North County Tipperary Groundwater Protection Scheme

Main Report

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1 Introduction

1.1 Groundwater Protection – A Priority Issue for Local Authorities

The protection of groundwater quality from the impact of human activities is a high priority for 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, many of which are used for water supply and recreational purposes. In many rivers, more than 50% of the annual flow is derived from groundwater and more significantly, in low flow periods in summer, more than 90% is groundwater. If groundwater becomes contaminated the rivers can also be affected and so the protection of groundwater resources is an important aspect of sustaining surface water quality;
- groundwater generally moves slowly through the ground and so the impact of human activities can last for a relatively long time;
- polluted drinking water is a health hazard and once contamination has occurred, drilling of new wells is expensive and in some cases not practical. Consequently 'prevention is better than cure';
- groundwater may be difficult to clean up, even when the source of pollution is removed;
- unlike surface water where flow is in defined channels, groundwater is present everywhere;
- EU policies and national regulations are requiring that polluting discharges to groundwater must be prevented as part of sustainable groundwater quality management.

1.2 Groundwater – A Resource at Risk

Groundwater is a resource that is under increasing risk from human activities, for the following reasons:

- since groundwater flow and contaminant transport are neither readily observed nor easily measured, and both processes are generally slow, there can be a lack of awareness about the risks of groundwater contamination;
- contamination of wells and springs is occurring;
- there is widespread application of domestic, agricultural and industrial effluents to the ground;
- the quantities of domestic, agricultural and industrial wastes are increasing;
- there has been a significant increase in the application of inorganic fertilisers to agricultural land and in the usage of pesticides in recent years;
- there are greater volumes of road traffic and more storage of fuels/chemicals; and
- chemicals of increasing diversity and often high toxicity are being manufactured, distributed and used for a wide range of purposes.

The main threats to groundwater are posed by (a) point contamination sources – farmyard wastes (mainly silage effluent and soiled water), septic tank effluent, sinking streams where contamination of surface water has occurred, leakages, spillages, pesticides used for non-agricultural purposes and leachate from waste disposal sites, and (b) diffuse sources – spreading of fertilisers (organic and inorganic) and pesticides. While point sources have caused most of the contamination problems identified to date, there is evidence that diffuse sources are increasingly impacting on groundwater.

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

There are a number of ways of preventing contamination, such as improved well siting, design and construction and better design and management of potential contamination sources. However, one of the most effective ways is integrating hydrogeological factors into land-use policy and planning by means of groundwater protection schemes.

Land-use planning (including environmental impact assessment), integrated pollution control licensing, waste licensing, water quality management planning, water pollution legislation, etc., are the main methods used in Ireland for balancing the need to protect the environment with the need for development. However, land-use planning is a dynamic process with social, economic and environmental interests and impacts influencing to varying degrees the use of land and water. In a rural area, farming, housing, industry, tourism, conservation, waste disposal, water supply, etc., are potentially interactive and conflicting and may compete for priority. How does groundwater and groundwater pollution prevention fit into this complex and difficult situation, particularly as it is a resource that is underground and for many people is 'out of sight, out of mind'? Groundwater protection schemes enable planning and other regulatory authorities to take account of both geological and hydrogeological factors in locating developments; consequently they are an essential means of preventing groundwater pollution.

1.4 'Groundwater Protection Schemes' – A National Methodology for Groundwater Pollution Prevention

The Geological Survey of Ireland (GSI), the Department of Environment and Local Government (DoELG) and the Environmental Protection Agency (EPA) have jointly developed a methodology for the preparation of groundwater protection schemes (DoELG/EPA/GSI, 1999). Three supplementary publications have also been published, namely, **Groundwater Protection Responses for Landfills, Groundwater Protection Responses for Landspreading of Organic Wastes,** and **Groundwater Protection Responses for On-site Wastewater Treatment Systems**. Similar 'responses' publications are planned for other potentially polluting activities and developments.

A groundwater protection scheme has two main components:

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

These are shown schematically in Figure 1.

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

There are three main hydrogeological elements to land surface zoning:

- Division of the entire land surface according to the **vulnerability** of the underlying groundwater to contamination. This requires production of a vulnerability map showing four vulnerability categories – extreme, high, moderate and low.
- Delineation of **areas contributing to groundwater sources** (usually public 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.

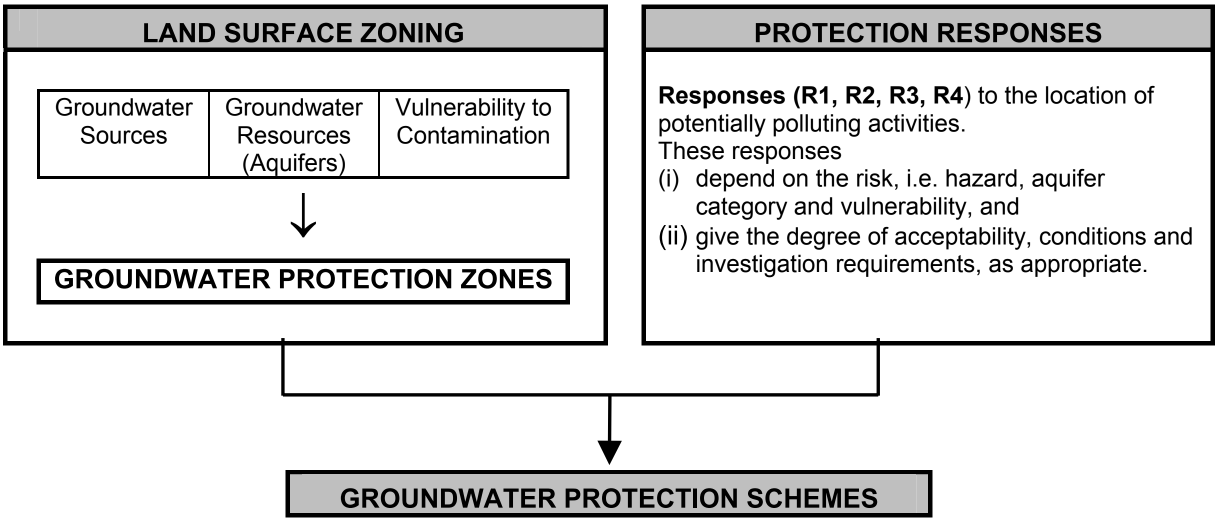

Figure 1: Summary of Components of Groundwater Protection Scheme

The vulnerability maps are integrated with each of the other two to give maps showing **groundwater protection zones**. These include source protection zones and resource protection zones.

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities, which describes: (i) the degree of acceptability of each activity; (ii) the conditions to be applied; and, in some instances (iii) the investigations that may be necessary prior to decision-making.

While the two components (the protection zone maps and the groundwater protection responses) are separate, they are incorporated together and closely interlinked in a protection scheme.

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

1.5 Objectives of the North Tipperary Groundwater Protection Scheme

The overall aim of the groundwater protection scheme is to preserve the quality of groundwater in North Tipperary for drinking purposes and other beneficial uses, and for the benefit of present and future generations.

The objectives, which are interrelated, are as follows:

- to assist the statutory authorities in meeting their responsibilities for the protection and conservation of groundwater resources;
- to provide geological and hydrogeological information for the planning process, so that potentially polluting developments can be located and controlled in an environmentally acceptable way;
- to integrate the factors associated with groundwater contamination risk, to focus attention on the higher risk areas and activities, and to provide a logical structure within which contamination control measures can be selected.

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

1.6 Scope of North Tipperary Groundwater Protection Scheme

The groundwater protection scheme is the result of co-operation between North Tipperary County Council and the Geological Survey of Ireland. North Tipperary covers the area shown in Figure 2 below. It is one of two local authority areas within County Tipperary (the other being South Tipperary). North Tipperary extends from the northern county boundary to just south of Thurles. It is bordered by the River Shannon on its northwestern boundary with Co. Galway, by Lough Derg on its boundary with Co. Clare and, to the southwest, by Co. Limerick, Co. Offaly, Co. Laois and a small part of Co. Kilkenny border North Tipperary from the northeast to the east.

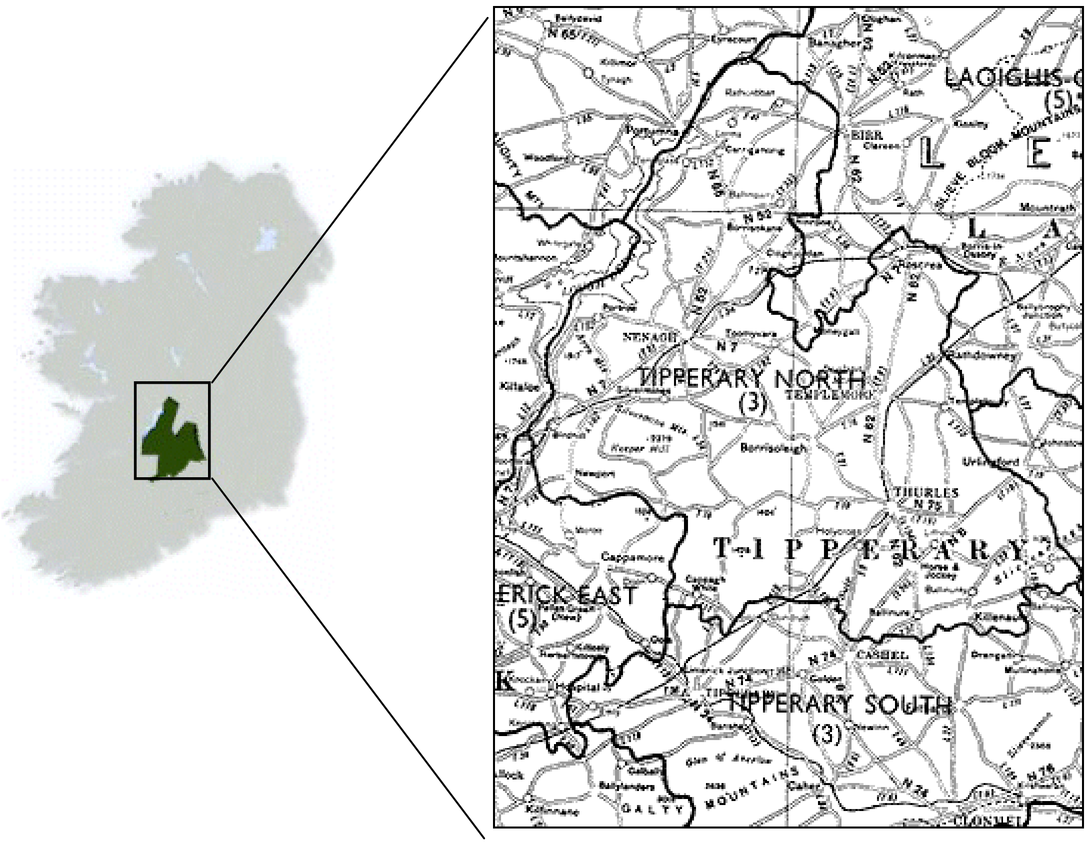

Figure 2: Location and extent of North County Tipperary

1.6.1 Interim nature of the Scheme

A full or 'comprehensive' Groundwater Protection Scheme requires certain minimum data availability. The most important elements in delineating the groundwater vulnerability of an area are outcrop and depth to bedrock maps, along with soil and subsoil maps. This is illustrated below in Figure 3. However, this level of detailed information was not available for North Tipperary at the inception of this project. Because of this, it was proposed that the Groundwater Protection Scheme for North Co. Tipperary be drafted as an 'interim' scheme until further information on subsoils (to be compiled by Teagasc as part of their F.I.P.S - IFS project; in progress) and their permeabilities become available.

The interim scheme as presented here assesses the bedrock units and delineates the aquifers. Sufficient information is not yet available to delineate regional vulnerability based on permeabilities and thicknesses of subsoils for North Tipperary. Once this has been done, this scheme can be upgraded to a comprehensive one. For now, only areas of Extreme (E) groundwater vulnerability are delineated. This has implications for land-use planning which are discussed in the Groundwater Vulnerability and Groundwater Protection Zone chapters of this report.

The available geological and hydrogeological data for North Tipperary are therefore interpreted to enable:

- delineation of aquifers;
- assessment of the groundwater vulnerability to contamination by delineating “interim” vulnerability areas which will highlight areas of extreme vulnerability *only*, due to the lack of detailed subsoil (Quaternary) mapping for North Tipperary;
- delineation of protection areas around and reports written for nine public supply sources – Aglish, Borrisokane, Borrisoleigh, Lorrha, Templederry, Templemore (College Hill), Tobernaloo (Thurles), Toomyvara and Two-Mile-Borris;
- 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 should enable the balancing of interests between development and environmental protection.

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

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

Primary Data or Basic Maps:

- Bedrock geology map (Map 1)
- Outcrop and depth to bedrock map (Map 2)
- Hydrogeological data map (Map 3)

Derived or Interpretative Maps

- Aquifer map (Map 4)
- Interim groundwater vulnerability map (Map 5)

Land-use Planning Map

- Interim groundwater protection zones map (Map 6)

The protection scheme incorporates these outputs into a digital Geographical Information System (GIS) dataset, registered to the standard Ordnance Survey (1:50,000) map base. This GIS dataset is designed to be compatible with the GIS systems in the Local Authorities. As well as the interpretive maps described above, the GIS incorporates groundwater protection responses, for each protection zone, for **landfill**, EPA-licensable **landspreading** of organic wastes, and **on-site wastewater treatment systems for single houses** (‘septic tanks’). It is envisaged that the protection responses will be the feature most of interest to the Local Authorities, as they have direct relevance to the planning process.

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

It is important to recognise that detailed regional hydrogeological investigations in North Tipperary are limited to a number of public supply sources, some environmental impact statements and research publications. One valuable source of information is a set of reports on the groundwater resources in the Templemore-Borrisoleigh area by K.T. Cullen (1986) and M.C. O'Sullivan (1991, 1994). These reports, which investigate local aquifer properties through pump tests and site investigations, and summarise the general aquifer characteristics of the area, including water quality information, provide a good starting point for assessing the hydrogeology of the Templemore-Borrisoleigh area. Despite this information, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of North Tipperary. However, this report provides a good basis for strategic decision-making and for site specific investigations.

1.7 North County Tipperary Development Plan

This is the groundwater protection scheme referred to in the Proposed Draft North Tipperary County Council Development Plan.

1.8 Structure of Report

The structure of this report is based on the information and mapping requirements for land surface zoning. The groundwater resources protection zone map (Map 6) is a land-use planning map and is the ultimate or final map as it is obtained by combining the aquifer (Map 4) and interim vulnerability maps (Map 5). The aquifer map boundaries, in turn, are based on the bedrock map (Map 1) boundaries and the aquifer categories are obtained from an assessment of the available hydrogeological data (Map 3). The interim vulnerability map is based on the depth to rock map (Map 2) and on an assessment of specifically relevant permeability and karstification information. This is illustrated in Figure 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. This is illustrated in Figure 4.

Chapter 2 provides brief summaries of the bedrock and subsoils geology. Chapter 3 summarises and assesses the hydrogeological data for the different rock units, gives the basis behind each of the aquifer categories, and describes the potential for future groundwater development. Chapter 4 gives a summary of a separate report on the hydrochemistry and groundwater quality in North Tipperary. Chapter 5 gives the basis behind the vulnerability categories and how the intervening areas between the areas of extreme vulnerability should be dealt with. Chapter 6 draws the whole lot together and summarises the final groundwater protection zones present in North Tipperary. Assessment of the hydrochemistry and water quality in North Tipperary is presented in a separate report. Similarly, the reports outlining the protection of the nine public supplies are provided separately.

1.9 Acknowledgements

The preparation of this groundwater protection scheme involved contributions and assistance from many people:

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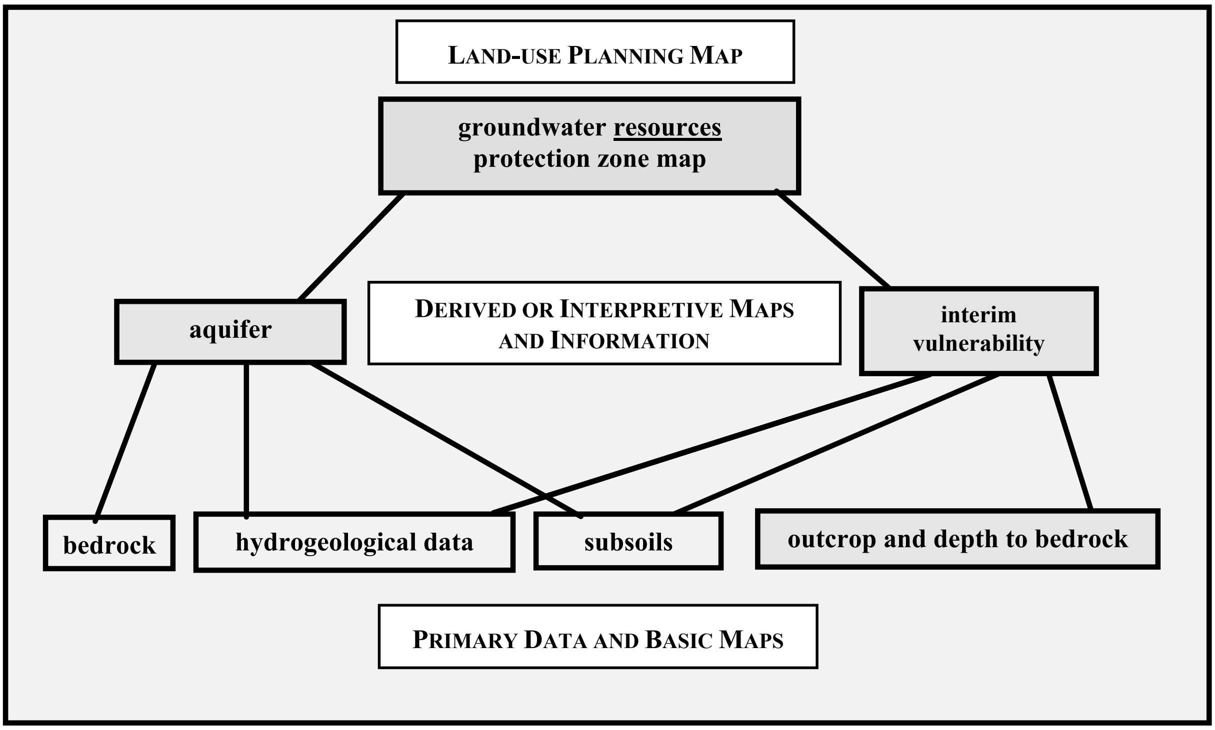


