County Offaly
Groundwater Protection Scheme

Prepared by:

Donal Daly, Colette Cronin, Catherine Coxon and Sarah Jane Burns

in collaboration with:

Offaly County Council

Offaly County Council
Courthouse
Tullamore
County Offaly

Geological Survey of Ireland
Beggars Bush
Haddington Road
Dublin 4

June 1998

AUTHORS

Donal Daly, Senior Hydrogeologist, Groundwater Section, Geological Survey of Ireland.

Colette Cronin, Hydrogeologist, Groundwater Section, Geological Survey of Ireland.

Catherine Coxon, Lecturer, Environmental Sciences Unit, Trinity College Dublin.

Sarah-Jane burns, formerly of the Geological Survey of Ireland and Trinity College Dublin.

TABLE OF CONTENTS

1. INTRODUCTION 1

1.1 Objective and Scope of Groundwater Protection Scheme 1

2. THE GROUNDWATER PROTECTION SCHEME – A MEANS OF PREVENTING CONTAMINATION 3

2.1 Introduction 3
2.1.1 Groundwater Protection – A Priority Issue for Local Authorities 3
2.1.2 The Threat to Groundwater 3
2.1.3 Groundwater Protection Through Land-use Planning 3
2.1.4 Environmental Principles 4
2.1.5 Risk and Risk Management - A Framework for Groundwater Protection Schemes 4
2.1.6 Objectives of the Groundwater Protection Scheme 7

2.2 How A Groundwater Protection Scheme Works 7

2.3 Land Surface Zoning for Groundwater Protection 8
2.3.1 Groundwater Vulnerability Categories 8
2.3.2 Groundwater Source Protection Zones 10
2.3.3 Groundwater Resource Protection Zones 13

2.4 Codes of Practice 14

2.5 Integration of Groundwater Protection Zones and Codes of Practice 14

2.6 Draft Code of Practice for Landfills 15

2.7 Draft Code of Practice for Septic Tank Systems 16

2.8 Information and Mapping Requirements for Land Surface Zoning 17

2.9 Flexibility, Limitations and Uncertainty 17

2.10 Conclusions 18

3. THE GEOLOGICAL FRAMEWORK 21

3.1 Introduction 21

3.2 Bedrock Geology 21
3.2.1 General 21
3.2.2 Silurian Slates and Sandstones 21
3.2.3 Old Red Sandstone (ORS) 21
3.2.4 Cadamstown Sandstone 21
3.2.5 Lower Limestone Shale (LLS) 21
3.2.6 Ferbane Mudstone and Cloghan Sandstone (FB) 22
3.2.7 Ballysteen Limestone (BA) 22
3.2.8 Waulsortian Limestone (WA) 22
3.2.9 Dolomitized Waulsortian Limestone (WAd) 22
3.2.10 Edenderry Limestone (ED) 22
3.2.11 Allenwood Limestone (AW) 22
3.2.12 Calp Limestone (CD) 22
3.2.13 Borrisokane Pure Limestone (BK) 22

3.2.14 Volcanics (V) 22
3.2.15 Structural Geology 23

3.3. Subsoils Geology 23
3.3.1 General 23
3.3.2 Till 23
3.3.3 Sand and Gravel 24
3.3.4 Limestone Till with Gravel 24
3.3.5 Marl 24
3.3.6 Alluvium 24
3.3.7 Peat 24

3.4 Depth to Bedrock 25

4. HYDROGEOLOGY AND AQUIFER CLASSIFICATION 28

4.1 Introduction 28

4.2 Data Availability 28

4.3 Rainfall and Evapotranspiration 28

4.4 Groundwater Usage 30

4.5 General Aquifer Classification 30

4.6 Silurian Slates and Sandstones 32

4.7 Old Red Sandstone 34

4.8 Cadamstown Sandstone 34
4.8.1 Zone 1 34
4.8.2 Zone 2 36
4.8.3 Zone 3 36
4.8.4 Zone 4 36

4.9 Lower Limestone Shale 36

4.10 Ferbane Mudstone and Cloghan Sandstone 36

4.11 Ballysteen Limestone 37

4.12 Waulsortian Limestone 37

4.13 Dolomitized Waulsortian Limestone and Edenderry Limestone 38

4.14 Calp Limestone 39

4.15 Allenwood Limestone and Borrisokane Pure Limestone 40

4.16 Volcanics 42

4.17 Potential Sand/Gravel Aquifers 42

4.18 Potential for Future Groundwater Development in County Offaly 43
4.18.1 Allenwood Limestone and Borrisokane Pure Limestone 43
4.18.2 Cadamstown Sandstone 43
4.18.3 Sand/gravel 44

4.18.4 Calp Limestone 44
4.18.5 Dolomitised Waulsortian Limestone 44
4.18.6 Edenderry Limestone 44
4.18.7 Volcanics 44
4.18.8 Remaining Rock Units 44

5. HYDROCHEMISTRY AND WATER QUALITY 45

5.1 Introduction 45

5.2 Overall Assessment 45

5.3 Conclusions 45

6. GROUNDWATER VULNERABILITY 47

6.1 Introduction 47

6.2 Sources of Data 47

6.3 Permeability of the Subsoils 47
6.3.1 Eskers 47
6.3.2 Sand and Gravel 47
6.3.3 Tills 47
6.3.4 Till with Gravel 48
6.3.5 Peat 48
6.3.6 Alluvium 48
6.3.7 Marl 48

6.4 Karst Features 49

6.5 Depth to Bedrock 49

6.6 The Vulnerability Map (Map 7) 49

7. GROUNDWATER PROTECTION 51

7.1 Introduction 51

7.2 The Groundwater Protection Maps 51

7.3 Groundwater Source Protection Reports and Maps 51

7.4 Conclusion 51

8. REFERENCES 52

APPENDIX 1 : GUIDELINES FOR CONTOURING DEPTH TO BEDROCK AND ASSIGNING VULNERABILITY IN COUNTY OFFALY 54

List of Tables

Table 2.1	Vulnerability Mapping Guidelines	9
Table 2.2	Matrix of Source Protection Zones	13
Table 2.3	Matrix of Groundwater Resource Protection Zones	14
Table 2.4	Groundwater Protection Scheme Matrix for Activity X	14
Table 2.5	Groundwater Protection Scheme Matrix for Landfills	15
Table 2.6	Draft Groundwater Protection Scheme Matrix for Septic Tank Systems	17
Table 2.7	Responses to the Proposed Location of a Septic Tank System	19
Table 3.1	Summary of Bedrock Geology	26
Table 3.2	Summary of Subsoils Geology	27
Table 4.1	Water Abstraction from County Council Schemes	32
Table 4.2	Details on Group Water Schemes	32
Table 4.3	Use of Well Yields in Defining Aquifers	33
Table 4.4	Well Yield Categories and Karst Features	34
Table 4.5	Summary of Well Details at Ferbane	35
Table 4.6	Hydrogeological Characteristics of Cadamstown Sandstone	37
Table 4.7	Summary information for Ferbane Mudstone and Cloghan Sandstone	38
Table 4.8	Summary information for Ballysteen Limestone	38
Table 4.9	Summary information for Waulsortian Limestone	39
Table 4.10	Summary information for Dolomitised Waulsortian Limestone and Edenderry Limestone	40
Table 4.11	Summary information for Calp Limestone	41
Table 4.12	Summary of hydrogeological information for Cullahill aquifer	42
Table 4.13	Summary information for Borrisokane Limestone and Allenwood Limestone	42
Table 4.14	Hydrogeological data for Hollimshill and Tully Wells	43
Table 4.15	Summary information for well in Volcanic aquifer	43
Table 4.16	Summary information for wells and springs in sand/gravel	44
Table 6.1	The Permeability and Distribution of Subsoils in County Offaly	51
Table 6.2	Vulnerability classification scheme	52
Table 7.1	Matrix of groundwater resource protection zones	53

List of Figures

Figure 2.1	A conceptual model of the elements of risk and risk assessment	6
Figure 2.2	Summary of Components of Groundwater Protection Scheme	8
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)	12
Figure 2.4	Conceptual framework for production of groundwater resource protection zones, indicating information needs and links	20
Figure 2.5	Conceptual framework for production of groundwater source protection zones, indicating information needs and links	20
Figure 4.1	Contoured Mean Annual Precipitation in Offaly	29
Figure 4.2	Schematic representation of groundwater movement in the Cadamstown Sandstone aquifer system	35

1. Introduction

1.1 Objective and Scope of Groundwater Protection Scheme

This report was initiated to provide Offaly 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 Offaly County Council, the Geological Survey of Ireland and Trinity College Dublin. The original work on the protection scheme was carried out by Sarah Jane Burns as part fulfillment for the M.Sc. degree at the Environmental Sciences Unit, Trinity College Dublin (Burns, 1993).

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

- ♦ delineation of aquifers;
- ♦ an assessment of the groundwater vulnerability to contamination;
- ♦ delineation of protection areas around public supply wells and springs; and
- ♦ 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:

Primary Data or Basic Maps

- bedrock geology map
- subsoils (Quaternary) geology map
- outcrop and depth to bedrock map
- hydrogeological data map

Derived or Interpretative Maps

- bedrock aquifer map
- potential gravel aquifer map
- groundwater vulnerability map.

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 Offaly are limited to a number of public supply sources – Edenderry, Banagher, Gormagh and Toberdaly – and to studies at Clara Bog and Raheenmore Bog. Consequently, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of County

Offaly. 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 Offaly protection scheme and they provide the structure for this report.

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 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 Offaly. 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**.

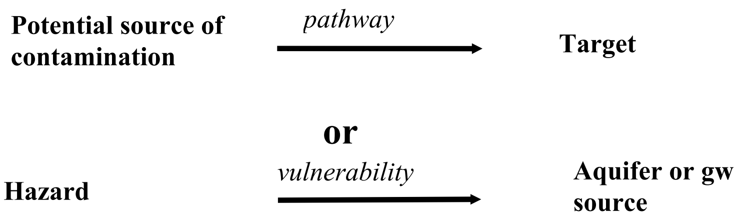
RISK = PROBABILITY OF AN EVENT × CONSEQUENTIAL DAMAGE

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:



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. A conceptual model of the relationship between these factors is given in 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.

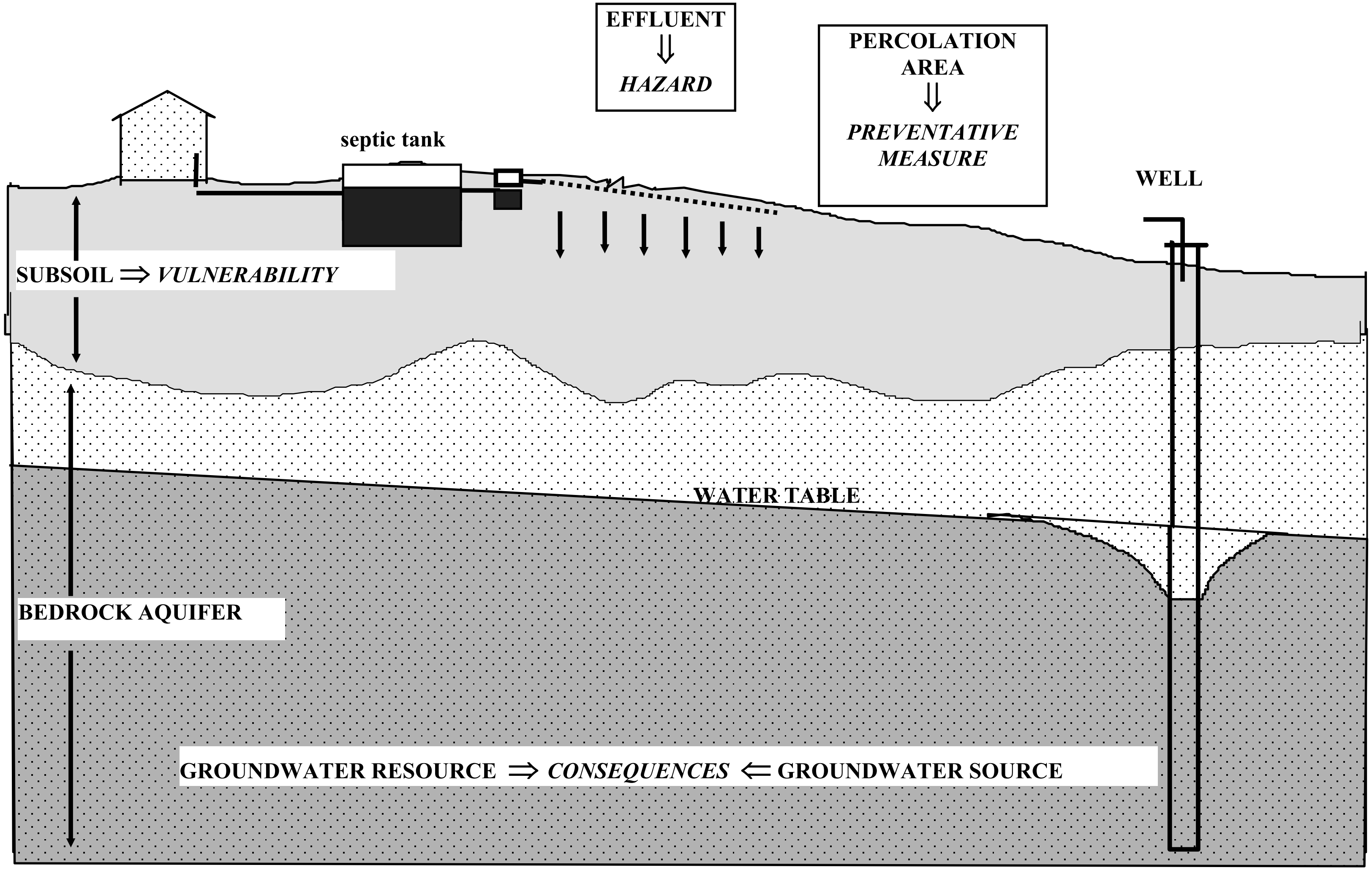


Figure 2.1 A Conceptual Model of the Elements of Risk and Risk Management

RISK TO GROUNDWATER

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

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.

