit. The variation in well yields and specific capacities is likely to be due not only to the presence of fissures caused by faulting, but also to the variation in rock composition (lithology).

Classification of this aquifer is difficult due to the lithology and permeability variations. For instance, the Ballyvergin Mudstone and the Ballymartin Formation could be classed as poor aquifers on the basis of their lithologies. The middle unit might be a regionally important aquifer if it has a sufficient areal extent.

The Ballysteen Limestone is classed as a **locally important aquifer** which is **moderately productive only in local zones** (**Ll**).

5.12 Waulsortian Limestone (WA)

The Waulsortian Limestone is one of the most extensive rock units in Co. Limerick and is the most important aquifer in the county. There are 13 ‘excellent’ wells recorded in the GSI database – the largest number for any rock type. There are also large springs, 23 ‘good’ wells and numerous karst features, particularly in the Aughinish area (see Table 5.3). Several public and group scheme supplies are located in this rock unit, including the south west region supply (Tobergal), Croom, Fedamore and Knocklong. A group water scheme borehole at Lough Gur yields more than 870 m^3/d. Also, the Ballygowan spring water source obtains the water from deep permeable zones in this aquifer.

Pumping tests were carried out on two sources – Croom and Fedamore (see Table 5.2) – which gave estimated transmissivities of 120 m^2/d and 34 m^2/d, respectively.

There are a number of large springs in this rock unit, several of which are thermal. Summary details are given below:

Cregan's Well
Cregan's Well which lies south of Newcastlewest (NGR 12656, 13133), is a large thermal spring yielding approximately 1140 m^3/d at temperatures of up to 14^{o}C. The supply is believed to come from the deep Waulsortian Limestones beneath the overlying Visean rocks along a major fault (Murphy and Brück, 1989).

Camas
Another large warm spring in the townland of Camas, known locally as Sconse Well (NGR 12839, 12865), has a similar yield to that at Cregan's Well and is also warm (12.8–13^{o}C). It is located to the south-east of Cregan's Well on the axis of the Corronoher anticline (Murphy and Brück, 1989).

Knocksouna Group:
A large spring system west of Kilmallock, the Knocksouna Group (NGR 15630, 12770), has been studied in detail as part of the Irish Geothermal Project (Brück, *et al*., 1986). The system comprises a group of 12 warm springs (mean temperature 15.6 ^{o}C) spanning approximately 700 m on an east-west trending line. The total output for the springs is in the region of 28,800 m^3/d and there is additional spring water bubbling up into the nearby stream.

Tobergal:
A large Council supply at Tobergal Spring (NGR 13161, 12788) yields 1640 m^3/d through four springs. The group is slightly warm ranging from 13.4–14.1^{o}C suggesting a deep origin for the groundwater. The chemical analyses however, when compared with other samples from the Waulsortian, show that the water is softer than one would expect although it is high in magnesium suggesting a dolomite aquifer. The source is not far from the Namurian scarp to the west and it is likely that the softer recharge waters from there are mixing with the up welling deeper waters from the dolomitic limestones.

There is evidence of karstification, dolomitisation and permeability variations with depth in this aquifer.

Site investigations in the Aughinish area have shown extensive karstification (solution) of the limestone and large variations in permeability (Ercon, 1974; Gutmanis, 1981; Clarke *et al*., 1981). Karst features such as sink holes, depressions, clints and grikes are common in this area (these are not listed in Table 5.3), and cavities have been encountered in drill holes. Karstification is reported to substantial depths of more than 60 m in places. Two sets of water bearing fissures have been isolated at Aughinish; one at sea level and the other approximately 40 m below sea level. A major north-easterly fault trend is expressed in the rocks, which is associated with both karstification and dolomitisation. The fault zones are up to 20 m wide and are associated with large troughs which are suggested to be indicative of karst solution (Ercon, 1974). These depressions are infilled with Quaternary and possibly Tertiary deposits. The limestones within the fault zones are altered to a yellow brown or pink secondary dolomite. (Dolomitisation is caused when magnesium is introduced into limestone ($CaCO^3$) forming dolomite. This results in an increase in the porosity and permeability of the limestone.) These dolomitised fault zones are conducive to further deep seated advanced weathering where the end result is a residue of yellow brown dolomitic sand (Gutmanis, 1981). Eighteen boreholes were drilled on Aughinish island and the adjoining mainland, and seven of these were completely dry. Some of the holes on the mainland remained dry for the period of a week, despite a head of water in the surrounding rock of up to 50 m (Ercon, 1974). A County Council well on Aughinish with a discharge of 1200 m^3/d had a specific capacity of 173 m^3/d/m during a three day pumping test.

While the evidence for the Aughinish area clearly indicates a significant degree of karstification, the question arises as to the boundary of this area of karstification. In particular, should all the Waulsortian Limestone in the area south of Aughinish, around Askeaton and stretching eastwards to the mouth of the River Maigue, be classed as a karstified aquifer? The evidence is less conclusive than that for Aughinish. However, during Quaternary geology mapping of the area in the 1960s, several turloughs were noted (see Map 3W). Also, according to C.R. Aldwell (1997), the Askeaton area is noted for large variations in well yields including many dry wells, suggesting concentrations of groundwater flow in karstified zones.