Figure 3: Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

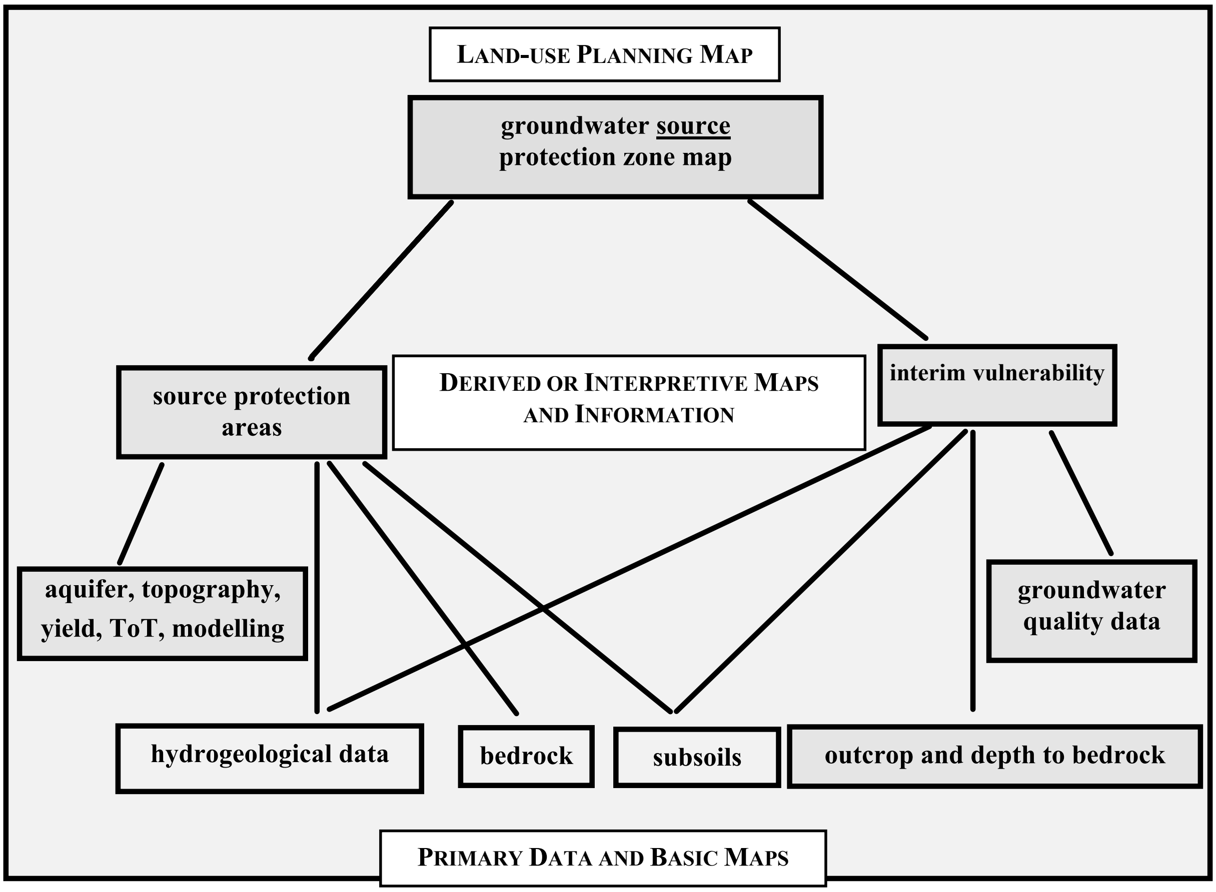


Figure 4: Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

2 Geology

2.1 Introduction

This chapter presents a brief description of the elements of the bedrock geology of North Tipperary that are relevant to the hydrogeology, namely the rock composition (lithology) and the rock deformation that occurred during the long geological history of the county. A brief outline of the subsoil types that occur throughout the county is also given.

2.2 Bedrock Geology

The rocks range in age from Silurian (c. 430 million years old) to the Upper Carboniferous (c. 310 million years old) and are mainly sedimentary in origin, with just a few very small occurrences of volcanic rocks in isolated areas. Consisting of limestones, sandstones and shales, the sedimentary rocks reflect deposition in both marine and terrestrial environments.

The striking variations in topography in North Tipperary can be related directly to the underlying bedrock geology. The Devonian and even older Silurian rocks form the upland areas such as the Arra, Silvermine and Devilsbit Mountains which run across the centre of the county, separating the limestone lowlands in the northwest and southeast. The Devonian (Old Red Sandstone) and Silurian (slate and greywacke) rocks are less readily weathered and eroded than the limestones which are susceptible to dissolution (dissolving of the limestone by rainwater).

The geology of the county is complex with both temporal and lateral changes in rock composition. A brief description of the different rock units and their inter-relationships is given in this report; a more detailed description is given in "Geology of Tipperary (Archer *et al.*, 1996) and in Brück (1986). In describing the rock units, the emphasis is placed on the rock lithology or composition because this is the feature of most relevance to groundwater flow. The formal rock formation name and letter code is also given (Table 1) to enable hydrogeologists to link the brief descriptions in this report to the more detailed descriptions in the literature. The rocks are described in groups according to their age, starting with the oldest:

(i) Silurian mudstones and siltstones
(ii) Devonian Old Red Sandstones;
(iii) Lower Carboniferous transitional sandstones and mudstones
and Lower Carboniferous Limestones.

The bedrock geology of the area is shown in Map 1. This map was compiled from:

- Bedrock Geology 1:100,000 scale GSI map series, Sheet 18 (Archer *et al.*, 1999)
- A published map and guide for the area north of sheet 18 by Brück (1986)
- unpublished field mapping (GSI, c. 1880's)
- "Chevron" series (sheet 15; Hitzman, 1994)

Table 1: Bedrock Succession in North Tipperary

Age	(million years)	Thickness (m)	Main Succession						
Lower Carboniferous	c.336		**Coolross Calp Fmn (CDcr)**	Dark grey & black 'earthy' muddy limestone with no chert					
		120	**Borrisokane Calcarenite Fmn (BK)**	Pale grey, coarse-, sometimes medium-grained, well-sorted calcarenite	**Ballyadams Fmn (BM)** 200m +	Pale grey crinoidal wackestone/ packstone limestone with clay wayboards			**Calp Formation (CD)** Dark grey to black limestone and shale **Lorrha Calp Fmn (CDlr)** 400m thick Dark grey & black 'earthy' muddy limestone with chert
		50 – 260	**Slevoir Limestone-Shale Fmn (SV)**	Dark grey homogenous muddy limestone & calcareous shales	**Durrow Fmn (DW)** 200m	Shaly fossiliferous & oolitic limestone			
	341	40	**Lismaline Micrite Fmn (LM)**	Medium grey, well-bedded "birds-eye" micrite	**Aghmacart Fmn (AG)** up to 200m	Dark shaly micrite, peloidal limestone			
		90	**Terryglass Calcarenite Fmn (TS)**	Grey, thick-bedded well sorted oolitic calcarenite	**Crosspatrick Fmn (CS)** up to 60m	Pale, cherty crinoidal limestone	**Lough Gur Fmn (LR)**	Pale grey cherty crinoidal limestone	
					Suir Fmn (SU) up to 250m	Pale cross-bedded oolitic limestone			
		0 – 180	**Oldcourt Fmn (OC)**	Grey limestone & dark chert	**Athassel Fmn (AT)** 250m +	Dark shaly cherty limestone			
		up to 300	**Waulsortian Limestones (WA)**	Massive, unbedded "mudbank" facies limestone, often dolomitised	**Waulsortian Volcanics (WAv)** **Dolomitised Waulsortian Limestone (WAdo)**				

Table 1 Continued: Bedrock Succession in North Tipperary

Age	(million years)	Thickness (m)	Main Succession					
Lower Carboniferous		300	**Ballysteen Fmn (BA)**	Fossiliferous dark grey muddy limestone becoming increasingly muddy upwards	**Ballynash Member (BAbn)**	Wavy-bedded cherty limestone, thin shale 5–100m		
					Lisduff Oolite Member (BAld)	Oolitic limestone 0–100 m		
	354	20 – 35	**Lower Limestone Shale (LLS)**	Sandstones, mudstones, & thin limestones				
Devonian			**Old Red Sandstone (ORS)**	Red conglomerate, sandstone, mudstone				
		70 – 110	**Cadamstown Fmn (CW)**	Pale & red sandstone, grit & claystone				
	417	300	**Cappagh White Sandstone Fmn (CA)**	Red & white sandstone, conglomerate	**Devils Bit Fmn (DV)**	Conglomerate & coarse sandstone	**Keeper Hill Fmn (KH)**	Pale & red sandstone, grit & claystone
Silurian			**Hollyford Fmn (HF)**	Greywacke, siltstone & grit				
			Slieve Bernagh Fmn (SB)	Slaty banded siltstones & fine to conglomeratic greywackes				
			Broadford Fmn (BF)	Fine to conglomeratic graded greywacke				
		130	**Fairyhill Fmn (FC)**	Chert, sandstone and quartz conglomerate				
	425	400	**Knockshigowna Fmn (KG)**	Greywacke sandstone, siltstone and slate				

The rocks of North Tipperary are almost entirely comprised of terrestrial and marine sedimentary rocks. The GSI and others have mapped these rocks, and this Geology chapter is a compilation of previous work and an integration of these works into one report. As such, this report is made up of elements from several sources, principally GSI Sheet 18 (Smith and Sleeman, 1996), Hitzman's (1994) sheet 15, and Brück (1986). These maps represent the most recently compiled geological information.

2.2.1 Silurian System Rocks

Knockshigowna Formation (KG)

This formation comprises green-grey to olive-grey greywacke-sandstones, greywacke-siltstones and slates and is thought to be 400 m thick – comparable to the rocks in the Slieve Bloom inlier, although older in age (upper Wenlock) and different in lithology.

Fairyhill Formation (FC)

This conglomerate contains abundant, mostly rounded clasts of pebble grade comprising chert, jasper, sandstone and vein quartz in a variably coloured grey to red sandy matrix. It is estimated to be 130 m thick. Again, these rocks resemble the Silurian of the Slieve Bloom Gledossaun Member.

Broadford Formation (BF)

This formation is dominated by argillaceous material (60% in outcrop) but also contains coarser-grained clastics, with predominantly fine-grained and occasionally medium-grained greywackes (shown as **gw** on the map and rare granule-grade conglomerates shown as **cg** on the map).

Slieve Bernagh Formation (SB)

The lower part of this formation is comprised of conglomerates of mainly granule-grade clasts with dispersed pebbles (**cg** on the map). The matrix is sandy, showing both grading and slumping and varying amounts of mud flake inclusions. The clasts are composed of igneous and metamorphic rocks in addition to vein quartz. Apart from the conglomerates, the formation consists largely of laminated siltstones and mudstones. South of the Portroe Fault these lithologies display a steep slaty cleavage. These slates are commonly referred to as the "Killaloe Slates". Fine-grained greywackes also occur with the silt-mudstone slates (**gw** on map) (GSI sheet 18).

Hollyford Formation (HF)

This formation is best known for its greywacke sandstones with several quarries in operation (Fantane, GR 19910 16850; Latteragh, GR 19580 17280 and Birdhill, GR 17220 16880). It is, however, dominated by finer-grained lithologies. Greenish-grey mudstones interbedded with thin, turbiditic siltstones and/or charcoal-grey, laminated siltstones predominate in some sections, but in others the mudstones and siltstones are interbedded with numerous thin, fine sand-grade, greywacke sandstones. The thick-bedded and usually coarser greywackes for which the formation is best known from quarry localities appear to be randomly distributed throughout the formation. These greywackes are usually bluish or greenish-grey but can be reddened to perhaps 24 m below the overlying Old Red Sandstone, and are commonly brownish from modern weathering.

Rare occurrences of very soft, water-saturated, white to whitish-green beds of bentonite clay, which range from a few centimetres to 0.45 m thick, may be found in the centre of the inlier.

2.2.2 Devonian System Rocks

The Devonian rocks rest unconformably on the underlying folded Silurian rocks.

Devilsbit Formation (DV)

This is thought to be the oldest of the Devonian sandstones in the Irish Midlands and is found only on the Devilsbit Mountain, with the "Bit" or col resulting from the weathering-out of a fault running through the mountain. Only 17 metres of the formation has survived erosion.

Old Red Sandstone (ORS), including **Cappagh White Sandstone Formation (CA), Cadamstown Formation (CW),** and **Keeper Hill Formation (KH)**

Rocks of Devonian age, the Old Red Sandstone (ORS), vary somewhat in lithology in different parts of County Tipperary, ranging from claystones through siltstones/and mudstones and sandstones to coarse conglomerates, often in fining-upwards sequences. Actual colours of the rocks can vary from red or purplish-red to yellowish-white or buff. Brief descriptions of the different rock units and their locations are given in Table 2.

Table 2: Old Red Sandstone rocks in North Tipperary

Rock Formation	Thickness (m)	Lithology	Location
Cappagh White (CA)	300	Coarse conglomerates overlain by red sandstones and interbedded black mudstones	Cappagh White
Cadamstown (CW)	70 to 110	Medium to coarse grained, pale often creamy coloured sandstone with siltstones & mudstones.	Moneygall
Keeper Hill (KH)		Pale and red sandstone, grit and claystone	Slieve Felim
Undifferentiated Red Sandstones (ORS)	up to 2000	Purple, red and grey sandstones, siltstones and conglomerates with interbedded mudstones	Arra Mountains

2.2.3 Lower Carboniferous Rocks

Lower Limestone Shale (LLS)

This suite of grey sandstones, siltstones and shales marks the transition from the Old Red Sandstones deposited in a semi-arid river environment to the ensuing limestone sequence formed in shallow seas. These rocks are undifferentiated in Co. Tipperary due to poor exposure in outcrop, but include rocks known from subsurface information as the Mellon House, Ringmoylan Shale, and Ballyvergin Shale Formations. The whole Lower Limestone Shale is thin, ranging between about 20–35 m in thickness.

Ballysteen Formation (BA)

This formation is generally characterised by well-bedded blue-grey to mid-grey argillaceous limestones. In quarries and stream sections they are characterised by ledges ca. 0.5 m thick. The formation is informally subdivided into upper and lower parts by one or more intermittently developed oolitic horizons, described as the Lisduff Oolite Member. Another distinct sequence, often developed at the top of the formation, is also separately described as the Ballynash Member.

Lisduff Oolite Member (BAld)

In local areas (especially around Templemore) conditions favoured the formation of oolites and fossiliferous coarse-grained limestones. Typically these rocks comprise thick bedded, pale blue-grey, cross-bedded, well-jointed oolite of variable thickness. At Galmoy Mine the oolite is 100 m thick; but at Lisheen it occurs as two separate horizons which are thinner overall. Where oolites did not develop, this member is more shaly. Unusually for the Ballysteen Limestone, this member shows some evidence of karstification with a cave system occurring at Ballagh (GR 20100 14870).

Ballynash Member (BAbn)

This "wavy nodular member" is often found at the top of the Ballysteen Formation and is associated with the transition to the Waulsortian Limestone. This member is characterised by shales and nodular, partly silicified micrites (mud grade limestones). It ranges in thickness from a few metres to probably over a hundred metres where, at the edge of the Waulsortian deposits, this "reef equivalent" limestone occupies the position that the Waulsortian reef does laterally.

Waulsortian Limestone (WA)

This widely-developed limestone is very characteristic of Irish limestones, with more of it occurring here than anywhere else in the world, including its type area of Waulsort in Belgium. It consists of accumulations or banks of massive but subtly bedded, often steep-sided mounds that coalesce into a thick unit surrounded by varied but related limestones. The dominant lithology is a very pale-grey micrite with large sparry masses, rich in fossils, deposited as a fine multi-component carbonate mud. Drilling in the Waulsortian Limestone has shown it can be at least 300 m thick, but a thickness of 200 m is probably more typical.

Topographically, the Waulsortian is expressed as abrupt and rounded hills or knobs and knolls, often reflecting the original mudbank nature of the formation. The Waulsortian is frequently dolomitised at both local and regional scale. The Dolomitised Waulsortian (**WAdo**) is frequently friable, weathered to yellow-buff or even black in outcrop. It is generally more porous and weathers more easily and is not known well in outcrop; for this reason the area of dolomitisation in the region may be more extensive than is known at present. Waulsortian limestones are also karstified and in general are characterised by large solution fissures, cavities, caves and swallow holes and collapses. However, there are very few recorded karst features in North Tipperary.

Oldcourt Formation (OC)

This formation occurs principally as cherty calcarenites (carbonate sands) deposited in hollows above the Waulsortian Limestones. It represents a mid- or distal carbonate ramp deposit in between the shallow Waulsortian Reef and the deep-water Calp deposits.

Terryglass Calcarenite Formation (TS)

This formation comprises medium to pale grey, very well sorted, medium to fine grain calcarenites which are more or less oolitic. The unit is thickly bedded (0.5 to 2.0 m) with irregular bedding planes which often have the appearance of joints. Commonly, it is referred to as "Bellstone", as loose slabs ring like a bell when struck with a hammer. It varies in thickness from 0 to 200 m, with a thickness of 90 m in the area between Terryglass and Lough Derg. Found overlying the Waulsortian Mudbank and Oldcourt Cherty Limestone units, it has been dated as being entirely Chadian (Lower Viséan) in age (Brück, 1986).

Athassel Formation (AT)

These basinal, fine, very cherty dark limestones are abruptly interbedded with volcanic ashes and lavas, and coarser oolitic limestones. The formation is thought to be at least 250 m thick

Suir Formation (SU)

The Suir Formation comprises pellety bioclastic or cross-bedded oolitic limestones up to 250 m thick.

Crosspatrick Formation (CS)

This formation consists of pale, well-bedded crinoidal limestones, often with copious seams and nodules of blue or black chert. These beds are often draped at considerable angles over the mound topography of the Waulsortian and, in this form, they resemble the Ballynash Member, although they are normally paler, more crinoidal and much less shaly.

Lough Gur Formation (LR)

These are cherty Basinal Limestones with several varied lithologies, and usually overlie the Waulsortian Limestones.

