County Laois
Groundwater Protection Scheme

Main Report
(Draft)

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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 pose increasing risks to groundwater quality: there is widespread disposal of domestic, agricultural and industrial effluents to the ground, and 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 as a resource is under increasing risk from human activities, for the following reasons:

- lack of awareness of the risks of groundwater contamination, because groundwater flow and contaminant transport are generally slow and neither readily observed nor easily measured
- contamination of wells and springs
- widespread application of domestic, agricultural and industrial effluents to the ground
- generation of increasing quantities of domestic, agricultural and industrial wastes
- increased application of inorganic fertilisers to agricultural land, and usage of pesticides
- greater volumes of road traffic and more storage of fuels/chemicals
- manufacture & distribution of chemicals of increasing diversity and often high toxicity, used for a wide range of purposes

The main threats to groundwater are posed by:

(a) point contamination sources: farmyard wastes (silage effluent, soiled water), septic tank effluent, leakages, spillages, non-agricultural pesticides, landfill leachate, contaminated sinking streams;

(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 groundwater 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 Preventing Groundwater Pollution

The Geological Survey of Ireland (GSI), the Department of Environment and Local Government (DELG) and the Environmental Protection Agency (EPA) have jointly developed a methodology for the preparation of groundwater protection schemes (DELG/EPA/GSI, 1999). Three supplementary documents 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 Systems for Single Houses**. Similar 'responses' publications will be prepared in the future for other potentially polluting activities and developments.

There are two main components of a groundwater protection scheme:
- **Land surface zoning**
- **Groundwater protection responses for potentially polluting activities**

These are shown schematically in Fig. 1.1.

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

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 and group 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.

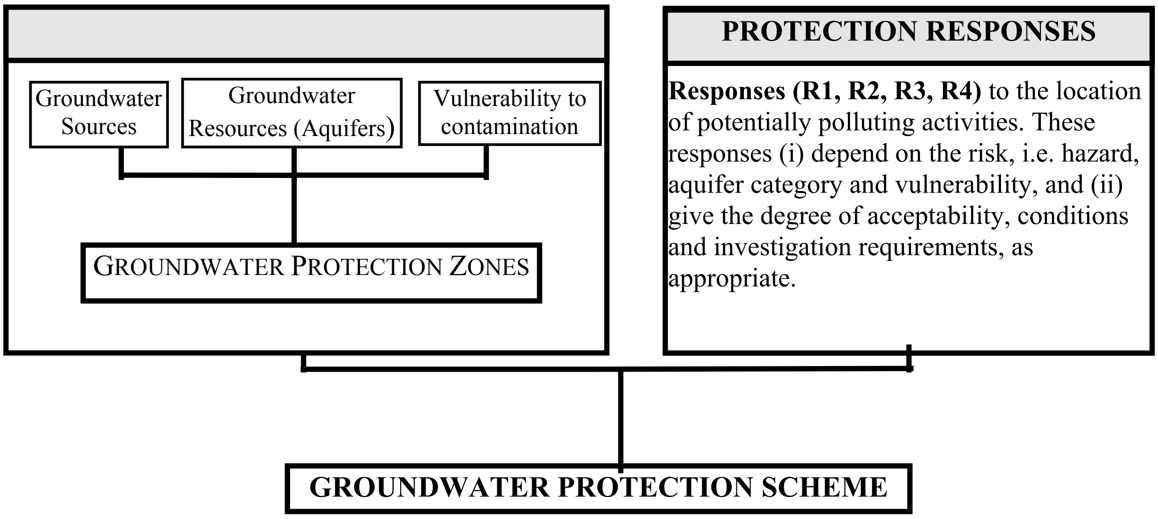

Fig. 1.1 Summary of Components of Groundwater Protection Scheme

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 (DELG/EPA/GSI, 1999) should be consulted.

1.5 Objectives of the County Laois Groundwater Protection Scheme

The overall aim of the groundwater protection scheme is to preserve the quality of groundwater in County Laois for drinking purposes and other beneficial uses, 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, but to 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 should be qualified by site-specific considerations.

1.6 Scope of County Laois Groundwater Protection Scheme

The groundwater protection scheme is the result of co-operation between Laois County Council and the Geological Survey of Ireland.