There is less evidence for karstification in this rock unit in the remainder of Co. Limerick. Few surface karst features have been recorded, although it can be argued that they might be masked by the subsoil cover. Borehole logs from wells in the Newcastlewest area indicate three main production zones: a high permeability band in the upper 10–15 m of bedrock; a middle zone from 35–50 m, where north/south trending fractures, spaced at between 500 m and 800 m apart, have been preferentially dolomitised; and a lower fractured zone at a depth of over 100 m (O'Neill, S., pers. comm.). The upper high permeability zone near Newcastlewest yields large quantities of water, up to 2600 m^3/d, while the dolomite zone is capable of providing 1300 m^3/d. In other high yielding wells in the county, there has been no mention of cavities. Consequently, fracturing and dolomitisation are likely to be the main processes influencing permeabilities. A possible reason for the preferential development of karstification in the Aughinish-Askeaton area is that groundwater has an easy outlet into the Shannon estuary, whereas in the rest of Limerick the Waulsortian Limestone is bounded by lower permeability rocks, thus reducing groundwater flows and solution.

Water levels in this formation are generally quite shallow at less than 10 m although there are records of unsaturated zones of up to 30 m. Groundwater fluctuations of 6 m between summer and winter are typical on Aughinish island (Ercon, 1974) and data from the public supply at Fedamore would suggest that this is also the case in other parts of the county; water levels there showed a fluctuation of more than 4 m over the period of six weeks. Hydraulic gradients in the Waulsortian Limestone are typically low (0.003–0.007).

The Waulsortian Limestone area in Co. Limerick is classed as a regionally important aquifer. In the Aughinish-Askeaton area it is classed as a **regionally important karstified aquifer,** where the development potential is limited by the concentration of flow (**Rk^c**). In the remainder of the county it is classed as a **regionally important fissured aquifer** (**Rf**).

5.13 Muddy Shelf Limestones (msl), Rathkeale Limestone (RC), Durnish Limestone (DU), Shanagolden Limestone (SG) and Parsonage Beds (pa)

The GSI well records show one 'excellent' well near Patrickswell and five 'good' wells. The Broadford Public Supply (abstraction rate 260 m^3/d) in this unit has a reasonably good specific capacity of 40 m^3/d/m and a 10 hour pumping test gave a transmissivity of 80 m^2/d [20–92 m^2/d].

The Western Muddy Shelf Limestones are considered to be of low permeability due to the high proportion of shale. Cleaner horizons are likely to become more common moving southwards away from the centre of the Shannon Trough at Foynes. These horizons may be karstified in places, particularly close to the contact with the Namurian rocks where relatively corrosive runoff facilitates solution.

This rock group lies to the west of the county on the lower gentle slopes at the base of the Namurian Scarp. The Quaternary cover is primarily limestone till which reaches up to 45 m in places. As the groundwater flows off the scarp and the Quaternary deposits thicken, a shallow perched water table develops which is separate from the deeper supplies accessed via boreholes. Groundwater from the bedrock aquifer is generally confined with potentiometric surfaces varying from above the ground surface to depths of up to 40 m.

As these rock units are generally shaly, they are classed as **locally important aquifers** which are **moderately productive only in local zones (Ll)**. The local zones are either cleaner bands or fault zones.

5.14 Aghmacart Limestone (AG)

There is little hydrogeological information for this rock unit – details on one 'good' well. Therefore, the aquifer classification is based on the rock lithology and the similarity with the muddy shelf limestones. Since it is a fine grained limestone with shales, it is classed as a **locally important aquifer which is moderately productive only in local zones (Ll).**

5.15 Clean Shelf Limestones (csl)

There are insufficient useful well records and hydrogeological data to provide a good basis for understanding the hydrogeology of this aquifer. The few well data available show one 'excellent' and two 'good' wells (see Table 5.3). The rocks of the Clean Shelf Limestones are generally clean oolitic limestones which would be expected to have relatively high permeabilities as is found in the Limerick Syncline. Fracturing is not likely to be as severe this far north however and the proportion of shale present is not known.

The rocks of this group are classed as a **locally important aquifer which is generally moderately productive (Lm)**. They are classed higher up the scale of productivity than the Western Muddy Shelf Limestones as the strata are generally cleaner and karstification and dolomitisation may be extensive in places. Detailed geological mapping and site investigation work may prove the groundwater potential to be as high in places as that found in similar rocks further south, i.e. **Rf** aquifer, but as there are currently insufficient data to suggest this, the group is classed as a whole in the lower category.

5.16 Kilsheelan Limestone (KS), Croane Limestone (CR) and Rathronan Limestone (RR)

There are no hydrogeological data for these limestones in Limerick, consequently their aquifer classification is taken from the Tipperary S.R. Groundwater protection Scheme (Keegan and Wright, 1997). While the information in Tipperary is also poor, they are tentatively classed as **regionally important karstified aquifers** with a good development potential **(Rk^d).** Evidence from Tipperary suggests that the Rathronan and Kilsheelan Limestones are cleaner, more karstified and therefore more permeable than the Croane Limestone.

5.17 Ballyadams Limestone (BM)

The GSI well records show one 'excellent' well and four 'good' wells in this rock unit. However, the unit extends into County Tipperary and County Kilkenny where the information is far better. The following summary of the hydrogeology of the Ballyadams Formation is taken largely from Keegan and Wright (1997).

The Ballyadams Limestone is a pure, poorly bedded limestone with a middle unit containing some clay wayboards (thin beds). The development of permeability results from fissures, joints and bedding planes which have been enlarged by solution. Because of the purity of the limestone, it is susceptible to karstification which is accentuated along structural features such as fold axes and faults and can result in high permeability and throughput in relatively narrow zones. The clay wayboards can restrict groundwater circulation and therefore the vertical development of secondary permeability. In certain situations, there may be horizontal development along the clay layers.

