County Waterford Groundwater Protection Scheme

Main Report

A quarry face at Waterford Harbour by G. V. Du Noyer (1817-1869). The illustration shows the contact between steeply inclined Ordovician slates which are overlain by near - horizontal beds of Old Red Sandstone.

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County Waterford
Groundwater Protection Scheme

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1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE OF GROUNDWATER PROTECTION SCHEME

This report was initiated to provide Waterford 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 Waterford County Council, the Geological Survey of Ireland, University College Galway and Trinity College Dublin. The original work on the protection scheme was carried out by Sara Duffy (University College Galway); the Quaternary geology was mapped by Irene Quinn as part of a PhD thesis; and work on the development of the vulnerability map was also undertaken by Hugh Fox (Trinity College Dublin).

This report has been compiled by Matthew Hudson of the GSI, assisted by Donal Daly (GSI) and Paul Johnston (TCD), and represents an integration and reassessment of previous work and data.

The geological and hydrogeological data for County Waterford 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
- 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 Waterford are limited to a study of the Dungarvan-Lismore syncline. Consequently, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of County Waterford. 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 Waterford 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 Waterford. Also, the concept of risk and the requirement to take account of the risk of contamination to groundwater from potentially polluting activities have been integrated into the groundwater protection scheme.

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

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

RISK = PROBABILITY OF AN EVENT × CONSEQUENTIAL DAMAGE

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

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

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

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

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

or

Hazard —*vulnerability*→ **Aquifer or gw source**

The GSI uses the following terminology and definitions.

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

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

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

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 Waterford County Council 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 should provide a framework for decision-making and guidelines for Waterford County Council 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.

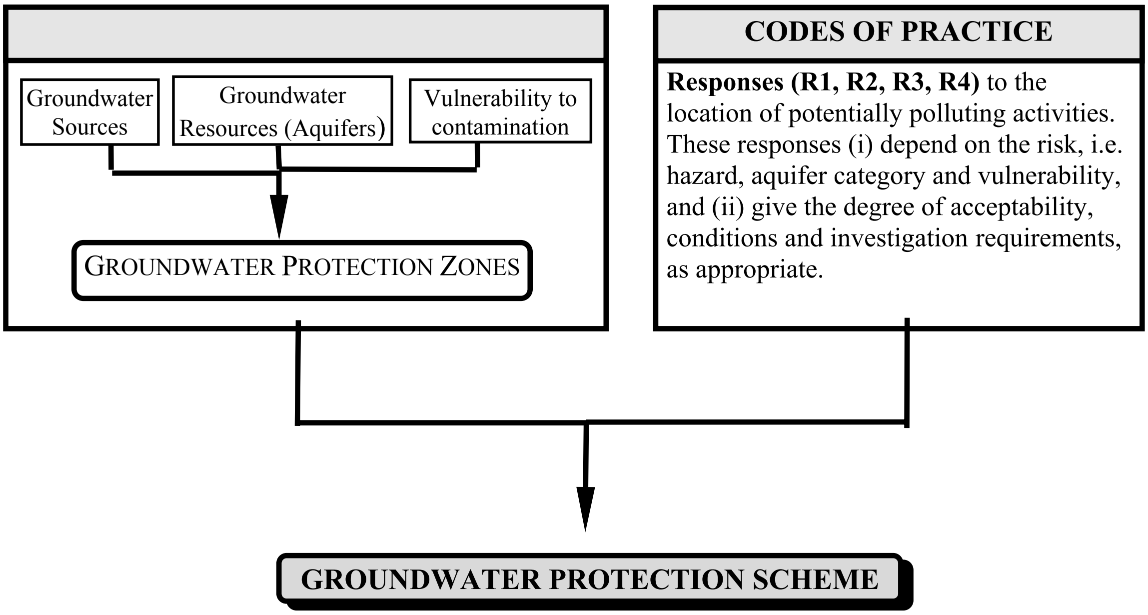
2.1.7 How A Groundwater Protection Scheme Works

There are **two main components** of the groundwater protection scheme (Figure 2.1):

- **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 2.1 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 describe (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.

2.2 LAND SURFACE ZONING FOR GROUNDWATER PROTECTION

2.2.1 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), peat, lake and alluvial silts and clays, - are the single most important natural feature in influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin and, in areas of karstic limestone, where surface streams sink underground at swallow holes.

The geological and hydrogeological characteristics can be examined and mapped, thereby providing a groundwater vulnerability assessment for any area or site. Four groundwater vulnerability categories are used by the GSI - **extreme**, **high**, **moderate** and **low**. Examples of each are given in Table 2.1 and further details can be obtained from the GSI. These 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 : Examples of Vulnerability Ratings

VULNERABILITY RATING	HYDROGEOLOGICAL SETTING
Extreme	Areas of outcropping bedrock or where bedrock is overlain by shallow (<3m) subsoil
High	Bedrock overlain by 3-10m of intermediate permeability subsoil such as sandy till or 3-5m of low permeability subsoil such as clayey till, clay or peat
Moderate	Bedrock overlain by >10m of sandy till or 5-10m of clayey till, clay or peat
Low	Bedrock overlain by >10m of clayey till, clay or peat

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.

2.2.2 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.

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

2.2.2.2 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.

2.2.2.3 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 2.2.

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.

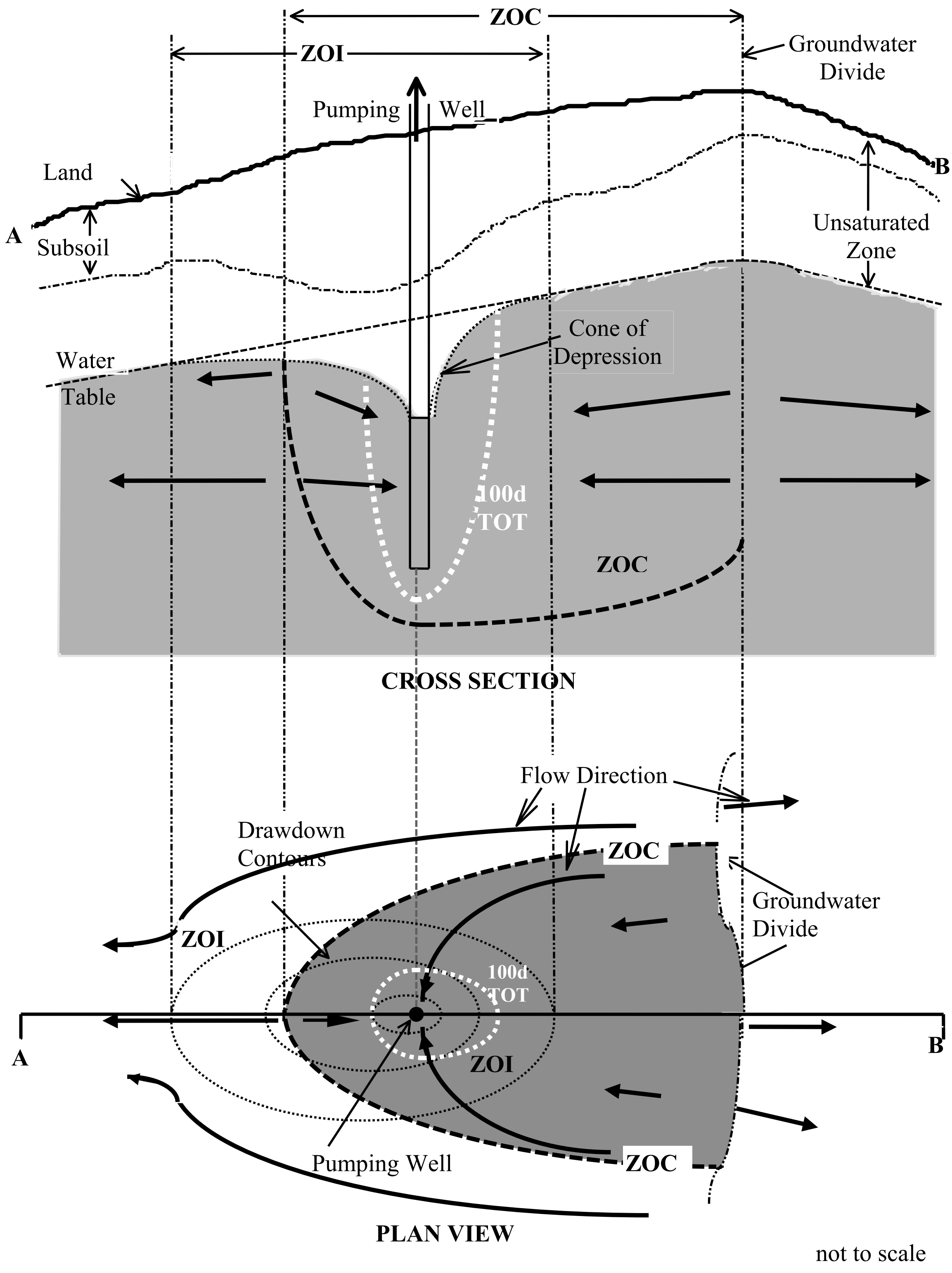


Figure 2.2 Conceptual Model of the Zone of Contribution (ZOC) and the Zone of Influence (ZOI) at a Pumping Well (adapted from U.S. EPA, 1987)

2.2.2.4 Delineation of Source Protection Zones

The matrix in Table 2.2 below gives the result of integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SO/H**, which represents an Outer Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around each local authority source. The outcome is a groundwater protection zone map.

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

2.2.3 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 nine resource protection areas.

Regionally Important (R) Aquifers
- (i) Karstified limestone (**Rk**)
- (ii) Fractured bedrock (**Rf**)
- (iii) Extensive sand/gravel **(Rg)**

Locally Important (L) Aquifers
- (i) Sand/gravel (**Lg**)
- (ii) Karstified limestone (**Lk**)
- (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). 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/Lk	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

2.3 CODES OF PRACTICE

The Codes of Practice contain a series of **Response Matrices**, each setting out the recommended response to a certain type of development. The level of response depends on the different elements of risk - the vulnerability, the value of the groundwater (with sources being more valuable then resources and regionally important aquifers more valuable than locally important and so on) and the contaminant loading. By consulting a Response Matrix in a Code of Practice, it can be seen (a) whether such a development is likely to be acceptable on that site, (b) what kind of further investigations may be necessary to reach a final decision, and (c) what planning or licensing conditions may be necessary for that development. The codes of practice are not necessarily a restriction on development, but are a means of ensuring that good environmental practices are followed.

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

R1 Acceptable subject to normal good practice.

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

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

R4 Not acceptable

2.4 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 and landspreading code of practices are 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

2.5 DRAFT CODE OF PRACTICE FOR LANDFILLS

Table 2.5 gives a Response Matrix for landfills (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]	↓
	→	→	→	→	→	→	→	→	

- 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.

2.6 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. As both the response matrix and the specific responses currently exist in draft form they should only be used as guidelines when considering the location of septic tank systems in any protection zones. It is expected that a Groundwater Protection Response Manual will be issued jointly by the EPA and the GSI at a later date.

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/L*	*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)

2.7 INFORMATION AND MAPPING REQUIREMENTS FOR LAND SURFACE ZONING

The **groundwater resources protection zone map** is the regional land-use planning map, and therefore is the critical and most useful map for the County Council. It is the ultimate or final map as it is obtained by combining the **aquifer** and **vulnerability maps.** The **aquifer map** boundaries, in turn, are based on the **bedrock map** boundaries and the **aquifer categories** are obtained from an assessment of the available **hydrogeological data**. The **vulnerability map** is based on the **subsoils map**, together with an assessment of relevant **hydrogeological data**, in particular indications of permeability and karstification. This is illustrated in Figure 2.3.

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 2.4.

The conceptual frameworks for groundwater resource and source protection shown in Figures 2.3 and 2.4 provide the structure for the remainder of this report:

- Chapter 3 bedrock geology
- Chapter 4 subsoils geology
- Chapter 5 hydrogeology and aquifer categories
- Chapter 6 groundwater vulnerability
- Chapter 7 groundwater resource protection
- Chapter 8 groundwater source protection

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

Response Code	Acceptability, Conditions or Exceptions
R1	**Acceptable**, subject to normal good practice (i.e. compliance with S.R.6 : 1991 (NSAI, 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). (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.
$R3^3$	**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.
R4	**Not acceptable**

2.8 FLEXIBILITY, LIMITATIONS AND UNCERTAINTY

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

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. In certain cases the scheme may not provide sufficient information for site specific decisions and it may be necessary to carry out further site investigations before arriving at a definate decision. In essence a Groundwater Protection Scheme is a tool which helps Council officials to respond to relevant development proposals and is a means of showing that the County Council is undertaking their responsibility for preventing groundwater contamination in a practical and reasonable manner.

2.9 CONCLUSIONS

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

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

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

♦ The scheme has the following benefits and uses:

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

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

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

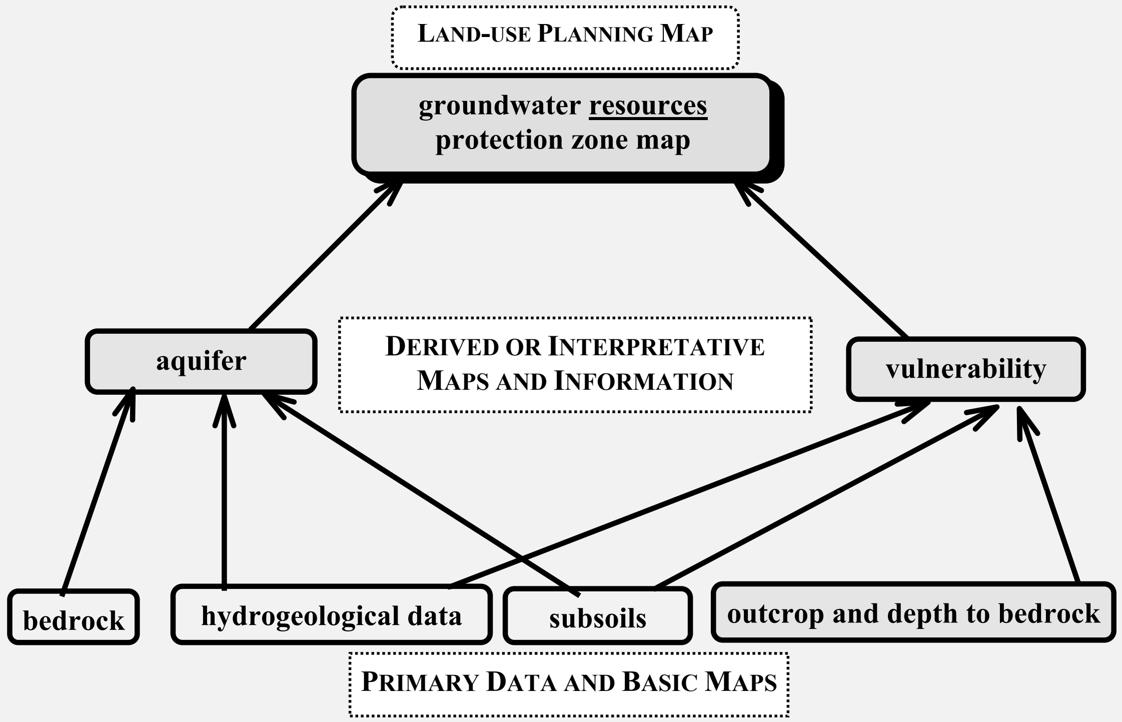


Figure 2.3 **Conceptual framework for production of groundwater <u>resource</u> protection zones, indicating information needs and links.**

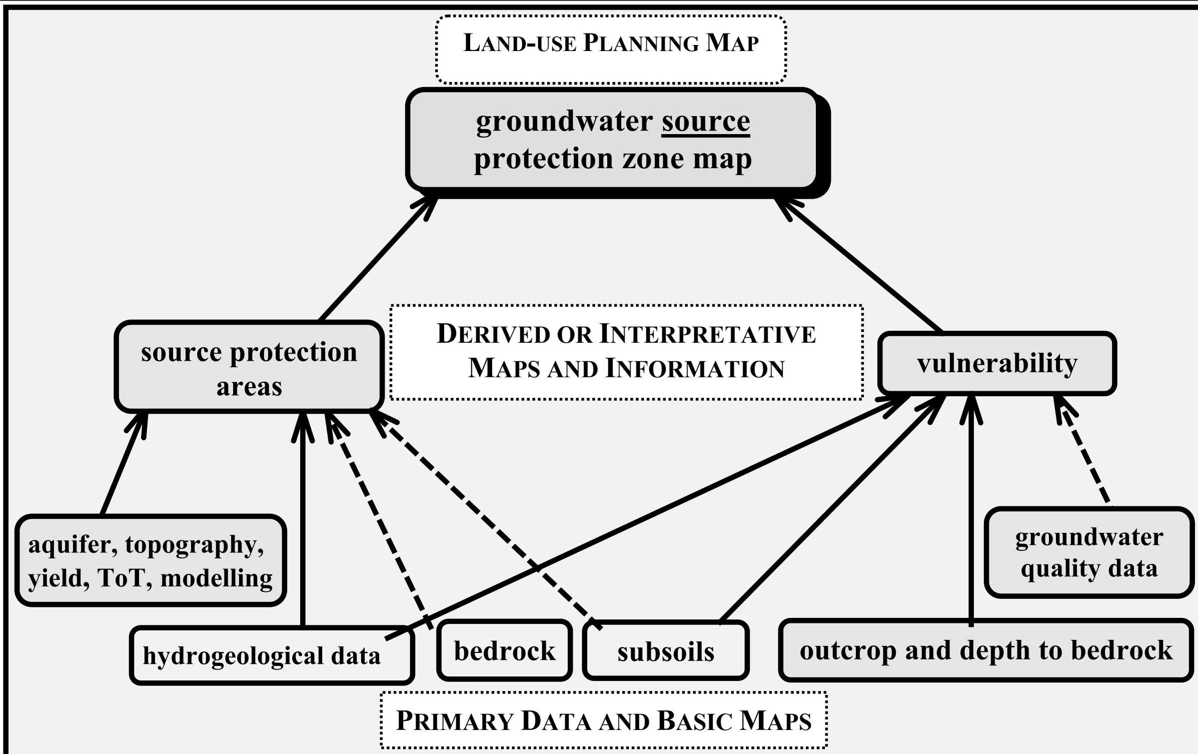


Figure 2.4 **Conceptual framework for production of groundwater <u>source</u> protection zones, indicating information needs and links.**

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

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

3. BEDROCK GEOLOGY

3.1 INTRODUCTION

The striking variations in topography in County Waterford can be related directly to the underlying geology. To the east the low lying rugged terrain is a reflection of the complex faulted sequence of sediments and volcanics. Large thicknesses of Old Red Sandstone rocks overlie these older rocks to the west of the county, forming upland areas such as the Comeragh, Monavullagh and Knockmealdown Mountains. These Old Red Sandstone rocks are 'harder' and less readily weathered and eroded than the 'softer' limestones which are susceptible to dissolution (dissolving of the limestone by rainwater). The topography of north and west Waterford has a pronounced 'grain' to it, with elongate east-west valleys separated by intervening ridges, reflecting the underlying geological structure. The ridges consist of Devonian Old Red Sandstone rocks while the valleys are floored by poorly exposed Carboniferous Limestones. As a result of the relatively thin covering of glacial sediments the bedrock in Waterford is generally well exposed.

The geology map of County Waterford (Map 1) is derived directly from the GSI 1:100,000 scale geology maps; sheet 22, (Sleeman, A.G. and McConnell, B., 1995) and sheet 23 (Tietzsch-Tyler, D. and Sleeman, A.G., 1994). These maps represent the most recently compiled geological information. Minor changes have been made in the names given to lithological units within the Campile Formation in order to make sheets 22 and 23 consistent; these are described in section 3.3.

A summary of the bedrock geology is given in Table 3.1, together with a more comprehensive description of each bedrock unit (formation). Where the relationship between formations is complicated (e.g. the Ordovician and Devonian rocks) the correlation between the different formations is further described and illustrated in Appendix 1 and Appendix 2.

3.2 CAMBRIAN ROCKS (540 - 510 million years ago)

3.2.1 Booley Bay Formation (BB)

The oldest rocks in County Waterford are exposed in the south east of the county, to the east and south east of Tramore. They have been named collectively as the Booley Bay Formation and consist of dark grey to black mudstones with minor siltstones. These rocks are structurally complex due to widespread slump deformation during deposition in the deep marine Cambrian basin.

3.3 ORDOVICIAN ROCKS (510 - 438 million years ago)

The Ordovician rocks in Waterford are divided into two successions, the early Ordovician Ribband Group and the Middle to late Ordovician Duncannon Group.

3.3.1 Kilmacthomas Formation (KI)

The Kilmacthomas Formation is a sequence of green and purple shales and siltstones, with minor grey shales and siltstones and acid tuffs (volcanic ash deposits). This rock unit outcrops north of Kilmacthomas and is believed to have faulted contacts with the younger Silurian rocks to the north west and the Campile Formation to the south east.

3.3.2 Bunmahon Formation (BM)

The Bunmahon Formation occurs along the coast and inland between Knockmahon and Stradbally. It consists of basic (dark coloured) to intermediate lavas, associated ash deposits (tuffs) and basic igneous intrusions. Stratigraphic relationships suggest that the Bunmahon Formation represents a long lived local centre of basaltic to andesitic volcanism.

3.3.3 Dunbrattin Formation (DB)

This formation consists of a series of submarine sediment pulses (turbidites). These are a series of graded and laminated shales, siltstones and fine sandstones. Minor ash layers and andesitic sheet intrusions are also present. This rock unit occurs along the coast between Ballyvoyle and Dunbrattin Head and is thought to be the lateral equivalent of the Tramore Shale Formation.

3.3.4 Tramore Shale Formation (TM)

The Tramore Shale Formation occurs in an area along the coast and inland of Tramore Bay. This rock unit consists of dark grey shales and siltstones and represents deposition into a deep marine basin.

3.3.5 Tramore Limestone Formation (TE)

The Tramore Limestone Formation only outcrops in small areas, primarily along the coast, south of Tramore. This rock unit consists of calcareous shales and siltstones to the west, and calcareous sandstones, siltstones and shales with impure limestones to the east.

3.3.6 Carrighalia Formation (CX)

The Carrighalia Formation also only occurs in a small area, to the north west of Tramore. This rock unit consists of black pyritic mudstones and siltstones which represent deeper water deposition. Volcanic ash is present within this unit and is believed to mark the beginning of the extensive volcanic activity which dominates the succeeding Campile Formation.

3.3.7 Campile Formation (CA)

The Campile Formation is the most extensive rock unit of Ordovician age in eastern County Waterford. It is characterised by (pale) rhyolitic volcanic flows and fine, medium and coarse grained tuffs and agglomerates (ash and coarse volcanic rock). Significant sedimentary units (primarily shales) occur throughout the formation and several members have been distinguished (e.g. the Ross Member, the Garraun Shale Member and the Ballyhack Member). Where shale predominates but stratigraphic correlation is not possible, e.g. in the area to the north and west of Dunbrattin Head, 'shale units' are used as a subdivision of the Campile Formation (on 1:100,000 scale bedrock sheet 22). This description has been applied to similar shale-dominated areas of the Campile Formation further west (sheet 23).

3.3.8 Ballynaclough Formation (BI)

The Campile Formation is overlain by the Ballynaclough Formation in central eastern Waterford. This rock unit represents a return to basic volcanism, silica rich rhyolites were replaced by dark green, silica-poor, basaltic rocks. These consist predominantly of basic lavas, volcaniclastics (ash and associated deposits), near surface intrusions and minor shale units.