Lismaline Micrite Formation (LM)

This formation comprises homogenous medium-grey micrite with a conchoidal fracture and occasionally displays ‘bird’s eye’ structures. The micrite is well-bedded with planar to undulating beds ranging from 10cm to 1m thick, but typically *c.* 35 cm. Closely spaced near-vertical jointing is common. The formation thickness is generally 40 m.

Aghmacart Formation (AG)

The Aghmacart Formation comprises dark shaly micrite and peloidal limestones, often dolomitised, up to 200m thick in the Durrow area.

Slevoir Limestone-Shale Formation (SV)

In general this formation comprises dark grey homogenous argillaceous limestones and calcareous shales in equal proportions. Beds range in thickness from a few centimetres to 1 m. These rocks are generally more coarsely shelly than the older limestones. The formation ranges in thickness from 50 m east of Lough Derg to around 260 m thick nearer Lough Derg and in the Borrisokane Syncline area. In the Borrisokane Syncline the formation rests everywhere on the Lismaline Micrite and passes up into the Borrisokane Calcarenite Formation. East of Lough Derg, however, it rests in the west on the micrites but farther east on the Waulsortian Limestones.

Durrow Formation (DW)

The shaly fossiliferous oolitic limestones of the Durrow Formation mark a transition to more open water limestones than the underlying succession.

Borrisokane Calcarenite Formation (BK)

This formation is the youngest of the rocks in the Borrisokane Syncline. It generally is a coarse- (occasionally medium-) grained, pale grey well-sorted calcarenite (Brück, 1982). Bedding is usually 1 m apart, with planes generally irregular. It occasionally yields large fossils but fossil material most commonly occurs as small fragments.

Ballyadams Formation (BM)

This formation is the classic "Burren" type limestone. Pale grey, thick-bedded clean fossiliferous limestone is intermittently separated by clay 'wayboards' (derived from volcanic ash). This limestone is thought to have formed in a shallow tropical sea with clay representing soil development during exposure above the water level. With an average thickness 200 m, its only occurrence in North Tipperary is just southeast of Holycross in the Moycarkey area.

Calp (CD)

This formation is generally described as a dark, argillaceous shaly limestone with some conglomeratic horizons.

Lorrha Calp Formation (CDlr)

This formation and the overlying Coolross Calp Formation are approximately equivalent to the Calp as mapped by the GSI and consists largely of limestones with rare thin shales. The limestones are very well sorted, dark grey, medium grained calcarenites with frequent bands and nodules of black chert. The limestones are well bedded, with beds ranging form 0.5 to 1 m in thickness. Rare shale beds range from 2 cm to 20 cm in thickness.

These limestones are very similar to the Oldcourt cherty limestone Formation, and several areas mapped by Brück (1986) as being Lorrha Calp, including south of Nenagh have since been mapped as Oldcourt Cherty Limestone by the GSI. However, Brück describes the type area as the region southeast of Lorrha and therefore not all areas of Lorrha Calp have been equated to Oldcourt Cherty Limestone.

Coolross Calp Formation (CDcr)

This formation is very poorly exposed and hence is poorly described. It is a dark grey and black "earthy" argillaceous limestone with no chert present. Beds are 0.5 to 1 m thick and locally are flaggy.

2.2.4 Igneous Rocks

There is only one occurrence of volcanic rocks known in North Tipperary, which occurs at Pollagh, 1 km west of Birdhill (GR 169200 168500). This appears to be a circular, perhaps volcanic pipe, formation but has no dramatic topographic expression.

2.2.5 Structural History

The regional structure of the area is influenced by two major structural events known as the Caledonian and Variscan orogenies (mountain building events). The effects of the Caledonian deformation can be seen in the Silurian rocks, which form the uplands for most of the county such as the Silvermine Mountains or the uplands south of Roscrea, which are tightly folded and cleaved in a northwest-southeast direction. The Variscan deformation of the Devonian and Carboniferous rocks is more subtle, with folds of large amplitudes and wavelengths. With both the early and late folding, associated tension jointing is found and is most intense at the peaks and troughs of folds.

Later faulting occurs along a regional northwest-southeast trend. These faults are generally planar and near vertical and result in many lithologies being compartmentalised or isolated and so the geology in some areas can be very varied or heterogeneous.

2.3 Subsoil Geology

This section deals primarily with the geological materials that lie above the bedrock and beneath the topsoil, referred to here as subsoils. The subsoils were deposited during the

Quaternary period of geological history which encompasses the last 1.6 million years and is sub-divided into the Pleistocene (1.6–10,000 BP) and the more recent Holocene (10,000 BP to the present). The Pleistocene, more commonly known as the 'Ice Age', was a period of intense glaciation separated by warmer interglacial periods. The Holocene, or post-glacial, saw the onset of a warmer and wetter climate approaching that which we have today.

During the Pleistocene, the glaciers and ice sheets laid down a wide range of deposits which differ in thickness, extent and lithology. Material for the deposits originated from fresh and weathered bedrock and previously deposited materials. They were subjected to different processes within (englacial), beneath (subglacial) and around the ice (ice-marginal). Some were deposited randomly and so are unsorted and have variable grain sizes, while others were deposited by water in and around the ice sheets and are relatively well sorted and often coarse grained. Features such as moraines, eskers and drumlins are less widespread in the area than in other counties. However, there are eskers mapped in the vicinity of Birr, and the area north of Nenagh (Synge, 1979; Daly, 1979; Teagasc, 1993), which can be clearly seen from the road. The only drumlins mapped in North Tipperary are those on the southern side of the Arra Mountains in the southwest of the county.

During the Holocene, rivers have deposited alluvial and estuarine deposits that vary from fine-grained to coarse-grained materials, depending on the energy of the system. Peats have also formed in low-lying poorly drained hollows, former lakes, and on high ground where precipitation is high.

2.3.1 Data Availability

Very little subsoil (Quaternary) mapping has been carried out in the North County Tipperary area, and the availability of this and any other compiled data on subsoils was relatively sparse. Data for the interim depth to rock maps were generated through the compilation of available data on outcrops, well and geotechnical data. As part of the interim groundwater protection scheme, only depth to bedrock of 3 m and less has been delineated. Production of a subsoil map has not been intended as part of this scheme, and the interim vulnerability map (explained in Section 1.6.1) is based on the existing drift mapping, outcrops, depth to rock compilation and available well data.

The depth to bedrock compilation programme involved:

- compilation of all existing archival GSI map data, borehole and outcrop data;
- a drilling programme of approximately 180 holes drilled to get an estimate of subsoil thickness to at least 3.5 m and to collect samples at depth;
- collection of samples for future potential laboratory analysis of the grain size characteristics of the samples;
- drawing of depth-to-rock contours using outcrop, well and geotechnical data, previously-mapped study areas, field observations, and digital aerial photographs;
- digitising, editing and checking the maps.

The outcrops and well data were compiled and digitised at 1:25,000 scale, while the depth-to-rock map was contoured at 1:50,000 scale. (The depth-to-rock contour map is not a stand-alone map but is an integral part of the vulnerability map.)

2.3.2 Subsoil Types

The main subsoil types in North County Tipperary are:

- till of differing parent lithologies (i.e. limestone or sandstone and shale) and textures
- sand/gravel

- alluvium
- peat

Areas where bedrock comes within 1 m of the surface, delineated as areas of 'rock close', were also used to help in contouring depth to bedrock.

2.3.2.1 Till

Till (often referred to as boulder clay) is by far the most widespread subsoil in North County Tipperary – Teagasc's (1993) mapping shows that more than 65% of soils in the county are derived from till parent material. It is a diverse material that is deposited subglacially, and has a wide range of characteristics due to the variety of parent materials and different processes of deposition. In North Tipperary, the tills are expressed morphologically by draping the rolling lowlands of the area. No detailed information is available on the morphology of subsoil deposits in North Tipperary.

Till can be classified on the basis of the dominant clast lithology (i.e. stone type) and the matrix composition (texture), e.g. silty limestone till is a boulder clay derived principally from limestone bedrock which has a high percentage of silt in the matrix. The subdivision of tills based on matrix composition depends on the proportions of fine gravel, sand, silt and clay particles present in the matrix. The method of determining the categories is by visual and manual assessment on-site and using laboratory particle size analysis where appropriate.

Limestone Tills (with some sandstone and shale)

Limestone tills are derived from the underlying Carboniferous limestone bedrock. In bedrock boundary areas, however, where they have been transported onto an adjacent different bedrock type material from these different rocks is also incorporated to greater or lesser degrees. Together with shaly Limestone tills (below), soils with this parent material cover about 40–45% of North County Tipperary.

The Soil Map (Teagasc, 1993) shows that nearly all of the limestone lowlands between just south of Nenagh and the Little Brosna River are covered by 'acid brown earths and grey brown podzolics' (with limited gley soil areas). The soils' parent tills are derived predominantly from clean limestones (e.g., Waulsortian Limestone, and Borrisokane Calcarenite, Terryglass Calcarenite and Oldcourt Formations). The boundary with other soil types is marked by a change in bedrock lithology in the west (sandstone and mudstone Arra Mountains) and east (sandstone and mudstone in the Knockanora and Borrisnoe foothills).

Soils with Limestone till parent material are also mapped as occurring over the southeastern part of North County Tipperary, roughly in a north-south strip east of Thurles. These tills would be derived from Waulsortian Limestone, dolomite, and the Crosspatrick, Aghmacart, Durrow and Ballyadams Formations.

Limestone tills vary from light-brown/grey to dark brown/black in colour, depending on the parent material and the weathering processes that have occurred. Textures may vary from sandy to silty but in the absence of detailed information it is difficult to give an idea on the range for the whole county. Tills found close to bedrock and where the deposits are relatively thin, comprise a coarse matrix with angular clasts and can be described as broken-up bedrock or immature till.

Shaly Limestone Tills

Shaly Limestone tills occur adjacent to the Limestone tills. They are derived predominantly from the underlying Carboniferous muddy limestone bedrock, although in bedrock boundary areas, where they have been transported onto an adjacent different bedrock type, material from these different rocks (for example the Lower Limestone Shale) is also incorporated. Additionally, transport of non-carbonate rock types onto limestone areas can occur due to glacier movement. In North Tipperary, the direction of glaciation was mainly northwest to southeast.

The Soil Map (Teagasc, 1993) indicates that shaly Limestone tills occur from just south of Nenagh down to the Silvermines Mountains and the boundary between Carboniferous limestones and Devonian and Silurian sandstones and mudstones. Although these deposits overlie clean limestones, it is probable that glacial action transported muddy and sandy rock fragments from the Arra Mountains to the west.

Soils with shaly limestone till parent material are also mapped as occurring over the southeastern part of North Tipperary, roughly in a strip between west of Thurles and the Cromoge River. These tills would be derived mainly from shaly limestones, such as the Ballysteen Formation, although some non-limestone material may be derived from the uplands to the west of the Cromoge River.

Shale Tills

Tills comprised mainly of shales (from Silurian siltstones and mudstones and fine-grained Old Red Sandstone rocks) are generally found overlying areas of Silurian and Old Red Sandstone age rocks. The Soil Map (Teagasc, 1993) shows that the Arra Mountains, the Silvermines Mountains, Mother Mountain and Knockalough are covered with a complex inter-arrangement of soils having a shale till parent material, and post-glacial peats (see section 2.3.2.4).

The soils derived from shale tills cover about 25% of North County Tipperary, and comprise ‘brown earth, brown podzolics, podzolics and gleys’. Although the dominant material in the tills is shale, they generally are a mixture of limestone and sandstone/siltstone/shale.

Sandstone/Sandstone-Shale Tills

The Soil Map (Teagasc, 1993) shows that sandstone-dominated sills (incorporating various proportions of siltstone and shale from Devonian Sandstones/ Silurian Siltstones) are found only overlying areas of Old Red Sandstone age rocks. These soils occupy a relatively small area of North Tipperary (6%). Along the southern County border, they occur in the far south west (south of Keeper Hill, and also northwest of Newport) and centre of the county (near Moher Hill and Upperchuch). They are also mapped as occurring between Templemore and Roscrea in the east of the county.

2.3.2.2 Sand/gravel

Deposition of sand/gravel takes place mainly when the glaciers are melting. This gives rise to large volumes of meltwaters with great erosive and transporting power. The sands and gravels deposited in this high-energy environment are primarily well-rounded and well-sorted gravels with sand, with the finer fractions of clay and silt washed out.

No detailed mapping of the gravel deposits of North Tipperary has been carried out, but large-scale mapping by E.P. Daly (1979), constrained by the GSI well data base, allows delineation of the larger sand and gravel bodies in the county. The nature of those deposits that *are* known to exist has not been looked at in detail regarding permeabilities and particle size analysis. Known sand and gravel deposits occur around Roscrea, as well as along the east-west valley north of the Silvermines Mountains, and at Birdhill in the southwest of the county. Smaller sand and gravel deposits can be found along the Little Brosna River north and west of Birr and at Ardcroney, as well as near Borrisoleigh on the River Cromoge, and along parts of the River Suir (Synge, 1979).

A second type of sand/gravel is referred to as morainic sand/gravel. These sediments are laid down either at the ice-margin or as heaps of sediment as the glacier retreats. They are not as well sorted and washed, therefore containing significant clay and silt fractions, and may have tills deposited amongst them in places. Deposits of this type may yet be found in North Tipperary, but in the absence of detailed information they are not discussed here.

2.3.2.3 Alluvial Deposits

Alluvial sediments are deposited by rivers and include unconsolidated materials of all grain sizes, from coarse gravels down to finer silts and clays. They may also contain organic detritus. Alluvial sediments in flood plains, where flow velocities are relatively low, are expected to be primarily silty deposits with some clay. Close to the hills and mountains, they are likely to be more sandy or gravelly, as flow velocities are faster. However, the grain size of the deposits is also controlled by the bedrock composition of the drainage region – river deposits from shale bedrock areas will be finer-grained even if a river is fast-flowing.

There are two Soil Series mapped by Teagasc (1993) as having alluvial parent material – (i) Limestone/ Sandstone/ Shale river alluvium (Camoge series) and (ii) Shale river alluvium (Feale series). The Camoge Series deposits are characteristic of river flood plains meandering through a drift-covered landscape, whilst the Feale deposits are interpreted to be associated with glacial valleys and outwash channels (Teagasc, 1993).

The shaly alluvium soils cover 2.4% of North Tipperary. They occur in the southwest of the county along two major rivers draining the Arra Mountains (which are made of Old Red Sandstone and Silurian siltstones); along the Fishmoyne and Clodiagh River basin (flowing along the boundary between sandstone and limestone bedrock); and, along the middle reaches of the Nenagh River where it drains the Silurian Hollyford Formation.

Deposits with a Limestone/Sandstone/Shale river alluvium parent material occur along rivers draining the eastern and northern parts of the County, and account for 3.7% of the soil cover in North Tipperary. For example, there are large areas mapped along the Suir River, and also along the Drish. There are also significant amounts mapped along the Ollatrim, Ballintotty, and lower reaches of the Nenagh River. Excepting the Drish, all these rivers drain or cross sandstone bedrock (LLS and ORS).

Sediments deposited by rivers occur mainly in the southern half of North Tipperary. Alluvial deposits are mostly patchy and isolated in North Tipperary, and are associated with relatively small rivers, such as the Ballyfinboy River near Borrisokane, and along the Little Brosna River. The soil types associated with these rivers belong to the Camoge Series.

2.3.2.4 Peat

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

Altogether, peats cover just over 14% of the total land in North Tipperary. Raised bog peats, which are formed where drainage gradients are low and rainfall is high, are most significant both in terms of total area covered and in the size of individual deposits. The largest deposits form the Redwood Bog alongside the Little Brosna River, the Schohaboy Bog east of Borrisokane, the Timoney/Monaincha Bog southeast of Roscrea, and cover a large (13 km x 3 km) area between Carrigahorig (GR 1900 2020) and Clonmona (GR 2020 2050).

Fen peats account for about ↓ of the peat deposits in North Tipperary but, since they are formed on river plains and in poorly-drained hollows, they are individually much smaller in area. Often associated with alluvium, estuarine deposits and marls, they are fed by alkaline groundwaters and therefore, in North Tipperary, only occur in areas underlain by limestone. The main occurrences are small patches along the Little Brosna River, along rivers draining into Slevoir Bay near Lorrha, east of Terryglass (GR 1910 1990), around 4 km southwest of Rathcabban along the Pallas River, a 6 km stretch along the Ballyfinboy River west of Borrisokane, near Templetouhy and along small stretches of the Black River and its tributaries.

Blanket bog forms peat deposits 1–2 m thick at elevations greater than about 300 m, due to high rainfall. It is found in North Tipperary on the Silvermine Mountains, mainly south of Keeper Hill, and accounts for 0.5% of the total land area.

2.3.2.5 Lake Sediments

Soils whose parent material is lake alluvium is mapped as covering only 0.42% (833 ha) of North Tipperary (Teagasc, 1993). The soils are regosols (immature) and gleys (saturated), reflecting the addition of material to the deposit during winter floodings and the proximity to rivers. The C horizon is described as marl or limestone marl (clayey), occurring in the interval around 20–80 cm below ground surface. These sediments are found in the county mainly north of a line through Nenagh, with larger occurrences being mapped at Claree Lough (GR 1850 1885), Rodeen Upper (GR 1885 1930) and along rivers: half way between Borrisokane and Ballinderry (Ballyfinboy River), and between Toomyvara and Nenagh (Ballintotty River).

2.3.3 Subsoil Thicknesses

The thickness of the subsoil (the depth to bedrock) is a critical factor in determining groundwater vulnerability. Borehole log data show that subsoil thicknesses vary considerably over the county, from very thin cover where rock is close to the surface, to depths of more than 60 m. Within the database of 922 records, about 50% of the subsoil thickness measurements (where bedrock has been reached) are 4.5 m or less.

Complex glacial processes and a variable landscape have given rise to different amounts of erosion and deposition throughout the county. The direction of ice movement and the height and competency of the bedrock, for example, have spatially influenced the thicknesses of the deposits.

An outcrop and depth-to-rock map (Map 2) has been created from the GSI databases. It highlights areas where rock crops out at surface, and plots accurately-located depth-to-rock data from borehole records. For the purpose of the Interim Groundwater Protection Scheme for North Tipperary, areas of subsoil less than 3 m thick have been delineated for the compilation of an Interim Vulnerability map (Map 5).