Water levels are variable within the aquifer, from lying close to surface to depths of more than 20 m. Subsoil thicknesses up to 80 m thick are present and groundwater may be confined in places.

While there is a significant development of karstification in places, in general flow is dominantly in fissures. Therefore, the Ballyadams Limestone is classed as a **regionally important fissured aquifer (Rf).**

5.18 Volcanics (KRf/KRt and KVf/KVt)

There are two 'excellent' and six 'good' wells in this rock unit. A ten hour pumping test carried out on the Herbertstown supply gave a relatively high consistent transmissivity of 102 m^2/d [74–117 m^2/d]. The specific capacity of the same supply is also high at 83 m^3/d/m. Two springs – Toberalunaght and Tobernagloria – are reported to have significant outputs. Toberalunaght Spring at Knocknacrohy (NGR 17481, 14433) is reported to have a good to medium sized yield (Burdon, 1986), while Tobernagloria (NGR 17448, 14648) has a yield of 540 m^3/d.

The volcanics present in Co. Limerick can be grouped into two hydrogeological units based on rock type: the tuffs, and the lava flows and intrusives. Permeabilities are developed primarily by fracturing. The tuffs are more acidic (silica-rich), weather more easily and contain vesicles which increase the porosity. Permeabilities are increased in the basaltic flows by columnar jointing which has opened up the otherwise hard rocks.

While it is usually thought that the more acidic volcanic rocks have the greater permeability, the well records suggest that the larger supplies come from the basaltic lavas. However, this is inconclusive as the lavas and tuffs are often interbedded and groundwater may originate in an underlying confined tuff band.

Water levels are variable, reaching up to 20 m below ground, and the groundwater is usually unconfined.

The volcanic rocks are classed as a **locally important aquifer which is generally moderately productive (Lm)**.

5.19 Herbertstown (HE) and Dromkeen Limestones (DK)

There is one reported 'good' yielding well in these rocks – the new public supply at Pallasgrean (370 m^3/d). However data from a three day pumping test gave a relatively low transmissivity of 26 m^2/d [2–36 m^2/d] and a low specific capacity of 8 m^3/d/m. There is also evidence of one failed well at Pallasgrean.

The limestones of the Herbertstown and Dromkeen Formations are of limited areal extent, being present only in the centre of the Limerick Syncline, and as a result the hydrogeological data are very scarce. The well bedded, clean oolitic limestones are expected to have a relatively high permeability. Ashby (1939) reports the presence of magnesium in the Dromkeen Limestones and this may indicate that a degree of dolomitisation has occurred. Karstification is also recorded by Strogen (1988) at the boundary with the Namurian rocks.

The rocks within the Limerick Syncline are covered by thick deposits (15–20 m) of primarily limestone till. There are a number of springs, and water levels are often less than 5 m below surface; these shallow water levels however, may reflect a perched water table in the Quaternary deposits as in the south-west where the rock is at surface, water levels reach depths of more than 20 m below surface.

The Herbertstown and Dromkeen Limestones are tentatively classed as **regionally important aquifers** which are dominated by **fissure flow (Rf)**.

5.20 Clare Shales (CS) and Longstone Shales(LOsh)

The rocks of the Clare Shale Formation and the Longstone Shale Formation are similar in that they both comprise a series of mudstones. Permeabilities are low as the shale content is high and the plasticity of the rocks reduces fracturing. Surface streams are common and runoff over the Clare Shales is high which indicates a low permeability.

There are no hydrogeological data for the Longstone Shales but wells in the Clare Shales have low yields and shallow water tables.

These rocks are classed as **poor aquifers** which are **generally unproductive (Pu)**.

5.21 Upper Namurian Rocks (Cummer Flagstones (CF), Upper Namurian Beds (NAMu), Longstone Formation (LO), Lackentadane Group (LA), Giants Grave Formation (GG))

The remaining Namurian rocks in Co. Limerick are classed together as one group as they are all composed of a variety of thin sandstones, siltstones, flagstones, mudstones and shales. Hydrogeological data are poor for all formations except the Upper Namurian Beds in the west of Limerick and these shall be used to extrapolate across the county. Experience from equivalent rocks in Co. Tipperary is also drawn upon where the formations cross the county boundary.

The sandstone beds within the rock groups have a slightly higher permeability than the shales due to their greater ability to fracture.

Water levels have been recorded at depths of more than 20 m but in general the water table is close to the surface reflecting the low permeability of the rock. There are also a number of artesian supplies where the sandstone beds are confined by the shales and mudstones.

Wells in these rocks are generally low yielding although there are seven recorded with supplies of more than 100 m^3/d. Three of these may have increased storage from overlying gravel deposits. Specific capacities are usually low being less than 5 m^3/d/m. A 10 hour pumping test at a rate of 400 m^3/d was carried out on the main public supply at Glin. Transmissivity was low, in the range 10–20 m^2/d, and the specific capacity was 19 m^3/d/m. The nearby gravels may be contributing to the supply. There is only one record of a failed well within the Namurian rocks.

This rock group is classed as a **poor aquifer** which is **generally unproductive except for local zones (Pl)**.

5.22 Crataloe Flagstones (CT)

There are no data for this rock unit, occurring in western Limerick, as the outcrop area is small and it is located in an upland area. The interbedded sandstone, flagstone and siltstone lithologies have reasonable potential for groundwater development with water supplies likely to come from within the sandstone beds. In the Castlecomer Plateau in the equivalent Clay Gall Sandstone, a confined sandstone unit provides supplies in the region of 200–500 m^3/d. Groundwater flow in the Clay Gall sandstone is fault controlled and yields may be higher where these faults are intersected (Daly, D., 1979).