3.3.9 Clashabeema Formation (CB)

The rocks of the Clashabeema Formation are the youngest Ordovician rocks in County Waterford (see Appendix 1.1) and represent a return to pale coloured rhyolitic volcanics (silica rich). The formation occurs in a broad band in the central part of eastern Waterford and forms the middle of a large synclinal structure.

Table 3.1 Summary of Bedrock Geology

Age (Million Years)	Rock Unit/Formation	Description	Distribution
Carboniferous (Approx. 330-355)	Waulsortian	Muddy limestones and coarse grained limestones.	This is the dominant rock type in the limestone synclines.
	Ballysteen	Calcarenite (sandy limestone) and muddy limestone.	Along the margins of the major limestone synclines.
	Ballymartin	Grey muddy limestones and shales.	Along the margins of the major limestone synclines.
	Lower Limestone Shales	Interbedded sandstones, mudstones and limestones.	Along the margins of the major limestone synclines.
Devonian (355-410)	Kiltorcan	Yellow and white sandstones with minor mudstones.	North of the Lismore syncline and northern and western Waterford.
	Gyleen	Green, grey and purple mudstones and sandstones.	South of the Lismore Syncline.
	Harrylock	Conglomerates, sandstones, siltstones and mudstones.	The extreme southeast of Waterford.
	Templetown	Red quartz conglomerates with minor sandstones.	The extreme southeast of Waterford.
	Carrigmaclea	Red conglomerates and sandstones.	Northern rim of the Comeragh Mountains.
	Knockmealdown	Red conglomerates and sandstones.	Knockmealdown Mountains.
	Kilnafrehan	Red conglomerates and sandstones.	Monavullagh Mountains.
	Sheskin	Conglomerates, sandstones and siltstones.	Monavullagh Mountains.
	Treanearla	Red conglomerates and sandstones.	Monavullagh Mountains.
	Coumaraglin	Green conglomerates, sandstones and siltstones.	Monavullagh Mountains.
	Croughan	Quartz rich conglomerates and sandstones.	Comeragh Mountains.
	Coumshingaun Conglomerate	Coarse red conglomerates and minor sandstones.	Comeragh Mountains.
	Ballytrasna	Red mudstone with minor fine sandstone.	Extensively in west Waterford
Silurian (410-438)	Ballindysert	Dark grey slates.	Central northern Waterford.
Ordovician (438-510)	Clashabeema	Pale coloured volcanic rocks.	Central eastern Waterford.
	Ballynaclough	Basaltic volcanic rocks.	Central eastern Waterford.
	Campile	Volcanic lavas and tuffs with interbedded shales (e.g. Ross Member).	Extensively in east Waterford.
	Carrighalia	Black pyritic mudstones.	North west of Tramore.
	Tramore Limestone	Impure limestones with calcareous shales and siltstones.	South of Tramore.
	Tramore Shale	Dark grey shales.	Along the coast and inland of Tramore Bay.
	Dunbrattin	Interbedded mudstones, siltstones and sandstones with minor tuffs.	Between Ballyvoyle and Dunbrattin Head.
	Bunmahon	Volcanic lavas and tuffs (ash deposits).	Along the coast and between Bunmahon and Stradbally.
	Kilmacthomas	Green and purple shales with minor volcanics.	North of Kilmacthomas
Cambrian (540-510)	Booley Bay	Dark grey and black mudstones and siltstones.	East and southeast of Tramore.

3.4 SILURIAN ROCKS (438 - 410 million years ago)

3.4.1 Ballindysert Formation (BE)

The Ballindysert Formation occurs to the north of Kilmacthomas, in north central Waterford; between the fault contact with the Kilmacthomas Formation to the southeast and the unconformity with the overlying Old Red Sandstone rocks to the north and west. This rock unit consists predominantly of dark grey slates, with minor silty laminations. Bands of sandstones (greywackes) occur within the slates.

3.5 DEVONIAN ROCKS (355-410 million years ago)

Following the (Caledonian) mountain building episode at the end of the Silurian period, large areas of land were eroded under semi-desert conditions. Where there had once been an ocean there was now a continental landmass covering much of northwest Europe. These rocks are collectively known as the Old Red Sandstone.

The Old Red Sandstone rocks in Waterford fall into four separate stratigraphical successions: the East Cork succession; the Comeragh Mountain succession; the Portlaw succession; and the Dunmore East succession.

3.5.1 Ballytrasna Formation (BS)

The Ballytrasna Formation is the most extensive Old Red Sandstone rock type in the county, dominating large areas of west Waterford, both to the north and south of the Lismore-Dungarvan syncline.

To the south of the Lismore-Dungarvan syncline the formation is composed predominantly of red mudstone (up to 90%), the remaining rocks are pale red, fine to medium grained sandstones. The sandstone dominant member of the Ballytrasna Formation is the Mine Head Member. This comprises approximately 750 m of interbedded pale red and yellowish green sandstones with minor grey-red mudstones. This member is only seen in the coastal section in the Mine Head area.

To the north of the Lismore - Dungarvan syncline the Ballytrasna Formation is up to 1500 m thick, and unlike in the East Cork succession, contains significant quartz pebbly sandstones.

3.5.2 Coumshingaun Conglomerate Formation (CM)

This rock unit has a maximum thickness of 850 m. The base of the formation rests unconformably on the older Ordovician and Silurian slates and volcanics. The formation is made up of coarse boulder, cobble and pebble conglomerates (very coarse sandstones), with minor sandstone lenses. There is an overall decrease in the size of clasts upwards through these units. Two lava members have been identified within the conglomerates (at Carrigduff):- the Coolnahorna Member and the Carrigduff Volcanic Member. South of Portlaw the Coumshingaun Formation is only present as a thin conglomerate unit.

3.5.3 Croughan Formation (CO)

The Croughan Formation is a sequence of quartz-rich pebbly conglomerates and coarse green pebbly sandstones, which may be correlated with the Comeragh Conglomerate Sandstone Group (see Appendix 2). These conglomerates and sandstones only outcrop in a small area north of Kilmacthomas.

3.5.4 The Coumaraglin Formation (CU)

This rock unit consists of a sequence of green conglomerates, sandstones and siltstones. These rocks only outcrop in a small area to the east of Kilbrien, in the Monavullagh Mountains.

3.5.5 Treanearla (TR), Sheskin (SN) and Kilnafrehan (KF) Formations

These rock units are very similar, and form the central and eastern parts of the Monavullagh Mountains. The Treanearla Formation consists of up to 750 m of thick bedded conglomerates and conglomeratic sandstones. The Sheskin Formation consists of up to 850 m of interbedded conglomeratic sandstones, sandstones and silty mudstones, and the Kilnafrehan Conglomerate Formation consists of up to 220 m of thick bedded red conglomerates and conglomeritic sandstones.

3.5.6 Knockmealdown Sandstone Formation (KM)

The Knockmealdown Sandstone Formation is a sequence of upward fining conglomerates and sandstones; with conglomerates being quite common near the base, but dying out upwards into sandstones. The sandstones are pink - purple in colour. This rock unit covers large areas of north western Waterford, to the north of the Dungarvan syncline.

3.5.7 Carrigmaclea Formation (CI)

The Carrigmaclea Formation occurs around the southern flank of the Suir syncline. The rock unit is poorly exposed and it consists of a sequence of conglomerates, pebbly sandstones and cross stratified sandstone.

3.5.8 Templetown (TT) and Harrylock (HL) Formations

These two formations are found around Dunmore East, in the extreme southeast of Waterford. The Templetown Formation is up to 260 m thick and consists predominantly of quartz conglomerates with minor red sandstones. The Templetown Formation is overlain by the Harrylock Formation which consists of interbedded quartz conglomerates, fining upwards to red sandstones, siltstones and grey mudstones.

3.5.9 Gyleen Formation (GY)

This rock unit is dominated by green, grey and purple mudstones (up to 80%) and sandstones. Fining upward sequences are characteristic throughout these beds, together with large and small scale cross lamination in the sandstones. In places a lower Ballyquinn Member and an upper Ardmore Member have been identified. The Ballyquinn Member is approximately 390 m thick and consists of alternating thick grey and red medium grained sandstones and thick red mudstones. The overlying Ardmore Member (107 - 154 m) is distinguished by regular alternations of grey and red sandstones and grey-yellow siltstones.

3.5.10 Kiltorcan Sandstone Formation (KT)

The youngest rocks in the Old Red Sandstone sequence are those of the Kiltorcan Formation. The rock unit is dominated by thickly bedded green, yellow and white sandstones arranged in fining upwards cycles, with interbedded purple and green mudstones (up to 5 m thick). The Kiltorcan Sandstone Formation occurs on the north flank of the Lismore Syncline and around the rim of the Comeragh, Monavullagh and Knockmealdown Mountains. On the south flank of the Lismore Syncline, and further south, the Kiltorcan Formation is roughly equivalent to the Gyleen Formation.

3.6 LOWER CARBONIFEROUS ROCKS (330 - 355 million years ago)

The Lower Carboniferous marked the return to marine conditions in Waterford and the deposition of shales and limestones.

3.6.1 Lower Limestone Shales (LLS)

The Lower Limestone Shales are represented by the Crows Point, Mellon House, Ringmoylan and Ballyvergin Formations, and by the Porters Gate Formation in northern Waterford. These rock units are poorly exposed and relatively thin (less than 100 m) and are therefore grouped together as one unit (LLS) over most of the map. Where individual rock units predominate or where they can be distinguished at the map scale they are included on the map. These beds represent the beginning of the marine flooding of the Old Red Sandstone continent.

The Crows Point, Mellon House, Ringmoylan and Ballyvergin Formations are best exposed around Whiting Bay and the Ardmore area. The Crows Point Formation (up to 73 m) is composed predominantly of thick, massive and cross-laminated grey sandstones with minor mudstones. This is followed by the Mellon House Formation (alternating fossiliferous limestones, silty mudstones and sandstones), the Ringmoylan Formation (fossiliferous, calcareous mudstone and limestones) and the Ballyvergin Formation (greenish grey non calcareous mudstone, which are only one metre thick at Whiting Bay).

These rock units are all poorly exposed in Waterford and it is the remaining limestones which dominate the Carboniferous sequence in Waterford.

3.6.2 Ballymartin Formation (BT)

The Ballymartin Formation is a thinly bedded succession of interbedded, dark grey, nodular, muddy limestones and calcareous shales. The formation is present on the outer limbs of the northern limestone synclines in Waterford, although it is generally poorly exposed and is sometimes absent due to faulting. The formation is though to be 30-40 m thick in the Lismore Syncline.

3.6.3 Ballysteen Formation (BA)

The Ballysteen Formation also occurs on the outer limbs of the limestone synclines in Waterford (overlying the Ballymartin Formation). The formation consists of lower calcarenite (sandy limestone) beds overlain by silty and muddy limestone; and is though to be in the order of 300 m thick.

3.6.4 Waulsortian Limestone Formation (WA)

The Waulsortian Limestones form the dominant rock type within the Carboniferous synclines in Waterford. The limestones are a combination of calcareous mudstones and coarser grained limestones, they are pale grey in colour, poorly bedded and often contain original calcite filled cavities. Thicknesses range from 400 to 750 m. These limestones have been subjected to fracturing, recrystallisation and dolomitisation.

3.7 STRUCTURE

The rocks in County Waterford were deformed during the Caledonian (Silurian to Devonian) and Variscan (at the end of the Carboniferous) mountain building episodes. The Caledonian deformation affected the Lower Palaeozoic rocks of eastern Waterford, resulting in complex folding, faulting and low grade metamorphism.

The Variscan mountain building episode produced a northward directed shortening of the rocks in this area of the order of 30 - 50%. As a result, structural deformation and dislocation increase in intensity moving from north to south across the country, producing a pronounced east-west trending structural ‘grain’. Waterford has therefore been subjected to greater structural deformation than areas to the north of the county; this has affected the development of permeability within the bedrock (see section 5.5)

The structure of the county is dominated by several major east-west trending synclines, between Clonmel and Carrick-on-Suir, Lismore and Dungarvan, east of Tallow and around Ardmore. The younger Carboniferous limestones outcrop in the centre of these structures while the surrounding anticlinal structures are composed of (Devonian) Old Red Sandstone rocks. These major synclines are large open structures with minor second and third order folds developed on the flanks.

Most of the major folds in Waterford are cut by strike-parallel faults (along the length of the synclines i.e. west-east) and by smaller faults perpendicular to the synclines (approximately north-south).

4. SUBSOILS GEOLOGY

4.1 INTRODUCTION

Subsoils or Quaternary deposits overlie much of the bedrock in County Waterford, although they are not as widespread or as thick as in many other parts of Ireland. The majority of these deposits were laid down in a glacial environment as till (boulder clay), below or at the margins of ice sheets. Large quantities of water from melting ice also produced sorted deposits such as sand and gravels. In addition the subsequent action of rivers has deposited alluvium and sand and gravel in many river valleys. In situ head deposits are also present in Waterford.

The type and thickness of the subsoils which overlie much of the bedrock in County Waterford are considered to be the single most important factor influencing the vulnerability of groundwater to pollution (see Chapter 6). Areas overlain by a thick cover of subsoils or subsoils with a low permeability such as clayey till (boulder clay) will provide greater protection than areas where the subsoil cover is thin or of a higher permeability (sand and gravel for example).

The subsoils geology of County Waterford was compiled (at a scale of 1:25,000) and described by Quinn (1987); this work was summarised by Browne (1992). The subsoils maps are derived from walkover surveys and from a compilation of available data.

This chapter briefly describes the Quaternary deposits in Waterford; their sequence and distribution, the different till types (matrix composition), the till lithology (clast composition) and the available grain size analyses. Other subsoils deposits such as alluvium, sand and gravel and head deposits are also briefly described.

4.2 THE SEQUENCE OF GLACIAL EVENTS

The entire glacial sequence in Waterford is regarded as the product of a single glacial event which is assigned to the most recent glaciation, approximately 20,000 years ago. The major ice sheets which affected Waterford are thought to have been broadly concurrent. Three main ice movements have been identified: an ice movement from the south which deposited the Irish Sea Till along the coastline; the main ice movement from the north which deposited the Ballyvoyle Till across the county; and the localised Comeragh Mountains ice sheet which appears to have been at its most extensive later on in this sequence. The direction and sequence of ice movements are shown in Figure 4.1.

4.3 DISTRIBUTION OF DEPOSITS

4.3.1 Irish Sea Till

The Irish Sea Till is recognised by its relatively stone free, chocolate brown, calcareous silty matrix and by its flint and shell content, indicative of an Irish Sea Basin origin. The Irish sea till occurs in the coastal areas of south Waterford and is not found at any great distance inland. The till is thickest to the west of Dungarvan and is only about one metre thick in east Waterford.

4.3.2 Ballyvoyle Till

The Ballyvoyle Till occurs throughout Waterford and is seen to overlie the Irish Sea Till along the coast. The till is generally a massive, structureless, sandy-stony deposit with a well defined fabric (usually aligned north to south). The composition of the matrix and clasts is variable and is largely

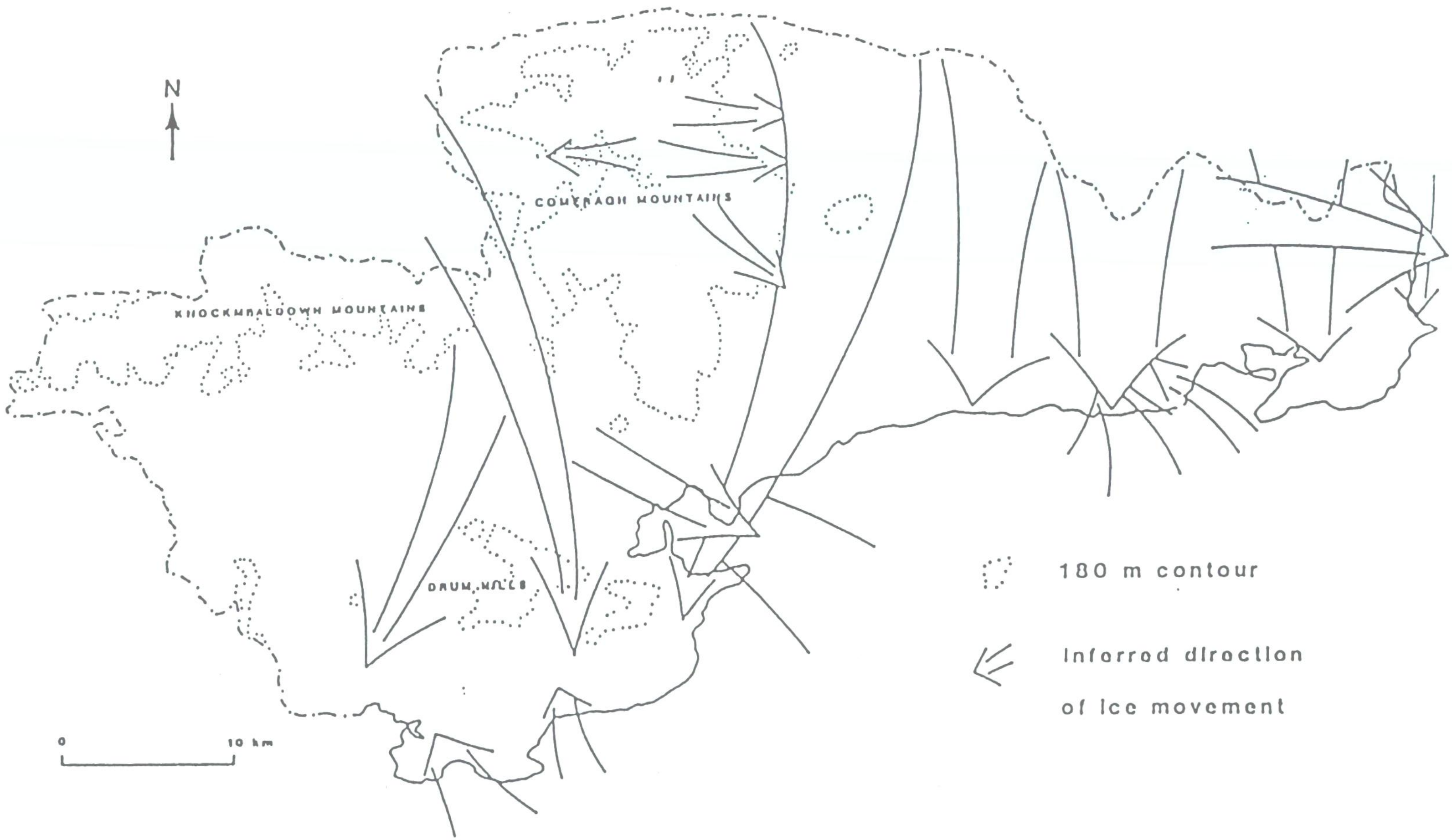


Figure 4.1 The Direction and Sequaence of Ice Movements in County Waterford *(After Quinn, 1987)*

controlled by the interaction of glacial processes and the underlying geology (for example; sandstone dominated tills occur in west Waterford, coinciding with large areas of Devonian sandstone bedrock). Sand and gravel within the till appears to be more common to the west of the Comeraghs, along the Nier River Valley, to the south of Ballynamult and at isolated locations within the till (in the townland of Ballylemon for example). These small gravel deposits are often overlain by the more typical sandy stony till.

4.3.3 Comeragh Valley Sediments

The Comeragh Valley sediments (called the Knockanaffrin Till) are a local, sandy-stony till dominated by Old Red Sandstone clasts with a sandy matrix. Till deposits of this type are found along the east and west flanks of the Comeragh Mountains and were deposited by local valley glaciers.

4.4 TILL TYPES

4.4.1 Clast Lithology

The clast composition of the tills in Waterford is largely dependant on the underlying geology and the geology of the areas over which glaciers have travelled before being deposited. Till composition can in turn exert a strong influence on the nature of the till matrix. Fine grained shale or muddy limestone clasts tend to break down into a fine grained matrix, coarse grained sandstones tend to break down into a coarser grained matrix. Glacial processes can also greatly influence the nature of the till matrix.

The dominant till lithology in Waterford is sandstone, derived from the Old Red Sandstone rocks which outcrop extensively the west and north of the county. Volcanic till is the next dominant till lithology in Waterford and coincides with large areas of volcanic outcrop in the east and south east of the county. Shale/slate till is found in the eastern-central region of Waterford, to the east of the Comeragh Mountains, in the area of Silurian rocks. Small concentrations of cherty and limestone tills occur in the extreme northern and south western part of Waterford .

The different till lithologies are represented on the subsoils map (Map 2) using a colour code; red for sandstone, dark green for volcanic till and light green for shaley till etc., together with a hatching pattern.

4.4.2 Till Composition

The composition of the till is illustrated at point locations on the subsoils map (Map 2) using the following till types:

- Till (Undifferentiated)
- Clayey Till
- Sandy Till
- Gravelly Till
- Stony Till
- Stony Sandy Till

These till types can give useful information on the sediment composition at point locations within the till. Sandy and gravely tills suggest a coarse grained matrix whereas clayey tills have a fine grained matrix. More quatitative information on the matrix composition of the till is provided by particle size analyses.

4.5 PARTICLE SIZE ANALYSES

Grain size analyses were performed on 20 sediment samples from county Waterford (Quinn 1987). From the grain size analyses it is clear that the Irish Sea Till is clay and silt rich, the Ballyvoyle Till has a highly mixed grain size distribution and the sand and gravel deposits are silt/clay poor. Table 4.1 and Figure 4.2 examine the relationship between till lithology and grain size in more detail.

Although the data set is small, it appears that the percentage of fine sediment is higher in the shale and volcanic till lithologies than in the sandstone till (particularly when the finest grain sizes are examined). This has implications when attempting to classify the subsoils as having a low or intermediate permeability (see chapter 7).

Table 4.1 Sediment lithology and % of fine sediment in samples analysed (Quinn, 1987)

Sample No. From Quinn (1987)	Sediment Lithology	% of the Sample less than 0.065 mm (clay and silt)	% of the Sample less than 0.0065 mm (clay and fine silt)
1	Volcanic Till	42	20
3	Volcanic Till	49	17
5	Volcanic Till	37	18
4	Clay/Silt (Irish Sea Till)	52	6
6	Clay/Silt (Irish Sea Till)	73	18
7	Clay/Silt (Irish Sea Till)	70	12
8	Clay/Silt (Irish Sea Till)	68	21
17	Clay/Silt (Irish Sea Till)	63	16
2	Sand and Gravel	13	3
9	Sand and Gravel	8	4
10	Sand and Gravel	3	0
15	Sand and Gravel	4	2
16	Sand and Gravel	7	3
12	Sand and Gravel	0	0
11	Sandstone Till	28	6
13	Sandstone Till	28	10
14	Sandstone Till	22	8
18	Sandstone Till	31	6
19	Sandstone Till	26	9
20	Shale Till	34	11

4.6 ROCK CLOSE TO SURFACE

Where rock is believed to be generally less than 1-2 metres below the surface this is described on the map as rock close to the surface. In Waterford a large area of rock close to the surface is exposed in mountainous regions such as the Comeragh Mountains, the Knockmealdown Mountains and the Drum Hills. Smaller areas of rock close to surface are marked on the map throughout the county, particularly over the Lower Palaeozoic volcanic areas of east Waterford and in the limestones north west of Dungarvan.

4.7 HEAD DEPOSITS

Head deposits are subsoils formed by frost shattering and weathering processes. These deposits are typically semi-stratified with angular clasts. Head deposits are found locally throughout Waterford, particularly in the upland valleys of mountainous regions and at the coast.