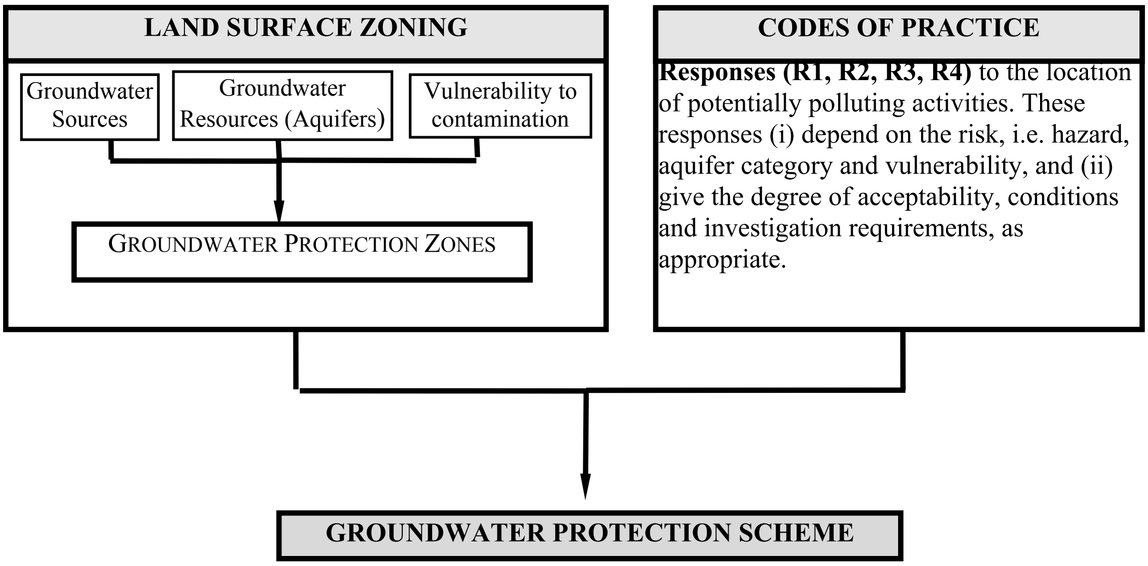
2.2 How A Groundwater Protection Scheme Works

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**.**

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.

Figure 2.2 Summary of Components of Groundwater Protection Scheme



There are three main hydrogeological elements to land surface zoning:

- Division of the entire land surface according to the **vulnerability** of the underlying groundwater to contamination. This requires production of a vulnerability map showing four vulnerability categories.
- 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;
(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), lake and alluvial silts and clays, peat - 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, in press)

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 (ZOC).

In delineating the Inner and Outer Protection Areas areas, there are two broad approaches: firstly, 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:
- ♦ Calculated Fixed Radius;
- ♦ Analytical Methods;
- ♦ Hydrogeological Mapping;
- ♦ 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 guide 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 sometimes 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.

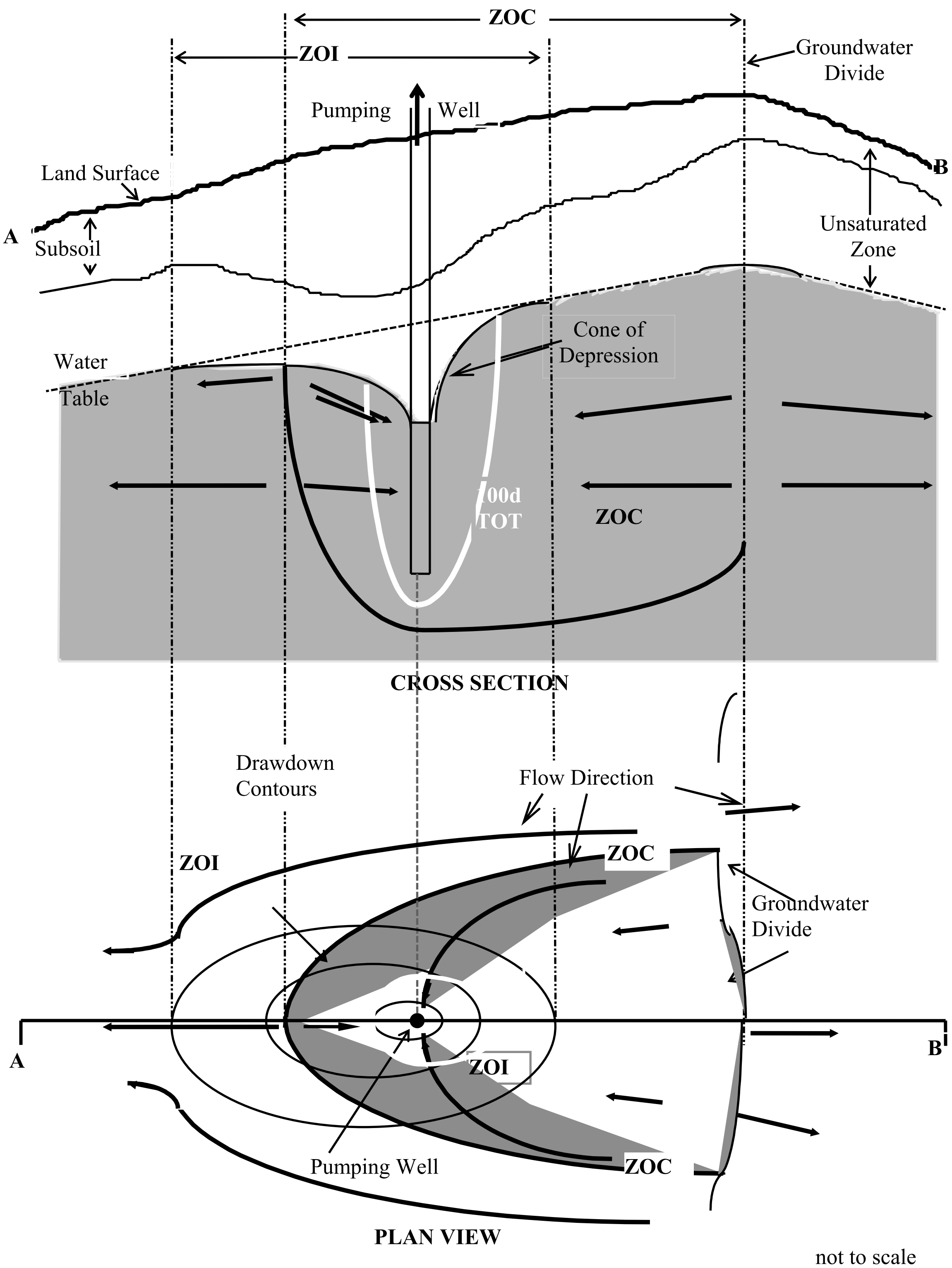


Figure 2.3 Conceptual Model of the Zone of Contribution (ZOC) and the Zone of Influence (ZOI) at a Pumping Well (adapted from U.S. EPA, 1987)

2.3.2.4 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 12 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SO/H**, which represents an Outer Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around each local authority source. The outcome is a groundwater protection zone map (see example in Figure 2.2).

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

2.3.3 Groundwater Resource Protection Zones

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

Regionally Important (R) Aquifers

(i) Karstified aquifers (where conduit flow is dominant) (**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 than 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 agricultural wastes; only the landfill code of practice is readily available (from the EPA). Preparation of codes of practice requires the involvement and, in most instances, the agreement of the local authority. As a means of illustrating the use of the scheme and the relationship between the groundwater protection zones and the codes of practice, draft codes of practice are given in the following sections.

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/Lg*	*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 Draft Code of Practice for Septic Tank Systems

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

Table 2.6 Draft Groundwater Protection Scheme Matrix for Septic Tank Systems

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

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

2.8 Information and Mapping Requirements for Land Surface Zoning

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

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 the geological framework
- Chapter 4 hydrogeology and aquifer classification
- Chapter 5 hydrochemistry and water quality
- Chapter 6 groundwater vulnerability
- Chapter 7 groundwater resource protection
- Chapter 8 groundwater source protection

2.9 Flexibility, Limitations and Uncertainty

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

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. 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.

2.10 Conclusions

- Groundwater protection schemes are an essential means of enabling local authorities to take account of (i) the potential risks to groundwater resources and sources and (ii) geological and hydrogeological factors, when considering the location of potentially polluting developments; consequently, they are now an essential means of preventing groundwater contamination.

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

- Groundwater protection schemes should not be seen as a panacea for solving all groundwater contamination problems. In practice their use needs a realistic and flexible approach. The maps have limitations because they generalise (with the degree of generalisation depending on data availability) variable and complex geological and hydrogeological conditions. Consequently, the proposed scheme is not prescriptive and needs to be qualified by site-specific considerations and investigations. The investigation requirements depend mainly on the degree of hazard provided by the contaminant loading and, to a lesser extent, on the availability of hydrogeological data.

- The scheme has the following benefits and uses:

    - it provides a hierarchy of levels of risk and, in the process, assists in setting priorities for technical resources and investigations.
    - it contributes to the search for a balance of interests between groundwater protection issues and other special and economic factors.
    - it can be adapted to include risk to surface water.
    - it acts as a guide and provides a 'first-off' warning system before site visits and investigations are made.
    - it shows generally suitable and unsuitable areas for potentially hazardous developments such as landfill sites and piggeries.
    - by controlling developments and enabling the location of certain potentially hazardous activities in lower risk areas, it helps ensure that the pollution acts are not contravened.
    - it can be used in preparing Emergency Plans, assessing environmental impact statements and the implications of EU directives, planning and undertaking groundwater monitoring networks and in locating water supplies.

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

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

Table 2.7 Responses to the Proposed Location of a Septic Tank System (draft, subject to alteration)

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

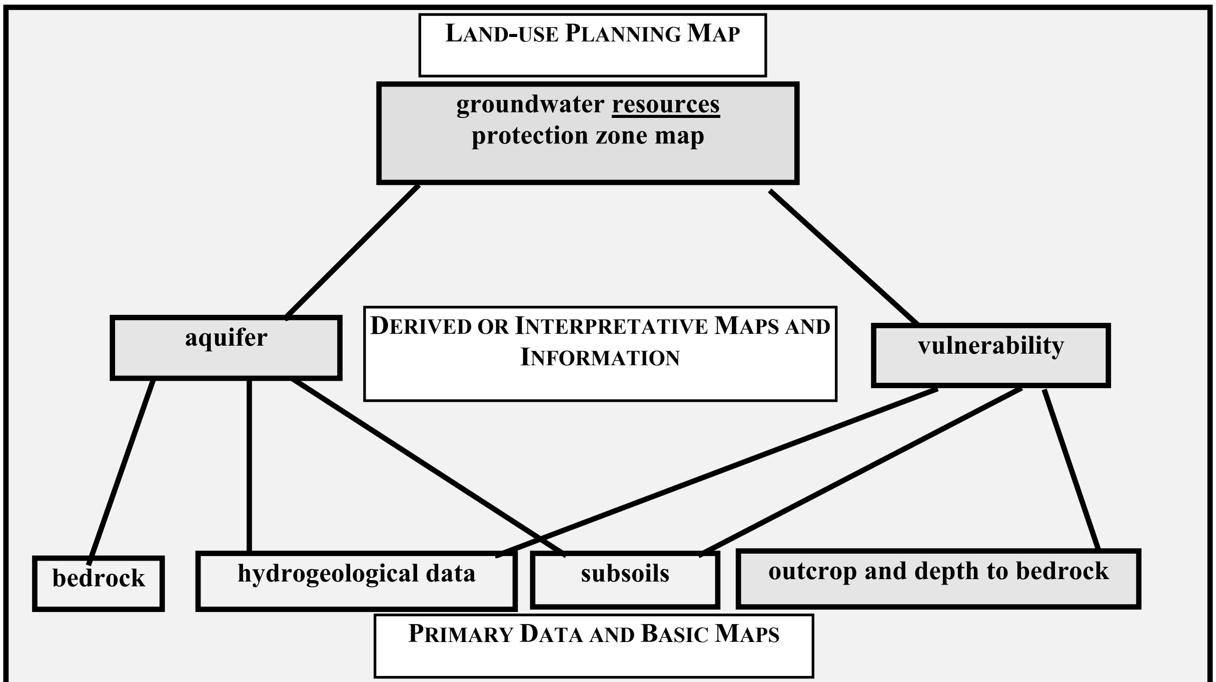


Figure 2.4 **Conceptual framework for production of groundwater <u>resource</u> protection zones, indicating information needs and links.**