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

(i) delineation of aquifers
(ii) assessment of the groundwater vulnerability to contamination
(iii) delineation of protection areas around five public supply wells and springs (Durrow, Fermoyle, Kyle, Lough, and Swan)
(iv) production of a groundwater protection scheme which relates the data to possible land uses in the county and to groundwater protection responses 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 compiles, for the first time, all readily available geological and groundwater data for the county and sets in place 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 as follows:

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

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

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

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

Detailed regional hydrogeological investigations in County Laois have been limited to a number of public supply sources, Environmental Impact Statements and research publications. Consequently, the available data are somewhat limited and it is not possible to provide a fully comprehensive scientific assessment of the hydrogeology of the county. However, this report provides a good basis for strategic decision-making and for site specific investigations.

1.7 Laois County Development Plan

It is envisaged that this Groundwater Protection Scheme should be incorporated into the County Development Plan, by whatever means the Council deems suitable.

1.8 Structure of Report

The structure of this report is based on the information and mapping requirements for land surface zoning. The final map, the Groundwater Protection Zone Map (Map 7) is obtained by combining the Aquifer (Map 5) and Groundwater Vulnerability maps (Map 6). The Aquifer Map, in turn, is based on the Bedrock Map (Map 1) boundaries and the aquifer categories as derived from an assessment of the available hydrogeological data (Map 4). The Groundwater Vulnerability Map is based on the Subsoils Map (Map 2), the Depth To Bedrock Map (Map 3), and an assessment of specifically relevant permeability and karstification information. This is illustrated in Fig. 1.2.

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 Fig. 1.3.

Chapters 2 and 3 provide brief summaries of the bedrock and subsoils geology, respectively. Chapter 4 summarises and assesses the hydrogeological data for the different rock units, explains the basis for each of the aquifer categories, and describes the potential for future groundwater development. Chapter 5 summarises a separate report on the hydrochemistry and groundwater quality in Co. Laois (Fitzsimons, 2000). Chapter 6 describes the subsoil permeability distribution and the derivation of the groundwater vulnerability categories. Chapter 7 draws the whole together and summarises the final groundwater protection zones delineated for Co. Laois.

1.9 Acknowledgements

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

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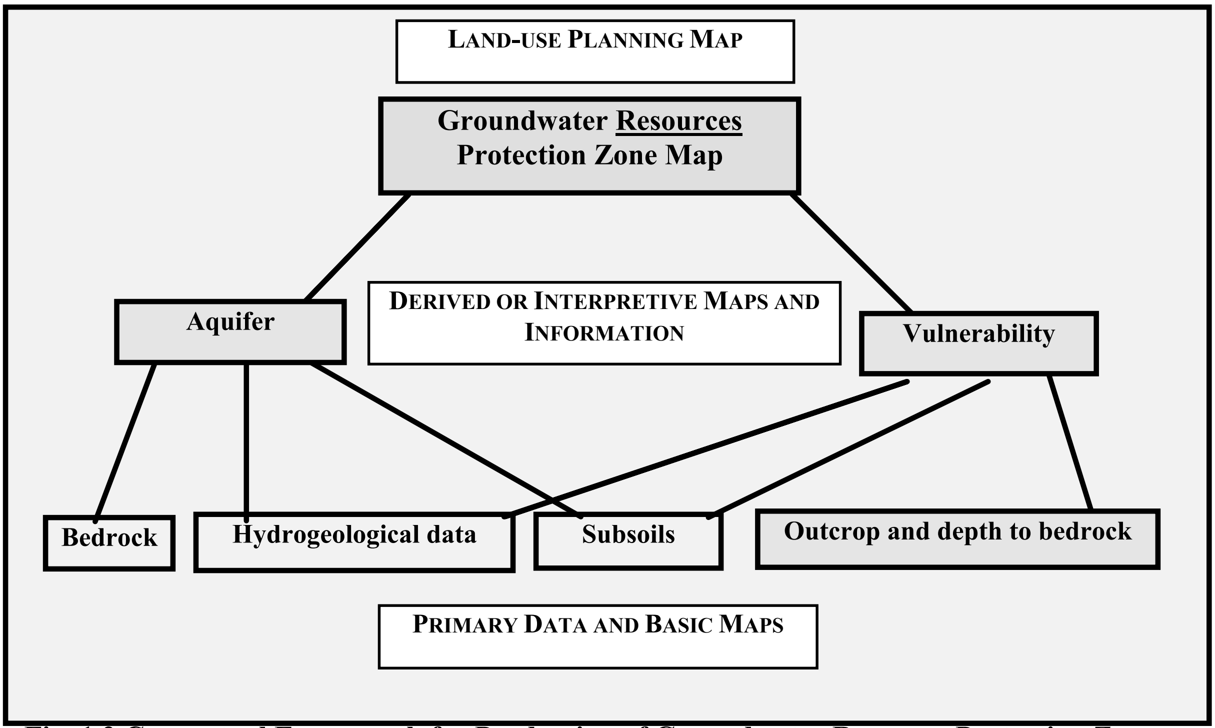