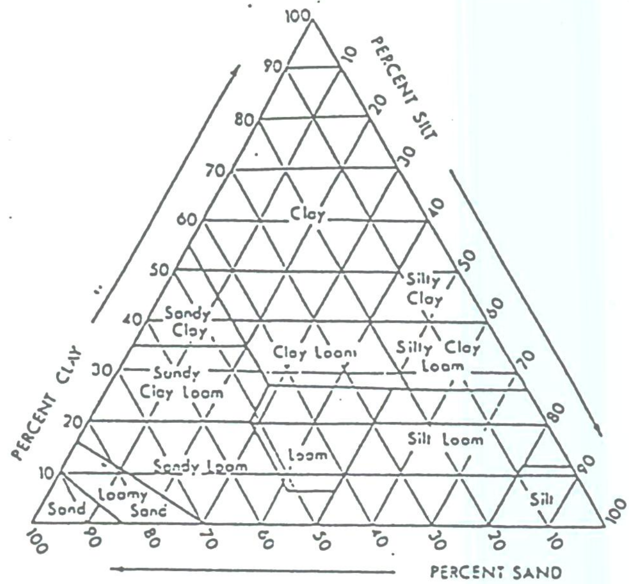


Chart showing the percentage of clay (less than 0·002 mm), silt (0·002 to 0·05 mm) and sand (0·05 to 2·0 mm) in the basic soil texture classes (After Soil Survey Manual, U.S.D.A. Handbook No. 18, Washington, D.C., 1951)

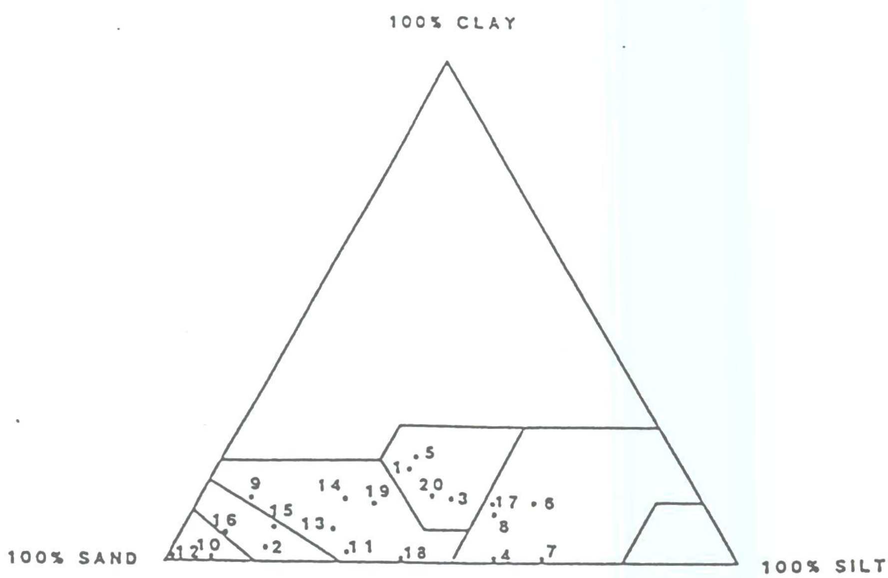


Figure 4.2 Ternary diagram displaying amounts of clay, silt and sand in twenty textural samples from County Waterford (from Quinn, 1987).

4.8 ALLUVIUM

Alluvium is an unconsolidated river deposit generally consisting of silts and clays, but which may also contain sands and gravels. In Waterford alluvium is present in river channels and along the flood plains of the major rivers such as the Blackwater and the Suir. Small deposits of alluvium are also associated with most of the mountain streams and rivers. Details on the exact nature of the alluvium is restricted to areas such as Waterford City where there are detailed geotechnical records available. The alluvium in Waterford City is composed predominantly of silts and clays (over 15 metres thick in places); although sand and gravels (greater than 10 metres thick) occur immediately adjacent to the Suir in central Waterford.

4.9 SAND AND GRAVEL

The distribution of sand and gravel deposits in Waterford is very scattered with most of the exposures in gravel pits or boreholes. These deposits tend to occur in the major valley systems in the western half of the county (Quinn, 1987). There is a concentration of sand and gravels in boreholes to the north and west of Dungarvan, in addition there is an obvious concentration of sand and gravel pits along the River Suir and at Lismore. Most of the sand and gravel units in County Waterford are small. In general, point locations where sand and gravel has been found are illustrated on the subsoils map (Map 2).

5. HYDROGEOLOGY AND AQUIFER CLASSIFICATION

5.1 INTRODUCTION

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

5.2 DATA AVAILABILITY

The aquifers in Waterford have been classified using information from the following sources;

- The GSI well database
- GSI reports
- Information supplied by Waterford County Council.
- Test pumping data from work undertaken by S. Duffy (1994). (The value and quality of the test data varied, as the tests were carried out on operational wells and many were of short duration.)
- The GSI database of karst features.
- General geological and hydrogeological experience from the GSI; including work carried out in adjacent counties. This includes work in Cork by G.R.Wright and in Kilkenny by E.P. Daly.

The limestone aquifer in the Lismore-Dungarvan valley was investigated, including the use of numerical groundwater modelling, by D. McDaid (1994). Source reports have been carried out for Ardmore, Ballinamuck, Ballyrohan, Cappoquin, Grange and Poulnagunouge Public Supply Wells.

5.3 CLIMATE, RAINFALL AND EVAPOTRANSPIRATION

A mean annual precipitation map (Figure 5.1) has been prepared for Waterford, based on the 1951-1980 average rainfall data provided by the Meteorological Service. Annual rainfall in upland areas such as Comeragh, Monavullagh and Knockmealdown Mountains ranges from 1200 mm/yr to over 1600 mm/yr. The lowland valleys in the west, the coastline and the east of the county generally receive between 900 and 1200 mm/yr.

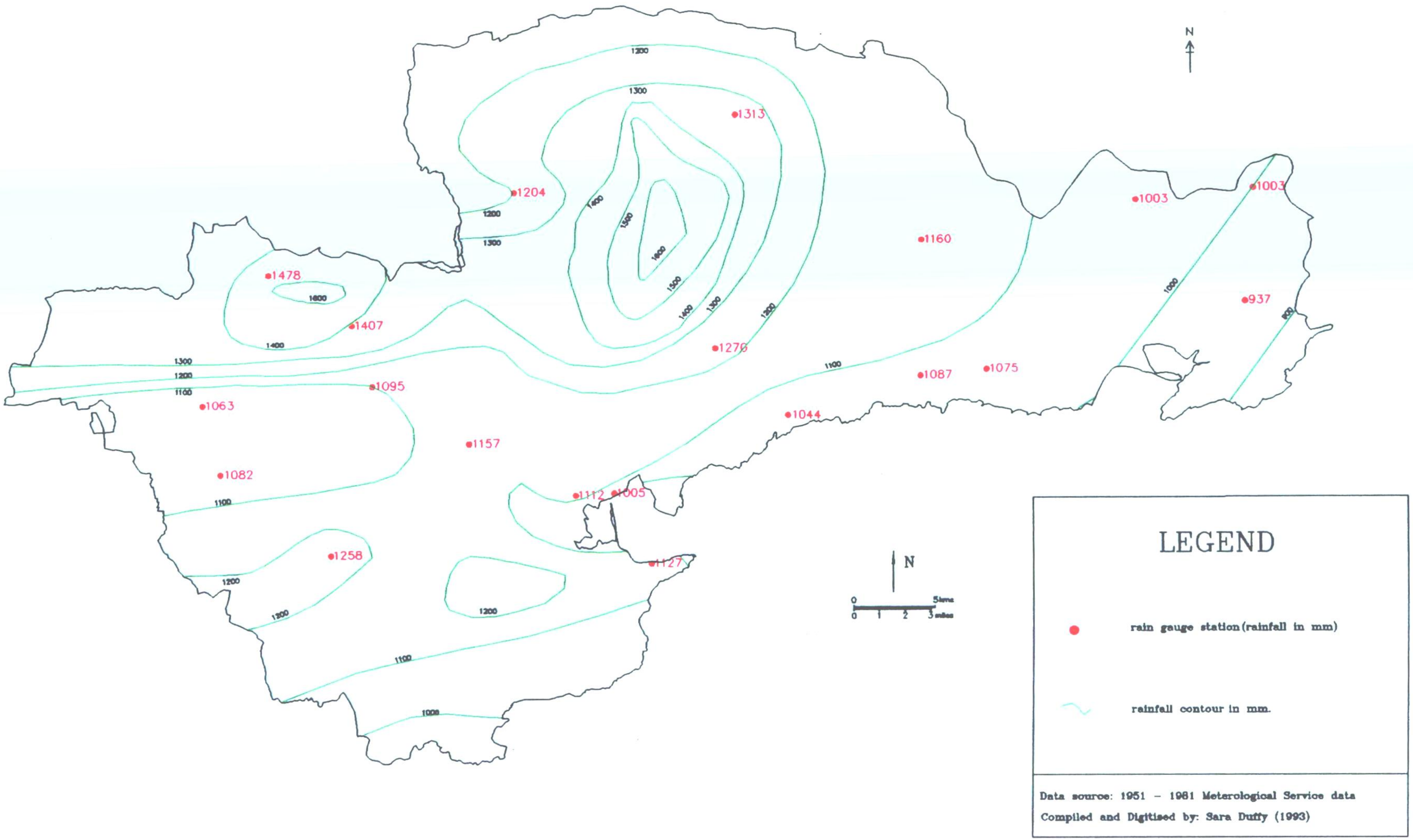
Actual evapotranspiration in Co. Waterford is estimated to be between 475 - 550 mm/yr, with the higher values occurring towards the coast. The effective rainfall (rainfall minus evapotranspiration) in the upland areas to the north of the county is likely to be in the range 650 - 1175 whereas the effective rainfall in low-lying eastern Waterford and in the valleys to the west of the county is likely to be in the range 350 - 650 mm/yr.

5.4 GROUNDWATER USAGE

There are 110 public water supplies in Waterford, (EPA, 1992); this figure includes two combined surface and groundwater schemes and the new supply at Ardmore. 92 of these public supplies are groundwater sources. The 23 groundwater public supplies with known yields greater than 100 m^3/d are given in alphabetical order in Table 5.1.

The most important groundwater public supply is at Ballinamuck which serves 8000 people (in Dungarvan) with an average daily abstraction of 5450 m^3/d.

Figure 5.1: Contoured Mean Annual Precipitation in Waterford



Of the 91 groundwater public supplies in Waterford 67 abstract less than 100 m³/d (see Appendix 3.1). Many of these groundwater public supplies are very small, serving a few houses, with a daily usage less than 10 m³/d. While the majority of groundwater supplies are boreholes there are approximately 30 (generally small) springs which are exploited as public supplies.

In addition, there are 106 group water schemes in Waterford (Dept. of the Environment, 1996). Most of these are very small (<25m³/d) and it is not known from the information provided whether they are surface or groundwater supplies, although most are assumed to be from groundwater.

Table 5.1 Groundwater Public Supplies With Maximum Yields Greater Than 100 m³/d

Scheme	Daily Usage (m³/d) and *(Maximum Yield*)*	Source Type	Aquifer	GSI Well No.	Grid Reference
Ardmore	300*(775*)*	BW	Waulsortian	2009SEW014	21852 07876
Ballyduff (LCB)/ Kilmeadon	200 (*400**)	Spr	Kilmacthomas		24835 10250
Ballylemon	*250(365)(S)#*	SPR	Kiltorcan	2009SEW083	22015 09655
Kilmeadon	250*(909)(S)#*	SPR	Kilmacthomas	2311SEW050	24825 11020
Ballyhane (LCB)	250*(1363*)*	BW	Waulsortian	2009SWW045	21367 09766
Ballykinsella	90*(300*)*	BW	Campile	2009NWW013	26024 10509
Ballynamuck	7300*(7300+*)*	BW	Waulsortian	2009SEW 69-72	22360 09476
Ballyrohan	145*(255*)*	BW	Ballytrasna	2011SEW003	21958 11090
Ballyogarty	150*(234*)*	BW	Campile	2309NWW002	24006 10453
Cappoquin (LCB)	450*(710*)*	BW	Kiltorcan	2009SWW046	21149 09928
Clashmore +Laurentum	115 (combined usage) (Ballynamultina - *92*)* (Laurentum - *1592)(Au)#*	SPR/BW SPR/BW	Ballytrasna Ballysteen	2007NWW049 2007NWW053	21369 08491 21288 08291
Derrinlaur	*5(105*)*	BW	Kiltorcan	2011NEW002	22493 12253
Fews	10*(198*)*	BW	Kilmacthomas	2309NWW001	23671 10740
Geoish	14*(110*)*	BW	Ballytrasna	2007NWW001	21330 08928
Grange	*55-11(250*)*	BW	Ballytrasna	2007NEW001	21739 08164
Kilmacthomas	160	BW/SPR	Campile	2309NWW098	23972 10586
Lefanta (LCB)	190*(1585*)*	BW	Waulsortian	2009SWW047	21066 09766
Monadiha	18*(141*)*	BW	Ballindysert	2311SWW001	23289 11763
Portlaw	400*(1520) (Av)#*	SPR	Kilmacthomas	2311SEW034	24616 11273
Poulnagunoge	*32(110*)*	BW	Knockmealdown	2011NEW001	22294 12132
Rathgormack	30 ?*(222*)*	BW	Ballindysert	2311SWW002	23393 11793
Tallow Hill	134	SPR	Ballytrasna	1709SEW008	19990 09473
Tooraneena	*50(140*)*	BW	Ballytrasna	2009NEW031	21935 11596

* Maximum yields are only given for sources where test pumping has been undertaken or where other information exists.
Daily usage is taken from the EPA (1994), except where actual readings have been examined.
Spring yields are average (Av), summer (S) or Autumn (Au) values. BW = Bored Well SPR = Spring
LCB denotes the Lismore Cappoquin Ballyduff Scheme - Ballyhane and Lefanta contribute to this scheme.

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

In addition to drinking water supplies, groundwater is also used for industrial purposes such as the metal, glass, meat and brewing industries, poultry farms and creameries.

The surface water public supplies in Waterford are listed in Table 5.2.

Table 5.2 Surface Water Public Supplies in Waterford

Scheme	Daily Usage (m^3/d)
Ballinacourty/Deelish	690
East Waterford Regional	22000
Belle Lake/Dunmore	550
Kill-Bonmahon	727
Kilmacomma	56
Lismore* (LCB)	600
Ring-Helvick-Seaview	370
Stradbally	115
Tallow	200
Tramore (including Dunmore East and Carrigavantry)	600

LCB denotes the Lismore Cappoquin Ballyduff Scheme - Ballyhane and Lefanta contribute to this scheme. *Combined surface and groundwater schemes (only the surface water component of the combined schemes is shown here)

It is estimated from the available data that approximately 29% of the public water supply in County Waterford comes from groundwater. This figure does not include group water schemes. Although this figure may not all be up-to-date, it gives a reasonable estimation of water usage.

5.5 GENERAL AQUIFER CLASSIFICATION

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

1. Regionally Important Aquifers
   - (i) Karstified aquifers (where conduit flow is dominant) (**Rk**)
   - (ii) Fissured bedrock aquifers (**Rf**)

2. Locally Important Aquifers
   - (i) Generally moderately Productive **(Lm)**
   - (ii) Moderately productive only in local zones **(Ll)**
   - (iii) Karstified aquifers (where conduit flow is dominant) (**Lk**)

3. Poor Aquifers
   - (i) Generally unproductive except for local zones **(Pl)**
   - (ii) 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.

- 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.

Although the main type of information available for aquifer classification in County Waterford are 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.

The bedrock units in County Waterford are listed in Table 5.3, together with a summary of the basic hydrogeological data associated with each formation and the resulting aquifer category.

The full range of bedrock aquifer categories are represented in County Waterford with the exception of **locally important aquifers** that are **generally moderately productive** (**Lm**) and **poor aquifers** which are **generally unproductive (Pu)**. No significant sand and gravel aquifers have been identified.

Table 5.3
Basic Hydrogeological Data and Aquifer Categories for Bedrock Formations

in Waterford

Rock Unit Name	Failed Wells	Good Wells (100-400 m³/d)	Excellent Wells (>400 m³/d)	Karst Features	Presence of Volcanics	Aquifer Classification
Waulsortian (Wa)	4	3	6	24	-	Rk/Lk
Ballysteen (BA)	-	5	1	-	-	Ll
Ballymartin (BT)	-	-	-	-	-	Ll
Lower Limestone Shale (undifferentiated) (LLS)	-	1	1	-	-	Ll
Lower Limestone Shale (Crows Point) (CP)	-	1	-	-	-	Ll
Kiltorcan (KT)	-	2	1	-	-	Rf
Gyleen (GY)	-	4	-	-	-	Ll
Harry Lock (HL)	-	-	-	-	-	Ll
Templetown (TT)	-	-	-	-	-	Ll
Carrigmaclea (CI)	-	-	-	-	-	Ll
Knockmealdown (KM)	-	6	-	-	-	Ll
Kilnafrehan (KF)	-		1	-	-	Ll
Sheskin (SN)	-	-	-	-	-	Ll
Treanearla (TR)	-	-	-	-	-	Ll
Coumaraglin (CU)	-	-	-	-	-	Ll
Croughan (CO)	-	-	-	-	-	Ll
Coumshingaun (CM)	-	1	-	-	-	Ll
Ballytrasna (BS)		11	-		-	Ll
Ballindysert (BE)	-	5	2	-	-	Ll
Clashabeema (CB)	-	-	-	-	Yes	Rf
Ballynaclough (BI)	-	3	-	-	Yes	Rf
Campile (CA) (undifferentiated)	2	15	6	-	Yes	Rf
Campile (CArs) (Ross Member)	-	7	15	-	Minor	Rf
Carrighalia (CX)	-	-	-	-	Minor	Rf
Tramore Limestone (TE)	-	-	-	-	No	Pl
Tramore Shale (TM)	-	-	-	-	No	Pl
Dunbrattin (DB)	-	-	-	-	Minor	Rf
Bunmahon (BM)	-	-	-	-	Yes	Rf
Kilmacthomas (KI)	-	4	1	-	Minor	Rf
Booley Bay (BB)	-	-	-	-	No	Pl
Granite Rocks (GR)	-	-	-	-	Yes	Rf ?
Volcanic Rocks (V) (Dolerite)	-	-	-	-	Yes	Rf ?

(I) Figures refer to the number of wells in each category.
(II) Specific capacity data for poor and moderate wells are included with pumping test data in Appendix 3.3.

5.6 REGIONALLY IMPORTANT AQUIFERS

The term “regionally important” is used in the context of local authority areas and local authority regional water supplies. It is equivalent to “major”.

Three main groups of rocks in Co. Waterford have been classified as **regionally important (R)** aquifers:

- The Ordovician volcanic rocks
- The Kiltorcan Sandstone (Devonian)
- The Waulsortian Limestone

5.6.1 Ordovician Volcanic Rocks

The volcanic rocks of Ordovician age dominate the geology of east Waterford (east and southeast of the Comeragh Mountains). The aquifer consists of a complicated sequence of interbedded and faulted lavas and ash deposits, with interbedded shales. The aquifer is dominated by the Campile Formation, although several other rock units are also considered to be Regionally Important. These are identified in Table 5.4. and described in section 3.3.2.

From the available well records, there are 43 wells with yields over 100 m^3/d within the Campile Formation in Co. Waterford; 21 of these are classed as ‘excellent’ wells with yields greater than 400 m^3/d (see Table 5.4 and Appendix 3.2). Many of these wells are concentrated in an area around Waterford City (Map 4) and 22 of them (15 of which are excellent) are within a subdivision of the Campile Formation called the Ross Member; which is composed predominantly of shales and slates (see section 3.3.2).

There are 2 groundwater public supplies with yields greater than 100 m^3/d in the Campile Formation, at Ballykinsella and Ballyogarty. Test pumping data are available for these public supplies and for 4 other wells in the Campile Formation (see Appendix 3.3). Specific capacities range from 2 to 200 $m^3/d/m$ with an average of 74 $m^3/d/m$ (specific capacity is yield per unit drawdown). Transmissivities range from 2 to 290 m^2/d with an average of 108 m^2/d.

High yielding wells occur in other rock units containing volcanics such as the Ballynaclough Formation and the Kilmacthomas Formation (there are 8 recorded yields over 100 m^3/d, one of which is greater than 400 m^3/d). One of the wells in the Kilmacthomas Formation (at Fews) is used as a public supply. This well has a yield of 200 m^3/d with an approximate specific capacity and transmissivity of 38 $m^3/d/m$ and 47 m^2/d respectively.

Ordovician volcanic rocks have also been exploited for groundwater supplies in Wexford and south-east County Kilkenny. The transmissivity of the volcanic rocks in southeast Co. Kilkenny can be over 500 m^2/d with well yields over 1100 m^3/d and specific capacities of 200 $m^3/d/m$ (Daly, E.P. 1982). Other wells drilled in the ash deposits in southeast Kilkenny and in the volcanic rocks in Wexford show similar aquifer properties to those described in Waterford. On the basis of the available data, it would appear that this aquifer is less productive in Waterford than in Wexford or south Kilkenny. There is very little information from Co. Waterford regarding storage coefficients for these rocks, however Daly (1982) suggests that in the unconfined state it will be less than 1% and in the confined state less than 0.01%.

Groundwater flow in the Ordovician volcanic sequence is considered to be entirely through fractures within these rocks (there may be a minor component of primary porosity as a result of vesicles (gas bubbles) in some lava flows. Well logging in southeast Co. Kilkenny (Daly, E.P., 1982) has shown that well developed fissures can occur down to 50 metres in these volcanic aquifers. In general though, detailed information on the location of groundwater entering wells is poor. The volcanic lavas and ash deposits are considered to be more fractured than the shales and slates (due to tectonic fracturing and cooling joints and fractures). According to E.P. Daly, (1982), the higher permeabilities coincide with the 'acid' (paler) volcanic rock units. The volcanic rock units are therefore considered to be the more important aquifers. Faulted and interbedded sequences are however, very complex, and can vary over small distances (vertically and horizontally); as a result, permeabilities are likely to be variable and unpredictable. There are likely to be zones where permeabilities are relatively low and therefore where the rocks will act more like a **locally important** aquifer.

While the aquifers are not as permeable as the Waulsortian Limestone, and the decision to classify them as **Rf** may be somewhat tentative, nevertheless:

- there are many high yielding wells which indicate high permeabilities;
- these volcanic rocks have been proven to be a **regionally important (Rf)** aquifer in Wexford.

Until more information is available all the formations with a component of volcanic rock are considered to be **regionally important** aquifers where fissure flow **(Rf)** is dominant. However, some Ordovician rock units are likely to be less permeable than others; and therefore have a lesser groundwater resource potential. Three of the Ordovician rock units (the Kilmacthomas Formation, the Dunbrattin Formation and the Carrighalia Formation) are composed predominantly of shales and slates and only have a minor component of volcanic rock. The aquifer classification **(Rf)** given to these units must be considered tentative due to the lack of good quality hydrogeological data, and may need to be revised when more data becomes available.

A significant area of the Kilmacthomas Formation immediately south of Clonea, in northern central Waterford, is less than the 25 km² required to constitute a regionally important aquifer. This area is given the aquifer classification **(Ll)**, a **locally important** aquifer which is **moderately productive only in local zones**.