However, because of the interim nature of the vulnerability map, some inherent difficulties in assessing the areas of shallow and deeper subsoils must be taken into account. Areas of shallow subsoils are easier to assess because the outcrops have been mapped, and to some extent the areas of rock close to surface (<3 m) have been mapped, albeit in draft, by Teagasc or by the GSI on 6" sheets in the late 1800s. However, most of the county has not been mapped with reference to subsoils. Therefore areas of deeper overburden can only be identified from isolated boreholes which encountered bedrock.

Generally speaking sand/gravel deposits are usually more than 10 m thick, in particular where they have been laid down with tills as morainic type deposits. Thicknesses of lake, alluvial and estuarine deposits are usually unknown but it is unlikely that they are more than 10 m thick. Peat on higher ground is typically 3 m thick or less.

3 Hydrogeology and Aquifer Classification

3.1 Introduction

This chapter summarises the relevant and available hydrogeological and groundwater information for North Tipperary. A brief description of the hydrogeology of each rock unit is given, followed by the aquifer category based on the GSI aquifer classification scheme. The hydrogeological data for the county and the aquifers are shown on Maps 3 and 4 respectively.

3.2 Data Availability

Groundwater data from the GSI and County Council files were compiled and all existing well records were entered into the GSI database. Relevant data were obtained from the main hydrogeological consultants and from published hydrogeological reports on North Tipperary. Local well drillers were also consulted to record some of their experience and knowledge.

The assessment of the hydrogeology of North Tipperary is based on the following data and reports:

- Information from more than 2200 well records now held in the GSI database (‘*Geodata*’).
- Well information for local authority and group schemes sources, and for a limited number of other high yielding private wells, e.g. creameries and industry.
- Information from the well improvement grant scheme.
- Specific capacity data for some (78) wells, mainly local authority owned and grant scheme wells. (Specific capacity is the rate of abstraction per unit drawdown; the unit used is m^3/d/m.).
- Pumping tests carried out on wells at five of the public supplies during this project.
- Information on large springs and overflow information at a source spring.
- The GSI karst database.
- Reports by engineering and hydrogeological consultants.
- Relevant academic research papers.
- Local drillers’ experience.
- General hydrogeological experience of the GSI, including work carried out in adjacent counties and for other groundwater protection schemes.

3.3 Rainfall, Evapotranspiration and Potential Recharge

Mean annual rainfall in North Tipperary for 1961–1990 ranged from <1000 mm in the lower topographic areas to over 1600 mm in the mountainous areas (Met Eireann data).

The closest Met Eireann evapotranspiration (synoptic) stations are at Shannon Airport (long term mean annual potential evapotranspiration 534 mm) and at Birr, on the Offaly-North Tipperary county boundary (long term mean annual potential evapotranspiration 445 mm). Actual evapotranspiration is taken to be about 95% of the potential evapotranspiration, i.e. about 422 mm/yr. The mean annual *potential* recharge (rainfall minus actual evapotranspiration) is, therefore, estimated to be of the order of 500 to 1100 mm, with the lowest levels in the low-lying areas and the highest in the upland areas. The *actual* annual recharge to the groundwater depends on the relative rates of infiltration and surface runoff (a function of subsoil permeability and thickness, and topography).

3.4 Groundwater Usage

There appear to be 26 substantial public water schemes in North Tipperary supplied by groundwater. In total these schemes abstract some 11,000 m^3/d (2.4 Mgal/d). Based on County Council records for total water consumption in 1998, groundwater contributes 35–40% of the total public water supply in the county. The principal sources are summarised in

Table 3 and shown on Figure 5). Areas not served by the County Council and Urban District Council water schemes generally rely on individual private wells or group water schemes as the main source of water supply. Therefore, the actual proportion of the population in North Tipperary served by groundwater may be significantly higher than the figure quoted.

Table 3: Summary of Principal Public Supply Groundwater Abstractions in North Tipperary

Supply	Source	Approx. current abstraction (or available yield) [m^3/d]		Max. Yield in dry summer [m^3/d]
Aglish	Spring	155	(1 year average Jan '97–98)	
Ballinaclogh	Borehole	341	pumping rate 3,000 gph x 24 hours	
Borrisokane	Spring	866	(1 year average Dec '97–98)	
Borrisoleigh	Boreholes (2)	1030		
Cloghjordan	Spring	778	(1 year average Dec '97–98)	
Clonakenny		23		
Creamery Well (Thurles)	Spring	1400	pumping rate 13,000 gph, 24 hours	
Glenbeha (Roscrea)	Spring	1000		
Holycross	Borehole	350	350,000 l/d	
Lady's Well (Thurles)	Spring	600	pumping rate 12,000 gph, 11 hours per day	
Littleton	Borehole	170	pumping rate 30 gpm, 20-21 hours per day	
Lorrha	Borehole	285	(1 year average Aug '98 – '99)	
Moycarky/Curaheen	Borehole	180	abstraction 40,000 gpd, max yield 327 m^3/d	
Rathcabban	Borehole	100 – 132	(1 year average Jan '91–92); pumping rate 25-29,000 gpd	Dries out in hot weather
Rieska/Kilcommon	Borehole	218	around 45,000 gpd, max pumping rate 490 m^3/d	
Riverstown	Spring	155	(1 year average Aug '98–99); pumping rate 177–195 m^3/d. Farmer also takes ~360 m^3/d off sump.	
Templederry	Borehole	82	pumping 18,000 gpd for 9 hours; max yield 332 m^3/d	
Templemore	Boreholes (2)	2180	Pumped 6–14 hours/day depending on SWL	1000 m^3/d during summer 2001
Terryglass	Borehole	62	(1 year average Jan 98–99)	
Tobernaloo (Thurles)	Spring	900		720 (20% less than winter yield)
Toomyvara	Springs (4)	145	pumping rate 64 gpm for 8–9 hours per day.	Probably about 200 m^3/d
Tullahedy	Borehole	28	(13 month average March '97 – April '99)	
Two-Mile-Borris	Borehole	114	abstraction 25,000 gpd	
Upperchurch	Borehole	23	"Max yield 23 m^3/d" (i.e., 5,000 gpd)	

Figure 5: Map of North County Tipperary showing the locations of the public supply sources. (Note that some of the sources, e.g., Loughmore and Templetouhy, are now closed).

Figure 5 Map of Locations of the public Supply Sources in North County Tipperary

3.5 Aquifer Classification

3.5.1 Aquifer Categories

The GSI aquifer classification (DoELG/EPA/GSI, 1999) has three main aquifer categories, with each category sub-divided into two or three classes:

Regionally Important (R) Aquifers

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

Locally Important (L) Aquifers

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

Poor (P) Aquifers

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

Aquifers are defined on the basis of the following:

- **Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water.** Clean washed and sorted sands and gravels for example, are more permeable than poorly sorted glacial tills. Clean limestones and sandstones are also more permeable than muddy limestones, and sandstones interbedded with shales, respectively. Areas where folding and faulting has produced extensive joint systems tend to have higher permeabilities than areas where this has not occurred.
- **Hydrological indications of groundwater storage and movement.** For example, the presence of large springs can indicate a good aquifer; the absence of surface drainage can suggest high permeability; and high groundwater base flows in rivers indicates good aquifer potential.
- **Information from boreholes**, such as high permeabilities from pumping tests, specific capacities (pumping rate per unit drawdown), and well yields.

3.5.2 Bedrock Aquifers

The bedrock 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 the 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').

3.5.3 Sand/Gravel Aquifers

A sand/gravel deposit is normally classed as an aquifer if the deposit is more than one square kilometre in area and is more than 10 m thick, or has a minimum saturated thickness of at least 5 m. The thickness of the deposit is used where, as is often the case, information on the saturated thickness in unavailable. It is assumed that, in most instances, a deposit more than 10 m thick will have a saturated zone of at least 5 m. This may not be true where deposits have a high relief (for example eskers), or where deposits occur in high topographic areas, since these gravels are often dry.

Sand/gravel aquifers are therefore classified based on the areal extent of the deposit, the thickness of the saturated zone, and the estimated annual throughput (see Table 4). The permeability of the deposits can vary considerably depending on how they were laid down, so in practice the geological history of the deposit is also considered if this is known. Morainic sand/gravel for example, rarely has a high enough permeability to enable sufficient throughput to be achieved due to the presence of clays and silts. Water-lain gravels are usually better-sorted and, as a result, have a higher permeability.

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

Table 4: Sand/Gravel Aquifer Classification

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

3.5.4 Karstification

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

There are gradations of karstification in Ireland from slight to intensive. To assist in the understanding and development of regionally important limestone aquifers, the GSI has divided the broad range of karst regimes into three categories. Where karstification is slight, the limestones are similar to fissured rocks and are classed as **Rf**, although some karst features may occur. Aquifers in which karst features are more significant are classed as **Rk**.

3.5.5 Dolomitisation

Dolomitisation is a chemical process whereby calcium ions are replaced by magnesium ions in the crystal lattice of dolomite ($CaMg(CO_3)_2$). There are two different types of dolomitisation, which have significantly different effects on permeability. The first is the typical, highly weathered, yellow/orange/brown dolomitisation, usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery occurring. This type often occurs along fault zones, can cross bedrock lithology boundaries and results in unpredictable very high permeability zones. The other is a less highly weathered, stratigraphically-controlled type which is often a black colour on the surface. This type is considered to be a barrier to groundwater flow.

3.5.6 Well Productivity

In order to provide a more consistent and objective measure of an aquifer's ability to yield water, GSI has developed a 'Productivity Index' with five classes: I (highest), II, III, IV, and V (lowest) (Wright, 2000). The Productivity class is read from a 'QSC Graph', which plots well discharge (Q) against Specific Capacity (SC).

To make the best use of all relevant available information, data from groundwater investigations in neighbouring counties (Clare, Galway, Kilkenny, Laois, Limerick, Offaly & South Tipperary) have also been used. The data are summarised in Table 5.

Where is Lough Gur FMn? (LR)

Table 5: Well Productivity & Yield Categories in North Tipperary and Neighbouring Counties

Formation	*Well Productivity*						*Well Yield*					Aquifer
	I	*II*	*III*	*IV*	*V*	*Total*	*E*	*G*	*M*	*P*	*Total*	category
Borrisokane Limestone Fm (BK)	1	4	0	2	1	8	2	3	2	1	8	Rf
Ballyadams Limestone Fm (BM)	11	4	9	8	6	38	9	13	13	6	38	Rk
Terryglass Limestone (TS)	0	1	0	0	0	1						Rf
Suir Limestone (SU)												Rf
Crosspatrick Limestone Fm (CS)	1	1	2	0	0	4	2	2	0	0	4	Lm
Old Court Formation (OC)	1	1	2	0	1	5	1	2	1	1	5	Lm
Lismaline Micrite Fm (LM)	0	0	1	0	2	3						Lm
Calp-type formations (AG, AT, SV, LM, DW)	1	2	8	8	13	32	2	12	13	5	32	Ll
Coolross Calp Formation (CDcr)	1	0	5	6	11	23	1	4	8	10	23	Pl
Lorrha Calp Formatiom (CDlr)	0	3	6	5	3	17	4	5	5	3	17	Ll
Waulsortian Limestone (WA)	4	6	33	20	43	106	9	31	26	43	109	Ll
Dolomitised Waulsortian Lst (WAdo)	12	4	8	2	0	26	18	5	2	1	26	Rf
Ballysteen Formation (BA)	2	11	24	30	42	109	7	28	31	43	109	Ll
Dolomitised Ballysteen Fm (BAdo)	0	3	2	1	1	7	2	3	1	1	7	Lm
Lisduff Oolite member (BAld)	1	2	2	3	4	12	3	3	2	4	12	Lm
Lower Limestone Shale (LLS)	0	0	2	3	4	9	0	2	3	4	9	Pl
Cadamstown Fm (CW) (& equivalents)	4	6	5	3	0	18	9	7	2	0	18	Rf
Old Red Sandstone (ORS) (incl. Cappagh White (CA) & Keeper Hill (KH) formations)	1	8	14	13	22	58	6	15	19	18	58	Ll
Silurian (undifferentiated) rocks	0	0	0	3	5	8	0	1	2	6	9	Pl
Slieve Bernagh Fm (SB)	0	0	3	5	11	19	0	5	3	11	19	Pl
Broadford Fm (BF)	0	0	2	2	0	4	1	2	1	0	4	Pl
Hollyford Fm (HF)	1	1	3	3	18	26	1	1	6	18	26	Pl
Fairy Hill Conglomerate Fm (FC)						0						Pl

Knockshigowna Fm (KG)						0						Pl
Totals	51	50	53	47	46	247	72	55	60	63	250	

Notes:
1. These data are drawn from North Tipperary and neighbouring counties: Clare, Galway, Kilkenny, Laois, Limerick, Offaly, & South Tipperary.
2. Well Yields:
   E = Excellent (>400 m^3/d); **G** = Good (<400>100 m^3/d); **M** = Moderate (<100>40 m^3/d); **P** = Poor (<40 m^3/d)

3.5.7 Aquifer classifications

Although aquifer classification in North Tipperary is mainly based on wellyields and productivities, other sources of information have been used, including bedrock lithology, structural deformation, surface drainage and the degree of karstification. It should be noted that 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 obtained 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.

Well data are considered to be useful if they indicate high yields, i.e. ‘excellent’ or ‘good’, if they are failed wells or if they have a specific capacity which enables an assessment of the productivity.

Well yields should not be used on their own as the basis for allocating a rock unit to a particular aquifer category, but they do allow the three main aquifer categories to be conceptualised. Regionally important (**R**) aquifers would have (or be capable of having) a large number of wells yielding in excess of approx. 400 m^3/d (4000 gph); locally important (**L**) aquifers are capable of moderate well yields 100–400 m^3/d (1000–4000 gph); and poor (**P**) aquifers would generally have low yielding wells, i.e. less than 100 m^3/d.

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

3.6 Silurian Rocks

In general, the permeability of Silurian rocks is relatively low. Permeabilities in the upper few metres may be higher where the rocks are more weathered but this decreases rapidly with depth. Local zones of higher permeability will be present along fault zones. It is likely that the rocks in North Tipperary will be somewhat more jointed as, being closer to the Caledonian suture line, they have undergone a greater degree of structural deformation than other areas of the country (refer to Bedrock Geology, Section 2.2). Further evidence of the relatively low permeabilities is provided by the high drainage density and flashy runoff response to rainfall in areas underlain by Silurian rocks.

Groundwater in the Silurian sandstones and shales can be confined by either the clayey till and peat deposits which usually overlie the rocks, or by lower permeability bedrock layers within the sequence. Low lying areas have better groundwater development potential as artesian (flowing) conditions can be encountered and there is good natural protection afforded in the immediate vicinity of the sources by the low permeability materials. Sustainable supplies will be only be accessible from the fault zones.

The Silurian rocks in North Tipperary include five named formations: from oldest to youngest, these are: the Knockshigowna Formation, the Fairyhill Conglomerate Formation, the Broadford Formation, the Slieve Bernagh Formation, and the Hollyford Formation.

3.6.1 Knockshigowna Formation (KG) & Fairyhill Conglomerate Formation (FC)

These units have small outcrops (about 3 km^2 and <1 km^2 respectively) to the east of Ballingarry. In the absence of hydrogeological data, they are classed as **poor aquifers** which are **generally unproductive except for local zones (Pl)**.

3.6.2 Broadford Formation (BF) and Slieve Bernagh Formation (SB)

These units occur in the Arra Mountains on the eastern side of Lough Derg. There are three well grant records for the Slieve Bernagh Formation from Co. Clare, all in productivity class V. Other productivity values from the Slieve Aughty area of Co. Clare, from similar Silurian rocks, comprise 13 from classes IV and V, and two (close together) from class II.

In the absence of other hydrogeological data, they are classed as **poor aquifers** that are **generally unproductive except for local zones (Pl)**.

3.6.3 Hollyford Formation (HF)

This unit has a substantial outcrop in the Silvermine Mountains, Slieve Felim, and across much of the southern part of North Tipperary.

24 well productivity values, mainly from recent well grant records, are recorded from counties North Tipperary and Limerick: 18 class V, 3 class IV, 2 class III, and one class II. This last value is from the site investigation for the proposed Slieve Felim landfill site. But for this value, the formation could have been given the lowest aquifer classification, i.e. Pu, but it appears that there are sometimes more permeable zones.

The Hollyford Formation is therefore classed as a **poor aquifer** which **is generally unproductive except for local zones (Pl).**

3.7 Old Red Sandstone (ORS)

This includes a number of Old Red Sandstone formations.

The permeability of the ORS in general in North Tipperary appears to be relatively low due to: (a) the competent nature of the relatively coarse grained sandstones and conglomerates; and (b) the presence of interbedded mudstones and siltstones. Drainage in the areas underlain by these rocks is also often poor with most of the rainfall running off to the nearest surface watercourse.

Groundwater may be confined in places under the lower permeability units but in general most of the flow is likely to be in the upper few metres of fractured, weathered rock. The optimum area for groundwater development is likely to be in the vicinity of the boundary with the overlying Lower Limestone Shales where groundwater will be confined. Good supplies may also be obtained where storage is increased by overlying sandy gravelly sediments, or where there are relatively low permeability horizons amongst the more permeable sandstones which can create artesian conditions. These rocks are suitable for smaller public supplies and group water schemes provided that the high permeability zones can be located. They may produce iron and manganese problems but otherwise the quality will be good as groundwater residence times are usually longer than the limestones, and there is good protection given by both the overlying low permeability rocks and subsoils.

As in neighbouring counties, there is some variation of aquifer classification of the ORS in North Tipperary.

The Old Red Sandstone (undifferentiated), Keeper Hill Formation (KH), and Cappagh White Formation (CA) are classed in North Tipperary as a **locally important aquifer** which **is**

moderately productive only in local zones (Ll). The Cadamstown Formation (CW) is classed as a Regionally Important Fractured Aquifer (Rf).

3.8 Lower Limestone Shale (LLS)

The Lower Limestone Shale is a relatively thin unit (20-35m thick) with a small outcrop area and there are few available data to enable the hydrogeological characteristics to be assessed.