Fig. 1.2 Conceptual Framework for Production of Groundwater Resource Protection Zones, Indicating Information Needs and Links

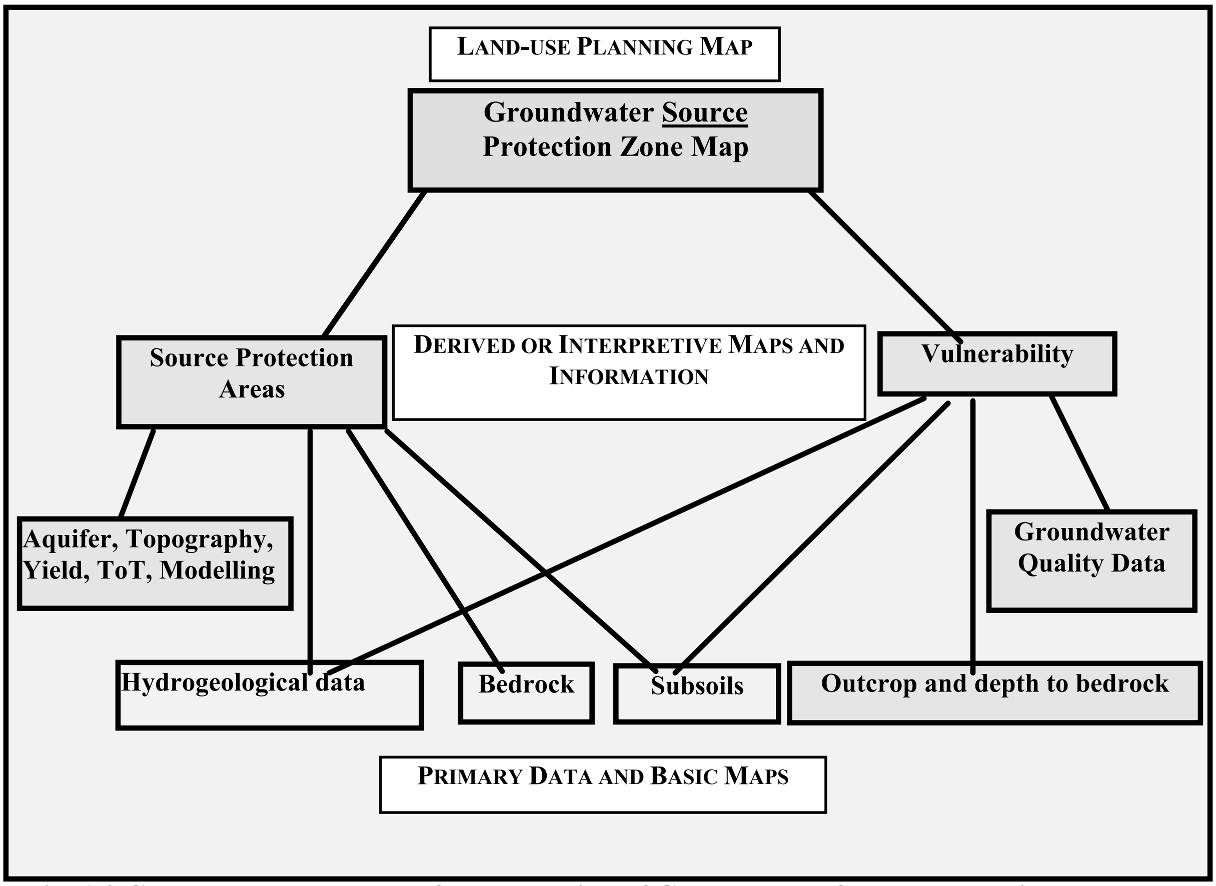

Fig. 1.3 Conceptual Framework for Production of Groundwater Source Protection Zones, Indicating Information Needs and Links