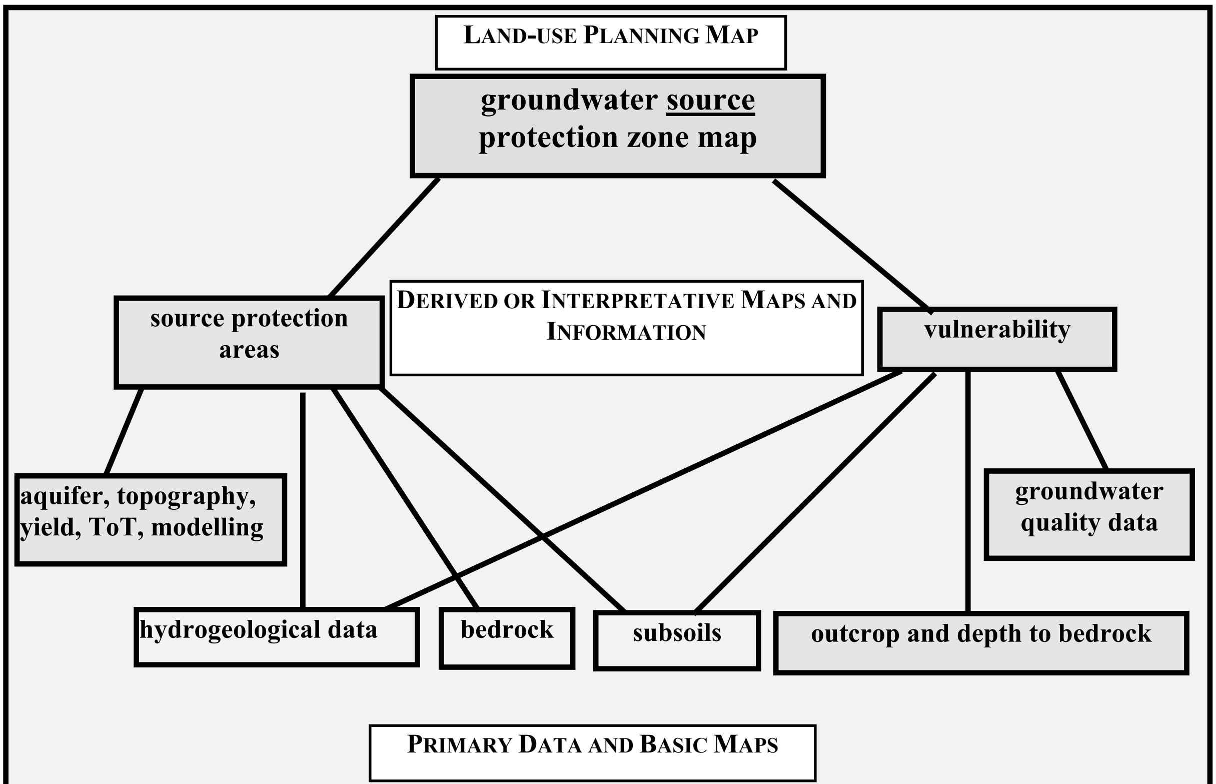


Figure 2.5 **Conceptual framework for production of groundwater <u>source</u> protection zones, indicating information needs and links.**

3. The Geological Framework

3.1 Introduction

Offaly forms part of the Central Lowland of Ireland, an area of low-lying rolling topography with occasional hills and one mountain - Slieve Bloom. The higher topographic features - Slieve Bloom, Croghan Hill, Bellair Hill, Cor Hill, Knockhill, etc - have bedrock at or close to the surface. However, the bedrock in most of Offaly is masked by Quaternary sediments or subsoils - peat, river alluvium, sand, gravel, till (boulder clay) - which form many of the irregular topographic features in the lowlands. In particular the esker sand and gravel ridges and the raised bogs are typical landscape features in County Offaly.

The purpose of this section is to describe the different bedrock types and subsoils that form the framework of County Offaly, delineate their distribution and assess the thickness of subsoil over bedrock. This information provides the basis for aquifer definition and groundwater vulnerability assessments.

3.2 Bedrock Geology

3.2.1 General

The bedrock geology of the area is shown on Map 1 and is summarised in Table 3.1. The different rock types, starting with the oldest, are now described.

3.2.2 Silurian Slates and Sandstones

These rocks are present in the core of Slieve Bloom and near Moneygall. They consist of grey and grey-green siltstones, clayey sandstones and slates. At the end of the Silurian period they were slightly metamorphosed by a phase of folding.

3.2.3 Old Red Sandstone (ORS)

Overlying the Silurian rocks in Slieve Bloom are a mixed sequence of red (sometimes green) sandstones, siltstones, mudstones and occasional conglomerates which were deposited on the Devonian landmass by meandering rivers. Sandstones make up about 40% of the succession. They dominate in the lower part, with siltstones and mudstones dominating in the upper part.

3.2.4 Cadamstown Sandstone

This consists of medium to coarse grained, pale, often creamy coloured sandstone with red and green siltstones and mudstones. Analyses of core and geophysical well logs show that sandstones account for over 70% of the upper part and close to 50% of the lower part of the unit (E.P. Daly, 1994). It varies in thickness from 70 to 105m.

In certain areas the rock cement has been dissolved and so the rock is crumbly and easily weathered.

3.2.5 Lower Limestone Shale (LLS)

At the beginning of Carboniferous times (363 million years ago), a sea gradually spread northwards and inundated Offaly. All the remaining rocks - mainly limestones - were deposited as sediments under a range of marine environments caused by variations in sea depth and the amount of mud washed in.

The onset of marine conditions caused the deposition of thinly-bedded, dark grey calcareous mudstones and occasional thin muddy limestones. These overlie the Clonaslee sandstone around Slieve Bloom. Few exposures are present in the area as they are easily eroded and weathered and are overlain by an extensive cover of subsoils.

3.2.6 Ferbane Mudstone and Cloghan Sandstone (FB)

This unit overlies the Clonaslee Sandstone in the Ferbane-Cloghan area.

It varies from mudstones with siltstones at the bottom, to mudstones with limestones, to mudstones, to mudstones and sandstones, and to sandstones with occasional limestones at the top (Philcox, 1983). The top sandstone has been called the Cloghan sandstone (Philcox, 1983) and is 30m thick at Cloghan. The remainder have been called the Ferbane Mudstone (Philcox, 1983), which is 50m thick at Cloghan.

3.2.7 Ballysteen Limestone (BA)

This is a medium-dark grey, well-bedded, muddy fossiliferous limestone with mudstone bands and some siltstones. The mud content increases towards the top. It is 325m thick at Cloghan (Philcox, l983). This rock unit surrounds Slieve Bloom and stretches southwards to Moneygall. It also occurs in the Ferbane - Cloghan area, around Clonmacnoise and south of Clonbullogue.

3.2.8 Waulsortian Limestone (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 pure sea where the sediment input from land was minimal.

This is the most abundant rock type in County Offaly, stretching as three broad bands across the county in a NE-SW direction. Many of the higher topographic features in west Offaly - Knockhill, Bellair Hill, Cor Hill, Endrim Hill, Knockbarron, Killeenbreaghan Hill - are composed of this rock type.

3.2.9 Dolomitized Waulsortian Limestone (WAd)

This is present in the eastern part of the county as small pockets within the Bank Limestone. Dolomitization is a process whereby the calcium in limestone ($CaCO_3$) is partially replaced by magnesium to give dolomite ($Ca\ Mg\ (CO_3)_2$). This results in an increase in porosity and permeability of the limestones as the crystal lattice of dolomite occupies about 13% less space than that of calcite (Freeze and Cherry, 1979).

3.2.10 Edenderry Limestone (ED)

In the Edenderry area, a pale grey, poorly-bedded oolithic (small spherical-shaped grains) limestone is present.

3.2.11 Allenwood Limestone (AW)

This is a poorly-bedded, medium to coarse grained limestone which overlies the bank limestone. It is equivalent to the Crosspatrick limestone in County Laois.

3.2.12 Calp Limestone (CD)

This is a dark, well-bedded, fine grained clayey limestone with calcareous mudstones. A large area east of Tullamore and north of Killeigh is underlain by this rock type, with smaller areas north of Clonbullogue, west of Portarlington, south of Birr, south of Banagher and at Shannonbridge.

3.2.13 Borrisokane Pure Limestone (BK)

This is mainly a thick-bedded, coarse grained, pale limestone with some darker fine grained beds and with occasional thin clayey bands (clay wayboards). It extends from Birr northeastwards through Tullamore and Durrow. It is equivalent to the Ballyadams Limestone in Laois and Kildare.

3.2.14 Volcanics (V)

Volcanic activity during the time of deposition of the upper black limestone deposited basaltic lavas and ash. They are dark grey and green in colour. The main outcrop is at Croghan Hill, which is the highest hill in east Offaly. Other small outcrops occur east and north of Croghan Hill, including an outcrop east of Edenderry.

3.2.15 Structural Geology

Movements in the earth's crust have caused the rocks to be folded, faulted and jointed. The different rock units have a NE-SW trend or strike and they generally dip either north-westwards or south-eastwards at a low angle. Two major fault sets are present - NE-SW and SE-NW. The joint pattern is likely to have similar orientations. Many more faults than are shown on Map 1 are likely to be present in the area. According to E.P. Daly (in press), the Devonian sandstones and the limestones are faulted every 500 - 1000m along stretches in the Nore Basin area. The same situation is likely to be present in County Offaly.

3.3. Subsoils Geology

3.3.1 General

Subsoils or Quaternary deposits conceal the bedrock over much of County Offaly. They were laid down in different environments - glacial, lacustrine (or lake) and fluvial (or river).

Most of the glacial deposition occurred during and following the maximum extent of the last glaciation about 18,000 years ago. Large volumes of detritus were deposited as till below or at the margins of the ice sheet. As the ice melted, water influenced sedimentation and sand/gravel was deposited. The depositional processes were chaotic and this has resulted in highly variable lithologies or sediment types over short distances.

As the ice melted, extensive lakes formed in the low ground. Clay and silt were washed into the lakes initially, but with time the lakes gradually became fens as vegetation encroached from the margins. They then grew as raised bogs which rose above the former lake levels. In some of the lakes, the hard groundwater and surface water caused the precipitation of calcium carbonate or marl prior to and during the onset of peat deposition. In the lowlying areas along the rivers, silt and clay have been deposited to form alluvium.

No lake deposits are shown on Map 2. However, they are present beneath a high proportion of the area shown as peat, alluvium and marl. These deposits are sticky, plasticine-like, grey clays and silts with some sand and stones in places.

The different sediments are shown on Map 2 and are summarised in Table 3.2. Each of the main sediment types is now described.

3.3.2 Till

Till (commonly called "boulder clay") is a poorly sorted deposit of boulders and stones in a matrix of sand, silt and clay. It is widely distributed throughout Offaly. The stone content is variable in type, size and quantity. Limestone-dominated tills, which are usually grey in colour, are by far the most common in Offaly, reflecting the underlying bedrock geology. Sandstone tills are present in Slieve Bloom. The stones and boulders are generally angular and subangular, and are often striated (gouged by the ice). However, from a groundwater protection point of view, the matrix material - sand, silt or clay - is the most important. The fine grade material (<0.06mm or silt and clay) in till can vary from 6 - 30%. Consequently, depending on this proportion, tills can be classified as free-draining, intermediate permeability sandy till or poorly-draining low permeability clayey till. However, there is insufficient information available to distinguish between the two on Map 2, although there is a fair likelihood that in the areas where the till overlies impure, black limestone, it is likely to be clayey.

Work by Warren (reported in Hammond *et al.* (1987)) on Slieve Bloom has shown that limestone-dominated material has been carried over and deposited on the Silurian and Devonian rocks over a distance of 6km. These calcareous deposits have impacted on the groundwater chemistry in the Devonian sandstones.

3.3.3 Sand and Gravel

Extensive fluvioglacial sands and gravels are present in County Offaly. They have been subdivided on Map 2 as "eskers" and as "sand and gravel". The latter are mainly outwash deposits and are generally associated with the eskers.

Eskers are typically long sinuous sand/gravel ridges which generally are 10-30 m high and 30-100 m wide (Warren, 1997). Most eskers are formed by meltwater flowing in tunnels under an ice sheet or in an ice-walled channel near the ice margin (Warren, 1997).

The outwash sands/gravel are generally coarse and poorly sorted (sorting coefficient SC > 5), but often have lenses of better sorted material (SC < 2.5). They normally contain less than 3% fine grade material.

3.3.4 Limestone Till with Gravel

The reconnaissance work in Offaly has shown that many of the sand/gravel units are small and are interbedded with tills (Warren in Hammond *et al.* (1987)). In many places it is not possible to map out separately the sand/gravel units and the till units during a reconnaissance mapping project. This has led to the term "till with gravel" being employed to categorise the sediments over relatively large areas.

3.3.5 Marl

Marl is a calcium carbonate ($CaC0_3$) deposit, often containing a small proportion of organic matter or clay minerals. Mollusc shells may also be present and as a consequence it is often referred to as "shell marl". It is cream, white or rusty white in colour. In situ samples taken below the water table are usually soft with a low plasticity.

The deposition of marl is caused by precipitation of calcium carbonate from the hard groundwater and surface water that entered the shallow lakes. It is usually a thin sediment - less than 1m - and is present on top of the lake clays and silts and beneath the fen peat.