By analogy with the Clay Gall Sandstone, this rock group in Limerick is considered to be a **locally important aquifer** which is **moderately productive (Lm)**.

5.23 Sand/Gravel Aquifers

Sand/gravel deposits have a dual role in groundwater development and supply in Co. Limerick. Firstly, they can supply significant quantities of water and are therefore classed as aquifers. Secondly they provide storage for underlying bedrock aquifers.

A sand/gravel deposit is classed as an aquifer if the deposit is more than 10 m thick and is greater than one square kilometre in areal extent. The thickness of the deposit is taken rather than the more relevant saturated zone thickness as the information on the latter is rarely available. In many instances it may be assumed that a deposit with a thickness of 10 m will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief, for example eskers or deposits in high topographic areas, as these gravels often have a thin saturated zone.

There are two categories of sand/gravel aquifers – regionally important and locally important. The two differ in areal extent and estimated annual throughput (see Table 5.4).

Table 5.4 Sand/gravel Aquifer Classification

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

A regionally important gravel aquifer will have an areal extent greater than 10 km^2. This is to ensure that in taking an average annual rainfall of 400 mm, there will be enough recharge to provide a supply of one million cubic metres per year from the whole aquifer. A locally important aquifer on the other hand is required to have enough storage to supply a small group scheme or village.

None of the sand and gravel deposits in Co. Limerick is large enough to be considered a regionally important aquifer. There are however, nine locally important sand and gravel aquifers and these are illustrated on the aquifer map (Maps 5E and 5W) and are summarised in Table 5.5. Seven of these are termed potential local aquifers as there are no water supplies currently developed in them and their resource availability is therefore not proven. They have been identified on the basis of the subsoils maps (Maps 2E and 2W) and the depth-to-rock maps (Maps 3E and 3W).

The gravel deposit at Carrigkerry has been classed as a locally important aquifer although it does not meet the areal extent requirement. It does however, have a saturated thickness of more than 12 m and this provides the necessary storage, which, in conjunction with the high rainfall, and hence high recharge that occurs in the west of the county, provides enough groundwater to maintain a supply which is adequate for the needs of the local community; the deposit is therefore locally important.

Table 5.5. Sand/gravel Aquifers in Co. Limerick.

Gravel deposit	Areal extent	Estimated deposit thickness
Sand and gravel aquifers		
Carrigkerry gravels	0.33 km^2	more than 12 m (saturated)
Montpelier gravels	1.44 km^2	> 25 m
Potential sand and gravel aquifers		

Ballycullane gravels	1.89 km^2	15 m
Duckstown gravels	1.57 km^2	> 25 m
Gardenhill gravels	1.44 km^2	20 m
Gooig gravels	1.70 km^2	> 20 m
Killacolla gravels	1.11 km^2	up to 35 m
Knockaderry gravels	1.30 km^2	> 15 m
Strand gravels	1.70 km^2	up to 25 m

Site investigation may also prove other gravel deposits to be aquifers but in the absence of more detailed information, the smaller deposits, and those of unknown thicknesses or suspected thin saturated zones, are not included here. In addition, some of the larger till-with-gravel deposits may prove, on investigation, to have lenses of clean gravel within them which meet the classification criteria.

5.24 Summary of Aquifer Categories

The rock units in County Limerick classified into the different aquifer categories in Table 5.6.

5.25 Potential for Future Groundwater Development in County Limerick

5.25.1 Waulsortian Limestone

This is the rock unit with the best proven aquifer potential in County Limerick. It is capable of supplying regional schemes and large industries. However, random drilling is not recommended as it will not give optimum results. A proper hydrogeological investigation, involving the use of geophysics, will increase the probability of success. Also, as improved geological information becomes available on dolomitised areas and zones, the ability to choose high permeability areas will improve. However, developing the karstified areas – in the Askeaton area – may be problematical due to the uneven distribution of permeability and, in places, to the vulnerable nature of the aquifer.

Table 5.6. Bedrock aquifer classifications

Aquifer Category	Subdivision	Rock Unit
Regionally important (R) (34%)	Sand/gravel (**Rg**)	none
	Karst (**Rk**) **Rk**[c] Development potential limited by concentration of flow **Rk**[d] Good development potential	Waulsortian Limestone at Aughinish and in Askeaton area Kilsheelan, Croane and Rathronan Lsts
	Fissure flow (**Rf**)	Ballyadams Lst Herbertstown/ Dromkeen Lsts Remainder of Waulsortian Lst Kiltorcan Sst
Locally important (L) (43%)	Sand/gravel (**Lg**)	nine deposits (see Table 5.5)
	Bedrock which is generally moderately productive (**Lm**)	Crataloe Flagstones Northern Clean Shelf Lsts. Volcanics
	Bedrock which is moderately productive only in local zones (**Ll**)	Aghmacart Lsts Muddy Shelf Lsts Ballysteen Lst Mellon Hse Beds Old Red Sandstone Silurian in south Limerick
Poor (P) (23%)	Bedrock which is generally unproductive except for local zones (**Pl**)	Upper Namurian Unit Silurian in north-eastern Limerick
	Bedrock which is generally unproductive (**Pu**)	Clare Shales/Longstone Shales Ringmoylan Shales

Note: The percentages refer to the proportional areal extent of each aquifer category in County Limerick

5.25.2 Pure Limestones (Ballyadams, Herbertstown, Dromkeen, Kilsheelan, Croane and Rathronan)

The relatively pure nature of these limestones and information from other counties would suggest that these have the potential to supply significant quantities of water. However, as with the Waulsortian Limestone, a proper hydrogeological investigation, involving the use of geophysics, will increase the probability of success.