2 Bedrock Geology

2.1 Introduction

This chapter presents a brief description of the elements of the bedrock geology of Co. Laois that are relevant to the hydrogeology.

Geologically, County Laois can be sub-divided into three areas:

- The Slieve Bloom uplands in the northwest
- The Castlecomer Plateau (Leinster Coalfield) in the southeast
- The Carboniferous Limestone lowlands, occupying the area between and around the two uplands

The bedrock geology of the area is shown on Maps 1N and 1S. (Formal rock unit names are used in this chapter, together with their letter code which is shown on the maps.) Much of this map was originally compiled and produced by the Bedrock Section of the GSI (Bedrock Geology 1:100,000 map series, Sheets 16, 18 and 19). Some simplification has been used. A brief summary of the bedrock geology is given below and the rock descriptions have been taken from the GSI reports.

2.2 Slieve Bloom

Slieve Bloom is roughly 24 km long (SW-NE) and 13 km wide, and about three-quarters of the area lies in County Laois, the remainder, in the northwest, being in County Offaly. The upland reaches a maximum elevation of 528.5 metres at Arderin.

The rocks of Slieve Bloom are the oldest in County Laois, the earliest dating from the middle Silurian period (c. 425 million years old). The entire upland is an anticline (an A-shaped fold), in which the younger Old Red Sandstone has been folded around a core of Silurian rocks which had been folded previously. There was some 70 million years between the deposition of the two groups of strata.

The **Silurian (SIL)** rocks are mainly exposed on either side of the summit ridge, in the headwaters of the streams which dissect the higher slopes, whereas the peaks are capped by the Old Red Sandstone strata. The Silurian rocks are derived from sediments deposited in deep seas, and are described as grey and grey-green banded and laminated siltstones, mudstones and slates, alternating with greywackes (sand grains in a fine matrix); there are occasional discontinuous conglomerates and micro-conglomerates within the sequence. Because of the folding, the rocks are often quite steeply dipping (at 40° and over, sometimes vertically) and are cleaved. The slates were once used for roofing.

The **Old Red Sandstone (ORS)** rocks were laid down on a land surface by meandering rivers, in a semi-arid climate. The rocks belong to one formation, the **Cadamstown Formation (CW on Map 2)** (Feehan, 1982), with a total thickness varying from about 120m in the Cadamstown area to perhaps 350m in the eastern areas. The strata generally dip gently (2°-30°) away from the summit ridge. Within this formation, two units can be distinguished:

Slieve Bloom Sandstone: This is the lower and thicker unit, about 90-250 metres thick, comprising red (sometimes green) medium to coarse sandstones, alternating with red mudstones, siltstones, fine red sandstones and caliches, and occasional conglomeratic horizons. Sandstones make up about 40% of the unit, being predominant in the lower part and subordinate in the upper part.

At the base of this unit the Barlahan Basal Bed can often be seen, a very thin (up to 0.6m) layer of angular to subangular fragments of Silurian rock in a silty, occasionally sandy, calcareous matrix. It is predominantly red in colour, with occasional green mottling. This layer represents the results of weathering of the Silurian rocks, prior to the deposition of the sandstones.