3.3.6 Alluvium

Alluvium, consisting of silts and clays, has been deposited along the flood plain of the Shannon, Brosna, Little Brosna, Silver, Figile and Yellow rivers.

3.3.7 Peat

Peat covers 32.2% of County Offaly (Hammond *et. al.,*1987) a higher proportion than any other Midland county. The three main Irish peatland types - blanket bog, fen and raised bog - are present although they are not distinguished on Map 2.

Blanket bog covers extensive tracts on Slieve Bloom. It forms in areas with cool summers, high rainfall (>1250mm) with more than 225 rain days per year (Hammond, 1979). The peat is acidic. It is generally shallow (<3m thick).

About 9,000 years ago peat deposition commenced in the shallow lakes, forming fen peat. As the water quality in the lakes was mineral-rich (usually calcium-rich), the fen peat is slightly alkaline. Fen peat is composed of dead accumulated reeds, rushes, sedges and grasses, and is dark and fibrous. It is generally 2-3m thick.

With time the top of the fen peat rose above the lake water level and the groundwater level in the surrounding area and so the only source of minerals for the plants came from rainfall. Sphagnum mosses, which can live in mineral-poor environments, colonized the fen. Peat continued to accumulate, forming flattened domes slightly higher than the surrounding area, which are called raised bogs. Sphagnum forms peat which is light and spongy. It is very acidic. Raised bogs can reach a total thickness of up to 15m. However, peat cutting has reduced and is continuing to reduce the thicknesses with the exception of a few bogs that have been conserved e.g. Clara, Raheenmore and Mongan.

3.4 Depth to Bedrock

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

Accurate information on the depth to bedrock in County Offaly is restricted to: outcrop data; geotechnical records; geological exploration boreholes and water well data. Some of the available depth to bedrock data from well records cannot be located accurately – only the townland is known. All the depth to bedrock data is shown on Map 3E and 3W, with the degree of locational accuracy indicated.

Depth to bedrock is quite variable throughout the county. The subsoils of the upland areas tend to be < 3m, but elsewhere in Offaly depths of 10 to 20m are frequently recorded.

TABLE 3.1 SUMMARY OF BEDROCK GEOLOGY

AGE (million years ago)	ROCK UNIT TITLE	DESCRIPTION	DISTRIBUTION
325	Volcanics (V)	Dark grey basalt and green ash.	Croghan Hill
	Borrisokane Pure Limestone (BK)	Pale grey, thick-bedded, medium-coarse grained limestones with occasional mudstone bands.	From Birr northeastwards to Durrow and near Clonbullogue and between Blueball and Tullamore.
	Calp Limestone (CD)	Dark grey to black, fine grained, well-bedded, clayey limestone with occasional mudstones.	East of Tullamore, south of Edenderry, west of Portarlington, around Shannonbridge, south of Banagher and near Birr.
CARBONIFEROUS	Allenwood Limestone (AW)	Poorly-bedded, medium-coarse grained, pure limestones.	Near Clara, west of Daingean
	Edenderry Limestone (ED)	Poorly-bedded, pure, medium-coarse grained, pure limestones.	West of Edenderry
	Dolomitized Waulsortian Limestone (WAd)	Pale brown-grey, poorly-bedded limestone	Small areas in east Offaly.
	Waulsortian Limestone (WA)	Pale to medium grey, fine grained, poorly-bedded limestone with calcite in-filled cavities.	South of Geashill and large tracts of west and south Offaly
	Ballysteen Limestone (BA)	Medium to dark grey, fossiliferous, muddy limestone with thin mudstones.	South Offaly, Ferbane, Cloghan and North of Shannonbridge.
	Ferbane Mudstone and Cloghan Sandstone (FB)	Pale grey, medium to fine grained sandstones, pale and dark limestones and dark grey mudstones.	Ferbane - Cloghan area.
	Lower Limestone Shale (LLS)	Dark fine grained mudstones.	Along the foothills of Slieve Bloom.
363 DEVONIAN	Cadamstown Sandstone (CW)	Yellow brown or white coarse grained sandstones with conglomerates, green siltstones and mudstones.	On lower slopes of Slieve Bloom
	Old Red Sandstone (ORS)	Red and occasionally green sandstones with siltstones, mudstones and occasional conglomerates.	Slieve Bloom
410	Silurian Slates and Sandstones (SIL)	Grey and grey-green clayey sandstones and slates.	Slieve Bloom and near Moneygall

TABLE 3.2

SUMMARY OF SUBSOILS GEOLOGY

SEDIMENT TYPE	DESCRIPTION	LOCATION
Peat	Raised Bog and Fen Blanket Bog	Large tracts throughout Offaly. Slieve Bloom.
Alluvium	Grey, fine grained silts and clays.	On flood plains of major rivers.
Marl	White, sometimes shelly, calcium carbonate deposit.	North of Portarlington, south-east of Tullamore, near Dunkerrin.
Esker Sand and Gravel	Long, narrow, sinuous ridges of sand and gravel.	E-W and NE-SW trending ridges, particularly in west Offaly.
Sand and Gravel	Generally poorly sorted and often associated with the eskers.	Areas throughout Offaly.
Till	Mixed deposit of stones, sand, silt and clay.	Areas throughout Offaly.

4. Hydrogeology and Aquifer Classification

4.1 Introduction

This chapter summarises the relevant and available hydrogeological and groundwater information for County Offaly. The aquifer category of each rock unit is given, using the GSI aquifer classification scheme. The aquifers are shown on Map 5.

4.2 Data Availability

Apart from the areas around Clara Bog and Raheenmore Bog, no regional hydrogeological studies have been carried out in County Offaly. As a result, the hydrogeological data available for this report are generally poor. All the groundwater data in the GSI and County Council files were compiled and all existing well records (500) were entered into a computer database in the GSI.

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

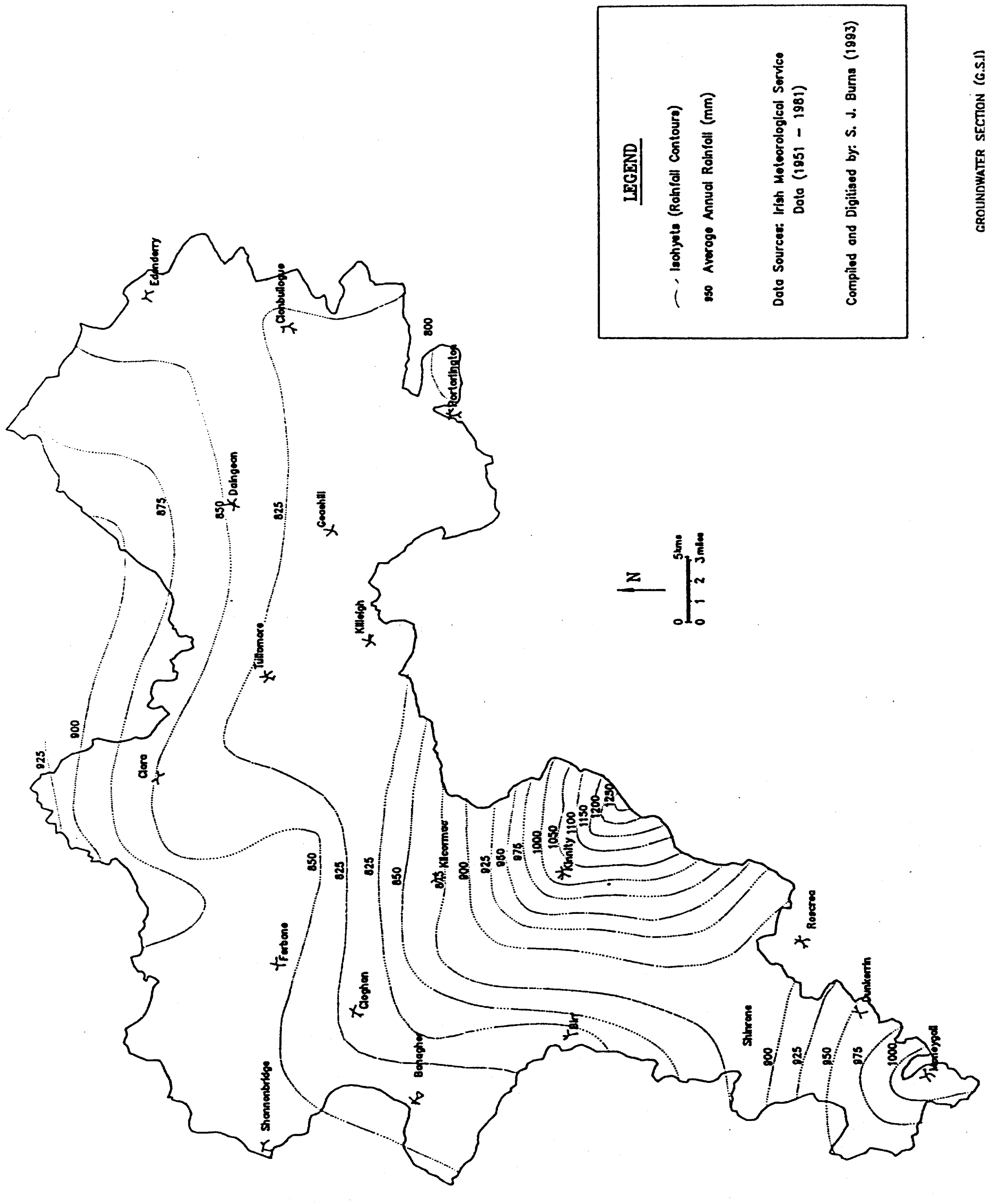
1. Groundwater abstraction rates for local authority and group schemes sources, and for a limited number of high yielding private wells (information from Land Commission wells were particularly useful).
2. Specific capacity data for some wells, mainly local authority owned. (Specific capacity is the rate of abstraction per unit drawdown).
3. Transmissivity data from pumping tests on the Hollimshill and the Tully bored wells. A report on the pumping test of the Hollimshill source was prepared by the GSI (Daly, 1979).
4. Information on springs.
5. Geophysical borehole logs for wells, carried out by the GSI.
6. Consultants reports on the Toberdaly, Gormagh and Banagher sources.
7. Reports and data from the Dutch-Irish Raised Bog Geohydrology and Ecology Study.
8. GSI reports and data on the hydrogeology of the River Nore catchment area
9. The experience accumulated in the GSI for the midlands during the last twenty-five years.

4.3 Rainfall and Evapotranspiration

A mean annual rainfall map for County Offaly is given in Figure 4.1. This shows that, as expected, rainfall in the upland areas is higher than in the lowland areas. Average rainfall on Slieve Bloom is between 1000 and 1250 mm/yr. Rainfall is also relatively high in the area around Moneygall in the southern tip of the county, where mean rainfall is just over 1000 mm/yr. The lowland areas of the county are in sharp contrast, with mean values in the range 800-900 mm/yr. The east-west trending central area of the county is among the driest in the country with mean rainfall less than 850 mm. Birr rainfall station has an mean annual rainfall of 816 mm.

Potential evapotranspiration values across County Offaly are not readily available. The average annual value at Birr weather station is 454 mm according to the Meteorological Service. The range of values across the county is estimated to be between 430 and 470 mm/yr, with an average value of 450 mm/yr. Actual evapotranspiration is estimated to be about 95% of the potential evapotranspiration. The mean annual potential recharge (rainfall minus actual evapotranspiration) values for the county are estimated to be in the range 550-800 mm on Slieve Bloom and from 375-475 mm in the lowland areas.

Figure 4.1 Contoured Mean Annual Precipitation in Offaly.



4.4 Groundwater Usage

There are 20 local authority water supply schemes in County Offaly. Thirteen schemes use only groundwater, while a further four schemes use both groundwater and surface water. Water abstraction figures for the schemes are given to Table 4.1. In total, groundwater provides 64% of local authority water supplies.

Information on 24 private group schemes are given in Table 4.2. All except one scheme - Brosna GWS - use groundwater sources. If it is assumed that the actual usage is equivalent to the demand figures in Table 4.2, then groundwater provides 91% of group schemes supplies.

In areas not served by local authority schemes and group schemes, individual private wells are likely to provide the main source of drinking water.

Excluding the individual private wells, the combined water usage figures for local authority and group schemes shows that groundwater provides about 69 % of water supplies in County Offaly.

4.5 General Aquifer Classification

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:

1. **Regionally Important Aquifers** (**R**) (or Major) **Aquifers**
   - (i) Karstified aquifers (where conduit flow is dominant) (**Rk**)
   - (ii) Fissured bedrock aquifers (**Rf**)
   - (iii) Extensive sand/gravel (**Rg**)

2. **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)**

3. **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. Pure limestones and clean sandstones are more permeable than muddy limestones and clayey sandstone, respectively. Areas where strong folding has produced strong joint systems has led to increased permeability.