The high yielding wells in the shale and slate dominated Ross Member are somewhat unusual. One explanation is that these tightly folded rocks are highly fractured, resulting in increased permeabilities. An examination of disused quarries along the south bank of the River Suir in Waterford City (Tietzsch-Tyler, 1989) demonstrates that the northern margin of the Ross Member is characterised by a complex alternation of slates, volcanics lavas, ash deposits and other sediments. It is also possible, therefore, that many of the wells which appear to be drilled in shale or slate in fact penetrate volcanic rocks at depth, either within the Ross Member or in the closely associated volcanic rocks of the Campile Formation proper.

5.6.2 Kiltorcan Sandstone

The Kiltorcan Sandstone is found on the northern margin of the Comeragh Mountains and at the northern margin of the Lismore syncline. The sandstones within this formation are typically yellow-white in colour and are interbedded with minor mudstone units (see section 3.5.2). This rock unit forms a major aquifer in many of the southernmost counties in Ireland. Although the formation is over 500 m thick in places it is often steeply dipping in Waterford, resulting in a limited outcrop area. As a result, hydrogeological data for the Kiltorcan in Waterford is scarce.

From the available records, three wells in the Kiltorcan Sandstone have yields in excess of 100 m³/d; two of these wells are public supplies, one of which is greater than 400 m³/d. The largest yielding well is the public supply at Cappoquin. Test pumping (see Appendix 3.3) provided a yield of 690 m³/d with a specific capacity of 160 m³/d/m and a transmissivity of 160-170 m²/d. The other public supply well with a yield over 100 m³/d is at Derrinlaur. During test pumping, this well was pumped at a rate of 105 m³/d , which produced a low drawdown (0.6 m) and a resulting high specific capacity of 175 m³/d/m. A more realistic value of specific capacity (77 m³/d/m) was obtained by extrapolating the drawdown data to 7 days, as the test was short (see Appendix 3.3).

The Kiltorcan Sandstone has been studied in more detail in areas other than Waterford, in particular the Nore basin (Daly, E.P., 1994). Groundwater is considered to flow almost entirely through fractures (these have been detected down to over 60 m), with values for hydraulic conductivity (permeability) ranging from 0.1 - 10 m/d. Storage (effective porosity) values range from 0.01-0.1; the higher storage coefficients are a result of a limited amount of intergranular porosity (the sandstone is susceptible to weathering). The Kiltorcan Sandstone in Waterford has been subjected to a higher grade of metamorphism, therefore the lower value of 0.01 (1%) is more applicable. In the Nore basin, yields are typically 500 m^3/d with a range between 50-1300 m^3/d.

Normally in the outcrop area the Kiltorcan Sandstone is unconfined, being overlain by thin sandy till or isolated patches of sand and gravel. However, near Waterford City the sandstones cross the Suir River valley and appear to be overlain by thick superficial deposits and are therefore probably confined (Daly, E., 1982).

5.6.3 Waulsortian Limestone

The Waulsortian Limestone forms the central core to the major Carboniferous synclines, in west Co. Waterford and along the Suir River valley to the north. These rocks are a combination of fine and coarser grained limestones, with a generally massive 'mudbank' facies (bedding is poorly developed or absent, see section 3.6.2). The limestones are folded, faulted and fractured and have been dolomitised in places (see Appendix 2.5). Many of these features make the limestone susceptible to karstification (the enlargement of fractures by chemical solution), which can greatly increase permeability (see Appendix 2.6).

Karstic features, including swallow holes, caves and collapse features can be seen in the Waulsortian Limestone, particularly along the Lismore-Dungarvan syncline (see Map 4).

From the available records, 9 wells in the Waulsortian Limestone have yields greater than 100 m^3/d, 6 of these are excellent wells (with yields greater than 400 m^3/d) and 4 of these are used for public supply. The public supply at Ballinamuck is capable of producing at least 7300 m^3/d, the largest recorded well yield in the Republic of Ireland. The other public supply wells are at Ardmore (775 m^3/d), Ballyhane (1363 m^3/d) and Lefanta (634 m^3/d). The following specific capacities have been calculated from test pumping: Ardmore (300 $m^3/d/m$); Ballinamuck (2570 $m^3/d/m$); Ballyhane (v. high) and Lefanta (1585 $m^3/d/m$). Transmissivity values for these wells have been calculated at 170 m^2/d, 1000-4000 m^2/d, v. high and 3600 m^2/d respectively. It is estimated that storage in these aquifers can be as high as 5%, but as low as 1% at depth (Daly E.P., 1982).

Transmissivities and specific capacities are very high for these individual boreholes, however it is difficult to relate these values to the aquifer as a whole. Zones of high permeability will be restricted to fissures, karstic conduits, faults and fracture zones and other areas within the aquifer will be less productive. Poor and failed wells have also been drilled in the Waulsortian Limestone.

From a more detailed examination of these boreholes, including geophysical logging at Ballinamuck, geophysical surveying at Ardmore, numerical modelling and an examination of borehole logs, several important features have been identified. The upper weathered and fractured zone of bedrock acts as a zone of high permeability; large fissures or karstic conduits are often present within the bedrock, through which a large proportion of groundwater flow takes place; and where sand and gravel is present above the bedrock (e.g. at Ballinamuck), increased groundwater storage will be available to the well.

The hydrogeology of the Lismore-Dungarvan syncline has been studied in detail by McDaid (1994), including the use of numerical modelling. In modelling this aquifer, the conceptual model assumptions were as follows:

- The limestone is unconfined, with the water table generally less than 10 metres below the surface and with an average annual fluctuation of 5 metres.
- Permeability is entirely secondary, as a result of faulting, dolomitisation and karstification.

- The central area of the syncline has a higher permeability (15-180 m/d) than the limestones to the north and south (15-70 m/d). This is attributed to a higher degree of fracturing and faulting associated with a minor anticlinal axis.
- The majority of groundwater flow occurs in the top 30-40 metres of the limestones.
- Groundwater generally discharges in a narrow zone along major rivers, this may be in the form of general baseflow, via springs or through sand and gravels that are in continuity with the rivers. Significant quantities of groundwater from the limestones of the Lismore-Dungarvan syncline are believed to discharge into the Blackwater, Brickley, and lower Finisk and Colligan Rivers in addition to Dungarvan Harbour.

This conceptual model was calibrated using water levels taken during a well survey and proved to be a good representation of the limestone aquifer.

Recharge to the limestone synclines is likely to be increased as a result of surface water running off the surrounding less permeable and topographically higher Old Red Sandstone rocks onto the more permeable limestones.

The location of higher yielding zones could be greatly improved by using geophysical techniques and was used successfully at Ardmore.

The Waulsortian Limestone in Waterford is considered to be a **regionally important** aquifer where there is a significant component of groundwater flow in karstic conduits. It is classed as an **Rk** aquifer, although it is not conclusive that conduit flow is the dominant flow regime in the aquifer.

The Waulsortian Limestone is the most permeable and the most important aquifer in County Waterford; in fact this is one of the most productive aquifers in the country. It supplies Dungarvan from a site which has highest yielding wells in the country.

Two areas of Waulsortian Limestone, west of Ardmore and Clashmore, are less than the required 25 km² which constitutes a regionally important aquifer (as set out in the GSI aquifer definition guidelines (Daly, 1995)). These areas are given the aquifer classification **(Lk)**, a **locally important** aquifer where conduit flow is dominant.

5.7 LOCALLY IMPORTANT AQUIFERS

The following rock units are classed as **locally important** aquifers which are **moderately productive only in local zones (Ll)**:

- Ballindysert Formation
- Ballytrasna Formation
- Coumshingaun Formation
- Croughan Formation
- Coumaraglin Formation
- Treanearla Formation
- Sheskin Formation
- Kilnafrehan Formation
- Knockmealdown Formation
- Carrigmaclea Formation
- Templetown Formation
- Harrylock Formation
- Gyleen Formation
- Lower Limestone Shale
- Ballymartin Formation

- ♦ Ballysteen Formation

5.7.1 Ballindysert Formation (Silurian)

The available hydrogeological data for the Ballindysert Formation is summarised in Table 5.4. From the available records, six wells in this formation have yields greater than 100 m^3/d, two of which are 'excellent' wells (with yields greater than 400 m^3/d). Two wells are used for public supply (at Monadiha and Rathgormuck) and test pumping was carried out on these wells (see Appendix 3.3). The tests produced (approximate) specific capacities of 76 and 150 $m^3/d/m$ with transmissivities between 80 and 190 m^2/d. Volcanic rocks are absent from the Ballindysert Formation, which is dominated by slates with minor siltstones; so these higher yielding wells are likely to be related to localised fracture zones or faults. Silurian rocks in Ireland are normally considered to have a low permeability and are classified as poor aquifers. The higher than expected aquifer classification (**Ll**) for the Ballindysert formation is attributed to the more intense structural deformation in southernmost Ireland (see section 3.7).

5.7.2 Ballytrasna Formation (Old Red Sandstone)

The Ballytrasna Formation is the most widespread Devonian rock type in Waterford. From the available records 11 wells have yields between 100-400 m^3/d (see Table 5.4). Test pumping data are available for eight wells, five of which are used for public supply (see Appendix 3.3). Specific capacities are variable, ranging from 5-75 $m^3/d/m$, with an median of 10 $m^3/d/m$. Estimated transmissivities are generally less than 50 m^2/d. The Ballytrasna Formation is dominated by red mudstone suggesting that the permeability of the formation will generally be low. High yielding wells are considered to be the result of enhanced permeabilities along faults or fracture zones. The formation is considered to be a **locally important** aquifer which is **moderately productive only in local zones (Ll)**.

5.7.3 Knockmealdown Formation (Old Red Sandstone)

From the available records, 6 wells in the Knockmealdown Formation have yields between 100-400 m^3/d. One of these wells is used for public supply (Poulnagunogue) and test pumping was carried out on this well. The maximum yield of the well was 110 m^3/d with a relatively low specific capacity of 10 $m^3/d/m$. These few high yielding wells are probably related to faults, fissures or fracture zones and the majority of the formation is massively bedded and indurated (subjected to a low grade of metamorphism resulting in a compact rock mass). The formation is considered to be a **locally important** aquifer which is **moderately productive only in local zones (Ll)**.

5.7.4 Gyleen Formation (Old Red Sandstone)

Hydrogeological data from Waterford (and Cork) suggests that 'high' yields can occasionally be obtained from the Gyleen Formation. Data exists for 4 wells with yields between 100-400 m^3/d in Waterford. One of these wells (at Kereen) is used for public supply and test pumping was carried out on this well (see Appendix 3.3). The test yield was only 35 m^3/d, however the specific capacity (estimated at 130 $m^3/d/m$) suggests a higher yield is sustainable. Specific capacities for three wells in this formation in Cork were low, ranging from 4-23 $m^3/d/m$. Although the Gyleen Formation is considered to be the equivalent of the Kiltorcan Formation to the north, this formation is dominated by mudstones (up to 80%) and at present the available data suggests that the formation should be considered a **locally important** aquifer which is **moderately productive only in local zones (Ll)**.

5.7.5 Other Old Red Sandstone Formations

Hydrogeological data for the remaining Old Red Sandstone formations is scarce (see Table 4.4). These rocks are lithologically and structurally similar to the other Devonian formations and in the absence of data they are also considered to be **locally important** aquifers (**Ll**). The relatively high number of wells with yields between 100-400 m²/d within the Devonian rocks is attributed to the greater degree of structural deformation which has taken place in Waterford, when compared to areas to the north.

5.7.6 Ballymartin Limestone and the Lower Limestone Shale (Carboniferous)

The Ballymartin and Lower Limestone Shale are only exposed in small areas of west Waterford; these rocks are predominantly muddy limestones and shales (with minor sandy units). The normal process of permeability development in limestones will not be particularly effective in these rocks due to their fine grain size and mud content. However, this complex sequence is likely to be fractured and faulted along the margins of the limestone synclines. Until more data is available the sequence is considered to be similar to the adjacent Ballysteen Formation (**locally important, Ll**). There is evidence of two wells with yields greater than 100 m^3/d within the Lower Limestone Shale (undifferentiated), however these wells are only located by a townland area and they may be located outside of this rock unit.

Where the Lower Limestone Shale has been sub-divided into different formations on the geology map (e.g. the Crows Point Formation); these formations are also considered to be **locally important (Ll)**. There is data for one well within the Crows Point formation with a yield between 100 - 400 m^3/d (see Appendix 3.2).

5.7.7 Ballysteen Limestone (Carboniferous)

From the available data, 6 wells in the Ballysteen Limestone have yields greater than 100 m^3/d, one of which is greater than 400 m^3/d. Test pumping data exists for 2 wells in the Ballysteen, however the interpretation of the data is complicated by the presence of sand and gravel overlying both sites (see Appendix 3.3). The specific capacities calculated are 58 and 260 m^3/d/m. The muddy nature of this limestone suggests that in general the permeability will be low. The limestone is considered to be a Locally Important (**Ll**) aquifer (moderately productive only in local zones).

5.8 POOR AQUIFERS

5.8.1 Tramore Limestone and the Tramore Shale (Ordovician)

The Tramore Shale consists predominantly of compact dark grey shales and siltstones; suggesting a low permeability. The Tramore Limestone consists of a complex sequence of shales, siltstones, sandstones and limestones. Both of these rock units are deformed and fractured, however no volcanic rocks are present within these formations. Little hydrogeological information is available for these rocks. In addition, the Tramore Limestone is very limited in extent. The generalised soil map of Ireland (Gardiner and Radford, 1980) shows an area of Gley soils to coincide with these formations, this may be the result of weathering of a low permeability bedrock. Until more hydrogeological information becomes available these formations are considered to be **poor aquifers** which are **moderately productive only in local zones (Pl)**.

5.8.2 Booley Bay Formation (Cambrian)

The oldest rocks in Waterford are those of the Booley Bay Formation. These rocks consist of compact black mudstones which have been metamorphosed. As a result these rocks are likely to have a low permeability. The generalised soil map of Ireland (Gardiner and Radford, 1980) also shows an area of gley soils to coincide with this rock unit. The formation is considered to be a **poor aquifer** which is **moderately productive only in local zones (Pl)**.

6. HYDROCHEMISTRY AND WATER QUALITY

6.1 INTRODUCTION

Hydrochemistry is the study of the inherent (natural) groundwater chemistry. Variations in these chemical parameters over space and time can be used to gain an understanding of groundwater flow systems. Water quality studies, on the other hand, examine the physical, chemical and microbiological characteristics of groundwater, relative to a standard or required limiting values. The drinking water standards referred to throughout this report are those required by the European Communities (Quality of Water Intended for Human Consumption) Regulations, 1988.

For the purposes of this study groundwater becomes 'contaminated' when substances enter it as a result of human activity. The term 'pollution' is only used when groundwater fails to meet the drinking water regulations as set out by the EC regulations.

6.2 SOURCES OF INFORMATION

The following hydrochemical data were available for examination:

- ♦ Chemical analyses for selected boreholes in Waterford City from Waterford Corporation.
- ♦ Chemical analyses supplied by Waterford County Council for public supplies in Waterford.
- ♦ Chemical analyses carried out between 1979 and 1981 on selected public supply wells by An Foras Forbatha.
- ♦ Chemical analyses carried out by the State Laboratory on groundwater samples taken from 50 public supplies in Co. Waterford in September 1992 and from 20 public supplies in June 1993 (Duffy, 1994).
- ♦ Summary data from the EPA (1994) on the quality of drinking water in Ireland.

Most of the data represent raw water samples, however some of the public supply sampling points are pre-chlorinated. The range of chemical and bacteriological parameters that were analysed from the samples was variable. Many analyses only record the most basic chemical details such as; hardness, total nitrogen, chloride, sulphate, ammonia, pH and general appearance. More comprehensive analyses showing all the major ions are less common. Data on faecal coliforms are also very limited.

Where public supply wells have been revisited as part of more detailed source protection work, conductivity and temperature measurements were taken at the well site.

It must be emphasised that there are some limitations on the type of sampling carried out in all of the above data. The physical conditions of a sample may change between the time of sampling and the laboratory measurements. Carbonate chemistry is frequently affected leading to carbonate mineral precipitation (this can also induce the precipitation of metals). Changes in redox conditions (involving oxidising and reducing agents) can lead to metal oxide precipitation or the oxidation of ammonia and nitrite. In addition it should be remembered that these samples represent average aquifer conditions, the groundwater sampled may be a mixture from different rock types or as a result of percolation through subsoils which may have affected the water chemistry.

The size of the groundwater supply from which the samples have been taken is also important. Larger groundwater sources normally provide a groundwater sample that is more representative of the aquifer (contaminants will be more diluted as a result of greater groundwater throughflow). Samples from small groundwater sources may be more readily influenced by local groundwater contamination. However, this does not appear to be the case from the available data. From the 172 compiled analyses, 50 are from the 'larger' groundwater supplies listed in Table 6.1. Of the analyses from the 'larger' sources, 47 % showed evidence of contamination (or pollution), this was true for only 27% of the analyses from the 'smaller' sources.

6.3 HYDROCHEMISTRY

The chemistry of groundwater depends largely on the composition and physical properties of the materials with which it comes into contact, together with other factors such as the age of the groundwater. Certain minerals (e.g. $CaCO_3$) are more liable to dissolution than others (e.g. quartz). Generally speaking, slow moving groundwaters with longer residence times will be more highly mineralised as there is less opportunity for chemical alteration.

For the purposes of this report the hydrochemistry of the following three main rock groups are considered separately:

- The Lower Palaeozoic volcanic and sedimentary sequence (the groundwater chemistry of the Campile, Kilmacthomas and Ballindysert formations is described).
- The Old Red Sandstone rocks (the groundwater chemistry of the Ballytrasna, Knockmealdown, Gyleen and Kiltorcan formations is described).
- The Carboniferous Limestones (the groundwater chemistry of the Waulsortian Limestone is described).

Due to the lack of data not all the rock units (formations) within each group are considered.

Data for the main rock units are summarised in table form and the data are also listed in Appendix 4.1. More comprehensive data are illustrated on Piper diagrams in Appendix 4.2. These allow the classification of natural groundwater types based on the proportion of major ions present. Ideally, contaminated samples should not be plotted onto the Piper diagrams as these samples may distort the natural groundwater chemistry; however data are scarce, so these analyses are included. Most of the contamination is in the form of elevated levels of nitrate and this is discussed in the following sections.

Throughout the following section, hardness values are classified into the following groups (mg/l are $CaCO_3$):

- **soft** <50 mg/l
- **moderately soft** 51-100 mg/l
- **slightly hard** 101-150 mg/l
- **moderately hard** 151-250 mg/l
- **hard** 251-350 mg/l
- **very hard** >350 mg/l

6.3.1 Campile Formation (Ordovician)

A total of 43 analyses were available, 12 of which were comprehensive (showing all the major ions).

The available data is summarised in Table 6.1. The groundwater sampled from the Campile Formation is generally, moderately soft (51 - 100 mg/l $CaCO_3$) to slightly hard (101-150 mg/l $CaCO_3$), with a slightly acidic pH (generally between 6.0-6.8). Alkalinity ranges from 21-170 mg/l $CaCO_3$, however the data in Appendix 4.1 shows that values for the Campile volcanics are generally at the lower end of this range (21-100 mg/l CaCO3).

Table 6.1 Summary of Hydrochemical Data for the Campile Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness ($CaCO_3$)	117	32	104	22-300	43
Alkalinity ($CaCO_3$)	79	46	73	21-170	39
pH	6.6	43	6.6	5.7-7.7	37
Conductivity (μS/cm)	345	60	325	158-725	25
Cl	34	42	30	13-72	43
NO3	22.1	38	19	1.1-54	34
SO4	21.4	40	20	10.2-43	15
Faecal Coliforms	Two samples show traces of pollution one shows 60 faecal coliforms per 100 ml (Dunhill)				5
Values in mg/l except where stated					

More comprehensive analyses are available for several public supplies, together with some private wells in Waterford city (see Appendix 4.1). The limited amount of data suggests that the groundwater is of an intermediate type, where no one cation or anion is dominant. The groundwater analysed had roughly equal proportions of calcium, magnesium and sodium (cations) and bicarbonate and chloride (anions). The data do not indicate more than one water type although in some of the samples elevated levels of chloride are associated with high nitrate values (due to contamination). The calcium-magnesium-sodium cation composition is partly the result of the dissolution of minerals in the volcanic/sedimentary sequence and the overlying volcanic till (volcanic rocks can have a relatively high component of magnesium and sodium). Some of the sodium is also likely to be associated with elevated levels of precipitation in coastal areas.

Bicarbonate is produced by the solution of atmospheric carbon dioxide and by the reaction of calcium carbonate with carbonic acid. Some calcium carbonate (limestone) is likely to be present within the sedimentary rocks of this sequence and in the overlying till (boulder clay).

Chloride can be derived from precipitation, or it can be associated with different types of pollution, or saline water (relict or modern).

Several of the samples had elevated nitrate values (see Section 6.4). Nitrate is commonly associated with modern recharge waters in unconfined aquifers and is usually derived from organic waste or fertiliser application. Nitrate is combined with chloride on the Piper diagrams (Appendix 4.2) so where nitrate is artificially high (from contamination) the points plotted on the Piper diagrams will be shifted slightly. As there are relatively few samples, these contaminated analyses are included for completeness (points are coloured red on the plots).

Iron and manganese values were also occasionally high within the Campile Formation.

6.3.2 Kilmacthomas Formation (Ordovician)

Only a few samples are available from other volcanic formations and most of these are from the Kilmacthomas Formation. These data are summarised in Table 6.2. The chemistry is very similar to the Campile Formation (Appendix 4.1). Hardness and alkalinity values for the Kilmacthomas Formation are lower than for the Campile Formation, as are values for chloride and nitrate. This is probably because these samples are relatively uncontaminated compared to those from the Campile Formation (many of which were taken in and around Waterford City). In addition, the samples from the Kilmacthomas Formation are further from the coast, so levels of chloride in precipitation will be lower.

The analyses from the (now abandoned) borehole at Kilmeaden are not included in the summary as the chemistry of the sample is very different to the other analyses. Hardness and alkalinity values are up to 10 times greater for this groundwater sample (see Appendix 4.1).

Table 6.2 Summary of Hydrochemical Data for the Kilmacthomas Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness ($CaCO_3$)	38.8	50	38.5	15-56	8
Alkalinity ($CaCO_3$)	25.2	38	19.5	17-46	8
pH	6.0	40	6.0	5.4-6.5	5
Conductivity (μS/cm)	148	50	139	105-210	6
Cl	17.6	50	18	14-22	8
NO3	14.6	33	12.8	7-34	6
SO4	7	50	8	<1-10	4
Faecal Coliforms	One sample, no pollution				
Values in mg/l except where stated					

6.3.3 Ballindysert Formation (Silurian)

A total of 13 analyses are listed in Appendix 4.1, 8 of which are comprehensive. These data are summarised in Table 6.3.

Table 6.3 Summary of Hydrochemical Data for the Ballindysert Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness ($CaCO_3$)	63.4	23	50	24-140	13
Alkalinity ($CaCO_3$)	45.7	22	25	10-110	9
pH	6.0	50	6.2	5.4-6.6	6
Conductivity(μS/cm)	213	33	185	154-386	9
Cl	20.6	38	19	14.7-35.2	13
NO3	16.3	54	18.1	0.5-37	13
SO4	7.9	38	7.5	1-16	8
Faecal Coliforms	1 sample, no pollution				
Values in mg/l except where stated					

The more comprehensive data are illustrated on a Piper diagram (Appendix 4.2). The groundwater sampled was generally soft (<50 mg/l CaCO3) to moderately soft (51 - 100 mg/l) with a relatively low alkalinity and a slightly acidic pH. Groundwater samples from Joanstown and Sheskin had higher values (double) of hardness, alkalinity, pH and conductivity than the remaining samples. These boreholes are near the Suir Valley and it may be that limestone till is more common in this area than is shown on the subsoils map.