Clonaslee Flagstone: (*Cadamstown Sandstone* in Offaly GWPS Report). This upper unit, about 70-105 m thick, comprises medium to coarse grained, predominantly white, creamy or yellow sandstones with plane bedding and prominent low-angle cross-stratification, with minor red and green siltstones and mudstones. Drill cores and geophysical well logs indicate that sandstones make up over 70% of the upper part and nearly 50% of the lower part of this unit (Daly, E.P. 1994). In places dissolution of the cement has rendered these rocks crumbly and easily weathered. Around Clonaslee and Rosenallis, these sandstones have been quarried for use as building stone, e.g in Barradoos and Glebe townlands (Howes, 1990). (**Note:** *Clonaslee Flagstone* (cf. *Cadamstown Sandstone* in Offaly Report) is used to avoid confusion: Feehan's *Cadamstown Formation* embraces the whole ORS in Slieve Bloom.)

2.3 Carboniferous Limestone

The Lower Carboniferous succession, which occupies the lowlands of County Laois, includes a number of different formations, mostly limestones. These formations are tabulated below, in approximate order of increasing age:

Clogrenan Formation (CL) around flanks of Castlecomer Plateau and Gattabaun Hills	Blue-grey coarse-grained fossiliferous limestone *or* Cherty muddy grey coarse-grained limestones.
Ballyadams Formation (BM) around Castlecomer Plateau and Gattabaun Hills and in Stradbally-Monasterevin area	Pale grey thick-bedded coarse-grained fossiliferous limestone with thin clay layers (wayboards).
Milford Formation (MI) Barrow Valley	Varied limestone succession (partly dolomitised), dominantly coarse-grained, with some finer beds.
Calp (CD) Limited to northeast Laois	Dark grey to black, shaly, cherty, poorly fossiliferous limestone.
Allenwood Formation (AW) 400m+thick; Occurs only in north of Laois	Mainly pale grey, clean massive limestone, commonly dolomitised.
Aghmacart Formation (AG) Narrow strip running from near Portlaoise to Rathdowney	Very dark grey fine-grained muddy limestone, with thin dark-grey shales.
Durrow Formation (DW) 200m thick; Durrow area only	Fossiliferous coarse-grained limestone, shales, and oolites with some fine-grained limestone.
Crosspatrick Formation (CS) Narrow strip running from near Portlaoise to Rathdowney	Pale grey fossiliferous coarse to fine-grained limestone with much chert and some grey shale.
Waulsortian Limestone (WA) & *Dolomitised Waulsortian (WAd)* Widespread in the southwest, centre and north of Laois	Pale grey crystalline, fossiliferous fine-grained unbedded limestones, often occurring as massive knolls, with fossiliferous or pale cherty shaly interbeds, often dolomitised.
Ballysteen Formation (BA) Widespread in centre and north of Laois	Dark grey fine to coarse-grained muddy limestone with shale partings, increasingly muddy upwards.
Lisduff Ooolite (BAld) restricted to southwest Laois	Pale grey cross-bedded oolite (composed of small near-spherical grains of calcite) and coarse-grained limestone, variably dolomitised. Occurs roughly in the middle of the Ballysteen Fm.
Boston Hill Formation (BN) Small outcrop in northeast, near Portlaoise	Mainly nodular and irregularly bedded muddy limestone, commonly dolomitised, some calcareous shale; some units of distinctive laminated limestone.
Lower Limestone Shale (LLS) around Slieve Bloom	Thin-bedded alternating mudstones, sandstones and thin limestones.

2.4 Castlecomer Plateau and Gattabaun Hills

The Castlecomer Plateau is a broad upland area which straddles the boundaries between counties Laois, Carlow and Kilkenny. The whole plateau is some 24 km wide (east-west) and 35 km long (north-south), but the northern portion within County Laois is only about 220 km^2 in extent. The plateau top is roughly saucer-shaped, sloping inwards from the rim, which reaches elevations of 180 to 245 metres.

The Gattabaun Hills lie between Durrow, Freshford and Johnstown, a few kilometres to the east of the Castlecomer Plateau, of which they are an extension. Only the northwestern part lies in Laois. The maximum elevation within Co. Laois is 254m.

Geologically, these two uplands are formed of rocks of Upper Carboniferous (Namurian and Westphalian) age. These sedimentary rocks were laid down in deltaic conditions, ie. in marshes, lakes and rivers, with occasional marine inundations. The deposition of abundant decaying vegetative material led to the formation of some seams of coal.