Table 4.1. Water Abstractions from County Council Schemes

Scheme	Groundwater Abstraction m^3/d	Groundwater Source	Surface Abstraction m^3/d
Banagher	500	BW	450
Birr			2000
Cloghan	not used at present	BW	
Clara			1325
Ferbane-Belmont	932	BW	
Rhode	2300	Sp	
Edenderry	546	BW	
Daingean	420	Sp	
Tullamore	1820	BW	2500
Rahan	1800	BW + Sp	
Kilcormac	350	BW	
Mountbolus	30	DW	
Geashill	230	Sp	
Clonbullogue	270	Sp/BW	
Walsh Island	345	BW	
Moneygall	200	Sp	
Kinitty	120	BW	110
Shinrone	180	BW	30
Dunkerrin	1200	Sp	
Coolderry	8	BW	
Total	11,251		6415
% of total	64		36
Notes: i) Info. supplied by Offaly County Council. ii) BW = bored well; DW = dug well; Sp = spring			

Table 4.2 Details on Group Water Schemes

Scheme	Water Demand m^3/d	Source
Aughancon	100	DW
Ballinagar	477	Sp
Ballyboy-Ballywilliam	55	Sp
Ballybruder	20	Well
Ballyfore-Ballykilleen	180	GW
Bloomhill	10	BW
Boher	320	Sp/DW
Bracknagh	200	DW
Brosna	350	Stream
Cangort	4	Sp
Clareen	400	Sp
Clerhane	12	BW
Clondelara	5	BW
Clonfanlough	5	BW
Clongowney	4	BW
Corndarragh	8	BW
Durrow	20	GW
Killeigh-Cloneygowan	1182	Sp/DW
Killooly	5	BW
Leamore-Leabeg	50	BW
Meelaghans	35	Sp
Mountlucas	109	GW
Tober	340	Sp/DW
Wood of O	30	BW
Total	3921	
i) Groundwater as % of total = 91% , ii) Information from Offaly County Council		

- Hydrological indications of groundwater storage and movement e.g. the presence of large springs (indicating a good aquifer); absence of surface drainage (suggesting high permeability) or high density of surface drainage (low permeability situation usually – the main exception is in low lying areas where there is no outlet for the water); high groundwater base flows in rivers, etc.

- Information from boreholes, such as high permeabilities from pumping tests, specific capacities (rate per unit drawdown), and well yields (see Table 4.3).

Although the main type of information available for aquifer classification in County Offaly is well yields, many other sources of information have been used (for example; test pumping, surface drainage, bedrock lithology and structural deformation). 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.

Table 4.3 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 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 hydrogeological data for County Offaly are shown on Maps 4E and 4W.

The rock units in County Offaly are listed in Table 4.4, together with a summary of the well data and karst features for each formation, and the aquifer category. The wells were categorised as “excellent”, “good”, “moderate” and “poor” for each rock unit. The sections that follow examine the hydrogeological information for each rock unit and conclude by giving the aquifer category.

4.6 Silurian Slates and Sandstones

There are no useful hydrogeological data for this rock unit in Co. Offaly mainly because it occurs in the core of Slieve Bloom. Consequently the section is based on experience and information from other areas.

The Silurian Slates and Sandstones have a relatively low permeability (< 10^{-2} m/d), apart from the upper few metres. Well yields are usually low (10-30 m^3/d); occasionally failed wells may be present and high yielding of wells are exceptional. Surface drainage density is usually high.

This unit is classed as a “**poor aquifer which is generally unproductive**” (**Pu**).

Table 4.4 Well Yield Categories and Karst Features

Rock Unit	Well Yield Categories					Karst Features	Aquifer Classification
	Excellent (>400m³/d)	Good (100 - 400m³/d)	Moderate (40 - 100 m³/d)	Poor (<40m³/d)	Failed		
Sand/gravel	6	6					**Lg**
Volcanics	1						**Lm**
Borrisokane Pure Limestone	4	5			2	5 swallow holes	**Rf**
Calp Limestone	3	6	5			2 swallow holes (small) 1 spring (2321NWW6)	**Ll**
Edenderry Limestone	1	3					**Lm**
Allenwood Limestone	3					1 cave 1 swallow hole 1 spring	**Rf**
Dolomitised Waulsortian Limestone		1					**Lm**
Waulsortian Limestone	1	6	4	7		1 turlough? 1 lst. pavement 1 swallow hole (small) 1 spring (small)	**Ll**
Ballysteen Limestone		1	3	4			**Pl**
Ferbane Mudstones and Cloghan Sandstones	-	3	1				**Lm**
Lower Limestone Shale	-	-	-	-	-	-	**Pu**
Cadamstown Sandstone	2 + Clonaslee wells	-	-	-	-	-	**Rf**
Old Red Sandstone			1				**Pl**
Silurian Slates & mudstones							**Pu**

4.7 Old Red Sandstone

There is only one well record with useful information in County Offaly for this unit. However, experience from other areas shows that it has a relatively low permeability in general apart from the upper few metres and in the vicinity of fault zones. Well yields are usually adequate for domestic supplies (10-30m^3/d), with higher yields (generally < 200m^3/d) obtainable along the fault zones. As much of the available recharge runs off these rocks, stream density is high and stream flow is "flashy".

This unit is classed as a "**poor aquifer which is locally productive**" (**Pl**).

4.8 Cadamstown Sandstone

Four wells, which are used for supplying the Tullamore regional scheme, are located east of Clonaslee in this rock unit. Their capacities vary from 400 m^3/d to 920 m^3/d and they supply an average of 1820 m^3/d.

Two public supply wells at Gallen, Ferbane (2021NWW009 and W010) are considered to draw water from this unit. At this locality, the sandstone is overlain by muddy limestone and is probably confined. During a site visit by GSI staff in 1978, reddish and green sandstone rock chippings were noted around the borehole. Significant water inflow was reported by the driller to occur at 55m and 64m. The well details are summarised in Table 4.5.

Table 4.5 Summary of well details at Ferbane

Well No.	Location	Depth (m)	Yield (m^3/d)	Specific Capacity (m^3/d/m)
2021NWW9	Gallen, Ferbane	73	760	23
2021NWW10	Gallen, Ferbane	73	780	78 (3 day)

The hydrogeology of the Cadamstown Sandstone has been studied and described by E.P. Daly (Daly 1985; Daly, 1988). The following sections summarise his work. He suggests a subdivision into four zones, with different hydraulic and flow characteristics (Figure 4.2), as a useful conceptual model which applies particularly in the Slieve Bloom area.

4.8.1 Zone 1

This is the outcrop and shallow bedrock area, generally highest on the slope of Slieve Bloom and underlain by the lower units of the Cadamstown Sandstone, where groundwater is unconfined, where recharge occurs and where the groundwater is more vulnerable to pollution. Flow paths are relatively short, with a high proportion of recharge discharging relatively quickly into the numerous "gaining" streams that cross the zone, due to the high proportion of mudstone beds, the moderate transmissivity and the confined nature of the other zones. In the higher steeper part of this zone, the water table is frequently in excess of 20m deep with an annual fluctuation of 10m and hydraulic gradients as high as 0.09 (90 m/km). In the lower more gently sloping area, the water table is normally within 5m of the surface, the annual fluctuation is a few metres and the gradient can be as low as 0.02.

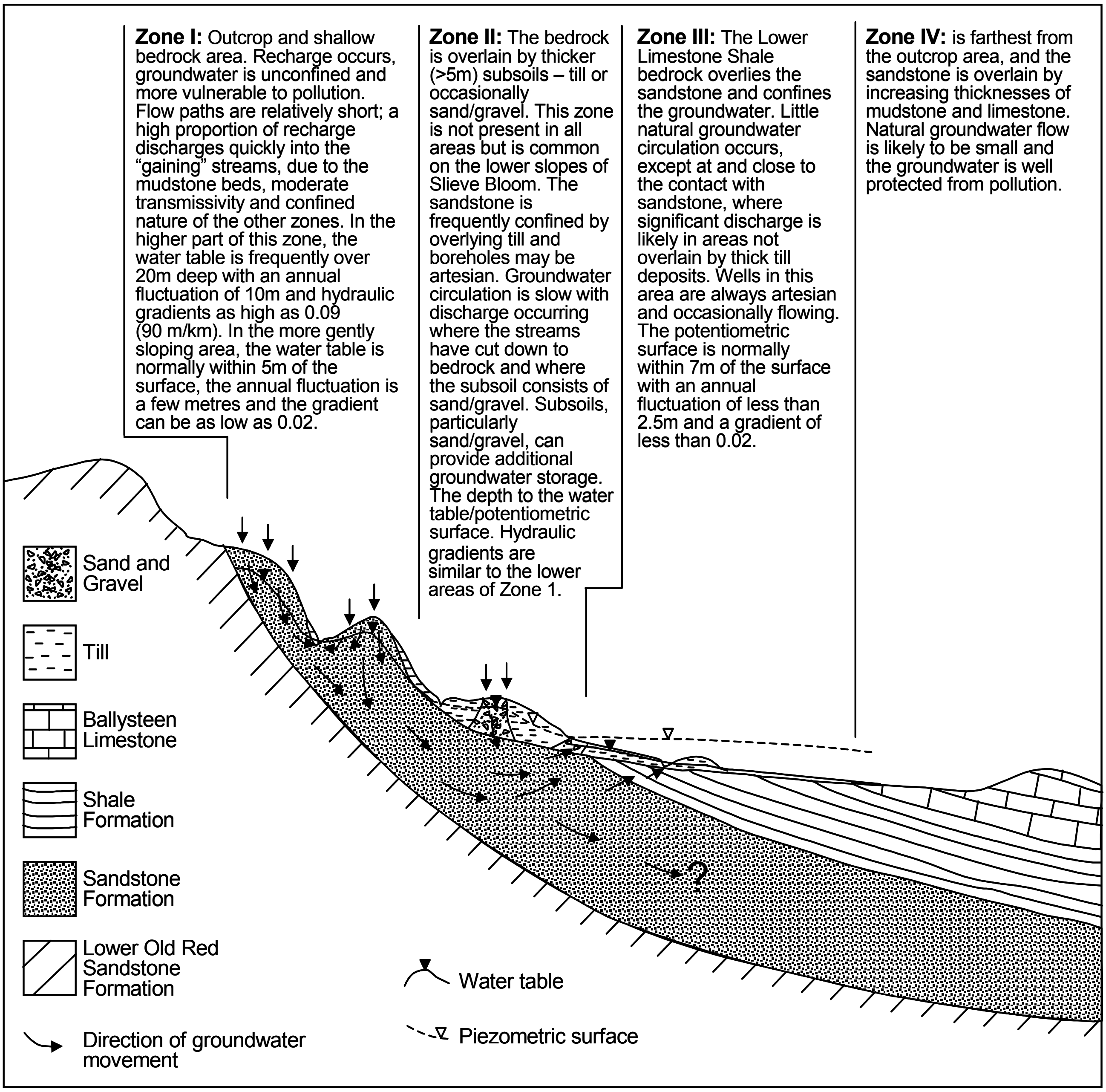


Figure 4.2 Schematic representation of groundwater movement in the Cadamstown Sandstone aquifer system (after Daly, 1988)

4.8.2 Zone 2

The underlying bedrock is the Cadamstown Sandstone, but it is overlain by thicker (> 5m) subsoils – till or occasionally sand/gravel. This zone is not present in all areas but is common on the lower slopes of Slieve Bloom. The sandstone is frequently confined by overlying till and artesian boreholes may be present. Groundwater circulation is slow with discharge occurring where the streams have cut down to bedrock and where the subsoil consists of sand/gravel. The subsoils, particularly the sand/gravel, can provide groundwater storage, which can be used in developing the aquifer. The depth to the water table/potentiometric surface and the hydraulic gradients are similar to the lower areas of Zone 1.

4.8.3 Zone 3

Here the bedrock is the Lower Limestone Shale, which overlies the sandstone and confines the groundwater. Little natural groundwater circulation occurs, except at and close to the contact with sandstone, where significant discharge is likely in areas not overlain by thick till deposits. Wells in this area are always artesian and occasionally flowing. The potentiometric surface is normally within 7m of the surface with an annual fluctuation of less than 2.5m and a gradient of less than 0.02.

4.8.4 Zone 4

In this zone, which is farthest from the outcrop area, the sandstone is overlain by increasing thicknesses of mudstone and limestone. Natural groundwater flow is likely to be small and the groundwater is well protected from pollution.

The general hydrogeological characteristics of the Cadamstown Sandstone in the Slieve Bloom area are summarised in Table 4.6. The unit has a relatively high fissure permeability and in areas where the sandstone is friable due to weathering it may have an intergranular permeability - a feature that is very unusual in Irish bedrock. At Clonaslee the sandstone dips northwards beneath the overlying mudstones at a low angle - 5-20^0. North-south faults are frequent in the area and the fissuring associated with these faults is likely to be the cause of higher transmissivities, specific capacities and yields for some wells. There are two sets of major vertical joints – NW-SE and NE-SW – and horizontal fractures can be reorganised in most exposures. These fractures can give exposures a blocky appearance with blocks ranging in size from 0.5m square to rectangles 1.5 x 2.0m. Their microfractures are present in many exposures and are frequently closely spaced - up to 0.2m apart. However the degree of fracturing and consequently development of permeability can vary over relatively short distances.

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

Table 4.6 Hydrogeological Characteristics of Cadamstown Sandstone

Well Yield m^3/d	Specific Capacity $m^3/d/m$	Transmissivity m^2/d	Permeability m/d	Specific Yield
250-1000	14-35	20-94	0.5-2.0	0.01-0.02

4.9 Lower Limestone Shale

These rocks generally have a low permeability (< 10^{-2} m/d) and act as a confining layer over the Clonaslee Sandstone. They are classed as a "**poor aquifer which is generally unproductive**" (Pu).