The plotted data suggest that groundwater within the Ballindysert Formation is the same type as the (uncontaminated) groundwater from the other Lower Palaeozoic formations.

6.3.4 Ballytrasna Formation (Devonian)

A total of 46 analyses were available, 17 of which were comprehensive.

The available data is summarised below (Table 6.4). The groundwater sampled from the Ballytrasna Formation ranged from soft (<50 mg/l CaCO3) to slightly hard (101 - 150 mg/l CaCO3), with a slightly acidic pH (generally between 5.5-6.5). Alkalinity (mg/l $CaCO_3$) ranged from 10-135 mg/l, however the data in Appendix 4.1 shows that values for the Ballytrasna Formation were generally at the lower end of this range (20-70 mg/l CaCO3).

Table 6.4 Summary of Hydrochemical Data for the Ballytrasna Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples

Hardness ($CaCO_3$)	72	43	65	17-241 (generally 35-70)	46
Alkalinity ($CaCO_3$)	43.2	36	32	10-135	33
pH	6.1	58	6.3	4.8-7.2	34
Conductivity (µS/cm)	223	58	232	92-574	24
Cl	24.4	46	23.7	12-60	46
NO3	15.9	35	9.4	2.9-70	42
SO4	9.0	37	8	<1-17	19
Faecal Coliforms	4 samples, one of these shows a trace of pollution				
Values in mg/l except where stated					

The data plotted onto a Piper diagram (Appendix 4.2) show a range of composition from calcium-bicarbonate type waters, to waters higher in chloride, nitrate and sodium and magnesium. The majority of samples fall between these extremes and the general water type is very similar to the Lower Palaeozoic groundwaters previously described.

Elevated chloride and nitrate values are also common in the analysed samples from the Ballytrasna Formation. This is the result of local aquifer contamination and/or proximity to the coast (higher chloride values will be present in coastal precipitation).

6.3.5 Knockmealdown Formation (Devonian)

A total of 12 analyses were available, 3 of which were comprehensive.

The available data is summarised below (Table 6.5). The groundwater sampled from the Knockmealdown Formation was generally soft (<50 mg/l CaCO3) with occasional samples being slightly harder. The pH values were slightly acidic (generally between 5.8-6.2). Alkalinity (mg/l $CaCO_3$) ranged from 16-68 mg/l.

The limited data plotted onto the Piper diagram (Appendix 4.2) indicated a similar water type to the Ballytrasna Formation.

Table 6.5 Summary of Hydrochemical Data for the Knockmealdown Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness (CaCO3)	48.7	33	36.5	15-120 (generally 30-50)	12
Alkalinity (CaCO3)	38.7	33	29	16-68	6
pH	6.1	40	6.0	5.8-6.3	10
Conductivity (µS/cm)	171	25	122	110-330	4
Cl	17.8	33	15.5	13-31	12
NO3	15.3	36	11.8	0.6-35.8	11
SO4	12.9	66	14	<1-18.4	6
Faecal Coliforms	1 sample, with 110 Faecal Coliforms/100 ml				
Values in mg/l except where stated					

6.3.6 Gyleen Formation (Devonian)

A total of 18 analyses were available, 8 of which were comprehensive. The available data is summarised below (Table 6.6).

The groundwater sampled from the Gyleen Formation was generally, moderately soft (51-100 mg/l) with occasional samples being softer or harder than the norm. The pH values were slightly acidic (generally between 6.5-7.0). Typical alkalinity values ranged from 20-70 mg/l ($CaCO_3$).

Although the groundwater samples from the Gyleen Formation plot in a similar position on the Piper diagram (Appendix 4.2) to the previous Old Red Sandstone (ORS) groundwaters, the calcium and bicarbonate values plot towards the higher end of the range. This may be because the Gyleen Formation is more calcareous than previous ORS rock types. The plots are typical of young recharge waters in sandstones/siltstones.

Table 6.6 Summary of Hydrochemical Data for the Gyleen Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness (CaCO3)	86	50	85	22-242	18
Alkalinity (CaCO3)	61	23	47	7-218	13
pH	6.5	58	6.8	5.4-7.4	12
Conductivity (μS/cm)	256	42	244	138-610	12
Cl	24.3	44	23.1	17-38	18
NO3	16	44	17.5	3.3-28.3	18
SO4	8	50	8	<1-11	8
Faecal Coliforms	2 samples, no pollution				
Values in mg/l except where stated					

6.3.7 Kiltorcan Formation (Devonian)

A total of 9 analyses were available, 4 of which were comprehensive.

The available data is summarised below (Table 6.7). The groundwater sampled from the Kiltorcan Formation was generally, moderately soft (51-100 mg/l). The pH values were generally neutral (generally around 7.0). Alkalinity (mg/l $CaCO_3$) ranged from 5-253 mg/l (more typical values were in the range 25-50).

Table 6.7 Summary of Hydrochemical Data for the Kiltorcan Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness (CaCO3)	58	62	66	15-75	8
Alkalinity (CaCO3)	50	50	34	5-253	6
pH	6.8	50	6.9	6.2-7.5	4
Conductivity (μS/cm)	171	60	179	85-590	5
Cl	19.1	57	21.2	12-26.4	7
NO3	21.6	43	13	0.9-55	7
SO4	7.5	50	8	4-10	4
Faecal Coliforms	One sample, no pollution				
Values in mg/l except where stated					

The available groundwater samples from the Kiltorcan Formation also plot in a similar position on the Piper diagram (Appendix 4.2) to the previous Old Red Sandstone groundwaters (calcium-magnesium-bicarbonate type with elevated levels of chloride and nitrate). In general the calcium and bicarbonate values were higher than previous ORS groundwaters (except where elevated nitrates values distort the ionic balance). This can also be put down to the more calcareous nature of the Kiltorcan Formation compared to other ORS lithologies.

A few analyses are available for other ORS formations. These analyses are typical of ORS groundwaters in general and the data are listed in Appendix 4.1.

6.3.8 Waulsortian Limestone (Carboniferous)

A total of 12 analyses were available, 9 of which were comprehensive.

The available data is summarised in Table 6.8. The groundwater sampled from the Waulsortian Limestone was much harder than the groundwaters from the Lower Palaeozoic and Devonian sandstone rocks; generally, moderately hard (151-250 mg/l CaCO3) to hard (251-350 mg/l CaCO3). The pH values were slightly alkaline (generally between 7.1-7.3). Alkalinity (mg/l $CaCO_3$) ranged from 64-275 mg/l (more typical values are in the range 190-250).

Table 6.8 Summary of Hydrochemical Data for the Waulsortian Formation

Parameter	Mean	% > Mean	Median	Range	No. of Samples
Hardness (CaCO3)	265	58	279	99-342	12
Alkalinity (CaCO3)	214	54	241	64-275	11
pH	7.1	66	7.3	6.5-7.4	6
Conductivity (µS/cm)	533	60	585	241-629	10
Cl	24	58	24	16.9-26.5	12
NO3	19.1	50	18.1	5-22.5	12
SO4	12.4	60	11.4	8-27	10
Faecal Coliforms	One sample, no pollution				
Values in mg/l except where stated					

The few samples for which a comprehensive analysis has been performed were plotted on the Piper diagram (Appendix 4.2). These calcium-bicarbonate type groundwaters are typical of recent recharge water in unconfined limestones. The conductivity values are higher than any of those previously described (as a result of the dissolution of calcium carbonate) and are also typical of limestone groundwaters. Chloride and nitrate values are similar to most of the other groundwaters described (slightly elevated).

6.4 WATER QUALITY

6.4.1 Natural Groundwater Quality Problems

The principal natural water quality problem identified from the data analysed are the occasionally high levels of iron. Thirteen of the available analyses showed elevated levels of iron. The iron is likely to be from a variety of sources:

- iron minerals in rocks or soils (these are common in the Old Red Sandstone and volcanic areas);
- pollution by organic wastes (six of these analyses with high levels of iron were also contaminated);
- the corrosion of iron fittings in the borehole (or water system). Some of the samples taken from the Ordovician volcanics and the Devonian Old Red Sandstones had relatively low hardness and alkalinity values, together with slightly acidic pH values. Groundwater will be mildly corrosive in some cases.

6.4.2 Indicators of Groundwater Contamination

As human activities have had some impact on a high proportion of the groundwater in Ireland, there are few areas where the groundwater is in pristine (natural) condition. Consequently most groundwater is contaminated to some degree although it is usually not polluted. In the view of the GSI, there is a need for assessment of the degree of contamination of groundwater as well as showing whether the groundwater is polluted or not. Consequently, in this report, thresholds for certain parameters are chosen to help indicate situations where significant contamination but not pollution is occuring. The parameters and the thresholds which are used to suggest a significant impact by human activities are;

nitrate (NO_3), potassium (K), chloride (Cl) and ammonia (NH3) with concentrations greater than 25 mg/l, 4 mg/l, 25-40 mg/l (depending on proximity to the coast) and 0.2 respectively, together with evidence of faecal bacteria.

Other parameters can also be useful indicators of contamination, some of these include conductivity, iron, manganese, sulphate and nitrite. The examination of groundwater quality in Waterford is hampered by the quality of the available data, particularly the lack of faecal bacterial analyses (data on faecal bacteria was only available for 18 samples out of a total of 172). Where comprehensive analyses are not available, chloride, nitrate, sulphate and conductivity were generally the most widely available parameters used to indicate contamination. Other parameters such as iron, manganese and ammonia were sometimes available for interpretation.

Background values for chloride and nitrate range between 15-30 mg/l and 5-15 mg/l respectively. Background chloride values are variable, depending on proximity to the coast. Sulphate and conductivity values are more variable, particularly conductivity which has different background values depending on rock type (100-250 μS/cm for the volcanics, slates and sandstones and 400-600 μS/cm for the limestones).

6.4.3 Groundwater Sources that Showed Evidence of Contamination

Out of the 172 analyses compiled (from 90 different sources) 51 (30%) show some evidence of contamination, (parameters deemed to represent possible contamination are highlighted in bold in Appendix 4.1). However, many of these are restricted to slightly elevated levels of chloride and nitrate (greater than 25 mg/l and 25-40 mg/l respectively). Data were available for 19 of the 22 largest groundwater supplies given in Table 5.1. Seven (36%) show evidence of contamination: Ballyhane, Ballykinsella, Ballyogarty, Geoish, Lefanta and Rathgormuck had elevated nitrate levels in some of the analyses. It should be noted that some contamination recorded from earlier analyses was not present in more recent data. This may in part be the result of seasonal changes in chemistry or as a result of different sampling techniques. Of more concern is the supply at Cappoquin where the levels of nitrate are approaching the EC MAC (maximum allowable concentration) of 50 mg/l (on one occasion the nitrate levels exceeded this concentration).

In general, contamination is minor or absent from most of the larger groundwater supplies in Waterford.

Out of 44 smaller groundwater public supplies analysed 12 (27%) showed evidence of contamination. It should be noted that faecal bacterial analyses were not generally available for any of these smaller sources. Evidence of contamination in most of the smaller sources was dominated by elevated nitrate values. These were sometimes associated with elevated chloride, conductivity and sulphate values and occasionally with faecal coliforms, nitrite, ammonia or iron and manganese.

6.4.4 Groundwater Sources that Showed Evidence of Pollution

Values above the EC MAC (maximum allowable concentration) are highlighted and shaded in Appendix 4.1.

Fourteen (< 10%) out of the 172 analyses showed some evidence of pollution; Seven of these are from public supply wells. Analyses from the public supply at Poulnagunogue showed significant faecal pollution and the supply at Grange had nitrate levels higher than the EC MAC, together with a high metals content in some of the analyses. Ballyrohan, Lefanta and Knockeylan showed traces of faecal pollution and one of the analyses from Cappoquin and Modeligo had a nitrate concentration above 50 mg/l.

Nitrate values above the MAC were present in several other groundwater sources in Waterford City (not public supplies); at Dunhill, Blenheim Heights, Glen (#13), Upper Grange (#8) Military Road and Williamstown (see Appendix 4.1).These parameters were sometimes associated with elevated levels of conductivity, sulphate, ammonia or iron.

High levels of iron were present in a few of the samples, however this was often iron measured in suspension and may reflect stagnant conditions in the borehole.

It is likely that more sources would have shown faecal bacterial contamination if more bacteriological analyses were available.

6.4.5 The Origin of Groundwater Contamination

The lack of data makes it difficult to comment on the likely origin of contamination in most cases, however some examples are given below.

- Where chloride is associated with nitrate and faecal contamination, in Waterford City, the source of contamination is likely to be from a leaking sewer (e.g. Glen).
- High levels of nitrate at the disused public supply at Military Road, Waterford have been attributed to an old bacon factory site (G. Wright, pers. comm).
- The high levels of nitrate, chloride, conductivity and trace metals at Grange public supply are almost certainly related to the storage of inorganic fertiliser around the well pumphouse.
- The elevated levels of nitrate at the Cappoquin source are likely to be the result of the application of fertiliser to the surrounding farmland.
- The faecal bacteria recorded at the Poulnagunogue supply is likely to be the result of effluent discharging from nearby septic tanks and/or farmyards.
- The general elevated levels of nitrate found in many of the samples may be derived from various sources, the most likely of these are: the spreading of slurry or the application of fertilisers (organic and inorganic) onto adjacent land, or effluent discharging from nearby septic tanks or farmyards.

6.5 CONCLUSIONS

6.5.1 Hydrochemistry

The limestone groundwaters analysed in Waterford are typical young calcium bicarbonate type waters. The remaining rocks in Waterford have a more mixed groundwater type (typically calcium - magnesium bicarbonate) often with elevated levels of chloride (due to proximity to the coast) and nitrate (due to local aquifer contamination).

The low general level of groundwater mineralisation in the Lower Palaeozoic volcanics and slates and the Devonian sandstone groundwaters means that the sodium, chloride and nitrate components constitute a relatively high proportion of the ionic balance in these groundwaters. This contributes to the complex groundwater types that have been described. Levels of sodium, chloride and nitrate in the limestone groundwaters are similar to other formations in Waterford but the higher level of natural groundwater mineralisation (calcium and bicarbonate) allows the natural groundwater chemistry to be more readily identified.

6.5.2 Water Quality

Natural water quality problems are restricted to occasionally high iron values in the Old Red Sandstone and Lower Palaeozoic rocks. In addition pH and alkalinity values are generally relatively low in these groundwaters which are also generally ‘soft’ to ‘moderately soft’.

From the available analyses, 30% of the groundwater public supplies sampled were contaminated (as defined in section 6.4.2.). This was generally restricted to elevated nitrate values. The most likely cause of this local contamination is likely to be the application of fertilisers (organic and inorganic), land spreading, or effluent discharging from nearby septic tanks or farmyards.

Pollution is rare in the samples analysed (<10%). Seven public supplies showed evidence of pollution in some of the available analyses (two of these public supplies, Grange and Poulnagunouge showed evidence of significant pollution).

A significant amount of data for the Campile Formation was from wells in Waterford City; this is likely to be the reason for the relatively high number of contaminated samples for this formation.

7. GROUNDWATER VULNERABILITY

7.1 INTRODUCTION

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

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

7.2 SOURCES OF DATA

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

- the subsoils map
- particle size analyses from sediments in Waterford (Quinn, 1987)
- a PhD on the subsoils in Co. Waterford (Quinn, 1987)
- additional work by J. Brown (1992) and S. Duffy (1994)
- the GSI karst database
- depth to bedrock data from all the GSI databases
- 6 inch to one mile scale geological and topographic maps
- site visits undertaken around several public supplies in Waterford
- work undertaken by Hugh Fox (1996) on the development of the vulnerability map

7.3 THE PERMEABILITY OF THE SUBSOILS

The permeability of a subsoil is largely a function of the percentage of fine clay and silt size grains present. The higher the percentage of clay and silt size particles the lower the permeability. Particle size analyses provide information on the grain sizes within a particular subsoil. The available analyses for subsoils in County Waterford are described in section 4.5. The distribution of the main subsoil types in Waterford are shown in Table 7.1, with their permeabilities.

7.3.1 Sand and Gravel

Sand and gravel deposits are relatively coarse grained and are considered to have a high permeability. Small areas of sand and gravel are delineated on the subsoils map (Map 2).

7.3.2 Tills

The tills in Waterford are classified according to their lithological composition. Three main lithological types are present: sandstone till; volcanic till; and shale till (see section 4.4.1). The sandstone clasts within the sandstone till tend to weather into relatively coarse grains. This is supported by the limited available particle size analyses; less than 10% of the samples were clay or fine silt size particles (finer than 0.0065 mm) and less than 30% were clay or silt size particles (finer than 0.065 mm). This till type is therefore considered to have an intermediate permeability.

The shale and volcanic tills are more likely to weather into a finer grained sediment. This is supported by the available particle size data (see section 4.4). Up to 20% of these subsoils were finer than 0.0065 mm (up to 50% are finer than 0.065 mm). These tills are therefore considered to have a low permeability.

No grain size analyses are available for the very limited areas of limestone and chert till. These tills only occur in isolated areas and are surrounded by much larger areas of sandstone till. The limestone is relatively clean and it is considered likely that both the limestone and chert clasts weather into a relatively coarse grained matrix. These tills are therefore classified as having a moderate permeability.

The Irish Sea Till is also limited in extent (see section 4.3.1). Grain size analyses suggests this till has a low permeability, however the till is only apparent in coastal sections and is generally not delineated on the subsoils map (with the exception of the Ardmore area) and occasionally in boreholes.

7.3.3 Alluvium and Head Deposits

Alluvium is a deposit of variable composition which can contain sand and gravel; however the distribution of sands and gravels within the alluvium are generally unknown.

In addition, outcrop data suggests that much of the alluvium (particularly in upland areas) is likely to be thin (< 3m). Therefore, for the purposes of vulnerability assessment, these deposits of alluvium are given the vulnerability category 'probably extreme'; unless there is evidence to the contrary or they are underlain by other subsoils.

Where there is little or no data on the thickness and type of alluvium in lowland areas, these deposits are also given the vulnerability category 'probably extreme' (Map 2).

More detailed information on the alluvium is available for some areas, such as Waterford City. Here the thickness of the alluvium is generally greater than 10 m thick and is dominated by silts and clays; apart from a small area adjacent to the south bank of the Suir which consists predominantly of sands and gravels. The area of sand and gravel is given the vulnerability category 'probably high' whereas the area of silts and clays is given the vulnerability classification 'probably low'.

Table 7.1 The Permeability and Distribution of Subsoils in County Waterford

Subsoil	Permeability	Distribution
Sand and Gravel	High	Small areas, scattered throughout Waterford
Sandstone Till	Moderate	Throughout west and north Waterford
Limestone Till	Moderate	Small areas in the north and south of Waterford
Chert Till	Moderate	One small area in the north west of Waterford
Shale Till	Low	North central Waterford
Irish Sea Till	Low	Ardmore and other coastal sections.
Volcanic Till	Low	East Waterford
Alluvium	Variable	Along major rivers and streams
Head Deposits	Variable	Scattered throughout Waterford

Head deposits are formed in situ and as a result their composition and permeability will be influenced by the underlying bedrock. Deposits formed from limestone and sandstone are likely to have a moderate permeability whereas deposits formed from shale and volcanic rock are likely to be of a low permeability. Head deposits are only shown at point locations on the subsoil map.

7.4 DEPTH TO BEDROCK

Along with permeability, the thickness of the subsoils (the depth to bedrock) is also important in determining groundwater vulnerability. The thickness of subsoils is a function of their depositional environment (how and when they were deposited) and their post depositional history (how the deposits have been affected by subsequent weathering and erosion). Topography plays a large part in these processes; glacial and fluvial deposits are often concentrated in valleys, along valley sides or on relatively flat outwash plains. In addition, subsequent weathering and erosion is often more prevalent on upland areas. The thickness and extent of subsoils in Waterford have been greatly influenced by these factors. Glacial deposits are relatively thin throughout most of the county because the last glaciation in Waterford was relatively minor. Glacial deposition on many of the upland areas may have been restricted to small valley glaciers rather than from large ice sheets. Significant weathering and erosion must also have taken place on the upland areas in Waterford.

Accurate information on the depth to bedrock in County Waterford is restricted to: outcrop data; geotechnical records; and geological exploration boreholes, together with some accurately located water wells and subsoil sections. Most of the depth to bedrock data from well records can only be located to the nearest townland.

Rock is at or near to the surface on upland areas such as the Comeragh and Knockmealdown Mountains, the Drum Hills and over many parts of rugged volcanic terrain in east Waterford. Elsewhere the data show that the subsoils in Waterford are relatively thin (generally less than 10 metres and often less than 3 metres).

There are few accurate data for areas where the depth to bedrock is greater than 10 m. Small areas were identified between Waterford City and Dungarvan and in some of the limestone valleys in west Waterford (for example, west of Ardmore and east of Ballyduff).

Where the subsoils have a moderate to high permeability, the depth to bedrock data was contoured at 3 and 10 metre intervals to assist in the production of the vulnerability map. Elsewhere the depth to rock was contoured at 3, 5 and 10 metre intervals. The guidelines used in contouring the depth to bedrock data are listed in Appendix 5. Depth to bedrock data are shown on Map 3.

7.5 KARST FEATURES

The limestone synclines in west Waterford have been subject to karstification (the enlargement of fractures by chemical solution) and various karst features are present. These include swallow holes, caves, enclosed depressions and springs. More details on karstification are given in Appendix 2.7. These karst features are considered to be point sources of recharge and therefore provide little or no attenuation of pollutants entering the groundwater. 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.

7.6 THE VULNERABILITY MAP (MAP 6)

The vulnerability map (Map 6) is derived from combining the contoured depth to bedrock data, the subsoil types (permeabilities) and the identified karst features. Accurately located data is 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 classification scheme is outlined in Table 7.2.

Table 7.2 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.

Large areas of County Waterford have a depth to bedrock of less than 3 metres and as a result groundwater in approximately one third of the county is classified as being extremely vulnerable to pollution. These areas include most of the upland regions in the county and much of the volcanic terrain in east Waterford.

Most of the remaining areas have a combination of subsoil types and depth to bedrock which results in a vulnerability rating of high. The sandstone till in the west and north of the county has an intermediate permeability and is generally less than 10 metres thick, and the shale and volcanic tills in east and central Waterford have a low permeability and are generally between 3 and 5 metres thick.

Due to the shallow depth of subsoil over most of the county, Waterford is likely to have a greater proportion of 'extreme' and 'high' vulnerability areas than most of the other counties in Ireland.

Small areas of moderate and low vulnerability have been delineated where data for thicker subsoil deposits exist; for example between Waterford City and Dungarvan, and in some of the limestone valleys in west Waterford (west of Ardmore and east of Ballyduff). There are indications from less accurate data which suggest that in places the depth to bedrock is relatively thick in some areas; however vulnerability zones have not been delineated around these data as their position has only been located to the nearest townland. These areas are marked on the map as having a 'moderate vulnerability in places'.

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 to determine the risk to groundwater.

8. GROUNDWATER PROTECTION

8.1 INTRODUCTION

In Chapter 2, the general groundwater protection scheme guidelines were outlined and, in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice for potentially polluting activities – was described. Subsequent chapters describe the different geological and hydrogeological land surface zoning elements as applied to County Waterford. 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.

8.2 THE GROUNDWATER PROTECTION MAP (MAP 7)

The groundwater protection map (Map 7) was produced by combining the vulnerability map (Map 6) with the aquifer map (Map 5). Each protection zone on the map is given a code which represents both the vulnerability of the groundwater to pollution and the groundwater resource (aquifer category). The codes are shown in Table 8.1. The vulnerability codes; Extreme (**E**), High (**H**), Moderate (**M**) and Low (**L**) have the same colour as on the vulnerability map (purple, red, blue and green respectively).