5.25.3 Kiltorcan Sandstone

This rock unit has proven potential, as shown by wells in north Cork, Waterford, Laois and Kilkenny. However, it is important to locate wells, as far as practicable, in optimum areas – close to faults and along the contact with the overlying less permeable rocks. Compared to limestone aquifers it has several advantages: it yields a softer water, it is often artesian or sub-artesian, and it generally has a lower vulnerability (Wright, 1997).

5.25.4 Sand/gravel

Carefully sited wells would be capable of supplying large quantities of water. These aquifers could be particularly important in areas not supplied or unlikely to be supplied by regional schemes.

5.25.5 Muddy Limestones (Muddy Shelf Limestones, Aghmacart, Ballysteen and Mellon House Beds)

While there are local zones of high permeability and a number of public supplies in these rock unit, they are not likely to have the potential to supply regional schemes. Even where significant quantities of groundwater are found from individual wells, there may be problems with high iron concentrations and with yield reductions in dry weather.

5.25.6 Volcanics

The areas of volcanics are too small to supply regional schemes. Also too little information is available to allow a proper assessment of these rocks.

5.25.7 Silurian Rocks in South Limerick and Old Red Sandstone

Although well yields are highly variable, wells in high permeability fault zones are capable of supplying small public and group scheme supplies.

5.25.8 Remaining Rock Units

None of the remaining rock units (see Table 5.6) have the potential to provide sufficient yield to satisfy the likely needs of Limerick County Council. While an occasional high yielding well is always possible in view of the folded and faulted nature of bedrock in Ireland, yields are generally low and may reduce further in dry weather. Also, wells in the Namurian rocks frequently have high iron concentrations.

6. Hydrochemistry and Water Quality

6.1 Introduction

An assessment of the quality of public and group scheme groundwater supplies in County Limerick was given in a report to Limerick County Council by the Geological Survey of Ireland (Deakin *et al.* 1997). This Chapter gives the main conclusions of the assessment.

6.2 Overall Assessment

- The hydrochemistry of groundwater in Co. Limerick is primarily influenced by the dominant limestone lithologies in both the bedrock and the subsoils. Dissolution is the principal hydrochemical process which takes place.

- The groundwater throughout most of County Limerick is hard and can be classed as a calcium bicarbonate ($Ca(HCO_3)_2$) water type. Softer waters are found in the upland areas in the west, south-east and south-west of the county where the bedrock comprises mainly sandstones and shales.

- The main groundwater quality problems due to the natural conditions in the ground and the natural chemistry of groundwater are caused by iron (Fe). A high proportion of wells in the Namurian rocks of west Limerick have high iron concentrations and to a lesser extent manganese (Mn).

- The main water quality problems caused by the impact of human activities are due to faecal bacteria and nitrate (NO_3). Chloride and potassium are good indicators of contamination.

- Mean nitrate levels were greater than the EU guide level (25 mg/l) in only eight (12%) out of 69 public and group scheme sources. However, peak levels were at or above the guide level in 19 sources (27%). Peak levels were above the EU MAC (50 mg/l) in three sources (4%).

- There was no evidence of a trend of increasing nitrate concentrations in any of the sources apart from the Cappagh GWS.

- Groundwater quality of the smaller and shallower sources tends to be poorer than the larger and deeper sources.

- Groundwater quality in the group scheme sources is poorer than in the public supplies. In particular, the presence of faecal bacteria in most of these sources is of concern. The location of many group scheme wells close to septic tank systems and/or farmyards is likely to be the main reason for the relatively poor quality.

- The group scheme and smaller sources are more likely to be affected by point source contamination (e.g. septic tank systems and farmyards) than by diffuse sources.

- There is a good correlation between groundwater vulnerability and groundwater quality – sources showing signs of contamination were usually located in areas where the groundwater was mapped in the extreme and/or high vulnerability categories.

- In general, the groundwater quality in County Limerick is relatively good and contamination is not extensive. However, some groundwater sources are polluted by faecal bacteria and there is evidence of contamination as shown by the chemical parameters. It is probable that the pollution and most of the significant contamination is caused by point sources, in particular farmyards and septic tank systems, and by poor sanitary protection of the sources.

6.3 Conclusions

- ♦ As a good database on groundwater quality is required to enable an improved and continuing assessment:
    - analyses of raw water rather than treated water will be carried out on a regular basis (at least twice a year until the situation and trend in each source is confirmed);
    - full analyses (including all major ions) will be carried out on these samples;
    - where there is evidence of contamination, the sampling frequency will be increased.

- ♦ Particular attention will be give to the County Council sources where the risk of contamination is considered to be high.

- ♦ It is recommended that the Council should embark on a programme of disinfecting all public schemes and in particular group schemes.

- ♦ The existing programme of undertaking groundwater protection zone delineation around public and group scheme supplies, using the GSI guidelines, will continue over the next few years.

- ♦ A programme of checking the sanitary protection at each well and spring site (i.e. on Co. Co. property in the immediate vicinity of the source) will be conducted to help ensure that shallow groundwater and surface water is not entering the source and that accidental spillages would not contaminate the source.