4.10 Ferbane Mudstone and Cloghan Sandstone

The lower part of this unit consists mainly of mudstones and siltstones whereas sandstones are more common towards the top. Consequently the lower part is likely to have a low permeability whereas relatively high permeabilities (perhaps similar to the Cadamstown Sandstone) are likely towards the top. However as the thickness of sandstones is less than in the Cadamstown Sandstone, it will not be as productive a unit as the Cadamstown Sandstone.

Information on four wells in this rock unit is available; this is summarised in Table 4.7.

Table 4.7 Summary information for Ferbane Mudstone and Cloghan Sandstone

Well No.	Location	Depth (m)	Abstraction rate (m^3/d)	Specific Capacity ($m^3/d/m$)	Comments
2021NWW2	Skehanagh, Ferbane	152	522	low	
2021SWW3	Cloghan	97	218	10	Co. Co. source
2021NWW7	Gallen, Ferbane	40	360	-?	
2021SWW4	Cloghan	34.4	70	low	(old Co.Co. well)

Classifying this aquifer is difficult – the upper part could be classified as a "**locally important** aquifer which is **generally moderately productive**" (**Lm**) whereas the lower part could be classified as a "**poor aquifer** which is "**generally unproductive**" (**Pu**). The geological map does not allow the unit to be subdivided.

4.11 Ballysteen Limestone

The muddy nature of this bedrock unit means that it has a relatively low permeability, with the possible exception of areas near faults. This is confirmed by the generally low yields of the wells listed in Table 4.8. Consequently, the Ballysteen Limestone is classed as a "**poor aquifer** which is **locally productive**" (**Pl**).

Table 4.8 Summary information for Ballysteen Limestone

Well No.	Location	Depth (m)	Discharge (m^3/d)	Specific capacity ($m^3/d/m$)	Comment
2023SWW1	Doon	106	218-545	?	Co. Co. data
2021SWW7	near Cloghan	55	45	?	Co. Co. data
2019SEW1	Ballybrit	45	43	?	Co. Co. data
2017NWW17	Barna, west of Dunkerrin	21.3	20	200	Land Comm.
2023SEW1	Ballycumber	35	63	9	Land Comm.
2021SWW5	Stonestown	152	<40	?	Co. Co. data
2021SWW6	Stonestown	76	<40	?	Co. Co. data
2321SEW2	near Portarlington	84	<40		high H_2S

4.12 Waulsortian Limestone

There are wells at 17 locations providing information useful in assessing the hydrogeology of this rock unit. Well yields are variable, as indicated in Table 4.9. The Leamore-Leabeg group scheme well (2021NEW1) has a demand of only 50 m^3/d but was reported to be capable of yielding 300 m^3/d when drilled. Two wells in the Cor Hill - Endrim Hill area gave contrasting yields. The first, high on Cor Hill (20 21 SW W11), gave a very low yield (33 m^3/d maximum), whereas the second in the low-lying area between Cor Hill and Endrim Hill was tested at 654 m^3/d. A well nearby in Doon (2023SWW02) is reported to yield 300 m^3/d, although this value is based on a short test and may not be sustainable in dry weather. A second well at Doon had a low yield and specific capacity. Four of the wells are classed as "moderate", while seven are classed as "poor".

As the Waulsortian Limestone is relatively pure, it might have been expected to be a good aquifer. However, its massive, unbedded nature has meant that fissuring is not widely developed except in the vicinity of fault zones, at the top of the rock or perhaps along the axes of anticlines. Most wells are likely to low (<100 m^3/d) and occasional failed wells are probable. Specific capacities are usually low – <20 m^3/d/m. Unless good geological and/or geophysical information is available, locating successful high yielding water supplies is difficult and unpredictable.

In modelling the Hollimshill PWS for the purpose of delineating the Source Protection Zones, the following aquifer parameters were used: permeability (K) = 0.75 m/d; effective porosity or specific yield (S) = 0.01; hydraulic gradient (i) = 0.01-0.015.

The Waulsortian Limestone is classed as a "**locally important** aquifer which is **generally unproductive except for local zones**" (**Ll**).

Table 4.9 Summary information for Waulsortian Limestone

Well No.	Location	Depth (m)	Discharge (m^3/d)	Specific capacity (m^3/d/m)	Comment
2021NWW8	near Endrim	83	>400		Co. Co.data
2019SWW6	Shinrone	61	180	7	Co. Co. source
2023SWW2	Doon	19	300 (estim.)	?	yield might not be sustainable
2023SEW2	Clara	30	220	8	GSI cards
2023SEW3	Boher	52	180	?	GSI cards
2023SEW5	Clara	91	218	?	Co. Co. data
2021NEW1	Leamore	91	300 (estim.)	?	Co. Co. data
2019SWW4	Kilfrancis	40	98	23	Land Comm.
2019SWW7	Ballyegan		50		Land Comm.
2021SEW4	Mountbolus	91	55	low	Co. Co.
2019SWW1	Ballaghboy	46	36	2	Land Comm.
2019SWW3	Galbally	35	26	2.4	Land Comm.
2019SWW21	Kilcolman, south of Birr	58.5	26	1.0	Land Comm.
2021SWW12	Derrinlough	53.6	18	2.6	Land Comm.
2021SWW13	Derrinlough	33	36	23	Land Comm.
2021NWW29	Doon	55.5	21	1.4	Land Comm.
2021NWW11	Rashinagh	152	32	low	Co. Co. data

4.13 Dolomitized Waulsortian Limestone and Edenderry Limestone

The Dolomitized Waulsortian limestone and the Edenderry Limestone are considered together as they are likely to have similar aquifer characteristics. The Dolomitized Waulsortian is likely to be somewhat more permeable than the Waulsortian limestone, due the effect of the dolomitization process (a process where magnesium is introduced into limestone thereby increasing the rock porosity and permeability).

The five groundwater sources with good quality information (Table 4.10) have yields greater than 180^3/d. However, only one well gave an excellent yield (2323SEW30 at Rhode power station) and this is located close to two others with significantly lower yields.

The Dolomitized Waulsortian Limestone and the Edenderry Limestone are classed as "**locally important** aquifers which are **generally moderately productive**" (**Lm**).

Table 4.10 Summary Information for Dolomotised Waulsortian Limestone and Edenderry Limestone

Well No.	Location	Depth (m)	Discharge (m3/d)	Specific capacity (m^3/d/m)	Comment
2323SEW30	Rhode	97	>490	?	info. from K.T. Cullen
2321NEW3	Mountlucas	?	180	?	Co. Co. info.
2323SEW29	Rhode	97	200	5.3	info. from K.T. Cullen
2323SEW28	Rhode	97	165	low?	
2321NEW4	Walsh Island	?	345	low	Co. Co. PWS

4.14 Calp Limestone

The Calp Limestone is one of the most extensive rock units in north Leinster. While there appears to be some variation in the hydrogeological properties over the region, overall permeabilities and well yields are relatively low. Groundwater flow tends to be concentrated in the upper fractured and weathered zone, along fractured fault zones and in more permeable beds. Consequently, groundwater throughput is low and groundwater circulation is shallow and localised, often with short flow paths. The water table is usually fairly close to ground level and closely mirrors topography. A relatively high density of streams and surface ditches is common.

The aquifer classification of the Calp Limestone has varied. At the planning appeal for the proposed landfill at Powerstown, County Fingal, the consultant to An Bord Pleanala concluded that the classification "locally important aquifer, moderately productive only in local zones (**Ll**)" was appropriate for that area (An Bord Pleanala, 1996). The GSI concurs with this classification and uses it for County Dublin. In Meath, a high number of "excellent" and "good" wells has led to the conclusion that the aquifer is relatively productive and should be classed as a "locally important aquifer, generally moderately productive (**Lm**)" (Woods, 1996). In the Nore Basin, E.P. Daly classified the Calp as an aquitard, which would be equivalent to GSI aquifer category "poor aquifer , generally unproductive except for local zones (Pl)" (Daly, E.P., 1994).

The thirteen sources with adequate quality data in County Offaly (Table 4.11) show a wide variation in well yields and specific capacities. In Edenderry, to the north of the town, a well for a local industry (2323SWW1) has a high yield. The three wells used by the Drumcooly group scheme, 2 km south of Edenderry, give contrasting yields although they are located within an area of 100 m radius. A substantial spring supplies the Killeigh group scheme. Water tracing by Offaly County Council proved that a nearby swallow hole is linked to the spring. This may be an area with a cleaner/purer unit. The Banagher PWS (2021SWW2) has a high yield for a high proportion of the time; however, the yield drops during prolonged periods of dry weather due presumably to a relatively low specific yield. This low specific yield may be an indication that the well is located in a fracture zone, which while permeable does not store sufficient water to maintain outputs during long periods without recharge. The Clonbulloge source (2621NWW1) is warm, with a measured temperature of 14.8ºC (Aldwell, 1997). It is located close to (and may be at) the faulted contact with the Edenderry Limestone. Wells in the Wood of O and Ballycommon areas generally have low yields, according to local people. Many wells in this rock type have high iron concentrations.

The muddy nature of the Calp Limestone would suggest that permeabilities and well yields would be low. However, the significant use of groundwater for public, group scheme and industrial supplies from a number of high yielding sources in County Offaly means that the Calp limestone cannot be classed as a “poor aquifer (P)”. Nor can it be classed as a “regionally important aquifer (R)”, as there are many low yielding wells, high iron is common and yields may drop in dry weather. The data for Offaly suggests that the Calp should be classed as a “**locally important aquifer, which is moderately productive only in local zones** (**Ll**)”. It could be argued that the presence of volcanic bands in the Edenderry area and the probable resulting increase of general productivity should improve the rating to Lm; however, this area cannot be delineated and so the Ll classification is maintained for all of the Calp Limestone.

Table 4.11 Summary information for Calp Limestone

Well No.	Location	Depth (m)	Discharge (m^3/d)	Specific capacity ($m^3/d/m$)	Comment
2623SWW1	Edenderry	60	545	?	info. from KTCullen
2321NWW6	Killeigh	spring	1300	-	group scheme source
2021SEW6	Killurin	?	160	?	info. from P. Fay
2321NWW1	Cloonagh	46	157	?	info. from GSI cards
1721NEW1	Shannonbridge	25	163	?	Co. Co. source
2021SWW2	Banagher	48	654 ?	100 ?	Co. Co. source; yield drops in summer
2621NWW1	Clonbulloge	4	286		Co. Co. source; warm
2621SWW1	Bracknagh		163		Bord na Mona well
2623SWW12	Edenderry	56	100	low	Drumcooly GWS
2623SWW13	Edenderry	32	100	low	Drumcooly GWS
2623SWW14	Edenderry	41	250	250	Drumcooly GWS
2321NWW5	Wood of O	30	80	6	Land Comm.
2321NWW80	Ballycommon	23	71	25	Land Comm.
2321NWW8	Ballard	?	50	2	GWS

4.15 Allenwood Limestone and Borrisokane Pure Limestone

The Borrisokane Pure Limestone and its lateral equivalents (for instance, the Cullahill/Ballyadams formation in Laois and Kilkenny) is one of the best aquifers in Leinster. In the Nore Basin area, work by the GSI (E.P. Daly, 1994) has shown that the Cullahill limestone is a major aquifer, which has a large groundwater throughput and makes a major contribution to baseflow in the Nore. The aquifer is karstified, although not to the same degree as the pure limestones in Galway and Clare. Details on this aquifer are given in Table 4.12.

Table 4.12 Summary of hydrogeological information for Cullahill aquifer

Rock Unit	Location	Well yield m^3/d		Specific capacity $m^3/d/m$		Transmissivity m^2/d		Permeability m/d	Specific yield
		typical	range	typical	range	typical	range		
Cullahill Limestone	Nore Basin	20-500	200-1000	5-100	1-3000	200	5-3000	0.1-100	0.005-0.05

(from E.P. Daly, 1996)

The availability of hydrogeological information for the Borrisokane Pure Limestone in County Offaly is limited compared to the Nore Basin. However, the data summarised in Table 4.3, 4.13 and 4.14 provide evidence of significant aquifer potential. Four large public supplies and one group scheme supply draws water from this aquifer. In addition, Sillogue spring (2323SWW1) is one of the largest springs in County Offaly, although it is not yet used for public supply. The results of pumping tests and numerical modelling of the wells at Hollimshill and Tully are summarised in Table 4.14; relatively high permeabilities are indicated.

Table 4.13 Summary information for Borrisokane Limestone and Allenwood Limestone

Well No.	Location	Depth (m)	Discharge (m^3/d)	Specific capacity ($m^3/d/m$)	Comment
2323SEW2	Toberdaly	1-2	2200		Co. Co. spring source
2321NWW2	Ardan/Gormagh Bridge	27	800+		Tullamore UDC source
2021NEW4	Aghall	≈1 m	1090	-	Co. Co. spring
2323SWW1	Sillogue spring, Durrow		4000		Tullamore UDC spring (not in use)
2021NEW5	Hollimshill	100	1090	77	Co. Co. source
2021NEW6	Tully, Rahan	91	654	65	Co. Co. source
2021SEW3	Kilcormac	30	545	?	Co. Co. source
2021SEW2	Kilcormac	65	260	18	Co. Co. source
2321NWW3	Tullamore	?	163	?	industrial use
2321NWW4	Ballydaly	20	110	?	group scheme ?
2019NWW3	Rathmount	91	"dry"		private well
2321NWW75	Muinagh	>50	"dry"		info from P Fay
2021SWW14	Whigsborough	36.6	87	>100	Land Comm.
2021SWW15	Whigsborough	23.7	110	72	Land Comm.