The high shale content, particularly at the top of the unit, suggests that the permeabilities will be low. The sandstone units at the base of the unit, however, are likely to have a greater degree of fracturing than the more plastic interbedded shales permitting small yields to be obtained in local areas. Bores should preferably be drilled through to the underlying more productive Old Red Sandstone.

Seven productivity values are recorded, one from North Tipperary, two from Limerick and three from Co. Clare. These break down as: 2 class III, 2 class IV and 3 class V.

The Lower Limestone Shale is classed as a **poor aquifer** which is **generally unproductive except for local zones (Pl)**.

3.9 Ballysteen Limestone (BA)

The permeability of the Ballysteen Limestone is somewhat variable due to the variations in lithology throughout the succession. Groundwater flow in these limestones is often concentrated in the upper few metres of fractured bedrock. There is limited evidence for highly permeable cavities at depth.

Groundwater development in the Ballysteen Limestone is often not particularly successful: yields are low and the shales and shaly limestones often give rise to iron and manganese problems. Obtaining good yields depends on locating fault zones and/or dolomitisation at depth. The upper, more permeable, layer is unlikely to provide sustainable enough supplies for larger wells and will often contain lesser quality water than the deeper permeable horizons.

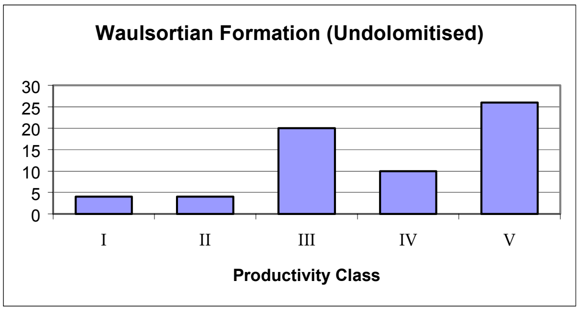
The Ballysteen Limestone in general is classed as a **locally important aquifer** which is **moderately productive only in local zones (Ll)**. However, the Lisduff Oolite Member (BAld where mapped), which occurs in the middle of the Formation, and those parts of the formation which have been mapped as dolomitised (BAdo) are classed as a **locally important aquifer** which is **generally moderately productive (Lm).**

3.10 Waulsortian Limestone (WA)

There are a good number of wells providing useful information to assess the Waulsortian Limestones for their aquifer potential.

The Waulsortian Limestone is clean and quite susceptible to karstification and dolomitisation, characteristics which are favourable to the development of secondary permeability and hence development as an aquifer. However, it is also a massive limestone, i.e. unbedded, so that few bedding planes are available for groundwater flow. In South Tipperary, Waterford, Cork and Kerry, and in some parts of Limerick, the Waulsortian is a very productive, though also quite variable, aquifer. This appears to be due to the extensive fracturing of the formation produced by the intense stress of the Variscan Orogeny (mountain-building episode). However, the intensity of the Variscan folding decreased northwards, and it appears that in North Tipperary the fracturing of the Waulsortian is much less, and wells are generally less productive except where the Waulsortian is dolomitised.

The diagrams below (Figure 6) illustrate the difference in productivity between the dolomitised and undolomitised Waulsortian in North Tipperary and surrounding counties.



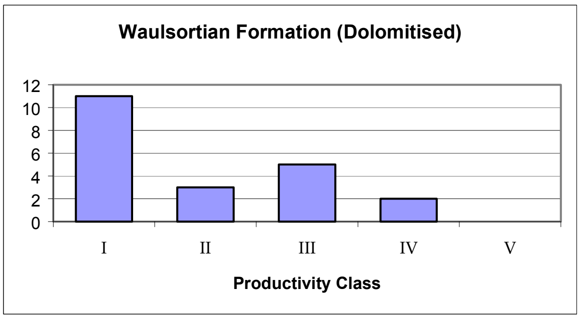


Figure 6: The difference in productivity between the dolomitised and undolomitised Waulsortian in North Tipperary and surrounding counties

The undolomitised Waulsortian is classed as a **locally important aquifer** which is **moderately productive only in local zones (Ll).** While better yields may be achievable in conduits in some areas, the rocks are not considered to be regionally important.

The dolomitised Waulsortian is classed as a **Regionally Important fissured Aquifer (Rf).** It should be noted that some dolomitisation may occur even in areas where the formation is not mapped as such. Equally, undolomitised rock will occur in areas mapped as dolomite. The Aquifer Map is based on the units as mapped by GSI.

3.11 Clean supra-Waulsortian Limestones

These comprise the Ballyadams Formation, Borrisokane Calcarenite Formation, Terryglass Calcarenite Formation, Lismaline Micrite Formation, Oldcourt Formation, Suir Formation, Lough Gur Formation and Crosspatrick Formation.

As Table 5 indicates, well yields and productivities in these formations, while quite variable, are generally good, particularly in the better-known Ballyadams and Borrisokane formations. The classification of the lesser-known formations largely depends on their similarity to their better-known analogues.

The Ballyadams formation is known to contain a number of important karst features, in both Tipperary and surrounding counties, and is classified as a **Regionally Important Karstified Aquifer (Rk)**. The other limestones are not known to be equally karstified. The Borrisokane, Terryglass and Suir formations are classified as **Regionally Important Fractured Aquifers (Rf)**, while the other formations are classified as **Locally Important Aquifers, generally moderately productive (Lm)**.

3.12 Impure supra-Waulsortian Limestones

These comprise the Aghmacart Formation, Athassel Formation, Durrow Formation, Suir Formation, Slevoir Limestone-Shale Formation, Lorrha Calp and Coolross Calp formations.

These formations comprise predominantly impure (muddy/shaly/clayey) limestones, which generally have a low permeability, rather similar to the Ballysteen Formation. The poor permeability is largely due to :

- Presence of interbedded shale/mudstone or claystone layers which impede downward movement of groundwater.
- Lack of development of extensive fracture systems, owing to the tendency of these weak rocks to deform plastically rather than by brittle fracture.
- The tendency of fractures to be infilled by clay weathering products.

- Lack of development of karstification to open up pathways for water movement.
- Lack of dolomitisation.

Well yields and productivities in these formations show a predominance of moderate or poor yields and Class II, IV and V productivities. However, higher yields and productivities are known in places.
These rocks have been classed as **locally important aquifers** which are **moderately productive only in local zones (Ll),** except for the Coolross Calp, which, by analogy with the Calp Formation in neighbouring areas of County Galway, is classed as a **poor aquifer** which is **generally unproductive except for local zones (Pl)**.

3.13 Volcaniclastic Rocks (v)

These rocks are very small in outcrop and hydrogeological data are lacking so they are therefore given the same classification as the surrounding rocks: **locally important aquifers** which are **generally moderately productive (Lm)**. This is also the classification given to equivalent nearby volcanic rocks in Limerick (Deakin et al., 1998).

3.14 Sand/Gravel Aquifers

Four sand/gravel aquifers have been tentatively identified in North Tipperary, largely based on mapping by Eugene Daly (Daly, 1979). From north to south, the four deposits are:

- Birr
- Roscrea
- Silvermines - Birdhill
- Newport

3.14.1 Birr Gravel Aquifer

This deposit extends in an arcuate belt, roughly 2 km wide, along the left bank of the Little Brosna river, around the northern part of the county. It has an area of approximately 29 km^2 within the county, and extends into Co. Offaly.

There is very little evidence of the deposit's thickness, but a borehole at Gurteen recorded 14.6 m to bedrock. The lack of confirmatory data suggests that this may be close to the maximum thickness. In view of this uncertainty, and until further information becomes available, this sand/gravel deposit is classed as a Locally Important Sand/Gravel aquifer (Lg), despite having a considerable lateral extent.

3.14.2 Roscrea Gravel Aquifer

This deposit has an area of approximately 46 km^2 within the county, and extends into Co. Offaly.

This is the only gravel aquifer in the county which has been significantly developed and can be regarded as confirmed. Several industrial enterprises in and around Roscrea (including the Bacon Factory) have developed high-yielding wells in the Roscrea aquifer, where the depth to bedrock is known to be at least 60 m in places, as shown by a borehole drilled for GSI in 1980 which hit rock at 63 m (Farrell & Horne, 1981). Particle size analyses of samples from from this borehole showed the percentage of fines to be less than 4%.

Pumping rates of over 1000 m^3/day have been obtained by industrial wells in this aquifer. In view of its areal extent, its thickness and proven yields, this aquifer has been classified as a Regionally Important gravel aquifer (Rg). However, it should be noted that its lateral extent has not been proven and the boundaries on the Aquifer Map (Map 5(N)) should be regarded as tentative.

3.14.3 Silvermines – Birdhill Gravel Aquifer

This deposit has an apparent area of approximately 38 km^2 within the county. It apparently extends over a long narrow area from the vicinity of Dolla (east of Silvermines) in the east, to the Co. Clare boundary between Ballina and Birdhill in the west. Its width (north-south) is generally only 1.5 to 3 km.

In the area around Silvermines, where many boreholes have been put down, mainly in the pursuit of mineral prospecting, there is substantial evidence of more than 20 m of sediment above bedrock. Elsewhere, the evidence is sparse. In view of this, and the narrowness of the aquifer, it may be better to regard the deposit as a series of loosely connected small gravel deposits, and hence the aquifer is classified as a Locally Important Sand/Gravel aquifer (Lg), in spite of its apparent lateral extent.

3.14.4 Newport Gravel Aquifer

This deposit has an area of approximately 11 km^2 within the county. Beginning about 1.5 km west of Newport, it extends to the county boundary and on into Co. Limerick. The thickness of the deposit is little known, but one borehole in Annaholty townland proved a depth to bedrock of 28.3 m.

Until further information becomes available, this sand/gravel deposit is classed as a Locally Important Sand/Gravel aquifer (Lg).

3.14.5 Other Sand/Gravel aquifers

Undoubtedly, other smaller gravel deposits exist around the county, such as the morainic gravel at Ballaghveny (Daly, E.P. 1983, B.J. Murphy & Associates 1998). Site investigation may also prove other sand/gravel deposits to be aquifers, but in the absence of more detailed information, the smaller deposits, those of unknown thicknesses or suspected thin saturated zones, those mapped as morainic sand/gravel and those which are interfingered with glacial tills, are not included here. Some of the larger morainic deposits may prove, on further investigation, to have lenses of cleaner gravel within them that meet the classification criteria.

3.15 Summary of Aquifer Categories

The aquifers in North Tipperary are summarised in Table 6.

Table 6: Aquifer Classifications

Aquifer Category	Subdivision	Geological Unit
Regionally important (R)	Sand/gravel (**Rg**)	Roscrea Gravel Aquifer
	Karstified (**Rk**)	Ballyadams Formation (BM)
	Fissure flow (**Rf**)	Dolomitised Waulsortian Lst (WAdo) Borrisokane Calcarenite Formation (BK) Terryglass Calcarenite Fm (TS) Cadamstown Formation (CW) Suir Formation (SU)
Locally important (L)	Sand/gravel (**Lg**)	Birr Gravel Aquifer Silvermines-Birdhill Gravel Aquifer Newport Gravel Aquifer
	Bedrock which is generally moderately productive (**Lm**)	Volcaniclastic rocks (V) Lisduff Oolite (BAld) Oldcourt Formation (OC) Lismaline Micrite Formation (LM) Crosspatrick Formation (CS) Lough Gur Formation (LG)
	Bedrock which is moderately productive only in local zones (**Ll**)	Undolomitised Waulsortian Lst (WA) Slevoir Limestone-Shale Formation (SV) Aghmacart Formation (AG) Athassel Formation (AT) Durrow Formation (DW) Old Red Sandstone (ORS) Cappagh White Formation (CA) Lorrha Calp Formation (CDlr) Ballysteen Lst (BA)
Poor (P)	Bedrock which is generally unproductive except for local zones (**Pl**)	Coolross Calp Formation (CDcr) Lower Limestone Shale (LLS) Hollyford Formation (HF) Slieve Bernagh Formation (SB) Broadford Formation (BF) Fairyhill Formation (FC) Knockshigowna Formation (KG)
	Bedrock which is generally unproductive (**Pu**)	n/a

4 Hydrochemistry and Water Quality

4.1 Introduction

An assessment of the quality of groundwater in North Tipperary is given in a separate report to North Tipperary County Council by the GSI (Hunter Williams & Wright, 2002). This chapter presents the main conclusions of that report.

4.2 Overall Assessment

The hydrochemistry of groundwater in North Tipperary is influenced primarily by the nature of the subsoil and bedrock that it passes through. The groundwater in the limestone areas (i.e. the lowlands between Nenagh and the Little Brosna River, and the region west of the Cromoge River) is hard and has a calcium bicarbonate ($Ca \cdot 2(HCO_3)$) type signature. Softer waters are found in areas where the bedrock comprises mainly sandstones, siltstones and shales, such as around the Silvermine Mountains, and at Toomyvara. In these areas underlain by sandstone and siltstone bedrock aquifers, the water type is mainly $Ca \cdot 2(HCO_3)$. The likely explanation for the 'limestone' signature of these waters is that the dissolved calcium/magnesium carbonate comes from the overlying Quaternary deposits, as recharge to the aquifer passes through the calcareous subsoils. Conductivities in the samples are low, typically ranging between 300 and 400 μS/cm. This suggests that these groundwaters have short residence times and largely contain the more readily-dissolved ions such as calcium and bicarbonate.

Of the 26 supply sources, 23 have a $Ca \cdot 2(HCO_3)$ chemical signature. The exception to this is at Terryglass WSS, where groundwater has a $Ca \cdot Mg \cdot (HCO_3)$ signature and high sodium content. The remaining two supplies - Clonakenny and Drumbane WSS - also fall into the more unusual 'calcium-magnesium-bicarbonate' category. At Clonakenny and at Drumbane, this signature is considered to be diagnostic of 'ion exchange' processes in the Lower Limestone Shale and the Cadamstown/Cappagh White Formations, which comprise layered sequences of sandstone, siltstone and mudstone/shale. Evidence of this type of process is relatively rare in Ireland, and usually indicates less vulnerable groundwater with slower, longer flow pathways.

Groundwater abstracted from about 58% of WSSs can be described as 'excessively hard', 22% as 'hard', 10% as 'moderately hard', 10% as 'slightly hard' (Figure 7). The hardest groundwaters are found at Loughmore, around Thurles, Lorrha and Templetouhy in both clean and shaly limestones, and the softest groundwaters are abstracted from sandstones and mudstones, at Templederry, Clonakenny and Kilcommon.

Sulphate concentrations range from 3 mg/l to 65 mg/l, but are typically (circa 70%) 10 to 20 mg/l. The highest sulphate concentrations were recorded at Lorrha, Templemore and Templetouhy, and seem to be associated with muddy limestones and some of the Waulsortian Limestone aquifers. Low concentrations occur at Kilcommon, Upperchurch and Templederry, where groundwater comes from the Silurian mudstones and siltstones. Chloride concentrations range from about 10 mg/l to 35 mg/l, with an average concentration of about 20 mg/l. Many samples (62%) are between 15 and 25 mg/l.

At Clonakenny, the barium concentration exceeds the EU MAC level of 0.5 mg/l, and at nearby Glenbeha (Roscrea), the concentration closely approaches it.

At Lorrha, fluoride concentrations are close to the EU MAC of 1 mg/l. Whilst this is less than the concentration in artificially fluoridised waters, it is important to know the amount of fluoride in water used by children to which extra fluoride may be added, since excessive fluoride causes mottling of tooth enamel. Teeth can also become brittle due to a decrease in tooth density.

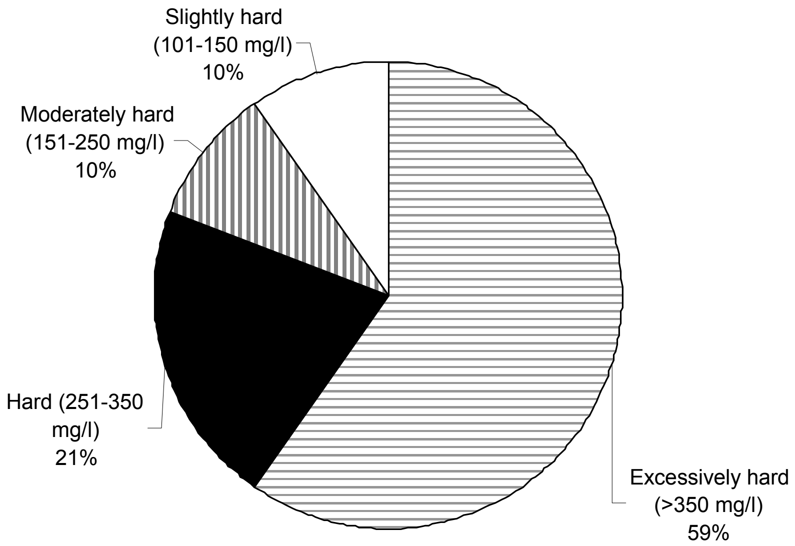


Figure 7: Pie chart showing the number of WSS *sources* falling within each hardness category in North County Tipperary.

Number of sources, 26. Number of samples: 45. See 'Water Quality' report for data.

Table 7: Variation in groundwater quality and characteristics as a function of rock type category.

Rock type category	Number of supply sources	Median major ion and other commonly-occurring ion concentrations for each rock unit category [mg/l] [4]										
		Ca	Mg	K	Na	HCO_3	SO_4	Cl	NH_x	Fe	Mn	EC [µS/cm]
LC: Clean Carboniferous limestones	9	122	22.3	3.7	10.7	417	12.3	23.6	< 0.015	0.024	0.006	740
LM: Muddy/ shaly Carboniferous limestones	9	118	22.5	1.7	9.6	417	15.2	21.0	< 0.015	0.027	0.030	734
SS: Carboniferous/ Devonian layered sand-stone/ siltstone/ mudstone	4	77.8	10.9	3.7	10.0	315	4.1	18.8	< 0.015	0.113	0.05	533
MS: Silurian layered mudstones and siltstones	4	54.6	9.0	0.7	8.6	189	5.5	11.4	< 0.015	0.05	< 0.005	325
Total	26											

4.3 Summary of 'Natural' Groundwater Characteristics

Analysis of data from 26 WSSs in North Tipperary indicates the following:

- The dominant chemical signature (88%) in the sources under consideration is 'calcium-bicarbonate'. This is typical of Irish groundwaters.
- Median sulphate and chloride concentrations are typical of groundwaters in the Irish Midlands.
- Waters in sources drawing groundwater from limestone aquifers are hard or extremely hard. Sources in layered sandstone, siltstone and mudstone range from slightly hard to hard.
- As expected, calcium, magnesium and bicarbonate concentrations are highest in limestone aquifers. Sulphate is also higher in limestone aquifers than in sandstone or mudstone areas. It is thought to originate either as iron sulphide (pyrite) in shaly limestones, or as calcium sulphate in the clean limestones.
- Iron concentrations are higher on average in sandstone aquifers, and probably derives from iron minerals that coat the sand grains.
- At Clonakenny, the barium concentration exceeds the EU MAC level of 0.5 mg/l, and at nearby Glenbeha (Roscrea), the concentration closely approaches it. At Lorrha, fluoride concentrations are close to the EU MAC of 1 mg/l. These high minor ion concentrations may be related to low-grade mineralisation in the area, especially in the Roscrea proximity.