Not all of the hydrogeological settings represented by the zones in Table 8.1 are present in County Waterford. There are no recognised sand and gravel aquifers (**Lg/Rg**) in Waterford, or locally important aquifers which are generally moderately productive (**Lm**). In addition there are few areas which have a low or moderate vulnerability.

The most extensive protection zones in County Waterford are those which combine the regionally important aquifers **Rk** and **Rf** and the locally important aquifer type **Ll**, with the extreme (**E**) and high (**H**) vulnerability classifications. The following protection zones are the result: **Rk/H, Rk/E, Rf/H, Rf/E, Ll/H** and **Ll/E**.

It is clear from the delineated protection zones that large areas of County Waterford have regionally important groundwater resources which are high or extremely vulnerable to pollution.

Table 8.1 Matrix of Groundwater Resource Protection Zones

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

8.3 GROUNDWATER SOURCE PROTECTION REPORTS AND MAPS

The techniques used to delineate source protection areas (Section 8.3) have been applied to 4 public supply wells in County Waterford, these are: Ballyrohan, Cappoquin, Grange and Poulnagunouge. These reports are a follow up to work carried out by Duffy (1994). Numerical modelling was used to assist in the delineation of all these source protection areas, except Poulnagunouge.

Preliminary work; including test pumping, site visits and numerical modelling has also been undertaken on the following public supplies: Lefanta, Ballyhane, Derrinlaur, Tooraneena, Ballymoate, Geoish, Kereen, Monadiha, Rathgormuck, Fews, Ballyogarty and Ballykinsella (Duffy, 1994) and Ballinamuck (McDaid, 1994). Additional work would be required to produce source protection reports for these sources; this would include more comprehensive site visits, the collection of water level data, and in some cases, additional test pumping. Some of the test pumping carried out was restricted to short periods of time (due to operational reasons) and in some tests the discharge was not constant.

8.4 CONCLUSION

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

9. REFERENCES

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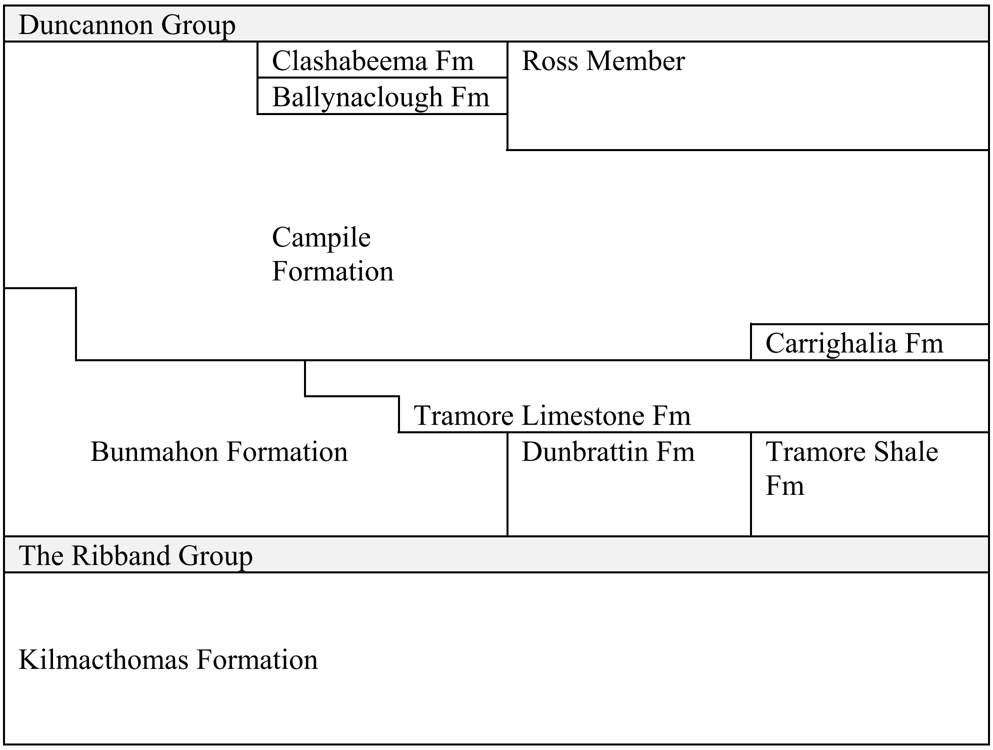
10. APPENDICES

APPENDIX 1 THE CORRELATION OF ORDOVICIAN ROCKS IN COUNTY WATERFORD

Ordovician rocks in Waterford are divided into two successions, the early Ordovician Ribband Group and the middle to late Ordovician Duncannon Group. The Duncannon Group predominates in Waterford and outcrops south of a line drawn through Kilmacthomas and Waterford City; the Ribband Group occurs to the north of this line.



(From Tietzsch-Tyler, D. and Sleeman, A.G., 1994 and Sleeman, A.G. and McConnell, B., 1995)

APPENDIX 2 THE CORRELATION OF DEVONIAN ROCKS IN COUNTY WATERFORD

The Old Red Sandstone rocks in Waterford fall into four separate stratigraphical successions, the East Cork succession, the Comeragh Mountain succession, the Portlaw succession and the Dunmore East succession.

The East Cork and Comeragh Mountain successions were deposited in the eastern section of the Munster Basin which stretched from Co. Kerry to the Comeragh Mountains. Up to 5 km of sediment is preserved in the Comeragh Mountain area, however this thins rapidly towards Ballyvoyle Head. The East Cork succession stretches westwards from Mine Head, occupying a more central position in the basin, and the succession is dominated by finer grained rock types. The Portlaw succession is found on the northern limb of the Comeragh Mountains. This thin sequence of conglomerates and sandstones was deposited outside of the Munster Basin. The succession found around Dunmore East is also different from those previously described, again reflecting the localised nature of sedimentation on the edge of and outside the Munster Basin. The sequence consists predominantly of fluvial sandstones and conglomerates with minor siltstones and mudstones. All Old Red Sandstone rocks in Waterford are Mid to Upper Devonian in age.

<table>
<tr><th colspan="2">East Cork Succession
(south of Lismore syncline)</th><th colspan="2">Comeragh
Succession</th><th>Portlaw
Succession</th><th>Dunmore East
Succession</th></tr>
<tr><td>Ardmore
Member</td><td rowspan="2">Gyleen
Formation</td><td colspan="2" rowspan="2">Kiltorcan Formation</td><td rowspan="2">Kiltorcan
Formation</td><td rowspan="3">?
Harrylock
Formation
?</td></tr>
<tr><td>Ballyquinn
Member</td></tr>
<tr><td colspan="2" rowspan="2">Ballytrasna
Formation</td><td colspan="2" rowspan="2">Knockmealdown Fm
Ballytrasna Fm
Kilnafrehan Fm
Sheskin Fm</td><td rowspan="2">Carrigmaclea
Formation</td></tr>
<tr><td rowspan="4">Templetown
Formation
?</td></tr>
<tr><td>Mine Head
Member</td><td></td><td colspan="2">Treanearla Fm</td><td rowspan="4">Coumshingaun
Formation</td></tr>
<tr><td colspan="2" rowspan="3"></td><td colspan="2">Coumaraglin Fm</td></tr>
<tr><td></td><td>Croughan
Fm</td></tr>
<tr><td colspan="2">Coumshingaun
Formation</td><td></td></tr>
</table>

(From Tietzsch-Tyler, D. and Sleeman, A.G., 1994 and Sleeman, A.G. and McConnell, B., 1995)

APPENDIX 3

HYDROGEOLOGICAL DATA

Appendix 3.1 Groundwater sources with known abstractions less than 100 m³/d (maximum yields are unknown)

Scheme	Daily Usage (m^3/d)	Source Type	Grid Reference	Formation
Adramone	-	BW	S338004	Bunmahon
Aglish	68	BW	W979960	Gyleen
Aglish-Glencairn	54	BW	X136905	Ballytrasna
Ballycurrane	14	BW	X150849	Gyleen
Ballyguiry	25	BW	X199903	Gyleen
Ballyheaphy	46	BW	R975041	Knockmealdown
Ballyknock	5	BW	S379187	Ballindysert
Ballymoat Lower+Upper	20	BW	X026913	Ballytrasna
Ballynoe	11	SPR	S081030	Knockmealdown
Ballysaggart	10	SPR	S012035	Knockmealdown
Ballyshunnock	6	BW	S450090	Campile (Ross)
Boolavonteen	20	BW	S199065	Ballytrasna
Briska Lower	8	BW	S320456	Coumshingaun
Briska Upper	8	BW	?	Coumshingaun ?
Camphire	13	BW	X084933	Waulsortian
Carrigeen	10	BW	S412102	Kilmacthomas
Carrignagower	45	SPR	S056027	Knockmealdown
Castlereagh	5	SPR	S206112	Ballytrasna
Clonea (Power)	20	SPR	S378146	Ballindysert
Clonea	5	BW	S397140	Kilmacthomas
Colligan	70	SPR	X210979	Knockmealdown
Cooneen-Dromore	5	BW	X108889	Ballytrasna
Crehanagh	5	BW	S415198	Ballindysert
Currabaha West	20	BW	S367044	Campile
Dromore Upper	5	BW	?	Gyleen
Dunhill	8	BW	S503025	Campile
Faha	10	BW	S359027	Campile
Feddans	5	BW	S364171	Ballindysert
Garravoone	15	BW	S404202	Ballindysert
Garryahylish	3	SPR	S341029	Campile
Glenawillin	10	BW	X030931	Waulsortian
Glenagad	20	BW	S211211	Knockmealdown
Graiguennageeha	10	SPR	S374001	Igneous rock (porphyry ?)
Graiguerush	14	SPR	S342084	Coumshingaum

Appendix 3.1 (cont)

Groundwater sources with known usage less than 100 m³/d (maximum yields are unknown)

Scheme	Daily Usage (m³/d)	Source Type	Grid Reference	Formation
Grallagh	14	BW	X156820	Ballytrasna
Inchinleamy	17	SPR	R911005	Knockmealdown
Joanstown	18	BW	S388187	Ballindysert
Kealfoun	5	SPR	S353067	Kilmacthomas
Kereen	10	BW	X142938	Gyleen (Bq)
Kilbrien	30	BW	S236035	Ballytrasna
Kilcooney	20	SPR	S202034	Ballytrasna
Kilgainy	16	BW	S234227	Ballysteen
Kilgobinet	20	BW	X238972	Kiltorcan
Kilmanahan	10	G	R905011	Kiltorcan ?
Kilmore-Kilbeg	12	BW	X004917	Ballytrasna
Kilnafrehan	11	BW	X263979	Knockmealdown
Kilrossanty	55	BW	S303009	Campile
Knockalisheen	20	SPR	S195157	Knockmealdown
Knockeylan	60	SPR	S324017	Campile
Lackan	15	SPR	S135003	Knockmealdown
Leagh Cross	2	BW	X255892	Gyleen (Bq)
Loskeran-Gates	55	SPR	X255854	Gyleen
Lyreanearla	10	BW	?	?
Modeligo	75	BW	S148019	Ballytrasna
Moores Well	-	BW	?	?
Mount Melleray	-	SPR	S103040	Knockmealdown
Nire	25	SPR	S249136	Ballytrasna
Roberts Cross	10	BW	X260886	Ballytrasna
Russelltown	15	BW	S176190	Kiltorcan
Scrahan	10	BW	S404068	Campile (Ross)
Scrothea	3	BW	?	Kiltorcan ?
Shanacoole	25	SPR	X137805	Crows Point / Gyleen
Shean	17	SPR	W960971	Gyleen
Sheskin	-	BW	?	Ballindysert ?
Smoor Beg	18	SPR	S484050	Campile
Strancally	14	BW	X080903	Ballytrasna
Ticknock (same as Tinnabinna)				
Tinnabinna	15	BW	X103820	Crows Point ?
Villierstown	60	SPR	X097935	Gyleen
Whitestown	10	SPR	S414137	Ballindysert

Grid References are taken from the EPA (1994)
Daily usage is taken from the EPA (1992).
BW = Bored Well SPR = Spring G = Gallery

Appendix 3.2 Hydrogeological Data For County Waterford (Including GSI Well Number)

Formation	Poor Well (with Spec Cap) (m³/m/d)	Moderate Well (with Spec Cap) (m³/m/d)	Good Well	Excellent Well
Waulsortian (Wa)			2009 SEW 042 2009 SEW 045 2009 SWW 010	2009 SEW 014 2009 SEW 039 2009 SEW 040 2009 SEW 041 2009 SEW 069 (2876) 2009SWW 047 (1585)
Ballysteen (BA)		2011 NEW 005 (261)	2007 NWW 030 2007 NWW 043 2007 NWW 045 2009 SEW 057 2011 SEW 018	1709SEW 036
Ballymartin (BT)	–	–	–	–
Lower Limestone Shale (LLS)			2009 SWW 052	2311 SEW 048
Ringmoylan Fomation (RM)	–	–	–	–
Mellon House Beds (MH)	–	–	–	–
Porter's Gate Formation (PG)	–	–	–	–
Crow's Point Formation (CP)	–	–	2007 NWW 048	–
Gyleen (GY)	2009 SWW 053		1709 SEW 004 2007 NWW 044 2007 NWW 046 2009 SEW 001	
Kiltorcan (KT)	2311 SEW 045 (5)		2011 NEW 002 (210) 2009 SWW 009	2009SWW 046 (254)
Knockmealdown (KM)			2009 NEW 038 2009 NWW 015 2009 SEW 003 2009 SEW 015 2011 NEW 001 2011 SEW 022	
Ballytrasna (BS)		2009 SWW 049 (5) 2009 SWW 087 (2) 2009 SWW 089 (2)	2007 NEW 001 2007 NEW 003 2007 NEW 005 2007 NWW 001 2007 NWW 019 2007 NWW 027 2007 NWW 042 2009 NEW 031 (39) 2009 NEW 032 2011 SEW 003 (20) 2009 SEW 044	

Appendix 3.2 (cont)

Formation	Poor Well	Moderate Well	Good Well	Excellent Well

	(with Spec Cap) (m³/m/d)	(with Spec Cap) (m³/m/d)		
Kilnafrehan (KF)			2009 NEW 028	
Sheskin (SN)	_	_	_	_
Carrigmaclea (CI)				
Treanearla (TR)	_	_	_	_
Coumaraglin (CU)	_	_	_	_
Croghan (CO)	_	_	_	_
Coumshingaun (CM)	_	_	2309 NWW 062	_
Harry Lock (HL)	_	_	_	_
Templetown (TT)	_	_	_	_
Ballindysert (BE)	_	_	2311 SWW 001 (117) 2311 SWW 002 (148) 2311 SWW 036 2311 SWW 066 2311 SWW 078	2311 SWW 076 2311 SWW 077
Clashabeema (CB)	_	_	_	_
Ballynaclough (BI)	_	2609 NWW 023 (2)	2611 SWW 015 2611 SWW 023 2609 NWW 071	_
Campile (CA) (undifferentiated)	_	2309 SEW 013 (22)	2309 NEW 012 2309 NEW 018 2309 NEW 073 2309 NWW 002 (156) 2309 NWW 035 2309 NWW 037 2309 NWW 038 2309 NWW 063 2309 NWW 064 2309 NWW 098 2309 NWW 099 2309 SEW 019 2309 SEW 021 2609 NWW 013 (500) 2609 NWW 059	2309 NEW 123 2309 NEW 124 2309 NWW 018 2611 SWW 001 (79) 2611 SWW 008 2611 SWW 014
Campile (CArs) (Ross Member)	_	_	2311 SEW 026 2311 SEW 027 2311 SEW 029 2311 SEW 047 2311 SEW 056 2311 SWW 006 2611 SWW 006	2311 SEW 020 2311 SEW 021 2311 SEW 022 2311 SEW 023 2311 SEW 025 2311 SEW 028 2311 SEW 040 2311 SEW 041 2311 SEW 046 2311 SEW 053 2311 SEW 055 2311 SEW 057 2311 SEW 058 2611 SWW 025 2309 NEW 125

Appendix 3.2 (cont)

Formation	Poor Well	Moderate Well	Good Well	Excellent

	(with Spec Cap) (m³/m/d)	(with Spec Cap) (m³/m/d)		Well
Carrighalia (CX)	–	–	–	–
Tramore Limestone (TE)	–	–	–	–
Bunmahon (BM)	_	_	_	_
Dunbrattin	_	_	_	_
Tramore Shale (TM)	–	–	–	–
Kilmacthomas (KI)	–	–	2309 NWW 001 2309 NWW 061 2311 SEW 006 2311 SWW 071	2309 NWW 096
Booley Bay (BB)	_	_	_	_
Granite Rocks (GR)	–	–	–	–
Volcanic Rocks (v) (Dolerite)	–	–	–	–

Appendix 3.3 Summary of Test Pumping Data For Waterford

Site	GSI Well No	Nat. Grid Reference	six inch	half inch	Aquifer	Depth m	Test Yield m3/d	Q/s m3/d/m	Transmissivity (approx.)m2/d	Max test Drawdown (m)	Rating	Aquifer class
Monadiha (Co. Co.)	2311SWW001	S 328 176	3	22	Ballindysert	32	141	*76	83 (95#)	1.2	good	Ll
Rathgormuck (Co. Co.)	2311SWW002	S 345 170	2	22	Ballindysert	27.4	222	***150	82 (190#)	1.5	good	Ll
Kilcaragh	2609NWW023	S 631 074	18	23	Ballynaclough	24.4	54.5	**2		27?	moderate	Rf
Ballymoate (Co. Co.)	2009SWW049	X 024 915	28	22	Ballytrasna	59	59	***5	55	6.7	moderate	Ll
Ballyrohan (Co. Co.)	2011SEW003	S 195 109	5	22	Ballytrasna	38	255	*15	41	6.5	good	Ll
Geoish (Co. Co.)	2007NWW001	X 133 892	34	22	Ballytrasna	11	110	***75	140	1.5	good	Ll
Grange (Co. Co.)	2007NEW001	X 173 816	38	22	Ballytrasna	25	250	***33	10_- 40	7.7	good	Ll
Headborough	2009SWW087	X 071 918	29	22	Ballytrasna	46.3	43.6	2		25.9	moderate	Ll
Kilmore	1709SEW006	W 996 922	28	22	Ballytrasna	48	56	5.5	(<10#)	10 ?	moderate	Ll
Kilmore West	2009SWW089	X 012 921	28	22	Ballytrasna	47.5	56.7	2		25.6	moderate	Ll
Tooraneena (Co. Co.)	2009NEW031	S 194 057	13	22	Ballytrasna	22	140	39	(50#)	3.5	good	Ll
Ballykinsella (Co. Co)	2609NWW013	S 603 053	17	23	Campile (volcanics)	35	300	* 200	112-290	0.6	good	Rf
Ballyogarty (Co. Co.)	2309NWW002	S 400 045	15	22	Campile (volcanics)	24	234	*** 156	37 (200#)	1.5	good	Rf
Islandkane (ILC 1722)	2309SEW013	X 529 990	36	23	Campile (volcanics)	39	44	2	(2.5#)	22 ?	poor	Rf
Military Road (not in use)	2311SEW053	S 599124	9	23	Campile (volcanics)	97.5	600	40	(55#)	15 ?	excellent	Rf
Snowcream Factory	2611SWW001	S 627 112	9	23	Campile (volcanics)	55	436	*35	20(44#)	6.5	excellent	Rf
Glennagad	2011NEW003	S 211 210	1	22	Gravel/Ballysteen	21	35	58	(72#)	0.6 ?	moderate	Lg/Ll
Poulboy	2011NEW005	S 234 224	2	22	Gravel/Ballysteen	9	78	260	(325#)	0.3 ?	mod/gd	Lg/Ll
Keereen (Co. Co.)	2009SWW053	X 141 930	30	22	Gyleen (Ballyquinn Mb)	30	35	*130	(160#)	0.2	mod ?	Ll
Feews (Co. Co.)	2309NWW001	S 367 074	15	22	Kilmacthomas	49	198	*38	20 (43#)	0.6	good	Rf
Coolroe	2311SEW045	S 464 161	8	22	Kiltorcan	26.2	40.9	**5		8.2	poor	Rf
Derrinlaur (Co. Co.)	2011NEW002	S 249 225	2	22	Kiltorcan	30	105	*77	12-48 (95#)	0.6	good	Rf
Cappoquin (Co. Co.)	2009SWW046	X 114 992	21	22	Kiltorcan	64	687	*163	169	2.8	excellent	Rf
Poulnagunoge (Co. Co.)	2011NEW001	S 229 213	1	22	Knockmealdown	34	110	***10	(12#)	8.2	moderate	Ll
Ardmore (Co. Co.)	2007SEW014	X 185 786	38	22	Waulsortian	?	775	311	160	2.5	excellent	Rk
Ballinamuck 1-4 (Co. Co.)	2009SE 69-72	X 236 947	31	22	Waulsortian	12.5	7194	2570	1000-4000	2.8	excellent	Rk
Ballyhane (Co. Co.)	2009SWW045	X 136 976	21	22	Waulsortian	18	1363	v high	v high	0.02	excellent	Rk
Lefanta (Co. Co.)	2009SWW047	X 106 976	21	22	Waulsortian	18	634	1585	3585##	0.5 ?	excellent	Rk

It should be noted that many of the tests were carried out over a short time period and many of the tests have low drawdown values.