The Allenwood Limestone is included with the Borrisokane Limestone because of its geographical proximity, geological continuity (it underlies the Borrisokane Limestone) and, on the available evidence, the similar aquifer potential. The Toberdaly source is the largest groundwater supply in Offaly. It acts as a spring in winter and as a dug well in summer. Deepening of the spring by the County Council has increased the yield. An unusual feature of this spring is the slightly elevated water temperature – 12.6º, which is 2º higher than the expected mean temperature (see source protection report for Toberdaly for further information). Similarly, the Agall source acts as a spring in winter and a dug well in summer. The sands/gravels south of the spring may be providing a significant contribution to the outflow and yield. Wells drilled at Gormagh Bridge (Ardan source) gave exceptionally high yields when tested – up to 3000 m^3/d in one well, with an estimated specific capacity, transmissivity and permeability of 240 $m^3/d/m$, 330 m^2/d and 27 m/d, respectively (Barber, 1976). However, in subsequent years, the yield gradually dropped until it reached 800 m^3/d in 1985. This was due to the presence of iron bacteria, according to County Council staff. Disinfection and cleaning can increase the yield somewhat. While there are problems with the production well, the well testing confirmed the potential productivity of the aquifer.

A small number of karst features are present in both the Borrisokane Pure Limestone and the Allenwood Limestone. However, the degree of karstification would appear to be relatively limited from the available information.

Both rock units are classed as "**regionally important fissured aquifers (Rf)**".

Table 4.14 Hydrogeological data for Hollimshill and Tully Wells

Well No.	Location	Transmissivity m^2/d	Permeability m/d	Specific yield	Hydraulic gradient
2021NEW5	Hollimshill	510	12	0.02	0.003
2021NEW6	Tully, Rahan	140	4.5	0.02	0.002

4.16 Volcanics

The public supply wells east of Edenderry are located in this rock unit. A summary of the production well details are given in Table 4.15. Problems with collapse of the borehole sides were encountered during drilling.

While the well yield indicates that the volcanics have a relatively high permeability at Edenderry, the outcrop areas of are small; consequently, the volcanics are not classed as a regionally important aquifer, but as a "**locally important aquifer**, which is **generally moderately productive (Lm)**"

Table 4.15 Summary information for wells in the Volcanic aquifer

Well No.	Location	Depth (m)	Discharge (m^3/d)	Specific capacity ($m^3/d/m$)	Comment
2623SWW2	Edenderry	55	654	28	Co. Co. source
2623SWW4	Edenderry	60.5	1082	28	Co. Co. source

4.17 Potential Sand/Gravel Aquifers

Sand/gravel deposits have the potential to supply significant quantities of groundwater as they have a relatively high permeability and specific yield (effective porosity). However, in order to have sufficient potential to be classed as an aquifer, a sand/gravel deposit must have a minimum saturated thickness and area. In classifying aquifers, the GSI requires (a) that regionally important sand/gravel (**Rg**) aquifers should be more than 10 km^2 in size and (b) that locally important (**Lg**) aquifers should greater than 1 km^2 in extent and have a saturated thickness greater than 5 m. These figures are somewhat arbitrary and can be changed depending on local circumstances. In Offaly, there is little information on saturated thicknesses; consequently potential aquifers were identified on the basis of areal extent and limited data from existing public and group scheme sources in sand/gravel (summarised in Table 4.16). The potential aquifers are shown on Map 6.

The most extensive sand/gravel deposits in County Offaly (for instance, between Blue Ball and Birr) are lenticular in shape, have many local groundwater divides and cannot be developed as one unit. Consequently, no **Rg** aquifers have been delineated in County Offaly. Only one area was considered as being a possible regionally important aquifer – the area near Roscrea. However, there is insufficient information to warrant this classification. Consequently, all gravel areas greater than 1 km^2 in extent are classed as <u>potential</u> locally important (**Lg**) aquifers. None of these aquifers have been investigated adequately, consequently the aquifer boundaries and the saturated thicknesses have not been proven.

There are twelve public and group scheme supplies located within sand/gravel deposits. With the exception of Skehanagh near Belmont, all originated as springs. Most if not all have been deepened and are now dug wells with overflow only occurring in wet weather. The Skehanagh source is a screened bored well. Clogging of the screen has caused problems in the past.

All the sources with the exceptions of Geashill and Daingean are in areas of extensive sand/gravel deposits. The Geashill source is located beside an esker with a hinterland of till with gravel (which is not shown on Map 6E). The aquifer providing water to the Daingean source is unclear. It is probably located in a pocket of sand/gravel, but with contributions from the top of the bedrock. While Aghall and Sillogue are located in sands/gravels, it is probable that limestone bedrock is the main source of water. However, the sands/gravels are likely to be important in providing storage of groundwater and therefore in maintaining yields in dry weather.

Table 4.16 Summary information for wells and springs in sand/gravel

Well No.	Location	Depth (m)	Yield m^3/d	Type	Comments
2017NWW3	Dunkerrin	3.0	200	dug well	Co. Co. source
2321NEW1	Geashill		490	spring	PWS and Group scheme supplies
2017NWW4	Moneygall (Guilfoyles well)	3.2	654	spring/dug well	Co. Co. source
2019SEW2	Clareen		400	spring	GWS
2021NEW2	Boher		373	spring/dug well	GWS
2021NWW3	Skehanagh	14.2	>1000	well	yield decreases due to clogging of screen
2321NEW2	Daingean		436	spring/dug well	Co. Co. source
	Lisduff		760	spring	Co. Co. source
2023SEW7	Tober GWS	4	350	well	
2017NWW1	Busherstown		218	well/spring	Co. Co. source
2021NEW4	Aghall		1090	spring	probably a combined gravel/limestone source
2323SWW1	Sillogue, Durrow		4000 (estimated)	spring	limestone is likely to be the main aquifer, but gravel probably contributes.

4.18 Potential for Future Groundwater Development in County Offaly

4.18.1 Allenwood Limestone and Borrisokane Pure Limestone

These are the rock units with the best aquifer potential in County Offaly. They are capable of supplying regional schemes. 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.

4.18.2 Cadamstown Sandstone

This rock unit has proven potential, as shown by the wells at Clonaslee and in County Kilkenny, and is capable of producing significant supplies for south Offaly. However well yields vary and the probability of getting a yield of more than 1000 m^3/d is low. Also it is important to locate wells, as far as practicable, in optimum areas – close to faults and in Zone 3 or Zone 4 (see Section 4.8). While the boundaries of this rock unit are known with reasonable certainty along the north-western slope of Slieve Bloom (i.e. Kinnity area), the geology map is less certain for the south-west end of Slieve Bloom (i.e. Coolderry area). One of the advantages with this aquifer is that its recharge area is mostly on the slopes of Slieve Bloom where there are few potential pollution sources; therefore groundwater quality is likely to be good. However, there is a slight probability of high iron and/or manganese concentrations.

4.18.3 Sand/gravel

Carefully sited wells would be capable of supplying large quantities of water, perhaps sufficient for regional schemes. The best areas are likely to be the deposits north of Roscrea and those in the Birr area. A proper hydrogeological investigation would be needed to confirm this conclusion.

4.18.4 Calp Limestone

While there are local zones of high permeability and a number of public supplies in this rock unit, it is 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.

4.18.5 Dolomitised Waulsortian Limestone

In County Laois, this rock unit is a regionally important aquifer. However, there is no evidence to suggest that it has a similar aquifer potential in County Offaly. This is probably due a reduction in the impact of dolomitisation moving northwards from the well dolomitised areas to the south; however, it might also be a conclusion drawn from insufficient data. Consequently, there may be areas in County Offaly with a relatively high permeability which could be located by a detailed investigation, probably involving geophysics.

4.18.6 Edenderry Limestone

As this is a pure limestone, a relatively high permeability could be expected. However, the available evidence suggest that this is not the case, perhaps because bedding is poorly developed. While insufficient investigations (in particular geophysics and exploratory drilling) have been carried out to enable a definite conclusion, it does not appear to have the potential to supply significant yields.

4.18.7 Volcanics

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

4.18.8 Remaining Rock Units

None of the remaining rock units (see Table 4.3) have the potential to provide sufficient yields to satisfy the likely needs of Offaly 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 yields may reduce in dry weather.

5. Hydrochemistry and Water Quality

5.1 Introduction

A brief assessment of the quality of public and group scheme groundwater supplies in County Offaly is given in the report on "Groundwater quality of Co. Offaly" (Cronin & Daly, 1998). This Chapter gives the main conclusions of the assessment.

5.2 Overall Assessment

- The groundwater in County Offaly is hard and can be classed as calcium bicarbonate ($Ca(HCO_3)_2$) water type.

- The main groundwater quality problems due to the natural conditions in the ground and the natural chemistry of groundwater are caused by iron (Fe) and hydrogen sulphide (H_2S). Iron may be present in areas underlain by muddy limestone, particularly if peat is present overlying the limestone, and where the bedrock is sandstone. Hydrogen sulphide is found in muddy limestones. High iron concentrations have been reported in the Ferbane and Gormagh (Arden) public supply wells and in private wells in the Ballycommon and Portarlington areas. Hydrogen sulphide has been reported in private wells in the Ballycommon and Portarlington areas.

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

- Mean nitrate levels were less than the EU guide level in 28 of the 32 public and group scheme sources. However, peak levels were at or above the guide level in 14 sources.

- Based on the nitrate levels, three sources are considered to require 'urgent action' (Walsh Island/Ballaghassan) or 'urgent study' (Mountbolus and Corndarragh). Seven sources (Ballyboy, Clerane, Coolgarry, Coolderry, Geashill, Daingean, Dunkerrin and Shinrone) require 'regular review of data'.

- The data for the larger sources – Toberdaly, Rahan, and Banagher – give a good indication of the general groundwater quality in Offaly. These data show that quality is good.

- Groundwater quality of the smaller, shallower sources tends to be poorer than the larger, 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 group scheme and smaller sources are more likely to be affected by point source contamination than diffuse sources.

5.3 Conclusions

- Overall, groundwater pollution is not extensive in County Offaly. However, some groundwater sources are polluted by faecal bacteria and there is evidence of chemical contamination. 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.

- This report is based on limited data and so the assessment and the conclusions are somewhat tentative. As a means of improving groundwater quality data:
    - analyses of raw water rather than treated water will be carried out where practicable.
    - full analyses (see below) will be carried out on a proportion of the samples.
    - where there is evidence of contamination, the sampling frequency will be increased.

Commonly Analysed Parameters

Gen. Characteristics/ Physical Parameters	**Major Ions**	**Bacteriological Analysis**	**Metals**
Colour	Alkalinity (mg/l $CaCO_3$)	Coliforms	Aluminium
Conductivity *and/or*	Ammonium	Faecal Coliforms	Boron
Total Dissolved Solids	Barium		Copper
Hardness	Calcium		Iron
Odour	Chloride		Lead
Suspended Solids	Fluoride		Manganese
Turbidity	Magnesium		Zinc
	Nitrate		
	Nitrite		
	Orthophosphate		
	Phosphate		
	Potassium		
	Sodium		
	Sulphate		

- A programme of undertaking groundwater protection zone delineation around public and group scheme supplies over the next few years will be carried out.

- 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 help ensure that shallow groundwater and surface water is not entering the source and that accidental spillages would not contaminate the source.

6. Groundwater Vulnerability

6.1 Introduction

The production of the groundwater vulnerability map for County Offaly required the following:

- differentiating between the subsoils in order to obtain three categories of permeability – high, moderate and low;
- contouring depth to bedrock data;
- the location of karst features.

6.2 Sources of Data

The following sources of data were used to produce the vulnerability map:

- the subsoils map (Map 2)
- the GSI karst database
- depth to bedrock data from all the GSI databases
- 6 inch to one mile scale geological and topographic maps
- work undertaken by Sarah Jane Burns (1993) on an aquifer protection plan for Offaly
- site visits undertaken in Offaly.

6.3 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. Apart from detailed hydrogeological investigations at Clara Bog and Raheenmore Bog (Flynn, 1993 and Daly and Johnston, 1994), there were no quantitative data on subsoil permeabilities. The qualitative permeability values of subsoils in County Offaly, given in Table 6.1, were assigned on the basis of the experience and knowledge of GSI staff.

6.3.1 Eskers

There are numerous esker complexes in west Offaly especially in the northern and central regions. These deposits are long, narrow ridges, which are very well drained. They are generally composed of coarse boulder gravels which are highly permeable.

6.3.2 Sand and Gravel

Large areas of sand and gravel are located at the foothills of Slieve Bloom. Elsewhere, they are the product of glaciofluvial deposition on outwash plains and are often found in close proximity to the eskers, for example at Clara. Sand/gravel deposits in County Offaly are relatively coarse grained and are highly permeable.

6.3.3 Tills

Till deposits in County Offaly show a widespread distribution and are classified according to their lithological composition. Three main lithological types are present: limestone till; sandstone till and volcanic till.

Limestone till is particularly widespread around Ballinagar and Mount Bolus. Isolated pockets also occur within peaty areas. At Clara, measured permeabilities were greater than 10^{-1} m/d. However, at Raheenmore, permeabilities as low as $5x10^{-3}$ m/d (Flynn, 1993) were estimated. The limestone tills in County Offaly are assumed to be free-draining and sandy, and therefore to have a moderate permeability. While this generalisation is likely to apply to most of the tills, it is probable that there are areas of clayey till, particularly overlying the Calp Limestone. However, it is not possible to delineate these areas.