The rocks of the Castlecomer Plateau and Gattabaun Hills are subdivided into:

- **Namurian:**
  - Luggacurren Shale Formation (LS), 80-90m thick: black to dark grey shales and mudstones.
  - Killeshin Siltsone Formation (KN), about 275m thick: mainly grey muddy siltstones or silty mudstones, with lesser amounts of sandstone and shale.
  - Bregaun Flagstone Formation (BE), about 50m thick: grey flaggy-bedded sandstones and siltstones with lesser amounts of silty grey, often micaceous shales.
- **Westphalian:**
  - Moyadd Coal Formation (MC), about 35-115m thick, silty shales, siltstones and thin sandstones, with two coal seams.
  - Clay Gall Sandstone Formation (CG), 30-50m thick, made up of fine-medium sandstone, overlain by 3-6m of siltstone, followed by up to 5m of coal (Ward's Seam). This formation is absent from the Gattabaun Hills.
  - Coolbaun Formation (CQ), 175-310m of shales, sandstones (including the Swan Sandstone, a laminated dark grey fine-grained micaceous unit, up to 28m thick), fireclay, and two coal seams (the Jarrow Seam and the Three Foot Seam). This formation also is absent from the Gattabaun Hills.

2.5 Tertiary deposits

The Tertiary period (approx. 65 to 1.6 million years -ago) was generally a time of erosion rather than deposition in Ireland. Solution of the extensive Carboniferous limestones led to the formation of extensive karstification. Tertiary sediments are rare and not known to be exposed at the surface, but have been encountered in several boreholes. One known deposit is in the townland of Hollymount, some 6.4 km north of Carlow Town, on the west side of the River Barrow (Creighton, 1978). The deposit was discovered in 1973 when the Irish Land Commission was drilling water wells. The initial well (ILC #) encountered Quaternary clays and gravels to a depth of 12.2m, followed by about 30m of blue clay, underlain by about 0.6m of white clay. Final depth was 42.3m. A GSI borehole was drilled in 1978 to confirm the occurrence, and penetrated 18.1m of Quaternary glacial drift, underlain by blue-grey stoneless clay which became black with depth. The borehole was stopped at 47.5m in weathered limestone shale. These deposits are thought to occupy a sinkhole in the limestone surface. Other Tertiary deposits located in boreholes throughout the county are orange clays lying beneath the glacial deposits in hollows in the limestone surface, e.g at Ballycarroll.

2.6 Folding and Faulting

County Laois has been affected by two mountain building episodes (orogenies) which folded and faulted the rocks. The earlier Caledonian Orogeny folded the Silurian rocks of Slieve Bloom along a NE-SW axis. The later Variscan Orogeny folded all the rocks (Silurian, Devonian and Carboniferous) along East-West axes. The Castlecomer Plateau is a broad, gentle syncline (a v-shaped fold) in which the strata generally dip towards the centre.

Faulting is very important in the county:

- Major NW-SE faults cut across the limestones
- The Castlecomer plateau is divided into a series of 'compartments' by faults
- Major N-S or NNE-SSW strike-slip faults affect all the Devonian and Carboniferous rocks.

3 Subsoil (Quaternary) Geology

3.1 Introduction

This chapter deals primarily with the geological materials which lie above the bedrock and beneath the topsoil. The subsoils were deposited during the Quaternary period of glacial history. The Quaternary period encompasses the last 1.6 million years and is sub-divided into the Pleistocene (1,600,000-10,000 years before present (BP)); and the more recent Holocene (10,000 years BP - present). The Pleistocene, more commonly known as the 'Ice Age', was a period of intense glaciation separated by warmer interglacial periods. The Holocene, or post-glacial, saw the onset of a warmer and wetter climate approaching that which we have today.

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

3.2 Subsoil Types

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

- till
- sands and gravels
- till with gravel
- alluvium
- peat
- lake deposits

Areas where bedrock comes within about 1 m of the surface are shown on the maps as "rock close".

3.2.1 Till

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

Till deposits in County Laois have a widespread distribution and are classified according to their lithological composition. Three main lithological types are present: (a) limestone till (dominated by fragments of Lower Carboniferous limestones); (b) sandstone till (dominated by fragments of Devonian or Namurian sandstones); (c) shale till (dominated by fragments of Namurian or Westphalian shales).