Specific Capacity (Q/s) derived from: *drawdown extrapolated to 1 week, ** after 72 hours, *** after a short period (1-2 hrs)

Transmissivity estimated from: #Specific Capacity, ##Tidal analysis

Appendix 4.1 Hydrochemical Data for Co Waterford

Location	Date	Aquifer	Hardness	Alkalinity	pH	Conductivity	Cl	NO3	SO4	Ca	Mg	Na	K	F. Coliforms	Notes
Ordovician (Bunmahone)															
Adramone	16/9/1992	Bunmahon ?	107	52	nd	298	34.3	30	13	29	6.5	13.6	1.3	nd	
Ordovician (Campile Formation and Ross Member)															
Ballykinsella	6/11/1970	Campile	122	nd	6.3	nd	33	23.4	nd	nd	nd	nd	nd	nd	
Ballyogarty	16/9/1992	Campile	22	21	nd	144	21	13	10.2	nd	nd	nd	nd	nd	
Ballyogarty*	25/1/1973	Campile	36	nd	6.4	nd	25	26.5	nd	nd	nd	nd	nd	nd	
Ballyshannock	16/9/1992	Campile	75	37	nd	220	20.8	24	15	nd	nd	nd	nd	nd	
Bawfune	23/7/1979	Campile	52	41	7.7	158	13	8.4	nd	nd	nd	nd	nd	nd	
Dunhill	23/8/1988	Campile	300	116	6	**445**	**72**	1.1	**23.4**	nd	nd	nd	nd	**60**	**Mn=4.8 Fe=1.2**
Dunhill	16/9/1992	Campile	137	54	nd	**388**	**36.6**	**54**	**25**	38	7.6	18.4	1.6	nd	
Dunhill	1/7/1993	Campile	143	74	6.7	**387**	**38**	11	10	35	14	21.3	2.1	**1**	
Faha	7/1/1975	Campile	52	15	6	nd	30	17.7	20	nd	nd	nd	nd	nd	
Faha	16/9/1992	Campile	56	22	nd	225	29.3	19	25	10	6.7	14.6	3	nd	**Al high**
Kilrossanty	17/1/1975	Campile	27	10	6	nd	19	14.1	nd	nd	nd	nd	nd	nd	
Kilrossanty	16/9/1992	Campile	35	40	nd	143	18.3	12	7	10	3.3	9	0.5	nd	
Kilrossanty	30/6/1993	Campile	27	28	5.7	126	19	2.3	<1	3	5	8.8	0.3	0	
Knockeylan	30/6/1993	Campile	63	39	6.4	206	20	19	7	12	8	11.8	2.1	**1**	
Ballygunner Cott	10/2/1981	Campile(RossMb)	172	139	7.1	430	25	8.8	nd	nd	nd	nd	nd	nd	
Ballygunner Sch	10/2/1981	Campile(RossMb)	148	128	7.1	430	25	20.8	nd	nd	nd	nd	nd	nd	
Ballykinsella	15/9/1992	Campile(RossMb)	103	35	nd	326	**36**	**34**	27	21	11.1	17.1	1.4	0	
Ballykinsella	1/7/1993	Campile(RossMb)	108	53	6.4	324	**35**	**44.2**	14	12	19	16.5	1.2	nd	
Belle Clare/Blenheim H	10/2/1981	Campile(RossMb)	147	105	6.6	420	27	35.4	nd	nd	nd	nd	nd	nd	
Blenheim Heghts	1/7/1980	Campile(RossMb)	159	109	6.6	440	29	**46.4**	nd	nd	nd	nd	nd	nd	
Fanning Inst	29/3/1979	Campile(RossMb)	211	156	6.8	***507***	**65**	nd	nd	nd	nd	nd	nd	nd	
Kilmacthomas (PS)(Scr	13/7/1981	Campile(RossMb)	49	25	6.1	170	19	11.9	nd	nd	nd	nd	nd	nd	More data available
Military Rd	31/1/1980	Campile(RossMb)	214	141	7.1	**635**	**39**	**53.1**	nd	nd	nd	nd	nd	nd	
Military Rd	1/2/1980	Campile(RossMb)	214	140	7	**645**	**42**	**44.2**	nd	nd	nd	nd	nd	nd	
Mt Pleasant	10/2/1981	Campile(RossMb)	91	53	6.6	320	27	20.8	nd	nd	nd	nd	nd	nd	
Riverview	1/7/1980	Campile(RossMb)	187	145	7.2	460	27	11	nd	nd	nd	nd	nd	nd	
Scrahan	30/9/1974	Campile(RossMb)	41	nd	5.7	nd	22	23	nd	nd	nd	nd	nd	nd	**Fe=0.4**
Upper Grange	1/2/1980	Campile(RossMb)	102	97	7	345	27	0.3	nd	nd	nd	nd	nd	nd	
Viewmount	1/7/1980	Campile(RossMb)	113	73	6.6	360	31	19	nd	nd	nd	nd	nd	nd	
Wat. City #13(Glen)	23/1/1979	Campile(RossMb)	189	125	nd	nd	25	7.9	**43**	173	16	8	3	nd	
Wat. City #13(Glen)	26/3/1980	Campile(RossMb)	216	127	7.2	**725**	**74**	**46.4**	**52**	157	54	**50**	3.05	nd	
Wat. City #2	(22/5/76)	Campile(RossMb)	90	nd	6.1	nd	25	nd	nd	nd	nd	nd	nd	nd	
Wat. City #4	(16/4/74)	Campile(RossMb)	116	96	6.9	*184*	**40**	nd	nd	nd	nd	nd	nd	nd	
Wat. City #4	(19/10/74)	Campile(RossMb)	104	80	7.3	*245*	26	nd	nd	nd	nd	nd	nd	nd	
Wat. City #5	(16/4/74)	Campile(RossMb)	177	155	7	***670***	**36**	nd	nd	nd	nd	nd	nd	nd	
Wat. City #6	(8/5/74)	Campile(RossMb)	66	44	6.5	*123*	**62**	nd	nd	nd	nd	nd	nd	nd	
Wat. City #6	(9/5/74)	Campile(RossMb)	64	34	6.3	*154*	**60**	nd	nd	nd	nd	nd	nd	nd	
Wat. City #7(Ardkeen#)	12/4/1977	Campile(RossMb)	192	108	6.2	nd	**48**	**26.5**	nd	nd	nd	nd	nd	nd	**(Ammon=0.2)**
Wat. City #8	6/6/1975	Campile(RossMb)	92	72	6.7	nd	**52**	4.4	nd	nd	nd	nd	nd	nd	**(Fe=2.0**

Appendix 4.1 Hydrochemical Data for Co Waterford

Location	Date	Aquifer	Hardness	Alkalinity	pH	Conductivity	Cl	NO3	SO4	Ca	Mg	Na	K	F. Coliforms	Notes
Wat. City #8	(16/4/74)	Campile(RossMb)	248	170	7	***692***	35	nd	nd	nd	nd	nd	nd	nd	
Wat. City #8	(30/4/74)	Campile(RossMb)	116	83	6.6	*215*	34	nd	nd	nd	nd	nd	nd	nd	
Wat. City #8	(6/6/75)	Campile(RossMb)	92	72	6.7	*185*	**52**	4.4	nd	nd	nd	nd	nd	nd	
Williamstown	1/7/1980	Campile(RossMb)	90	44	6.5	310	35	**44.2**	nd	nd	nd	nd	nd	nd	
					Ordovician (Clashabeema)										
Butlerstown GWS	26/10/1970	Clashabeema	85	nd	6.7	nd	28	11.5	nd	nd	nd	nd	nd	nd	
					Ordovician (Kilmacthomas)										
Ballyduff/Kilmeaden	13/7/1981	Kilmacthomas	56	39	6.3	210	22	17.25	nd	nd	nd	nd	nd	nd	More data available
Clonea (O'Sullivan)	16/9/1992	Kilmacthomas	54	17	nd	189	20.4	34	10	8	9.2	9.7	0.8	nd	
Fews	16/9/1992	Kilmacthomas	20	16	nd	105	12.8	7	8	4	3	7.8	1.3	nd	
Fews	30/6/1993	Kilmacthomas	15	16	5.6	108	14	8.9	<1	<5	5	8.9	0.07	0	
Fews*	2/6/1976	Kilmacthomas	53	46	6.5	nd	19	8.14	nd	nd	nd	nd	nd	nd	**Fe=0.5 Zn=12 ?**
Glenagad	17/9/1992	Kilmacthomas	37	29	nd	128	15.2	14	3	7	3.9	8.2	1	nd	
Kilmeaden	25/10/1979	Kilmacthomas	200	195	7.1	450	19	0.9	nd	nd	nd	nd	nd	nd	More data available
Portlaw	11/1/1977	Kilmacthomas	36	18	5.4	nd	21	nd	nd	nd	nd	nd	nd	nd	
Portlaw	13/7/1981	Kilmacthomas	40	21	6	150	17	12.8	nd	nd	nd	nd	nd	nd	
					Silurian (Ballindysert)										
Ballyknock	16/9/1992	Ballindysert	45	24	nd	164	18.6	19	8	13	2.7	9.4	0.6	nd	
Crehanagh	16/9/1992	Ballindysert	62	25	nd	248	30.8	**37**	10	13	5.9	15	**5.3**	nd	
Feddans*	20/9/1972	Ballindysert	35	nd	6.4	nd	17	4	nd	nd	nd	nd	nd	nd	
Feddans	16/9/1992	Ballindysert	50	24	nd	159	14.7	**27**	6	14	2.6	9	0	nd	
Joanstown	16/9/1992	Ballindysert	104	131	nd	280	17.6	7	7	38	4.8	11.2	0.7	nd	
Joanstown*	5/5/1966	Ballindysert	124	nd	6.6	nd	22	0.5	nd	nd	nd	nd	nd	nd	
Monadiha	16/9/1992	Ballindysert	59	29	nd	185	21.8	**25**	7	19	3.8	8.6	0.6	nd	
Rathgormuck	16/9/1992	Ballindysert	42	10	nd	154	15.8	**30**	8	9	4.9	9.1	1.5	nd	
Rathgormuck	30/6/1993	Ballindysert	40	19	5.4	157	16	8.3	1	4	7	8.7	1.5	0	
Rathgormuck*	13/7/1971	Ballindysert	24	nd	5.7	nd	19	3.3	nd	nd	nd	nd	nd	nd	
Sheskin	15/9/1992	Ballindysert	140	110	nd	386	**35.2**	**29**	16	45	6	18.9	2.1	nd	
Monadiha*	31/1/1977	Ballindysert	37	nd	5.9	nd	21	3.7	nd	nd	nd	nd	nd	nd	**Fe=0.6**
Clonea (Power)	13/7/1981	Ballindysert	62	40	6.4	190	19	18.1	nd	nd	nd	nd	nd	nd	More data available
					Devonian (Ballytrasna)										
Aglish-Glencairn	7/7/1978	Ballytrasna	102	90	4.8	nd	**60**	8.8	nd	nd	nd	nd	nd	nd	
Aglish-Glencairn	19/6/1979	Ballytrasna	96	83	6.6	239	16	9.7	nd	nd	nd	nd	nd	nd	
Aglish-Glencairn	15/9/1992	Ballytrasna	107	65	nd	273	23.3	20	5	31	6.1	10	1.5	nd	
Ardmore(Spring ?)*	2/5/1973	Ballytrasna	101	nd	6.6	nd	26	5.7	nd	nd	nd	nd	nd	nd	More data available
Ardmore(Spring)	15/7/1981	Ballytrasna	91	82	6.7	250	20	3.5	nd	nd	nd	nd	nd	nd	More data available
Ballydasoon*	1/10/1970	Ballytrasna	64	nd	6.5	nd	33	22.1	16	nd	nd	nd	nd	nd	More data available
Ballymoate	25/7/1978	Ballytrasna	28	5	5.1	nd	29	15.5	nd	nd	nd	nd	nd	nd	More data available
Ballymoate	15/6/1979	Ballytrasna	32	22	6.2	124	18	8.8	nd	nd	nd	nd	nd	nd	
Ballymoate	16/9/1992	Ballytrasna	59	25	nd	213	23.4	7.9	11	14	4.6	10.4	**6**	nd	

Appendix 4.1 Hydrochemical Data for Co Waterford

Location	Date	Aquifer	Hardness	Alkalinity	pH	Conductivity	Cl	NO3	SO4	Ca	Mg	Na	K	F. Coliforms	Notes
Ballymoate	29/6/1993	Ballytrasna	64	27	6.2	227	28	9.1	8	13	8	11.7	**5.5**	0	
Ballyrohan	17/9/1992	Ballytrasna	119	37.4	nd	288	20.9	17	5	39	4.5	12	0.9	nd	
Ballyrohan	30/6/1993	Ballytrasna	115	89	6.5	246	14	3.5	<1	46	5.9	6.8	0.6	**2**	
Ballyrohan*	19/3/1975	Ballytrasna	92	nd	6.7	nd	14	8.8	nd	nd	nd	nd	nd	nd	
Boolavonteen	14/7/1981	Ballytrasna	30	17	5.8	110	12	7.9	nd	nd	nd	More data available, Temp=8-15			
Boolavonteen	17/9/1992	Ballytrasna	50	18	nd	160	26.7	11	6	11	3.1	10.2	0.6	nd	
Boolavonteen	?	Ballytrasna	69	64	6.2	nd	19.8	nd	nd	nd	nd	nd	nd	nd	
Castlereagh*	11/3/1970	Ballytrasna	96	nd	6.6	nd	14	2.9	nd	nd	nd	nd	nd	nd	
Clashmore	17/9/1992	Ballytrasna	126	69	nd	321	26.4	**29**	11	28	12.8	13.9	1.8	nd	
Clashmore	29/6/1993	Ballytrasna	129	65	6.9	306	27	**30.1**	8	21	19	14.2	1.8	0	
Geoish	17/9/1992	Ballytrasna	71	45	nd	235	24.3	**32**	8	18	6.4	12.2	2.2	nd	
Geoish	29/6/1993	Ballytrasna	81	42	6.4	230	25	**39.9**	<1	16	10	12.8	2.1	0	
Geoish*	2/4/1978	Ballytrasna	58	nd	7.1	nd	23	20.35	nd	nd	nd	nd	nd	Fe=4.2 in suspension	
Grallagh	30/4/1975	Ballytrasna	82	nd	6.5	nd	39	4.8	nd	nd	More data availabl			nd	Fe=0.16
Grallagh	17/9/1992	Ballytrasna	91	59	nd	272	31.1	13	11	18	10.2	15.9	0.7	nd	
Grange	31/1/1972	Ballytrasna	188	nd	6.8	nd	32	**27.9**	**17**	nd	nd	nd	nd	nd	
Grange	23/5/1975	Ballytrasna	115	nd	7.6	nd	29	8.8	nd	nd	nd	**Fe=3.2 in Suspension Mn=0.4**			
Grange	9/6/1975	Ballytrasna	119	nd	7.2	nd	27	8.8	nd	**Fe=1.8 in Suspension Mn=0.27 Cu=0.5 Zn=0.14**					
Grange	17/9/1992	Ballytrasna	241	135	nd	**574**	**44.5**	**75**	**17**	75	11.1	16.4	3.5	nd	
Kilbrien	14/7/1981	Ballytrasna	17	10	5.5	92	12	6.2	nd	nd	nd	nd	nd	nd	More data available
Kilbrien	17/9/1992	Ballytrasna	25	11	nd	117	23.5	12	4	5	2.3	10.3	0.9	nd	
Kilbrien	?	Ballytrasna	20	35	5.2	nd	28	nd	nd	nd	nd	nd	nd	nd	
Kilbrien*	27/7/1976	Ballytrasna	16	nd	5.7	nd	16	6.1	nd	nd	nd	nd	nd	nd	More data available
Kilmore(Tallow)*	23/2/1968	Ballytrasna	35	nd	5.8	nd	16	2.6	nd	nd	nd	nd	nd	nd	More data available
Kilmore-Kilbeg	26/7/1978	Ballytrasna	36	15	5.1	nd	26	19.9	nd	nd	nd	nd	nd	nd	
Kilmore/Kilbeg	16/9/1992	Ballytrasna	66	27	nd	245	38.7	33	11	16	6.7	12.7	2.8	nd	
Loskeran	29/8/1979	Ballytrasna	95	82	6.4	330	38	5.3	nd	nd	nd	nd	nd	nd	
Modeligo	26/1/1976	Ballytrasna	36	24	5.7	nd	24	**57.5**	nd	nd	nd	nd	nd	nd	**Fe=0.4**
Modeligo	14/7/1976	Ballytrasna	27	20	5.4	nd	18	8.8	nd	nd	nd	nd	nd	nd	
Modeligo	14/7/1981	Ballytrasna	28	19	6.4	118	14	10.1	nd	nd	nd	More data available, Temp=9-16			
Modeligo	17/9/1992	Ballytrasna	34	16	nd	148	17.8	20	4	9	3.4	9.6	0.7	nd	
Strancally (Knockanore	27/11/1973	Ballytrasna	57	nd	6.1	nd	29	**26.5**	nd	nd	nd	nd	nd	nd	More data available
Strancally (Knockanore	16/10/1978	Ballytrasna	32	22	4.9	nd	33	11	nd	nd	nd	nd	nd	nd	
Tallow Hill*	23/2/1968	Ballytrasna	80	nd	6.4	nd	23	0.4	nd	nd	nd	nd	nd	nd	
Tooraneena	17/9/1992	Ballytrasna	38	29		125	12.9	9	8	10	3.1	8.3	0.4	nd	
Tooraneena	30/6/1993	Ballytrasna	31	35	5.9	119	12	8.9	4	5	4	8.2	0.6	nd	
Tooraneena*	15/10/1970	Ballytrasna	31	nd	5.9	nd	16	5.9	nd	nd	nd	nd	nd	nd	More data available
						Devonian (Gyleen)									
Aglish	5/7/1976	Gyleen	40	nd	6.1	nd	22	7.1	nd	nd	nd	nd	nd	nd	More data available
Aglish	15/4/1980	Gyleen	40	27	6.2	150	20	9.3	nd	nd	nd	nd	nd	nd	More data available
Ballycurrane	17/9/1992	Gyleen	72	30	nd	200	23.2	18	8	14	5.4	11.4	1.5	nd	
Ballyguiry	5/5/1975	Gyleen	30	nd	5.5	nd	19	17.7	nd	nd	nd	nd	nd	nd	**Fe=1.8 ?**
Ballyguiry	15/9/1992	Gyleen	34	16	nd	155	21.8	25	5	7	3.3	11.2	2.6	nd	
Ballynamultina (Clashm	1/5/1973	Gyleen	95	nd	7.4	nd	26	17.3	nd	nd	nd	nd	nd	nd	Fe=0.12
Ballynamultina (Clashm	9/8/1978	Gyleen	118	38	6.2	nd	**38**	17.7	nd	nd	nd	nd	nd	nd	
Ballynamultina (Clashm	24/9/1980	Gyleen	242	218	7.3	610	25	7.5	nd	nd	nd	nd	More data available		Temp=10.5-13

Appendix 4.1 Hydrochemical Data for Co Waterford

Location	Date	Aquifer	Hardness	Alkalinity	pH	Conductivity	Cl	NO3	SO4	Ca	Mg	Na	K	F. Coliforms	Notes
Barranastook	29/8/1979	Gyleen	22	7	5.4	138	26	7.96	nd	nd	nd	nd	nd	nd	
Keereen	17/9/1992	Gyleen	105	76	nd	270	22.6	24	7	31	4.6	12.3	1	nd	
Keereen	29/6/1993	Gyleen	101	58	6.8	257	23	**28.3**	<1	31	6	12.1	1	0	
Shean	15/9/1992	Gyleen	159	144	nd	368	19.8	14	8	53	4	10	**4.6**	nd	
Shean*	10/2/1975	Gyleen	145	nd	7	nd	17	14.1	nd	nd	nd	nd	nd	nd	
Villierstown	15/7/1981	Gyleen	42	30	6.7	170	28	4.4	nd	nd	nd	More data available, Temp=10-14			
Villierstown*	28/3/1973	Gyleen	40	nd	6.8	nd	31	3.3	nd	nd	nd	nd	nd	nd	More data available
Leagh Cross	17/9/1992	Gyleen (Ballyquin Mb	82	47	nd	238	18.9	**29**	11	24	4.9	10.7	1.8	nd	
Talllow Hill	16/9/1992	Gyleen/Balltyrasna	88	55	nd	265	26.9	20	10	27	5.9	13.5	1.8	nd	
Talllow Hill	29/6/1993	Gyleen/Balltyrasna	92	51	6.8	251	28	23.9	7	24	8	13.4	0.7	0	
						Devonian (Harrylock)									
Ballymacaw*	30/1/1974	Harrylock	202	162	7.4	nd	72	10.6	3.3	nd	nd	nd	nd	nd	
						Devonian (Kiltorcan)									
Cappoquin	3/7/1979	Kiltorcan	274	253	7.5	**590**	26	**40**	nd	nd	nd	nd	nd	nd	Temp=13
Cappoquin	17/9/1992	Kiltorcan	72	43	nd	195	26.4	**29**	10	12	7.6	11.5	1.8	nd	
Cappoquin	29/6/1993	Kiltorcan	71	39	nd	228	23	**42.5**	7	6	14	12.9	1.8	0	
Cappoquin	?	Kiltorcan	48	24	6.6	nd	21.6	**55**	nd	nd	nd	nd	nd	nd	**Fe=0.96**
Derrinlaur*	7/10/1969	Kiltorcan	56	nd	6.2	nd	16	4.5	nd	nd	nd	nd	nd	nd	
Garrabane	23/9/1980	Kiltorcan	15	5	7.1	85	12	0.9	nd	nd	nd	More data available, Temp=8-12			
Kilmanaghan	17/9/1992	Kiltorcan	70	59		179	13.9	6	4	19	4.3	8	0.8	nd	
Kilmanahan*	7/10/1969	Kiltorcan	70	nd	7.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	More data available
Russelstown	17/9/1992	Kiltorcan	63	29	nd	170	21.2	13	9	19	2.5	7.1	1.5	nd	
						Devonian (Knockmealdown)									
Mount Mellery*	21/9/1970	Knockmealdowm	15	nd	6.1	nd	11	nd	nd	nd	nd	nd	nd	nd	More data available
Ballyheaphy*	23/8/1971	Knockmealdown	41	16	5.9	nd	15	4.4	14	nd	nd	nd	nd	nd	More data available
Ballynoe	1/2/1972	Knockmealdown	32	nd	6	nd	16	11.8	nd	nd	nd	nd	nd	nd	More data available
Cooledelane	?	Knockmealdown	69	68	6.3	nd	16.2	**28.7**	nd	nd	nd	nd	nd	nd	
Inchinleamy*	18/11/1969	Knockmealdown	50	nd	5.9	nd	20	19.4	14.2	nd	nd	nd	nd	nd	
Kilnafrehan	16/9/1992	Knockmealdown	115	68		330	29.3	**39**	14	36	6.4	9	0.5	nd	
Kilnafrehan*	25/2/1970	Knockmealdown	120	nd	6.8	nd	31	**35.8**	**18.44**	nd	nd	nd	nd	nd	
Knockalisheen*	25/4/1967	Knockmealdown	25	nd	6.2	nd	15	0.6	nd	nd	nd	nd	nd	nd	
Lackan*	4/11/1975	Knockmealdown	15	nd	5.8	nd	19	10.6	nd	nd	nd	nd	nd	nd	More data available
Poulnagunogue	17/9/1992	Knockmealdown	45	32	nd	127	14.4	14	4	9	3.6	7.3	1	nd	
Poulnagunogue	30/6/1993	Knockmealdown	29	26	6	117	14	2.7	<1	3	5	7.1	0.8	**110**	
Poulnagunouge	16/7/1981	Knockmealdown	28	22	5.8	110	13	1.5	nd	nd	nd	nd	nd	nd	
						Devonian (Carrigmaclea)									
Garravoone	5/9/1979	Carrigmaclea	103	99	6.9	290	20	10.2	nd	nd	nd	nd	nd	nd	
Garravoone	16/9/1992	Carrigmaclea	113	65	nd	287	18.9	21	15	34	5	12.3	0.8	nd	
						Carboniferous (Waulsortian)									

Appendix 4.1 Hydrochemical Data for Co Waterford

Location	Date	Aquifer	Hardness	Alkalinity	pH	Conductivity	Cl	NO3	SO4	Ca	Mg	Na	K	F. Coliforms	Notes
Ballinamuck	27/7/1994	Waulsortian	234	210	nd	512	23.4	20.7	11.8	78	9.3	11.8	2.2	nd	
Ballinamuck	30/6/1993	Waulsortian	238	192	7.1	471	25	23.9	8	78	10	13.4	2.2	**1**	
Ballyhane	17/9/1992	Waulsortian	311	250	nd	629	25.6	**34**	14	90	12.9	10.5	1.5	nd	
Ballyhane	14/7/1981	Waulsortian	282	252	7.3	610	22	14.6	nd	nd	nd	nd	nd	nd	More data available
Ballyhane	29/6/1993	Waulsortian	342	275	7.4	601	25	7.8	9	104	20	10.3	1.4	0	
Camphire	27/6/1978	Waulsortian	240	192	6.5	nd	31	15.5	nd	nd	nd	nd	nd	nd	More data available
Camphire	16/9/1992	Waulsortian	229	195	nd	479	16.9	11	12	88	5.5	8.5	1	nd	
Glenawillin ??	17/9/1992	Waulsortian	99	64	nd	241	26.5	5	9	25	6.1	11.9	0.8	nd	
Glenawillin*	28/6/1973	Waulsortian	277	nd	7.2	nd	21	22.5	27	nd	nd	nd	nd	nd	More data available
Glenawillin	17/9/1992	Waulsortian	299	246	nd	602	23.1	23	13	112	4.7	8.1	**5.2**	nd	
Lefanta	17/9/1992	Waulsortian	315	244	nd	622	24.3	**41**	11	101	85	10.5	1.3	nd	
Lefanta	29/6/1993	Waulsortian	317	241	7.3	570	24	10	9.3	105	13	9.3	1.2	**8**	
				Carboniferous (Crows Point)											
Ticknock	12/9/1978	Crows Point	65	46	6.2	220	24	7	nd	nd	nd	nd	nd	nd	More data available
Ticknock	5/9/1979	Crows Point	65	46	6.2	220	24	7	nd	nd	nd	nd	nd	nd	
Pilltown*	9/9/1971	Crows Point	154	nd	6.6	nd	33	16.2	26	nd	nd	nd	nd	nd	More data available
Tinnabinna*	22/1/1968	Crows Point	145	nd	6.4	nd	25	1.8	nd	nd	nd	nd	nd	nd	More data available
				Carboniferous (Ballysteen)											
Cappagh Creamery	26/2/1973	Ballysteen	299	250	7.4	nd	25	21	21	nd	nd	nd	nd	nd	