4.4 Groundwater Quality Problems

The supply sources are divided into four group to aid in the water quality assessment. The classification is based on concentrations of key contaminant indicators in relation to the European Union Maximum Admissible Concentration (MAC) and to the GSI threshold levels. The grouping is intended to help categorise supply sources in the context of potential contaminant hazards and to help prioritise sources for the purpose of recommending remedial action. The four groups are described as follows:

Category 1: Sources in which one or more contaminant indicators in the available data set exceed the MAC (or 10 counts per 100 ml for faecal coliforms).

Category 2: Sources which show concentrations of the contaminant indicators chloride, nitrate, ortho-phosphate, iron, manganese and potassium:sodium ratio *GENERALLY* in excess of the GSI threshold levels (or more than 0 faecal coliforms in any one sample). Some interpretation is required as levels in excess of these thresholds can reflect naturally occurring conditions (e.g. elevated potassium and/or iron in certain rock types).

Category 3: Sources with slight anomalies in the analyses which may be naturally induced or indicative of some slight contamination (i.e. indicator levels *OCCASIONALLY* in excess of the GSI threshold levels).

Category 4: Sources showing no evidence of contamination from the analyses carried out for the project.

Notes accompanying Table 8:

- NO_3: Nitrate; Cl: Chloride; NH_x: Ammonia; K: Potassium; K:Na: Potassium – sodium ratio; Fe: Iron; Mn: Manganese.

- Coliform data represent untreated samples and treated samples where e.coli or faecal coliforms were detected. Though useful in terms of identifying contamination sources, they are not necessarily indicative of human health concerns.
- Fluoride was detected above the detection limit in a sample from Lorrha. Strontium was detected above the MAC at Clonakenny and at Roscrea (Glenbeha). These compounds, though important in human health considerations, are not major factors in assessing sources of agricultural or domestic contamination. As such, these results have not been used in assessing groupings outlined above.

Table 8: Groundwater quality classification of North County Tipperary WSS groundwater supply sources.

Category	Supply source	Aquifer type	Vulnerability	Exceedance of Key Contaminant Indicator								
				NO_3	Cl	PO_4	NH_x	E/F coli	K	K:Na	Fe	Mn
1	Aglish	Rf (BK)		> T (1/6)	> T (2/3)	> T (1/2)	•	>>MAC	> T (1/2)	> T (1/2)	•	>MAC (2/5)
1	Borrisokane	Ll (SV)		> T (15/25)	> T	> T (2/2)	•	>MAC	•	> T (2/3)	>MAC	>MAC
1	Borrisoleigh	Ll (BA)		> T (2/35)	•	•	•	>>MAC	•	> T (1/2)	•	•
1	Clonakenny	Pl/Rf (LLS/ CW)		•	•	•	> T (2/4)	>>MAC	>> T (2/2)	•	•	
1	Riverstown	Ll (WA)		> T (3/9)	> T	> T (1/2)	•	>>MAC	•	> T (2/2)	•	•
1	Roscrea – Glenbeha	Rf (CW)		>MAC (1/13) >T(2/13)	•	> T (1/2)	•	>MAC	> T (1/2)	> T (2/2)	>MAC (1/7)	•
1	Templetouhy	Ll (WA)		>MAC (3/15) >T (12/13)	> T	>>T (1/2)	•	•	>> T (2/2)	> T (2/2)	•	•
1	Terryglass	Ll/Rf (WA/ TS)		> T (2/14)	> T	•	> T (1/5)	>MAC	•	•	>MAC (1/6)	>MAC (1/6)
1	Toomyvara	Rf (CW)		> T (5/14)	•	•	•	>>MAC	•	•	>MAC (1/8)	•
1	Two-Mile-Borris	Ll (AG)		>MAC (1/11) >T(9/11)	•	•	•	>>MAC	•	•	•	•
1	Cloghjordan	Ll (WA)		>MAC (1/21) >T (18/21)	> T	> T (1/2)	•	•	>>T (2/2)	>> T (1/2)	•	•
2	Drumbane			•	•	> T (1/1)	•	>MAC		•	•	•
2	Holycross	Ll (AG)		> T (5/10)	•	•	•	>MAC	•	•	•	•
2	Littleton	Ll (AG)		> T (4/16)	•	•	•	>MAC	•	•	•	•
2	Loughmore	Ll (BA)		•	> T	•	•	>MAC	> T (1/1)	> T (1/1)	•	•
2	Templemore	Ll/Lm (BA/ BAld)		> T (2/31)	> T	> T (1/2)	•	>MAC	•	•	•	•
2	Thurles – Creamery	Ll (WA)		> T (23/54)	•	>>T (1/2)	•	>MAC	•	> T (2/2)	•	•
2	Thurles - Lady's Well	Ll (WA)		> T (8/8)	•	•	•	>MAC	•	> T (1/2)	•	•
2	Thurles – Tobernaloo	Rf (WAdo)		> T (2/7)	•	•	•	•	•	•	•	•
2	Ballynaclogh	Pl (HF)		> T (1/24)	•	•	•	•	•	•	•	•
3	Tullahedy	Ll (WA)		> T (1/30)	•	•	•	•	•	•	•	•
3	Kilcommon	PL (HF)		> T (1/14)	•	•	•	•	•	•	•	•
4	Lorrha	Ll (CDlr)		•	•	•	•	•	•	•	>MAC (1/17)	>MAC (12/17)
4	Moycarky	Ll (DW/ AG)		•	•	•	•	•	•	•	•	•
4	Templederry	Pl (HF)		•	•	•	•	•	•	•	•	•
4	Upperchurch	Pl (HF)		•	•	•	•	•	•	•	•	•

The main groundwater quality problems in North Tipperary are:

(a) high nitrate levels in several important sources (e.g., Two-Mile-Borris, Roscrea – Glenbeha, Creamery at Thurles), as well as in GWS and private supplies;

(b) high iron (Fe) and manganese (Mn), especially in the northern part of the county

(c) bacteriological pollution;

- Nitrate concentrations are generally above 'background' levels and often give cause for concern (Figure 8).

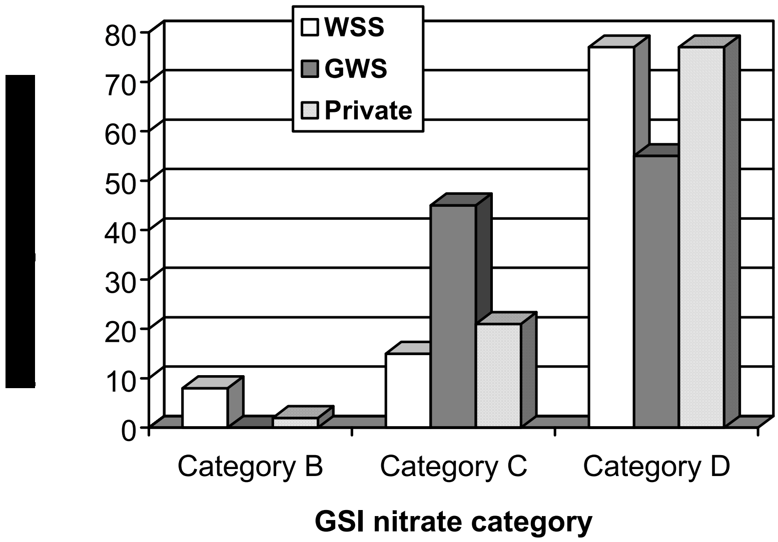
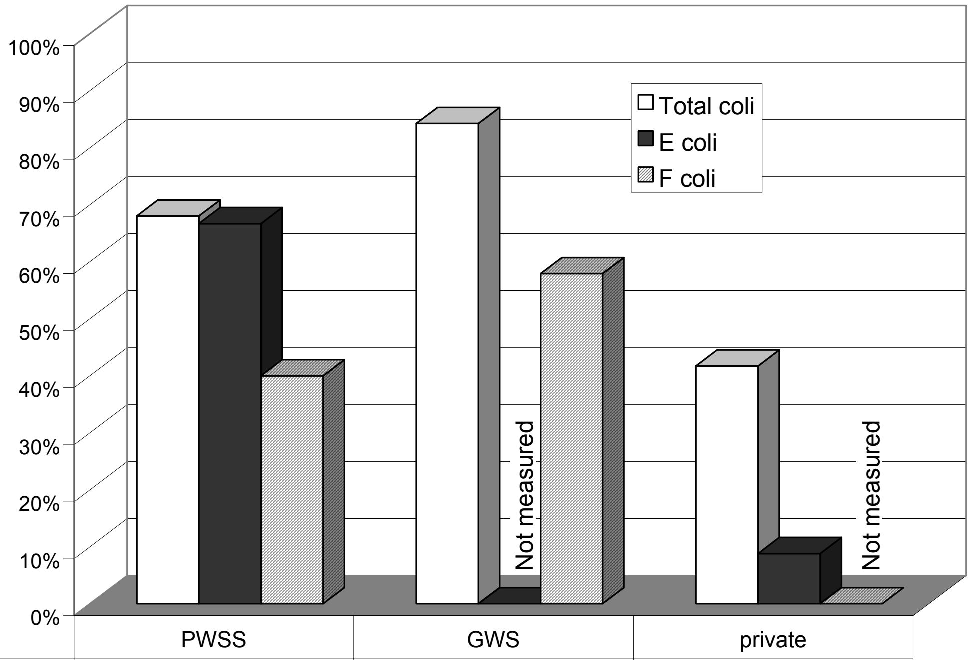


Figure 8: Percentage of WSS, GWS and private supply sources falling within the "GSI nitrate categories".

Category B: Average nitrate levels exceed 25mg/l and peaks regularly approach or exceed 50 mg/l; **Category C:** Average nitrate levels exceed 25 mg/l, peaks rarely approach 50 mg/l but give cause for concern; **Category D:** Average nitrate levels are <25 mg/l and peaks do not give cause for concern.

- The high iron (Fe) and manganese (Mn) concentrations are caused mainly by the natural conditions in the ground and the natural chemistry of the groundwater. This may occur in areas underlain by peat, or muddy limestones where reducing conditions result in solution of Fe and/or Mn from the geological materials. This causes taste and aesthetic problems. High manganese levels may also occur from pollution by silage effluent.
- The most important groundwater quality issue in North County Tipperary is the presence of faecal bacteria in public and private water supplies. A significant proportion of the public groundwater supplies (16/26 sources) have been contaminated at least once in the past 12 years, and in the GSI sampling of raw waters, 10/26 sources were contaminated (38.5%). 9% of private wells sampled were contaminated by coliforms of a faecal origin, but as the sources were sampled only once it may mask a more severe problem. The

presence of faecal bacteria is not only a problem in itself, but is an indicator of the possible presence of viruses and, in exceptional circumstances, Cryptospiridium.



	PWSS	GWS	private
Total coli	68.0%	84.2%	41.7%
E coli	66.7%	0.0%	8.8%
F coli	40.0%	57.9%	0.0%

Figure 9: Percentage of WSS, GWS and private groundwater supply sources that were contaminated at the time of measurement in at least one sample by general coliform organisms (Total), *E. coli* or faecal coliforms.

- The bacteriological pollution of a relatively high proportion of groundwater supplies in North Tipperary is due to the following:
  - (a) 'extremely' vulnerable conditions in some areas, where either bare rock or thin subsoils provide only limited protection;
  - (b) poorly designed, located and constructed septic tank systems and farmyards;
  - (c) landspreading of organic wastes;
  - (d) poor siting and construction of wells.

4.5 Overall Assessment and Conclusions

- The hydrochemistry of groundwater in North Tipperary is primarily influenced by the dominant limestone lithologies in both the bedrock and the subsoils. The groundwater throughout most of North Tipperary is hard and can be classed as a calcium-bicarbonate water type. Softer waters are found in the Devonian and Silurian sandstones, siltstones and mudstones.
- Of the 26 supply sources studied, the most contaminated supplies are considered to be:

Riverstown	Clonakenny
Aglish	Roscrea (Glenbeha)
Two-Mile-Borris	Toomyvara

These sources require the highest priority for corrective action, having at least one or two contaminant indicators above the MAC and at least one or two indicators above the GSI threshold (Table 3).

- Eleven supply sources are 'polluted', i.e. at least one indicator compound is, or has been, above the drinking water MAC. A further eleven supplies showed evidence of contamination (but not pollution). These supplies could become polluted if corrective or preventive action is not taken.
- The highest priory supplies in terms of nitrate problems are the following six sources:

Cloghjordan	Two-Mile-Borris
Borrisokane	Thurles Creamery
Thurles Lady's Well	Templetouhy (if it is to be kept as reserve)

It is recommended that action is taken at these supplies to increase the frequency of monitoring and to identify the origin of the contamination. The latter requires a delineation of the water catchment for each supply and an on-site hazard survey within each catchment. This study, and subsequent decisions on alleviation measures, would be greatly enhanced by the delineation of source protection zones within each supply catchment. Source Protection Zones have already been delineated by the GSI for Two-Mile-Borris and Borrisokane.

Restrictions on landspreading (such as those identified in the European 'Nitrates Directive') are unlikely to adequately address the nitrate contamination issues in those supplies where farmyard waste and other point sources are important contributors to the levels of contamination identified. The water quality data from at least four of the twelve supplies of concern provide evidence that this is the case. However, on-site hazards surveys are required to augment these interpretations.

- E.coli were 'regularly' present in six WSS sources (23% of the total). This suggests that farmyard point sources, septic tank systems, or sewage pipes lie relatively close to these supplies (usually within a few hundred metres) and that faecal bacteria, viruses, or even cryptosporidium may also occur in the water.
- Levels of iron and/or manganese were identified above the EU MAC in six supply sources (23% of the total). Levels in at least two of these (Lorrha and Aglish) are likely to have a 'natural' origin.
- The potassium:sodium ratio exceeds the GSI threshold in ten supply sources, possibly indicating strong contamination from an organic waste source.

4.6 Recommendations

- The six supply sources listed above require action to identify and remove or mitigate the nitrate contamination, the likely origins of which cannot be adequately assessed without considering other indicator compounds and a field survey of potential hazards. Further, the hazards cannot be adequately examined without consideration of the water catchment for each supply.
- Hazard surveys are recommended for Group 1 and 2 sources to remove or improve contaminant hazards. For public supplies, these surveys should be conducted within the delineated source protection areas. Priority surveys might first concentrate within the inner

source protection areas (SI) of each supply. For group scheme and industrial supplies where no source protection areas have been delineated, surveys might be best concentrated within 300 to 500 m upslope and 100 m downslope for boreholes. For springs, recommended upslope and downslope distances are 1 km 100 m, respectively. However, these figures are arbitrary, and source protection area delineation for all group schemes planned for long-term use is recommended.

- Sampling of raw water as well as treated water is recommended for all sources on a regular basis. Full analysis (including major ions) should be carried out on these samples. The frequency of sampling is best determined by the degree of concern at each supply. The following is recommended. In addition to the usual analytes, indicators of petroleum, sheep dip, pesticides and herbicides should also be examined, perhaps on a less frequent basis (e.g. twice yearly):

Group	No. Supply Sources in Each Group	Recommended Sampling Frequency
1	11	At least *monthly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then downgrade to Group 3 sampling frequency.
2	9	At least *quarterly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviations measures are taken.
3	2	At least *quarterly*.
4	4	At least *twice yearly*.

- Disinfection should be maintained at all public supplies to provide protection against microbial contamination of the supply. All group scheme water supplies should be adequately disinfected.
- A programme to undertake groundwater protection zone delineation around public and group scheme supplies, using the DoELG/EPA/GSI guidelines, is recommended over the next few years.
- A programme to check the sanitary protection at each well and spring site (i.e. on Council property immediately around the source) would help to ensure that shallow groundwater and surface water is not entering the source and prevent contamination from accidental spillages.
- In order to try and minimise the potential for contamination, new supplies would ideally comprise boreholes drawing water from confined aquifers or from moderate to low vulnerability groundwater. These boreholes should preferably be constructed to seal off shallow water strikes close to the top of the rock and to eliminate the potential for surface water ingress to the well. The bottle water standards produced by the Irish Standards Authority give guidance as to the correct procedure for well production and maintenance (EOLAS, 1992).
- A database should be developed of available data on all group scheme and public groundwater supplies in the county, including information on the following:
  - Supply location.
  - All available groundwater quality data (including historical data) for the supply.
  - Construction details (e.g. borehole depth, depth of casing, etc).
  - Pumping and treatment details, along with details of spring overflows, etc.
  - Population served.

- Reference links to reports on testing, pollution incidents, etc.

5 Groundwater Vulnerability

5.1 Groundwater Vulnerability Mapping

Groundwater 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 (DoELG/EPA/GSI, 1999).

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 type and permeability of the subsoils that overlie the groundwater;

(ii) the thickness of the unsaturated zone through which the contaminant moves; and

(iii) the recharge type – whether point or diffuse.

Details of the hydrogeological basis for the vulnerability assessment can be obtained from the DoELG/EPA/GSI publication on Groundwater Protection Schemes (DoELG/EPA/GSI, 1999). 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 characteristics, provided the necessary information to delineate these areas is available (refer to Table 9, below). The vulnerability map shows the vulnerability of the first groundwater encountered (either in sand/gravel aquifers or in bedrock) to contaminants released at depths of 1–2 m below the ground surface. The map is intended as a guide to the likelihood of contamination of groundwater if a contamination event occurs. It does not replace the need for site investigation. The characteristics of individual contaminants are not considered.