Sandstone till is confined to the Slieve Bloom upland area. These sediments reflect a change in the underlying bedrock from Carboniferous limestone to Silurian and Devonian sandstone and shale deposits. These tills tend to be sandy and are considered moderately permeable.

Volcanic tills have a limited distribution tending only to occur around Moneygall and on Slieve Bloom. In the absence of suitable information, they are taken to have a moderate permeability.

6.3.4 Till with Gravel

Till containing sands/gravel are found in various parts of the county, and are quite extensive between Geashill, Clonygowan and Portarlington. They can be subdivided into limestone till with gravel and sandstone till with gravel.

Areas of limestone till with gravel are underlain mainly by till but contain pockets of sand/gravel. As no detailed Quaternary mapping has been carried out in most of Offaly, it is not possible to delineate the boundaries of these sand/gravel pockets. 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.

Sandstone till with gravel occurs in the southern region of the Slieve Blooms, north of Roscrea. It is considered to be similar to limestone till with gravel in terms of permeability.

6.3.5 Peat

Peat permeabilities depend on the degree of peat decomposition (humidification) and the effects of subsidence. Apart from the upper layer of intact bogs, peat has a relatively low permeability. At Raheenmore Bog, permeabilities ranged from $1x10^{-5}$ - $4x10^{-1}$ m/d with a mean of $1.5x10^{-3}$ m/d. At Clara Bog, values were similar. Subsidence, due to drainage, decreases the permeability. However, piping and cracking can also occur.

In many parts of Offaly, the peat is underlain by lake clay and silt. This usually has a low permeability – $<10^{-4}$ m/d, although the permeability will increase somewhat approaching the boundary of the lake clay/silt, where the proportion of clay decreases.

6.3.6 Alluvium

Alluvium can be found along the channels and flood plains of the major rivers. A long narrow strip of alluvium occurs along the banks of the Clodiagh River. Similarly there are alluvium deposits along the Camcor River (Birr - Kinnity) and along the River Brosna, between Ballycumber and Ferbane. Alluvium deposits are normally composed of fine grained silts and clays which have a moderate to low permeability.

6.3.7 Marl

Marl is a calcareous freshwater deposit commonly found beneath the peaty areas of Offaly. Although limited in extent, it is found scattered throughout the county and can be examined along the banks of the Little Brosna River, Figile River and Slate River. Marl is fine grained and is generally assumed to have a low permeability. It is also present beneath the peat in places.

Table 6.1 The Permeability and Distribution of Subsoils in County Offaly

Subsoil	Permeability	Distribution
Sand and Gravel	High	Outwash plains of Offaly, foot of Slieve Blooms
Eskers	High	North and central Offaly
Till with gravel	High	Widespread occurrence in Offaly
Limestone/Sandstone Till	Moderate	Scattered throughout Offaly
Volcanic Till	Moderate	South Offaly
Peat	Low	Throughout the low-lying areas of Offaly
Alluvium	Low - moderate	Along major rivers
Marl	Variable	Isolated pockets

6.4 Karst Features

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

6.5 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.

Much of the peat in the county is being cut away and it is not known if data indicating thicknesses of >10m in the peat areas is truly representative of present day thicknesses. In assessing vulnerability of peaty areas, it is assumed that the peat and underlying marl and lake deposits are at least 5m thick (unless accurate data indicates thicknesses of <5m) but not more than 10m thick. While this is likely to be a reasonable assumption for much of the peat areas, it is not a correct assumption close to the peat boundaries. Also there will be some areas where the peat is underlain by gravel and where the combined thickness of peat and lake clay will be less than 5 m.

Marl deposits are assumed to be <1m thick in Offaly. Little information regarding the thickness of esker deposits exist, however they are assumed to be at least 10m thick. Alluvial deposits are generally thin (<1m) in upland areas, however in low-lying areas, these thicknesses could be significantly greater.

The guidelines used in contouring the depth to bedrock data are listed in Appendix 1.

6.6 The Vulnerability Map (Map 7)

The vulnerability maps (Maps 7E and 7W) 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 6.2.

An estimated 7% of east Offaly (Map 7E) has a depth to bedrock of less than 3 metres and is classed as being extremely vulnerable to contamination. The remaining area of east Offaly has a combination of subsoil type and depth to bedrock which results in a high to moderate vulnerability rating. 51% is highly vulnerable and 42% is moderately vulnerable. Till with gravel is the predominant lithology over much of the highly vulnerable areas. In assigning vulnerability, it is treated as a sand/gravel with a high permeability. However, some of this area will consist of till with a thickness greater than 10 m, and therefore will have a moderate or low (depending on the permeability) rating. Consequently, the area of high vulnerability is overestimated and the areas of moderate and low vulnerabilities are underestimated. (This emphasises the point that the vulnerability map is intended as a guide, which can readily be checked by a site investigation.) In west Offaly (Map 7W), 13% of the area is classed as extremely vulnerable, 57% as highly vulnerable and 30% as moderately vulnerable. While there is a significant area of till with gravel in west Offaly, most of the area classed as highly vulnerable is underlain by sand/gravel. Overall for County Offaly, 11% of the area is classed as extremely vulnerable, 55% as highly vulnerable and 34% as moderately vulnerable.

As there was no information that there are significant thicknesses (>10m) of low permeability materials in Offaly, no areas of low vulnerability are delineated.

All peatland areas (low permeability, <10m thick) are assumed to have a moderate vulnerability unless there is evidence to the contrary.

Due to lack of accurate data, the vulnerability of alluvial areas was assessed on the basis of the surrounding subsoil deposits. The vulnerability of marly areas (in general <1m thick) was classified in a similar manner.

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 map (Map 6) is a good basis for decision-making in the short and medium term.

Table 6.2 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.

7. Groundwater Protection

7.1 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 – were described. Subsequent chapters describe the different geological and hydrogeological land surface zoning elements as applied to County Offaly. This chapter draws together all the elements of land surface zoning 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.

7.2 The Groundwater Protection Maps

The groundwater protection maps (Maps 8E and 8W) were produced by combining the vulnerability maps (Maps 7E and 7W) with the aquifer maps (Maps 5E, 5W and 6). 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 7.1.

Not all of the hydrogeological settings represented by the zones in Table 7.1 are present in County Offaly. There are no regionally important karst limestone (**Rk**) or sand/gravel (**Rg**) aquifers delineated in County Offaly. In addition there are no areas delineated with a low vulnerability. Therefore there are 15 groundwater resource protection zones in County Offaly.

7.3 Groundwater Source Protection Reports and Maps

The techniques used to delineate source protection zones (section 2.3.2) have been applied to 4 public supply wells in County Offaly: Toberdaly. Mountlucas, Tully and Hollimshill. Numerical modelling was used to assist in the delineation of the source protection zones for the Tully and Hollimshill sources. (Updated reports for these two sources are currently being written.)

7.4 Conclusion

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

Table 7.1 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)	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

8. References

Aldwell, C.R. (1997). Personal communication. Geological Survey of Ireland.

Barber, M. (1976). Report for Offaly County Council on the Gormagh Bridge source.

Burns, S.J., (1993). *An aquifer protection plan for Co. Offaly*. Unpublished M.Sc. thesis, Environmental Sciences Unit, Trinity College Dublin.

Cronin, C. and Daly, D. (1997). *A water quality assessment of the Mountbolus public supply*. GSI report to Offaly County Council.

Cronin, C and Daly, D. (1998). *Groundwater quality of Co. Offaly*. GSI report to Offaly County Council.

Daly, D. (1995) "*Groundwater Protection Schemes in Ireland: a proposed approach*", Internal Report Series, Geological Survey of Ireland, 38pp.

Daly, D. & Johnston, P. (1995). *The hydrodynamics of raised bogs : an issue for conservation*. Proceedings of AGMET Group (Ireland) and Agricultural Group of the Royal Meteorological Society (UK) Conference "The Balance of Water – Present and Future", TCD, September 7-9, p105-121.

Daly, D. and Flynn, R. (1994) *Source reports on Tully and Hollimshill public supply wells*. GSI reports to Offaly County Council.

Daly, D. and Ryan, T. *An assessment of the quality of public and group scheme groundwater sources in County Offaly*. GSI report to Offaly County Council.

Daly, D. & Warren, W. P. (1994) *"G.S.I. Guidelines on Groundwater Vulnerability and Vulnerability Mapping*", Groundwater Newsletter, Geological Survey of Ireland, No.25.

Daly, D. and Warren, W.P. (in press*). Mapping groundwater vulnerability – the Irish perspective*. Geological Society (London) Special Publication "Groundwater Pollution, Aquifer Recharge and Vulnerability".

Daly, E. P. (1994). "*Groundwater Resources of the Nore River Basin*" Internal Report, Geological Survey of Ireland.

Daly, E.P. (1988). *The Kiltorcan Sandstone Aquifer*. Proceedings of Eight Annual International Association of Hydrogeologists (Irish Branch) Seminar, Portlaoise.

Daly, E.P. (1985). Hydrogeology of the Kiltorcan Aquifer System. Internal Groundwater Section, GSI Report.

EPA, (1996). "EPA Landfill Manuals, Manual on Site Selection" (2nd Draft)", Environmental Protection Agency.

EPA. (1997). *Nitrates in groundwater in County Offaly (Draft).* Environmental Protection Agency.

Flynn, R. (1993). *The hydrogeology of Clara Bog and the surrounding area*. Irish-Dutch Geohydrology and Ecology Study. Geological Survey of Ireland and National Parks and Wildlife Service.

Freeze, R. A. & Cherry, J. A. (1979). "*Groundwater*", Prentice Hall, 604pp.

Hammond, R.F. (1979). *The Peatlands of Ireland*. Soil Survey Bulletin No. 35, An Foras Taluntais. 58pp.

Hammond, R.F., Warren, W.P. and Daly, D. (1987). *IQUA Field Guide No. 10, Offaly and west Kildare*. Irish Association for Quaternary Studies.72pp.

Hudson, M. (1996). *Groundwater source protection zones for Mountlucas group water scheme*. Geological Survey of Ireland.

Gardiner, M. J. & Radford, T. (1980). "*Soil Associations of Ireland and Their Land Use Potential: Explanatory Bulletin to Soil Map of Ireland 1980*", An Foras Taluntais, Dublin.

N.S.A.I. (1991). Septic tank systems - recommendations for domestic effluent disposal from a single dwelling house. S.R.6 : 1991, Eolas, Dublin, 30pp.

Philcox, M.E. (1984). *Lower Carboniferous Lithostratigraphy of the Irish Midlands*. Ir. Assoc. Econ. Geol. 89pp.

Warren, W.P. (1997). Personal communication. Geological Survey of Ireland.

Wisconsin Geological and Natural History Survey (1991) "*Delineation of Wellhead Protection Areas in Fractured Rocks*", Groundwater Protection Division, Office of Groundwater and Drinking Water, USEPA.

Woods, L., Meehan, R. and Wright, G.R. (1996). *Groundwater protection in County Meath*. Meath County Council/Geological Survey of Ireland.

Appendix 1 : Guidelines for Contouring Depth to Bedrock and Assigning Vulnerability in County Offaly

General Guidelines

- Areas with outcrops and thin subsoils were contoured to produce the three metre 'depth to bedrock' contour where accurate data were available. In the absence of accurate data a buffer of 200m was chosen on the basis that for every 70m along the ground there is a 1m change in subsoil thickness in Offaly. This value is an average 'distance from outcrop to the 3m contour' calculated for 30 areas in Offaly. This buffer distance is believed to represent a conservative value. In practice the outcrop is a point of extreme vulnerability surrounded by an area of probably extreme vulnerability.

- Rock close to the surface (from subsoils map) was contoured using a 130m buffer. This figure is based on the assumption that subsoils are 1m thick at the perimeter of these areas.

- Several areas in County Offaly have a general depth to bedrock of less than three metres. Points indicating a thickness of 2m were extrapolated 70m to produce the three metre contour. Similarly points indicating a 1m thickness were extrapolated 130m.

- Karst features were marked as points of extreme vulnerability.

- Accurate borehole/well data were contoured by extrapolating depth to bedrock from these points to 3m contours around adjacent outcrops (townland data were taken into consideration where appropriate). Contour shapes were influenced by topographic contours in some places.

- Townland accuracy data were not contoured on their own but were used to give a general indication of depth to bedrock in the area and were useful in the absence of other data.

- 6 inch to 1 mile geology maps were used throughout the exercise.

Guidelines Specific to Subsoils

- Alluvium is assumed to be less than 3m thick except in flat areas. Generally vulnerability was assigned by considering the surrounding subsoils and their thickness.

- As marl is generally <1m thick, vulnerability of marly areas was taken to be that of surrounding subsoils.

- In general, areas of peat overlie lacustrine clay or marl and are taken to be at least 5m in thickness (unless accurate data indicates thicknesses of <5m) but no greater than 10m as much of the peat in Offaly has been cut away. Therefore most peat areas were assigned a moderate vulnerability. Site investigations are likely to reveal that peat, marl and lake clay in some areas is >10m in which case groundwater vulnerability is low.

- Points of actual vulnerability in the peat were based on the assumption that till of moderate permeability underlies the peat.