All values in mg/l where appropriate except * values in ppm **nd = no data**

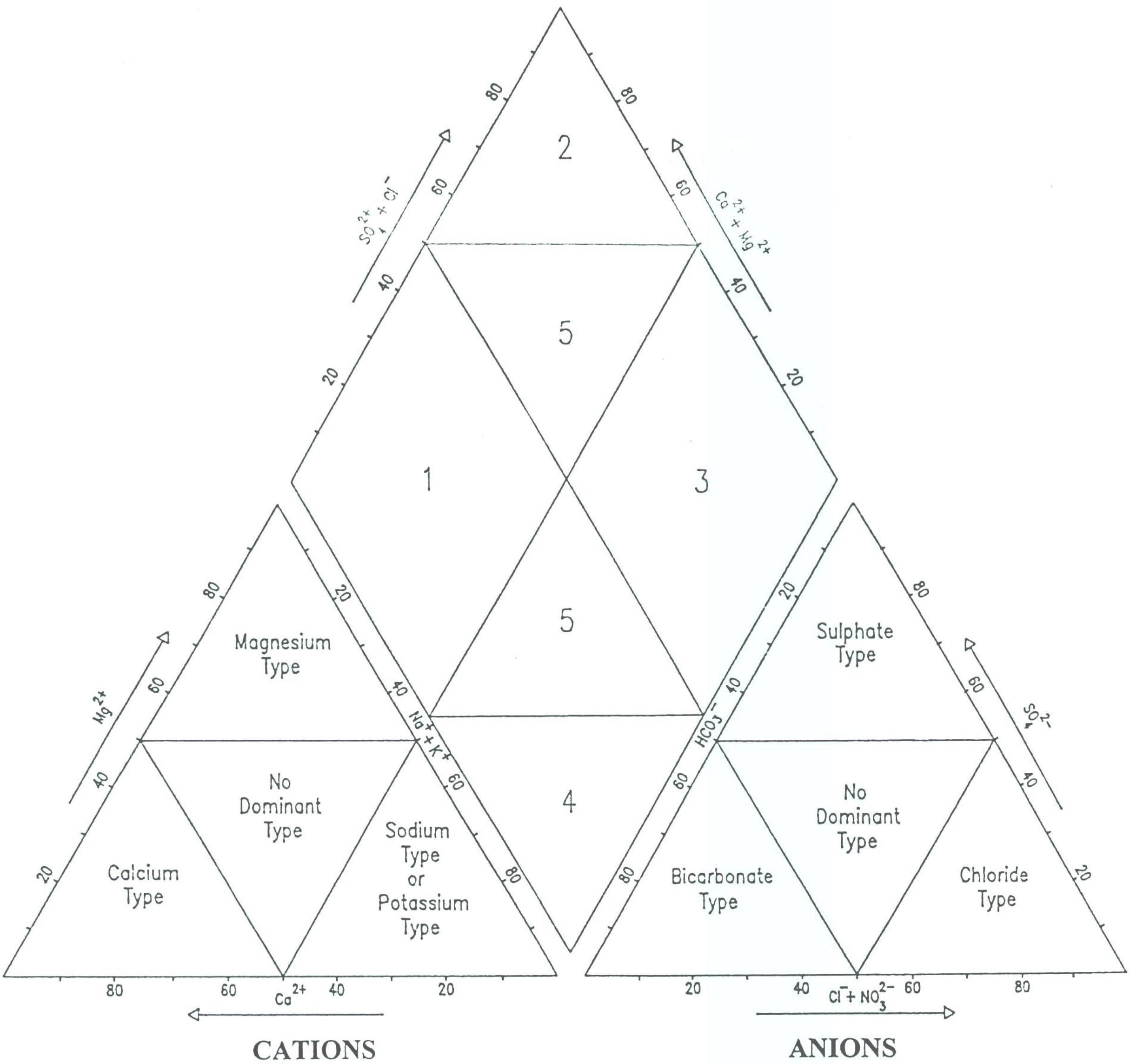
Values under Conductivity in Italics are calculated fromTotal Dissolved Solids

'More Data Available' describes where several samples are available from different dates but only a few parameters are analysed, a representative analyses is

Values in bold are higher than the general background and indicate contamination

Values shaded are above the EC MAC (maximum allowable concentration)

Appendix 4.2: Subdivisions of the Piper Diagram.



Distinct groundwater types can be distinguished according to their plotted position in certain subareas of the diamond shaped field. These areas are shown on the Piper diagram (above) and are described as follows:

1. Calcium bicarbonate type waters. Carbonate hardness exceeds 50% and the chemical properties of the groundwater are dominated by alkaline earths and weak acids (typical of recharging waters in limestones).

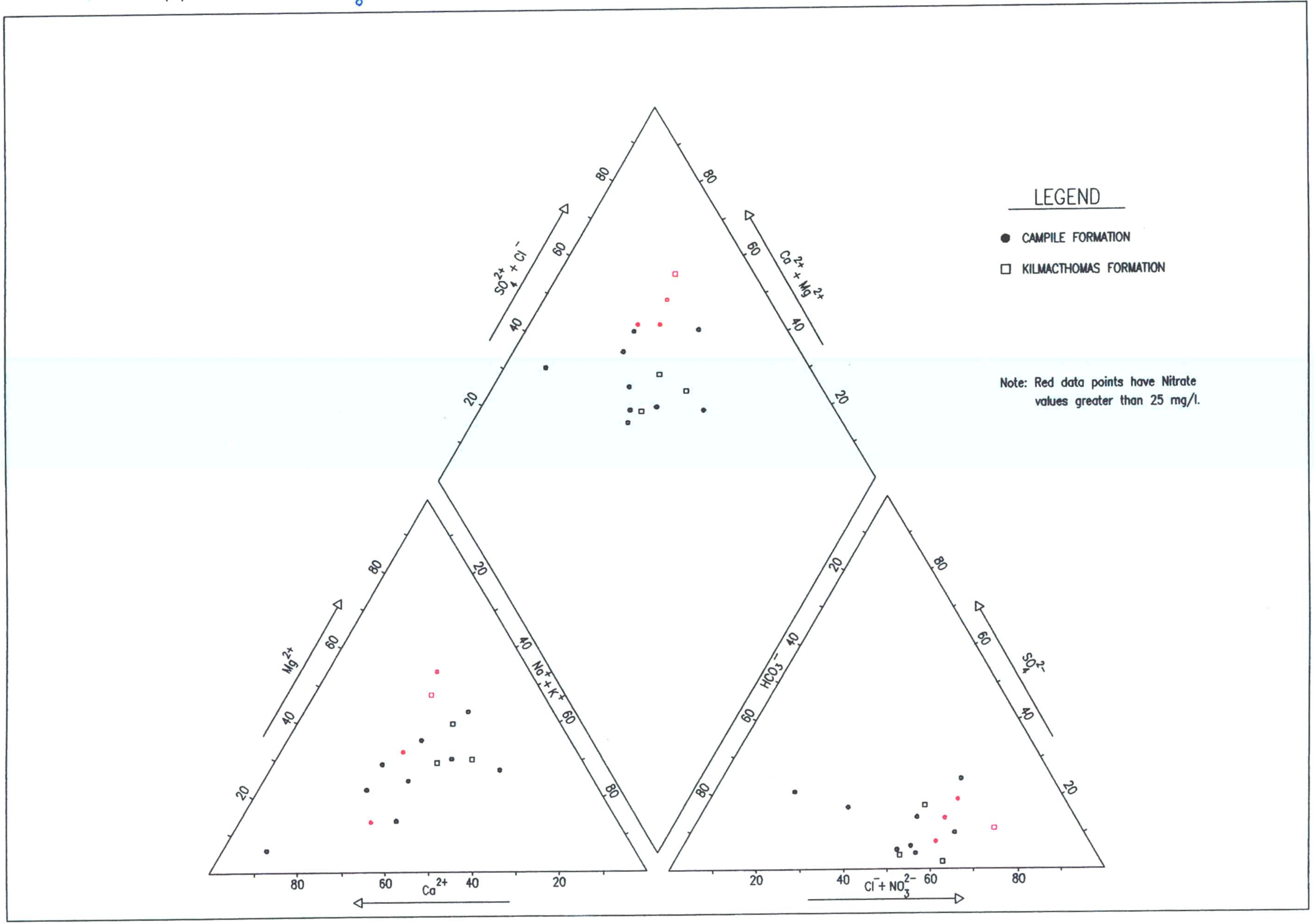
2. Groundwater high in calcium/magnesium and chloride/sulphate. Non carbonate hardness exceeds 50% (where bicarbonate and magnesium are dominant this can indicate the presence of dolomite).

3. Sodium chloride type waters. Non carbonate alkali exceeds 50%, chemical properties are dominated by alkalies and strong acids (saline waters plot in this area).

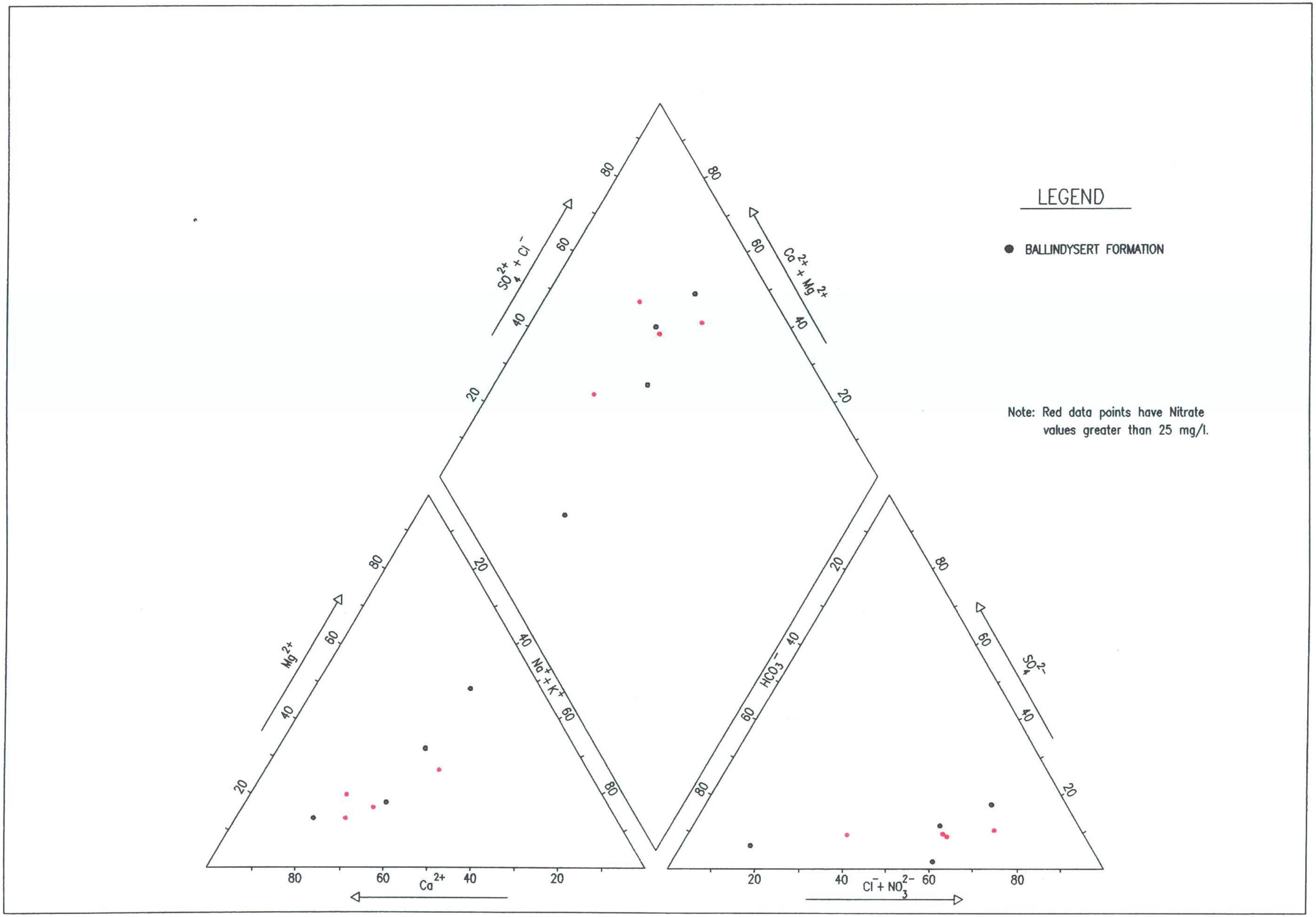
4. Sodium-potassium bicarbonate type waters. Carbonate alkali exceeds 50%, these groundwaters are very soft in proportion to their content of dissolved solids (can indicate ion exchange)

5. No one cation-anion pair exceeds 50% (groundwaters may be mixed or may be the result of simple dissolution).

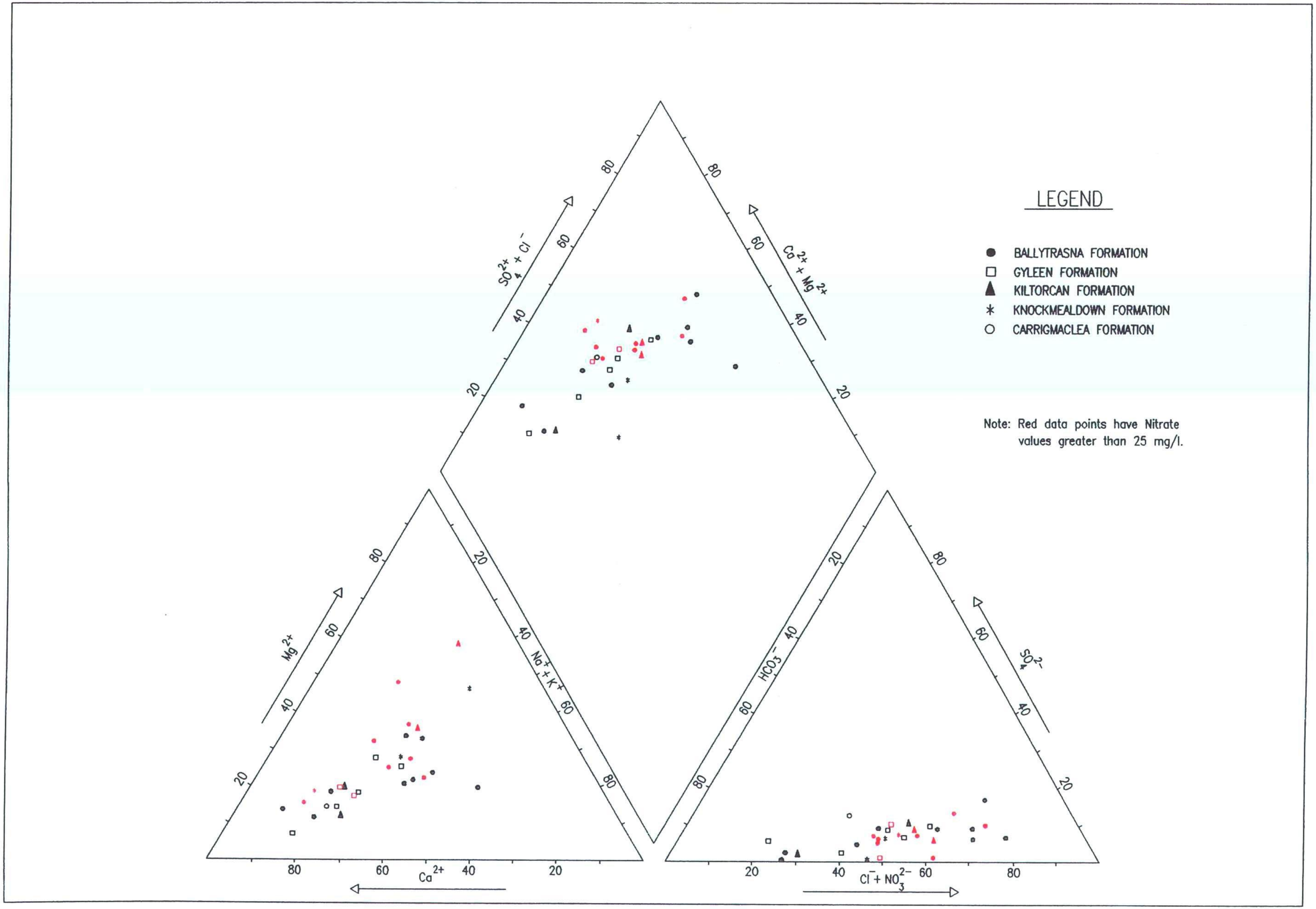
Appendix 4.2: Hydrochemistry of the Campile and Kilmacthomas Formations.



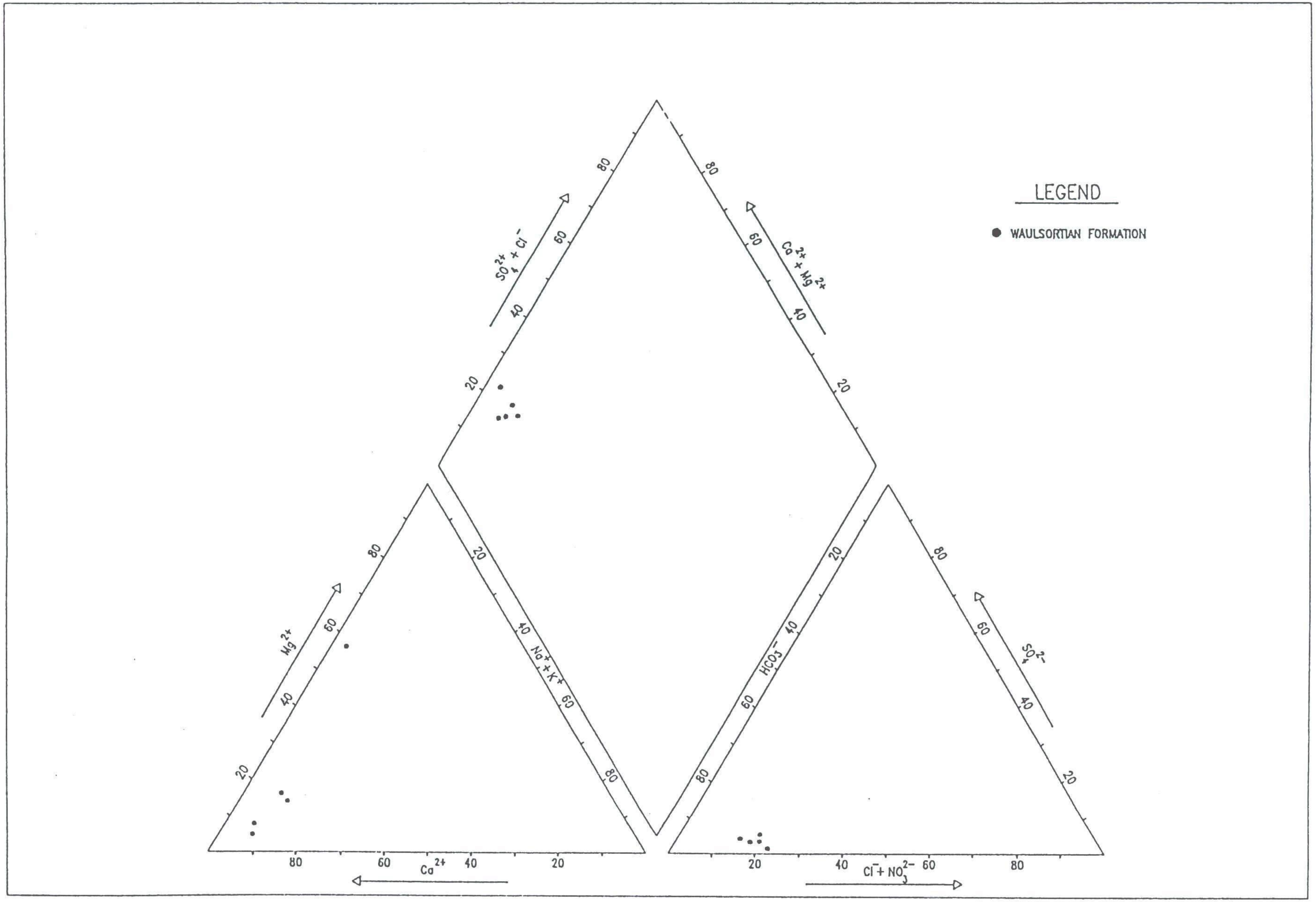
Appendix 4.2 (cont.): Hydrochemistry of the Ballindysert Formation.



Appendix 4.2 (cont.): Hydrochemistry of the main Old Red Sandstone Formations.



Appendix 4.2 (cont.): Hydrochemistry of the Waulsortian Limestone Formation.



APPENDIX 5

Guidelines For Contouring Depth to Bedrock in County Waterford

Rock close to surface (obtained from the subsoils map) was contoured with a buffer of 150 metres to produce the three metre depth to bedrock contour. This buffer was derived from work in Limerick where, by using accurate data it was possible to derive an average distance from outcrops and rock close to surface to a general subsoil depth of three metres. This quality of data was not present in Waterford so the buffer derived from work in Limerick was used as the best estimate. This buffer distance is believed to represent a conservative value.

Outcrops were also contoured using a 150 - 200 m buffer. In practice the outcrop is a point of extreme vulnerability, surrounded by an area of probably extreme vulnerability.

Accurate borehole and well data was contoured by extrapolating the depth to bedrock from these data points to the 3 metre contours around adjacent outcrops (townland accuracy data was taken into consideration where appropriate). This process was aided by a GIS project that was conducted as part of an MSc. in Environmental Engineering at Trinity College (Fox, H., 1995). Isolated accurate data were not contoured, this data is represented by a point symbol on the vulnerability map.

Townland accuracy data was not contoured on its own (only together with outcrop data and accurate borehole data), this data indicates the general depth to bedrock over an area. Where concentrations of townland accuracy data occur, this information is represented on the vulnerability map using text (see Map 6).

Several areas on the volcanics of east Waterford have a general depth to bedrock of less than 3 metres, as indicated by borehole data and outcrop density. These areas were contoured by taking account of topography and/or bedrock geology where these factors appeared to have a controlling influence on the depth to bedrock. Where outcrop density was low or where townland data suggested otherwise the arbitrary radius of 150 metres was used.

The six inch to one mile geological maps were used together with the half inch and one inch topographic maps throughout the excercise.