Outside the areas (e.g. swallow holes) where point recharge occurs, the vulnerability depends on the type, permeability and thickness of the subsoil. Each subsoil type is assessed in terms of its permeability, using information from an augering programme and field evaluation using BS 5930.

An assessment of the permeability of the subsoils is probably the most important part of assessing the groundwater vulnerability of an area. Auger holes are drilled to help produce a depth to bedrock map. Samples are taken of the subsoils encountered. Other subsoil samples can be obtained from trial pits, quarries, sand and gravel pits or shell and auger boreholes. Each sample is assessed for permeability. Each of the approaches used in assessing the permeability is discussed briefly below. Some are described in more detail in the relevant research theses (Lee, 1999, and Swartz, 1999):

1. *BS5930.* Using BS5930, subsoils described as sandy CLAY or CLAY have been shown to behave as low permeability materials. Subsoils classed as Silty SAND and sandy SILT, on the other hand, are found to have a moderate permeability (Swartz, 1999). In general, sands and gravels that are sorted and have a low fines content are considered to have a high permeability. In some instances it was found that subsoils described as 'clayey

SAND' or 'clayey GRAVEL' had a high enough proportion of clay to behave as low permeability materials.

2. *Parent material.* The parent material, in this case the bedrock, plays a critical role in providing the particles which give rise to different subsoil permeabilities. Sandstones, for example, give rise to a high proportion of sand-size grains in the deposit matrix, clean limestones provide a relatively high proportion of silt, while shales, shaly limestones and mudstones break down to the finer clay-size particles. A good knowledge of the nature of the bedrock geology is therefore critical.
3. *Recharge characteristics.* Examining the drainage and recharge characteristics in an area gives an overall representative assessment of the permeability. Poor drainage and vegetation suggest low permeability subsoils once iron pans, underlying low permeability bedrock, high water tables, and excessively high rainfall can be ruled out. Well-drained land on the other hand suggests a moderate or high permeability once artificial drainage is taken into consideration (Lee, 1999).

None of these methods can be used in isolation. A holistic approach is necessary to gain an overall assessment of each site and thereby build up a three dimensional picture of the regional hydrogeology and permeability.

The vulnerability map is then derived by overlaying the permeability categories with the depth to rock information. There are three subsoil permeability categories: high, moderate and low; and four depth to rock categories: <3 m, 3–5 m, 5–10 m and >10 m. The resulting vulnerability classifications are shown in Table 9. The vulnerability categories depicted on the vulnerability map will be a qualitative regional assessment of how quickly potential contaminants can reach groundwater.

Table 9: Vulnerability Mapping Guidelines (adapted from DoELG *et al.*, 1999a)

	HYDROGEOLOGICAL CONDITIONS				
	DIFFUSE RECHARGE: SUBSOIL PERMEABILITY AND TYPE			UNSATURATED ZONE	POINT RECHARGE
SUBSOIL THICKNESS	**High Permeability** *(sand/gravel)*	**Moderate Permeability** *(e.g. sandy subsoil)*	**Low permeability** *(e.g. Clayey subsoil, clay, peat)*	*(Sand/gravel aquifers only)*	*(e.g. Swallow Holes, losing streams)*
0 - 3.0 m	Extreme	Extreme	Extreme	Extreme	Extreme (30 m radius)
3.0 - 5.0 m	High	High	High	High	N/A
5.0 - 10.0 m	High	High	Moderate	High	N/A
> 10.0 m	High	Moderate	Low	High	N/A

Notes:
(i) N/A = not applicable.
(ii) Permeability classifications relate to the engineering behaviour as described by BS5930.
(iii) Release point of contaminants is assumed to be 1 - 2 m below ground surface.
(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability.

5.2 Interim Vulnerability Mapping

For a significant proportion of Ireland there is insufficient information available to map the vulnerability of the subsoils as described above, owing to a lack of detailed information on subsoils. Without adequate maps of subsoils and depth to bedrock, production of a regional vulnerability map requires the undertaking of a substantial mapping programme. In the meantime, the vulnerability of a particular site or small area can be ascertained by site investigations. However, if regional information is needed, interim measures are required, which may include the delineation of extremely vulnerable areas *only*, or vulnerability mapping on regionally important aquifers.

These interim measures form a defensible basis for decision-making regarding groundwater protection (DoELG/EPA/GSI, 1999). However, because an interim scheme lacks a comprehensive vulnerability map, it may be less efficient in the evaluation of some proposed developments or activities. Site investigations may therefore need to be more extensive and the decision-making process may be slower. The Council should aim to upgrade the interim scheme to a comprehensive one as soon as possible.

5.3 Interim Vulnerability Mapping in North Tipperary

Detailed Quaternary geology or subsoils maps have not yet been produced for North Tipperary. Teagasc (1993) has provided information on soil types (although not permeabilities) for the county. In their absence, this Groundwater Protection Scheme for North Tipperary is an interim one, which delineates areas of extreme vulnerability only. The bases for delineating these extremely vulnerable areas are:

- available information on depth to bedrock < 3 m
- location of karst features
- an unsaturated zone < 3 m in sand and gravel aquifers

5.4 Sources of Data

Specific vulnerability field mapping was not carried out regionally as part of this Protection Scheme. Some field work was carried out around specific Council sources which, along with pumping tests, focused on assessing the permeability of the different subsoil types, so that they could be categorised with respect to their permeability characteristics. This involved the following:

- describing selected exposures/sections and samples from auger holes according to the British Standard for Site Investigations (BS5930:1981), taking account of the new draft revised standard (Norbury, 1998).
- assessing the recharge characteristics of selected sites using drainage, vegetation and other secondary indicators.

The following additional data sources were used to produce the interim map:

- the contoured depth to bedrock data produced using rock outcrops and individual depth to bedrock points (see section 2.3);
- the bedrock geology map (see section 2.2 and Map 1);
- the GSI karst database;
- the GSI well database;
- experience from two M.Sc. research projects on vulnerability mapping (Lee, 1999; Swartz, 1999).

5.5 Depth to Bedrock

The thickness of the subsoils (the depth to bedrock) is a critical factor in determining groundwater vulnerability to contamination. A brief description of the variations in subsoil thickness is given in Section 2.3.3.

For the purposes of compiling the interim vulnerability map for North Tipperary, the land area was contoured for only the 3 m depth-to-bedrock contour. The depth to bedrock information came primarily from well or borehole data for the area, along with ‘rock close’ areas, which were delineated mainly from primary geological mapping (Geological Survey of Ireland, 1880s).

5.6 Thickness of the Unsaturated Zone

The thickness of the unsaturated zone is relevant only in vulnerability mapping of sand/gravel aquifers. In North Tipperary, this applies to the areas along the Clodiagh and

Cromoge river valleys and other smaller isolated pockets of gravel deposits such as along the Mulkear River that runs west to the Shannon from Moher Mountain, and at Templederry (see Section 3.5.3 in the Aquifers chapter). The depth to water table in these areas is generally uncertain. Where it is found from site investigation to be more than 3 m below the surface, the vulnerability classification will be 'high', while where it is less than 3 m below the surface, e.g. near the river, it will be 'extreme'.

5.7 Karst Features

Karstification of limestones (the enlargement of fractures by chemical solution) in North Tipperary has given rise to the development of various karst features including swallow holes, caves, enclosed depressions, turloughs and sinking streams (refer to Section 3.5.4). All of these features can provide easy access to groundwater for potential contaminants. The karst features are shown on Map 3 (the aquifer and hydrogeology data map), and on Map 5 (the interim groundwater vulnerability map), where they represent points of 'extreme' vulnerability.

In North Tipperary there are relatively few known karst features occurring in the limestone aquifers, when compared with other counties (e.g. Cork). Areas within 30 m of a karst feature, such as a swallow hole or a cave, are delineated as having extreme vulnerability. It should be borne in mind that, due to lack of data on karst features, although a certain area may not be shown as 'extreme' on the interim vulnerability map (Map 5), there may be small areas which have not yet been delineated as extreme.

5.8 Areas of Extreme Vulnerability

These are areas where depth to bedrock is less than 3 m, as discussed in Section 2.3.3, as well as areas of karstified bedrock and areas where gravel deposits have thin unsaturated zones, as mentioned above in Sections 5.6 and 5.7.

Extremely vulnerable areas comprise the following:

- areas of outcropping rock
- areas where soils and subsoils are < 3 m thick
- areas within 30 m of karst features
- sand and gravel aquifers where the unsaturated zone is < 3 m thick

Groundwater is considered to be extremely vulnerable to pollution in areas where the thinnest soil and subsoil is deposited, for example, adjacent to Lough Derg, and along the southwest-northeast trending ridges in the northern part of the County. The ridge of higher ground between Portumna and Rathcabban forms a continuous line of extreme vulnerability. In the rest of the area south to Nenagh, areas of extreme vulnerability on higher ground are more patchy and dissected. This is probably because the direction of glacier movement was generally from the northwest to the southeast, almost at right angles to the geological grain.

Large areas of extreme vulnerability are mapped across much of the south west of the County, in the Arra and Silvermines Mountains, extending over to the Devilsbit Mountains in the east. Rock is exposed on many crags and in many of the stream beds in these very steep areas.

The mountainous, high vulnerability regions are separated by areas of thicker subsoils. These areas of thicker and high, moderate and low permeability subsoils will determine the areas of high, moderate and low vulnerability. These will be examined once this interim scheme becomes upgraded to a comprehensive scheme when further information on subsoils becomes available and a full programme of mapping the permeabilities of these subsoil units gets underway. In general, thicker subsoil deposits lie in some of the major river valleys, for example: the Kilmastulla River along the Silvermines valley; the River Suir basin; the Mulkear River draining west between the Silvermines Mountains and Keeper Hill; and the Nenagh River, which drains off the Silurian hills and flows northwest into Lough Derg.

Thicker deposits also occur between the patches of high vulnerability in the lowlands north of Nenagh. The soils in this region are mapped as being derived mainly from limestone till (Teagasc, 1993), which would have a moderate to low permeability. There are also areas of deeper subsoils around the Borrisoleigh area which (depending on the permeability of the subsoils) may allow lower vulnerability ratings to be assigned in some of these areas. The density of data in this area (due to a large number of geotechnical investigations) will be useful once subsoil information becomes available. However, the permeability of these subsoils will have to be examined carefully before a vulnerability rating can be assigned. Across nearly the entire region south of Templemore between the Clodiagh River and the eastern County boundary, the depth to bedrock appears to be highly variable over short distances, with numerous isolated rock outcrops resulting in very small patches of high vulnerability within a background of high-low vulnerability.

The regional map is our best estimate of the interim vulnerability with the available information and should always be supported by site investigation in specific areas.

5.9 Interim Groundwater Vulnerability Map

The interim groundwater vulnerability map (Map 5) is derived by combining the contoured depth to bedrock data and the identified karst features. The areas are classified as ‘extreme’, or ‘high to low’.

Overall, almost one third (32.5%) of the county is classed as having ‘extreme’ vulnerability, and two thirds (66.9%) as having ‘high to low’ vulnerability. The remaining areas lie within source protection areas (0.57%). (Areas of lakes and islands have been discounted.)

It is emphasised that the boundaries on the vulnerability map are based on the available data, and that local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments, and will frequently require site investigations in order to assess the risk to groundwater. The regional map is useful as a guide to highlight the type of hydrogeological conditions present, and the likely variations.

5.10 Using the Interim Groundwater Vulnerability Map (Assessing areas of ‘high’, ‘moderate’ and ‘low’ where necessary)

Although the interim vulnerability map delineates only areas of *extreme* vulnerability, there are methods to define areas of lower vulnerability on a site by site basis if necessary. Data are available on depth to bedrock for large areas of North Tipperary, but only as point data; no attempt has been made to contour the data because of the lack of any detailed morphological maps or digital elevation models (DEMs). Detailed mapping of the permeability of the subsoils of North Tipperary has not yet been carried out. However, by looking at the drainage characteristics and other observations on field size or vegetation in a particular area, it may be possible to assess the broad permeability of a particular area.

As outlined in section 5.1, Lee (1999) showed that the indicators of low permeability subsoils are poor drainage and marshy vegetation (once factors such as high water tables are ruled out). Well-drained land on the other hand suggests moderate or high permeability, once artificial drainage is taken into consideration. From some walkover surveys of particular areas and some quick outline observations of other areas, it appears that there are few large areas of poorly-drained land within the county (excepting where there is peat development, or along rivers). This appears to be the case particularly in the northern parts of the county that are covered by well-drained soil with Limestone till parent material (Patrickswell Series, Teagasc 1993). There may be some areas of 'moderate' vulnerability at Aglish, Borrisokane and Two-Mile-Borris owing to less thick subsoil cover in these areas, coupled with well-drained soils.

High vulnerability areas will tend to be found close to, and in some cases surrounding, the extreme vulnerability areas. This will be mainly due to the depths to rock encountered as, irrespective of the subsoil permeability, a thickness less than 5 m warrants a 'high' classification. High permeability materials such as sand and gravel will also be classified as 'high' vulnerability whatever their thickness (greater than 3 m). If water table data are available for sand and gravel aquifers, those with an unsaturated zone greater than 3 m are classified as 'highly vulnerable'. Therefore the sand and gravel aquifers, as marked on the Aquifer Map (Map 3), are classified as highly vulnerable in the absence of detailed data on the thickness of the unsaturated zone.

Although some indications can be made of potential areas of high, moderate and low vulnerability, at this stage in the absence of detailed field work and soil sample characterisation, boundaries cannot be drawn definitively around these or other areas.

The interim vulnerability map combines the best available permeability and depth to rock information. The regional map will be used as a guide in land-use planning and is not intended to be prescriptive. The vulnerability classification framework however, can be applied on a site to site basis following appropriate site investigation and this is to be recommended to potential developers.

6 Groundwater Protection

6.1 Introduction

In Chapter 1 (see also Appendix A) the general groundwater protection scheme guidelines were outlined and, in particular, the two components of the scheme – land surface zoning and groundwater protection responses to potentially polluting activities – were described. Subsequent chapters described the different geological and hydrogeological land surface zoning elements as applied to North Tipperary. This chapter draws these together to give the ultimate elements of land surface zoning – the groundwater protection scheme map and the source protection maps. It is emphasised that these maps are not intended as 'stand alone' elements, but must be considered and used in conjunction with the groundwater protection responses for potentially polluting activities. Three such responses have been published: **Groundwater Protection Responses for Landfills** (DoELG/EPA/ GSI, 1999) **Groundwater Protection Responses for Landspreading of Organic Wastes** (DoELG/EPA/GSI, 1999), and **Groundwater Protection Responses for On-Site Wastewater Treatment Systems** (DoELG/EPA/GSI, 2001), and further responses are planned. Groundwater Protection responses are discussed briefly in Sections 6.4 and 6.5 below.

6.2 The Groundwater Protection Map

The Groundwater Protection Map (Map 6) was produced by combining the interim vulnerability map (Map 5) with the aquifer map (Map 4). Each protection zone on the map is defined by a code that represents both the vulnerability of the groundwater to contamination and the value of the groundwater resource (aquifer category). The codes are shown in the general Groundwater Protection Scheme matrix in Table A.3. Since the Interim vulnerability mapping only distinguishes 'Extreme' vulnerability, the remaining vulnerability areas are coded 'H-L', i.e. High to Low vulnerability. Not all of the possible hydrogeological settings are present in North Tipperary. Those present are listed in Table 10, with the proportion of the county falling within each zone.

Table 10: Groundwater Resource Protection Zones in North Tipperary

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf	Lm/Lg	Ll	Pl	Pu
Extreme (E)	Rk/E (0.02%)	Rf/E (3.1%)	Lm/E (0.85%)	Ll/E (10.4%)	Pl/E (18.3%)	*(absent)*
High (H) Moderate (M) Low (L)	Rk/H-L (0.64%)	Rf/H-L (7.74%)	Lg/H (6.27%) Lm/H-L (5.41%)	Ll/H-L (36.45%)	Pl/H-L (10.79%)	*(absent)*

(Areas of lakes and islands omitted from calculations)

6.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around nine local authority public supply sources in North Tipperary: Aglish (chambered spring), Borrisokane (chambered spring), Borrisoleigh (2 boreholes), Lorrha (borehole), Templederry (borehole), Templemore (College Hill, 2 boreholes), Tobernaloo (Thurles, chambered spring), Toomyvara (5 springs piped to one chamber) and Two-Mile-Borris (borehole). These have been produced as separate source reports. In total, the protection areas around these nine sources amount to 11.55 km^2, or 0.57% of the area of North Tipperary.

6.4 Groundwater Protection Responses

Three groundwater protection responses for potentially polluting activities have been published to date: for Landfills, Landspreading of Organic Wastes and for On-Site Wastewater Treatment, and further responses are planned.

The responses are designed for use with 'full' groundwater protection schemes, and need some adjustment for use with an interim scheme such as this. Where a 'composite' protection zone (with a vulnerability of 'H-L'), there may not be a unique response. However, within these limitations, the relevant responses have been calculated for North Tipperary under the interim scheme:

Landfills:

R1 – R2[2]	(generally acceptable)	75.5%
R1 – R3[1]	(mixed acceptability)	11.6%
R3[2]	(generally unacceptable)	0.9%
R4 – R3[1]	(generally unacceptable)	12.0%

Licensed Landspreading of Organic Wastes:

R1	(generally acceptable)	66.7%
R2[1]	(generally acceptable subject to maximum loading)	0.4%
R3	(probably acceptable subject to confirmation)	29.0%
R3	(probably unacceptable)	3.7%
R4	(generally unacceptable)	0.2%

On-Site Wastewater Treatment Systems (Septic tanks, etc.):

R1	(generally acceptable)	66.3%
R2	(generally acceptable subject to confirmation)	33.6%
R3	(generally unacceptable)	0.1%

6.5 Using Groundwater Protection Responses in an Interim Scheme

An interim vulnerability rating for a particular site or small area can be ascertained by detailed site investigations. The onus is still on a developer to prove a vulnerability category at a site. In assessing the impact of a proposed development (in the area outside of the ZOCs of groundwater supplies) an interim groundwater protection zone can be obtained by:

(i) using the aquifer map produced for North Tipperary to obtain an aquifer category; and

(ii) undertaking a site investigation to determine the vulnerability rating, if it is outside an area that has already been delineated as extreme.