7. Groundwater Vulnerability

7.1 Introduction

The production of the groundwater vulnerability map for County Limerick required the following:
- differentiating between the subsoils in order to obtain three categories of permeability – high, moderate and low
- in the case of sand/gravel aquifers, the thickness of the unsaturated zone;
- the location of karst features
- contouring depth to bedrock data.

Summary information on vulnerability categories are given in Section 2.3.1; more detailed information can be obtained from the GSI.

7.2 Sources of Data

The following sources of data were used to produce the vulnerability map:
- the subsoils maps (Maps 2E and 2W)
- depth to bedrock data from all the GSI databases (Maps 3E and 3W)
- the GSI karst database
- six inch to one mile scale geological and topographic maps
- site visits undertaken in Limerick.

7.3 Permeability of the Subsoils

The permeability of a subsoil is largely a function of the percentage of clay and silt size grains present. The higher the percentage of clay and silt size particles, the lower the permeability. Permeability can also be assessed by examining the drainage characteristics of the various subsoils. The qualitative permeability values of subsoils in County Limerick, given in Table 7.1, were assigned on the basis of textural descriptions, particle size analyses and general relationships between subsoil types and matrix compositions.

7.3.1 Tills

Till deposits in County Limerick have a widespread distribution and are classified according to their lithological composition. Five main lithological types are present: limestone till; sandstone till; Silurian till; volcanic till and Namurian till.

Limestone till in south Limerick (south of a line between Fedamore and Askeaton) are generally clayey and therefore are taken to have a low permeability. In north Limerick, they are generally more gravelly and are considered to have a moderate permeability.

Sandstone till deposits are present in two areas – the north-east and the south-east. While there is little information on the matrix composition on the till in the north-east, it is assumed to be sandy and therefore to have a moderate permeability. To the south-east of the county however, despite some sections where the deposits have been mapped as sandy tills, the overall matrix composition is predominantly clayey. Investigations at Ballyguyroe on the Limerick-Cork border for example have shown the permeabilities of the sandstone tills to be in the region of 10^{-8} m/d. The south-easterly deposits are therefore considered to be generally of low permeability.

As the Silurian till is generally clayey, it is taken to have a low permeability.

Although the volcanic till is clayey in places, it is assumed to have a moderate permeability as it has a predominantly stony matrix.

Namurian till is classed as having a low permeability as, although in some areas it has a stony matrix, there is still generally a high clay content due to the weathering of shale clasts.

7.3.2 Sand and Gravel

Sand and gravel deposits in County Limerick are relatively coarse grained and are highly permeable.

7.3.3 Till with Gravel

Areas of till with gravel are underlain by both till and sand/gravel. The existing Quaternary mapping was insufficient to delineate the boundaries of the two deposits. Therefore this subsoil unit has hydrogeological characteristics typical of both till and sand/gravel, and the resulting permeabilities will vary depending on the underlying lithology. For the purposes of categorising vulnerability, the precautionary approach is taken, and therefore it is assumed that these deposits have a high permeability. However, site specific investigations will frequently show a moderate permeability and, on occasions, a low permeability.

7.3.4 Slope Deposits (Head)

Head deposits are all assumed to be coarse grained with a sandy matrix and therefore to have a moderate permeability.

7.3.5 Lake Bottom Deposits

Lake clays and silts have a low permeability – usually $<10^{-3}$ m/d (10^{-8} m/s) and frequently $<10^{-4}$ m/d.

7.3.6 Alluvium Deposits

These are variable ranging from highly permeable sandy gravelly deposits to clayey silty low permeability deposits and they will also vary depending on their topographic location. For the purposes of this study, alluvial deposits in upland and lowland areas are considered separately.

Upland areas:

1. Deposits are classed as high permeability deposits as they are likely to be coarser grained and more gravel rich than in lowland areas.

Lowland areas:

1. Deposits are generally classed as moderate permeability, i.e. considered in terms of a sandy silty deposit.
2. Where depth-to-rock is more than 10 m thick in an area mapped as alluvium, it is the composite vulnerability that must be considered, as it is often the case that alluvial deposits do not reach these depths. In these cases, the vulnerability of the likely underlying deposit is combined with the alluvium to give an overall estimate of the vulnerability of the entire deposit. Large alluvial flood plains, where deposits are likely to be thicker however, are an exception. In these areas the alluvium is given more weighting in the composite vulnerability and is assumed to be a sandy silty deposit of moderate permeability. Undoubtedly there are substantial areas where the deposits are silty/clayey; however, in the absence of better quality data the more conservative assumption on the permeability is taken.
3. In areas where alluvial deposits are mapped as 5–10 m thick they are given priority in the composite vulnerability as underlying deposits are likely to be thin and they are therefore considered to be of moderate permeability.

7.3.7 Peat

Peat permeabilities depend on the degree of peat decomposition (humification) and the effects of subsidence. Apart from the upper layer of intact bogs, peat has a relatively low permeability – often $<10^{-3}$ m/d (10^{-8} m/s).

In many lowland parts of Limerick, the peat is underlain by lake clay and silt. This usually has a low permeability, although the permeability will increase somewhat approaching the boundary of the lake clay/silt, where the proportion of clay decreases.

Although peat has a relatively low permeability, each peat deposit is considered separately because in places it is just a thin cover over an underlying permeable deposit where its presence may be due to a high water table. The vulnerability is based on consideration of the composite of all the subsoils overlying the bedrock in these instances. An area of peat east of Fedamore for example, where the depth-to-bedrock is 5–10 m, which would normally be classed as having a moderate vulnerability, is in fact classed as high vulnerability as the deposit is likely to be thin and therefore takes the vulnerability of the underlying moderate permeability alluvium.