From this information the groundwater protection zone for any location and the associated groundwater protection response can be determined. Consequently the response for any particular activity at any site and the appropriate control measures can be implemented.

An important potentially polluting activity in North Tipperary regarding the risk to groundwater quality is the landspreading of organic wastes. In the Groundwater Protection

Responses for Landspreading of Organic Wastes (DoELG/EPA/GSI, 1999), the extreme vulnerability category is the most important one to delineate. Outside of source protection areas around groundwater sources (i.e. outside the ZOC) landspreading of these wastes is normally acceptable except in extremely vulnerable areas. Even in the extremely vulnerable areas, landspreading can be acceptable where a consistent thickness of at least 1 metre of subsoil (2 metres over 'Rk' aquifers) can be demonstrated to exist. This is illustrated by the response matrix shown below, in Table 11.

Table 11: Groundwater Protection Response Matrix for Landspreading

VULNERABILITY RATING	SOURCE PROTECTION AREA		RESOURCE PROTECTION Aquifer Category					
			Regionally Important (R).		Locally Important (L).		Poor Aquifers (P)	
	Inner	*Outer*	*Rk*	*Rf/Rg*	*Lm/Lg*	*Ll*	*Pl*	*Pu*
Extreme (E)	R4	R4	R3[2]	R3[2]	R3[1]	R3[1]	R3[1]	R3[1]
High (H)	R4	R2[1]	R1	R1	R1	R1	R1	R1
Moderate (M)	R3[3]	R2[1]	R1	R1	R1	R1	R1	R1
Low (L)	R3[3]	R2[1]	R1	R1	R1	R1	R1	R1

The appropriate response to the risk of groundwater contamination is given by the assigned response category (**R**) appropriate to each protection zone (refer to DoELG/EPA/GSI (1999) for further information):

R1 Acceptable, subject to normal good practice.

R2[1] Acceptable subject to a maximum organic nitrogen load (included that deposited by grazing animals) not exceeding 170 kg/hectare/yr.

R3[1] Not generally acceptable, unless a consistent minimum thickness of 1 m of soil and subsoil can be demonstrated.

R3[2] Not generally acceptable, unless a consistent minimum thickness of 2 m of subsoil can be demonstrated.

R3[3] Not generally acceptable, unless it is shown that there are no alternative areas available and detailed evidence is provided to show that contamination will not take place. (No spreading will be allowed within a 50 m radius of a groundwater source.

R4 Not acceptable.

The Groundwater Protection Responses for the location of septic tank systems has recently been drafted (DoELG/EPA/GSI, 2001). In these responses, the delineation of extremely vulnerable areas will also be most important. Hence delineation of 'extreme' areas is a useful tool in development planning.

6.6 Conclusions

The groundwater protection scheme given in this report will be a valuable tool for the County Council in helping to achieve sustainable water quality management as required by national and EU policies. It will enable the Council to take account of: (i) the potential risks to groundwater resources and sources; and (ii) geological and hydrogeological factors, when considering the location of potentially polluting developments. Consequently, it will be an important means of preventing groundwater contamination.

In using the scheme, it is essential to remember that: (a) it is intended to provide guidelines to assist decision-making in North Tipperary on the location and nature of developments and activities with a view to ensuring the protection of groundwater; and (b) delineation of the groundwater protection zones is dependent on the data available. The Council should apply the scheme in decision-making on the basis that the best available data are being used. The maps have limitations because they generalise variable and complex geological and hydrogeological conditions. The scheme is therefore not prescriptive and needs to be qualified by site-specific considerations and investigations in many instances. The investigation requirements depend mainly on the degree of hazard provided by the contaminant loading and, to a lesser extent, on the availability of hydrogeological data. The onus is then on a developer to provide new information to confirm, revise, or improve the zonation.

The scheme has the following uses for North Tipperary County Council:

- it provides a hierarchy of levels of risk and 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 acts as a guide and provides a 'first-off' warning system before site visits and investigations;
- it shows generally suitable and unsuitable areas for potentially hazardous developments. The interim scheme is sufficient for highlighting areas that are unsuitable for landspreading and the siting of septic tanks;
- it can be adapted to include risk to surface water;
- it will assist in the control of developments and enable the location of certain potentially hazardous activities in lower risk areas;
- it helps to ensure that the pollution acts are not contravened.

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Appendix A

Appendix A

The following text is taken from **Groundwater Protection Schemes**, which was jointly published in 1999 by the Department of Environment and Local Government (DELG), Environmental Protection Agency (EPA) and Geological Survey of Ireland (GSI). This Appendix gives details on the two main components of groundwater protection schemes – land surface zoning and groundwater protection responses. It is included here so that this can be a stand alone report for the reader. However, it is recommended that for a full overview of the groundwater protection methodology, the publications **Groundwater Protection Schemes, Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses to the Landspreading of Organic Wastes** should be consulted. These publications are available from the GSI, EPA and Government Publications Office.

Land Surface Zoning

Vulnerability Categories

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The vulnerability of groundwater depends on: (i) the time of travel of infiltrating water (and contaminants); (ii) the relative quantity of contaminants that can reach the groundwater; and (iii) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is considered to be more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:
(i) the subsoils that overlie the groundwater;
(ii) the type of recharge - whether point or diffuse; and
(iii) the thickness of the unsaturated zone through which the contaminant moves.

In general, little attenuation of contaminants occurs in the bedrock in Ireland because flow is almost wholly via fissures. Consequently, the subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays), are the single most important natural feature influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin and, in areas of karstic limestone, where surface streams sink underground at swallow holes.

The geological and hydrogeological characteristics can be examined and mapped, thereby providing a groundwater vulnerability assessment for any area or site. Four groundwater vulnerability categories are used in the scheme – **extreme (E)**, **high (H)**, **moderate (M)** and **low (L)**. The hydrogeological basis for these categories is summarised in Table A.1 and further details can be obtained from the GSI. The ratings are based on pragmatic judgements, experience and available technical and scientific information. However, provided the limitations are appreciated, vulnerability assessments are essential when considering the location of potentially polluting activities. As groundwater is considered to be present everywhere in Ireland, the vulnerability concept is applied to the entire land surface. The ranking of vulnerability does not take into consideration the biologically-active soil zone, as contaminants from point sources are usually discharged below this zone, often at depths of at least 1 m. However, the groundwater protection responses take account of the point of discharge for each activity.

Vulnerability maps are an important part of groundwater protection schemes and are an essential element in the decision-making on the location of potentially polluting activities.

Table A.1 Vulnerability Mapping Guidelines

Vulnerability Rating	Hydrogeological Conditions				
	Subsoil Permeability (Type) and Thickness			**Unsaturated Zone**	**Karst Features**
	high permeability (*sand/gravel*)	moderate permeability (e.g. *sandy subsoil*)	low permeability (e.g. *clayey subsoil, clay, peat*)	(*sand/gravel aquifers* only)	(<30 m radius)
Extreme (E)	0–3.0 m	0–3.0 m	0–3.0 m	0–3.0 m	–
High (H)	>3.0 m	3.0–10.0 m	3.0–5.0 m	>3.0 m	N/A
Moderate (M)	N/A	>10.0 m	5.0–10.0	N/A	N/A
Low (L)	N/A	N/A	>10.0 m	N/A	N/A

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

Firstly, the vulnerability rating for an area indicates, and is a measure of, the likelihood of contamination. Secondly, the vulnerability map helps to ensure that a groundwater protection scheme is not unnecessarily restrictive on human economic activity. Thirdly, the vulnerability map helps in the choice of preventative measures and enables developments, which have a significant potential to contaminate, to be located in areas of lower vulnerability.

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

Source Protection Zones

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

There are two main elements to source protection land surface zoning:
Areas surrounding individual groundwater sources; these are termed source protection areas (SPAs).
Division of the SPAs on the basis of the vulnerability of the underlying groundwater to contamination.

These elements are integrated to give the source protection zones.

Delineation of Source Protection Areas

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

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

Where the hydrogeological information is poor and/or where time and resources are limited, the simple zonation approach using the arbitrary fixed radius method is a good first step that requires little technical expertise. However, it can both over- and under-protect. It usually over-protects on the downgradient side of the source and may under-protect on the upgradient side, particularly in karst areas. It is particularly inappropriate in the case of springs where there is no part of the downgradient side in the ZOC. Also, the lack of a scientific basis reduces its defensibility as a method.

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

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

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

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

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

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

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

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

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

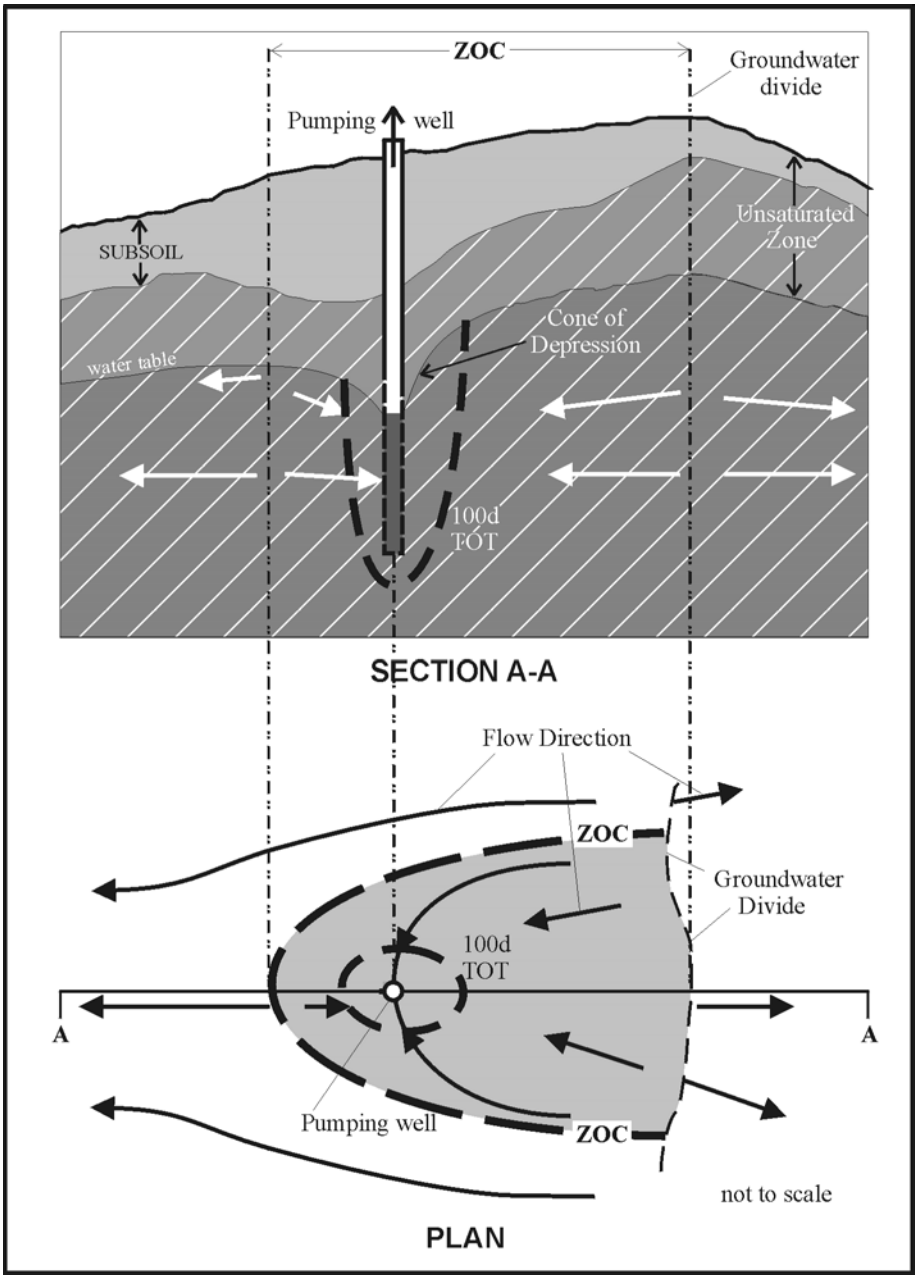

Fig. A.1 Conceptual model of the zone of contribution (ZOC) at a pumping well (adapted from US EPA, 1987)

Delineation of Source Protection Zones

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

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

Resource Protection Zones

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

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

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

Poor (P) Aquifers

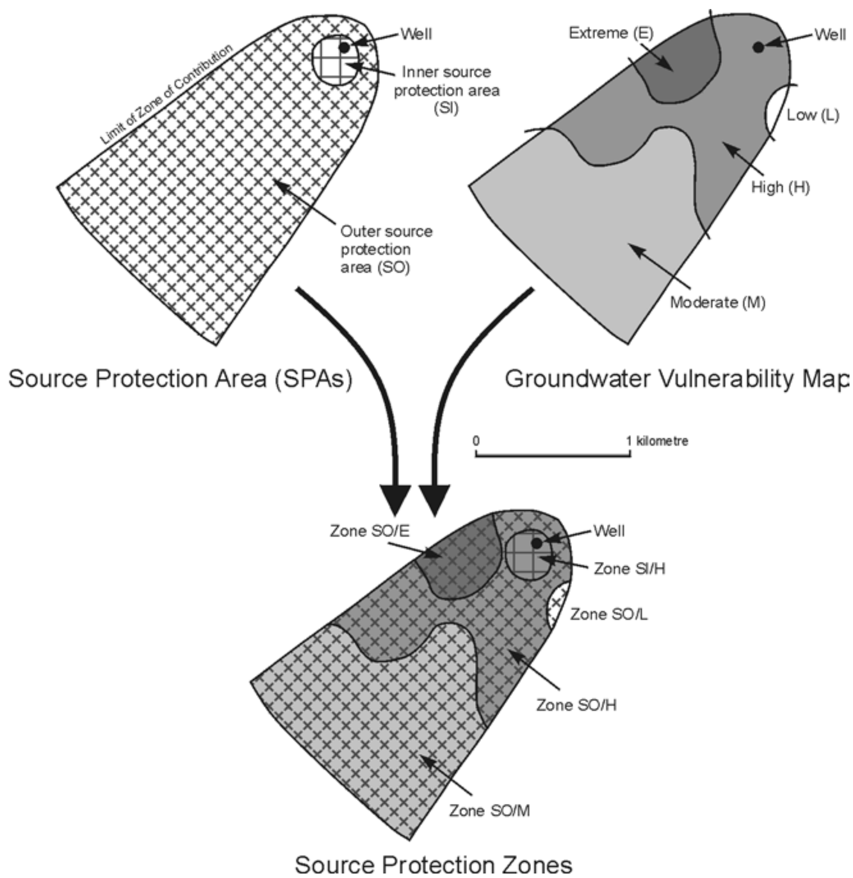

Fig. A.2 Delineation of Source Protection Zones Around a Public Supply Well from the Integration of the Source Protection Area Map and the Vulnerability Map

(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 a groundwater protection scheme but also for groundwater development purposes.

The matrix in Table A.3 gives the result of integrating the two regional elements of land surface zoning (vulnerability categories and resource protection areas) – a possible total of 24 resource protection zones. In practice this is achieved by superimposing the vulnerability map on the aquifer map. Each zone is represented by a code e.g. **Rf/M**, which represents areas of regionally important fissured aquifers where the groundwater is moderately vulnerable to contamination. In land surface zoning for groundwater protection purposes, regionally important sand/gravel (**Rg**) and fissured aquifers (**Rf**) are zoned together, as are locally important sand/gravel (**Lg**) and bedrock which is moderately productive (**Lm**). All of the hydrogeological settings represented by the zones may not be present in each local authority area.

Flexibility, Limitations and Uncertainty

The land surface zoning is only as good as the information which is used in its compilation (geological mapping, hydrogeological assessment, etc.) and these are subject to revision as new information is produced. Therefore a scheme must be flexible and allow for regular revision.

Uncertainty is an inherent element in drawing geological boundaries and there is a degree of generalisation because of the map scales used. Therefore the scheme is not intended to give sufficient information for site-specific decisions. Also, where site specific data received by a regulatory body in the future are at variance with the maps, this does not undermine a scheme, but rather provides an opportunity to improve it.

Groundwater Protection Responses

Table A.3 Matrix of Groundwater Resource Protection Zones

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

Introduction

The location and management of potentially polluting activities in each groundwater protection zone is by means of a **groundwater protection response matrix** for each activity or group of activities. The level of response depends on the different elements of risk: the vulnerability, the value of the groundwater (with sources being more valuable than resources and regionally important aquifers more valuable than locally important and so on) and the contaminant loading. By consulting a **Response Matrix**, it can be seen: (a) whether such a development is likely to be acceptable on that site; (b) what kind of further investigations may be necessary to reach a final decision; and (c) what planning or licensing conditions may be necessary for that development. The groundwater protection responses are a means of ensuring that good environmental practices are followed.

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

Integration of Groundwater Protection Zones and Response

The integration of the groundwater protection zones and the groundwater protection responses is the final stage in the production of a groundwater protection scheme. The approach is illustrated for a hypothetical potentially polluting activity in the matrix in Table A.4.

The matrix encompasses both the geological/hydrogeological and the contaminant loading aspects of risk assessment. In general, the arrows (→↓) indicate directions of decreasing risk, with ↓ showing the decreasing likelihood of contamination and → showing the direction of decreasing consequence. The contaminant loading aspect of risk is indicated by the activity type in the table title.

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

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

It is advisable to map existing hazards in the higher risk areas, particularly in zones of contribution of significant water supply sources. This would involve conducting a survey of the area and preparing an inventory of hazards. This may be followed by further site inspections, monitoring and a requirement for operational modifications, mitigation measures and perhaps even closure, as deemed necessary. New potential sources of contamination can be controlled at the planning or licensing stage, with monitoring required in some instances. In all cases the control measures and response category depend on the potential contaminant loading, the groundwater vulnerability and the groundwater value.

In considering a scheme, it is essential to remember that: (a) a scheme is intended to provide guidelines to assist decision-making on the location and nature of developments and activities with a view to ensuring the protection of groundwater; and (b) delineation of the groundwater protection zones is dependent on the data available and site specific data may be required to clarify requirements in some instances. It is intended that the statutory authorities should apply a scheme in decision-making on the basis that the best available data are being used. The onus is then on a developer to provide new information which would enable the zonation to be altered and improved and, in certain circumstances, the planning or regulatory response to be changed.

Use of a Scheme

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