7.3.8 Marine Deposits

In the absence of adequate information on the type and permeability and in view of their variable nature, marine deposits are classed as having a moderate permeability, even though they are likely to be silty and clayey in places.

Table 7.1. Permeability and Distribution of Subsoils in County Limerick

Subsoil	Assumed Permeability	Distribution
Limestone Till	Low Moderate	lowland area south of a line between Ardagh and Caherconlish lowland area north of a line between Ardagh and Caherconlish
Sandstone Till	Moderate Low	Slieve Felim area SE of county, south of a line between Mortlestown and Galbally.
Silurian Till	Low	SE of county between Ballylanders and Mitchelstown.
Volcanic Till	Moderate	East of county between Pallasgrean and Oola.
Namurian Till	Low	West of county in patches around Abbeyfeale, Drumcollogher, Ballyhahill and Glin.
Sand and Gravel	High	In lowland areas and adjoining the foothills of Slieve Felim and the Galty mountains.
Till with gravel	High	In lowland areas and adjoining the foothills of Slieve Felim and the Galty mountains.
Slope Deposits	Moderate	Slieve Felim, Galty mountains, and upland areas in west, with small patches north of Kilteely.
Lake Deposits	Low	Scattered small patches in low lying areas.
Alluvium	High Moderate	Along streams in upland areas. Flood plains along R. Mulkear, R. Maigue and R. Deel river.
Peat	Low	Upland areas, and around Castleconnell and small patches in lowlying areas.
Marine Sediments	Moderate	Along Shannon estuary.

7.4 Thickness of the Unsaturated Zone

The thickness of the unsaturated is only relevant in vulnerability mapping in the case of sand/gravel aquifers (see Table 2.1). The water table is generally >3 m deep, except where the sand/gravel is in a low-lying area (usually close to major rivers), therefore the vulnerability is generally high rather than extreme.

7.5 Karst Features

Karstification (the enlargement of fractures by chemical solution) of limestones in Limerick has given rise to the development of various karst features. Such features include swallow holes and caves. The karst features are shown on Maps 4E and 4W (the hydrogeology data maps), and on Map 6 (the vulnerability map), where they represent points of 'extreme' vulnerability.

7.6 Depth to Bedrock

Along with permeability, the thickness of the subsoils (the depth to bedrock) is also a critical factor in determining groundwater vulnerability to contamination.

A brief description of subsoil thicknesses is given in Section 4.11. The guidelines used in contouring the depth to bedrock data are listed in Appendix 1.

7.7 The Vulnerability Maps

The vulnerability maps (Maps 6E and 6W) are derived from combining the contoured depth to bedrock data, the subsoil types (permeabilities) and the identified karst features (see Section 2.3.1). Accurately located data are given the vulnerability category of low, moderate, high or extreme, whereas areas of interpreted vulnerability are classified as 'probably' low up to 'probably' extreme. This general classification scheme is outlined in Table 7.2.

Table 7.2. Summary of 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. 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. Locations where *moderate* permeability subsoil is known to be 3-10m thick. Locations where *low* permeability subsoil is known to be 3-5m thick.
Probably High	Areas of *high* permeability subsoil interpreted to be >3m thick. Areas of *moderate* permeability subsoil interpreted to be 3-10m thick. Areas of *low* permeability subsoil interpreted to be 3-5m thick.
Moderate	Locations where *moderate* permeability subsoil is known to be >10m thick. Locations where *low* permeability subsoil is known to be 5-10m thick.
Probably Moderate	Areas of *moderate* 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.
Probably Low	Areas of *low* permeability subsoil interpreted to be >10m thick.

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.

A large proportion of the county (74%; see Table 8.2) is classed as having either extreme or high vulnerability while areas of moderate and low vulnerability are much less common. This is a consequence of the often relatively shallow thicknesses of subsoils in Co. Limerick but it may also be a reflection of the distribution of borehole data. The 3 m contour, which influences the extreme and high vulnerability categories, is based on outcrop information, Quaternary mapping and borehole data. The presence or absence of 5 m and 10 m contours, which influence the moderate and low categories, is reliant solely on borehole data and uses the shallower contours as a guide for their interpretation. Where relevant borehole data to suggest greater depths are not available, these contours cannot be drawn and it is probably the case that there are more areas of moderate and low vulnerability than are currently depicted on the map. As more information becomes available, the maps can be up-dated.

The large areas of extreme vulnerability where rock is generally at or close to surface include the upland areas of the Slieve Felim and Galty Mountain ranges, higher areas such as the Namurian scarp to the west of the county, the area around the volcanic Limerick Syncline in the east and a large region to the north of the county north of a line from Rathkeale to Croom to Fedamore. When the upland areas, which have little development or potential for development, are excluded, the proportion of the county's groundwater that is extremely vulnerable is significantly reduced. High vulnerability areas are the most common category over the county and there are isolated patches of moderate vulnerability in places.

Areas of low vulnerability appear for the most part on the northern flanks of rock features, in particular the three anticlinal inliers at Ballingarry, Corronoher and Rockhill and the Galty Mountains, where thick deposits have accumulated due to the southerly ice movement direction. Generally speaking the morainic deposits are quite thick and those found stretching round the foot of the Namurian scarp from Dromcollogher to the area west of Newcastlewest reach up to 40 m. The limestone tills within these deposits class as low vulnerability. The largest area of low vulnerability stretches over the region south of Kilmallock and Bruree to Charleville and Kilfinnane. The area is mapped as limestone till which reaches depths of up to 80 m in places and is hence of low vulnerability. It is expected however that with this thickness of deposit it is not likely to be a uniform till but may have interbedded sands and gravels in places; further confirmation that site investigation is essential to verify the vulnerability for specific developments.

Water quality variations in the public supply sources were found to have a good correlation with the vulnerability classifications assigned to the zones of contribution of the sources (Deakin, 1994). Thus, sources with relatively poor quality were located in areas of extreme and high vulnerability.

8. Groundwater Protection

8.1 Introduction

In Chapter 2, the general groundwater protection scheme guidelines were outlined and in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice for potentially polluting activities – was described. Subsequent chapters describe the different geological and hydrogeological land surface zoning elements as applied to County Limerick. This chapter draws these together to give the ultimate and final elements of land surface zoning – the groundwater protection scheme map and the source protection maps. It is emphasised that these maps are not intended as 'stand alone' elements, but must be considered and used in conjunction with the codes of practice.

8.2 The Groundwater Protection Maps

The groundwater protection maps (Maps 7E and 7W) were produced by combining the vulnerability maps (Maps 6E and 6W) with the aquifer maps (Maps 5E and 5W). Each protection zone on the map is given a code which represents both the vulnerability of the groundwater to contamination and the groundwater resource (aquifer category). The codes are shown in Table 2.3, the general groundwater protection scheme matrix, and in Table 8.1. Not all of the possible hydrogeological settings are present in County Limerick; the zones not present are omitted from Table 8.1. The proportion of the county in each zone is shown in Table 8.2.

Two regionally important karst aquifer sub-types (**Rk^c** and **Rk^d**) are shown on the aquifer maps (Maps 5E and 5W). However, these are distinguished to indicate groundwater development potential and the difference does not affect the groundwater protection responses. Therefore, both are shown on the groundwater protection zone maps (Maps 7E and 7W) as **Rk**.

Table 8.1. Matrix of Groundwater Resource Protection Zones

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

Table 8.2. Proportion of County in Each Zone

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf	Lm/Lg	Ll	Pl	Pu
Extreme (E)	6%	7%	4%	10%	9.5%	0.6%
High (H)	1%	11.6%	4.2%	13%	7.5%	0.2%
Moderate (M)		3%		3.7%	3.5%	
Low (L)		6%		8.5%	0.5%	0.2%

8.3 Groundwater Source Protection Reports and Maps

The techniques used to delineate source protection zones (described in section 2.3.2) have been applied to eighteen public supply wells in County Limerick: Ardagh, Ballingarry, Ballyagran, Bruff, Bruree, Cappaghmore Faileen, Carrigkerry, Clouncagh, Croom, Fedamore, Glin, Herbertstown, Hospital, Kilcoleman, Mortlestown, Murroe, Pallasgrean, Tobergal (South West Region). These have been produced as separate source reports.

8.4 Conclusion

The groundwater protection scheme given in this report will be a valuable tool for Limerick County Council in helping to achieve sustainable water quality management and in the location of potentially polluting activities.

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Appendix 1 Guidelines for Contouring Depth-to-bedrock in County Limerick

- Contouring was carried out by hand at the scale of 1 inch to one mile in order to incorporate topographical information on the Ordnance Survey one inch maps and as it was deemed the most suitable scale for the available data.

- The boundaries of areas where rock is mapped as being close to the surface on the Quaternary maps are taken to represent a 1 m depth-to-rock contour.

- An average interval distance from the 1 m to the 3 m contour was estimated, using the available point depth-to-rock data, to be in the region of 100–150 m in the lowland areas, and 50–100 m in the upland areas.

- The interval distance from the 3 m to the 5 m contour was estimated from the available point data to be 130–190 m in the lowland areas and 100–130 m in the upland areas.

- The 10 m contours are more dependent on the presence of adequate borehole information although an interval distance between them and the 5 m contours of 200 m was used as a guide. It appears to be the case in Co. Limerick that deposits that reach thicknesses of 10 m or more do so with a steeper gradient than the more shallow deposits.

- Only data which had been plotted with an accuracy of plus or minus 50 m were used in the actual contouring although less accurately plotted data were used, within their respective limitations, for confirmation of the general spatial thicknesses.

- Depending on the size of the area to be contoured at least two or three data points were necessary to include a contour. The average interval distances were consistently used except where there were point data to the contrary. The deeper 5 and 10 m contours were included only where the data facilitated it. Their absence from an area does not necessarily imply the deposits do not reach those thicknesses but that their existence was inconclusively proven from the available data.

- Due to the spread and variable quality of data, the irregularity of the bedrock topography, and the subjective opinions of the drillers in logging the bedrock surface, it was inevitable that some of the data points did not fit the interpreted depth-to-rock contours. This was particularly highlighted in areas where there were extensive investigations and may be a consequence of boreholes encountering fault zones, karst or extensive dolomitisation. It must be emphasised that the contours are only interpretations highlighting *areas* of different thicknesses and are not definitive boundaries.

- As the contours are only to be used as a guide a smoothing function was used within AutoCAD during the course of the digitising the eastern portion of the map to round off the lines. This function takes an average of all the digitised points and as a result the contours are not as accurately positioned as they were drawn. This is not seen as a problem in terms of accuracy as the data do not merit it although it does decrease the apparent level of consistency in the contour interval distances.