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

Boundaries based on till texture are not shown on the subsoils map, but symbols indicate the texture at specific locations. A limited number of particle size analyses were carried out to help assess the till texture.

3.2.2 Sands and gravels

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

The presence of sand and gravel is often reflected in the topography as ridges (eskers), hummocks and hollows (kames and kettle holes) or in large fan shaped deposits (outwash, deltas). Laois has a number of important eskers, many of which have been extensively exploited as gravel workings.

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

3.2.3 'Till with gravel'

This term encompasses those areas where till and gravel are intimately mixed, either vertically or horizontally, or both, so that individual areas of one sediment or the other cannot be delineated.

3.2.4 Alluvial deposits

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

Alluvial deposits may be subdivided into gravels, sands and silts, but insufficient information exists for Laois to enable such subdivision to be shown on the subsoils map. Alluvial sediments are expected to be primarily silty deposits. They are likely to be more sandy where flow velocities are faster – on and close to the hills and mountains. Alluvial gravels also occur in places.

3.2.5 Peat

Deposition of peat occurred in post-glacial times with the onset of warmer and wetter climatic conditions. Peat is an unconsolidated brown to black organic material comprising a mixture of decomposed and undecomposed plant matter which has accumulated in a waterlogged environment. Peat has an extremely high water content averaging over 90% by volume. Two main types of peat bog are distinguished: blanket bog, which is characteristic of upland areas with excessive rainfall, and raised bogs, which are characteristic of lowland areas with impeded drainage. Blanket bog, as found on Slieve Bloom, is typically quite thin (less than 2 metres), whereas raised bogs may be much deeper. Both types have been worked for peat, but only the lowland raised bogs are worked commercially by machinery.

3.2.6 Lake deposits

One small area of lake deposits has been mapped, in the extreme northeast of the county, north of Monasterevan. These sediments are typically silty material, similar to the finer type of alluvium.

3.3 Depth to Bedrock

The depth-to-bedrock (i.e. subsoil thickness) is a critical factor in determining groundwater vulnerability. Subsoil thicknesses vary considerably over the county, from very thin to depths of more than ? metres. The direction of ice movement has spatially influenced the subsoil thicknesses.

Depth-to-rock maps (Maps 3N and 3S) have been prepared from the GSI databases and from field mapping and air photo interpretation. These maps show areas where rock crops out at surface and depth-to-rock data from borehole records. The borehole records are colour-coded according to the degree of locational accuracy: data points coloured red are plotted to within an accuracy of 100 m, the green data pointsare less accurately located, to +/-200-500 m. Generally speaking, the thickest deposits are tills or gravels, and they are found scattered throughout the county.

The gravel deposits vary considerably in thickness. There are a number of deposits which are over 10 m thick, at least in part (see Chapter 5).

4 Hydrogeology and Aquifer Classification

4.1 Introduction

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

4.2 Data Availability

All the groundwater data in the GSI and from County Council files, consultants and drillers were compiled and all existing well records (2100) were entered into a computer database in the GSI.

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

- ♦ Groundwater abstraction rates for local authority sources (Table 5.1), group scheme sources, and for a limited number of other high yielding private wells
- ♦ Information from approximately 2100 well records in the GSI
- ♦ Specific capacity data for some 200 wells in Laois and the surrounding counties. (Specific capacity is the rate of abstraction per unit drawdown; the unit used is $m^3/d/m$.)
- ♦ Pumping tests carried out on 6 public supply wells as part of this project (see summary of results in Table 5.2), and other available pumping test data
- ♦ Information on large springs
- ♦ Reports by engineering and hydrogeological consultants
- ♦ General hydrogeological experience of the GSI, including work carried out in adjacent counties (Carlow, Kildare, Kilkenny, Offaly, Tipperary)

4.3 Rainfall, Evapotranspiration and Recharge

Mean annual rainfall in Laois for 1951–1980 varied from just under 800 mm along the Barrow valley on the eastern margin, to over 1500 mm on the top of Slieve Bloom (Met Eireann data). Over most of the county, the average is 800-1000 mm.

There are no Met Eireann synoptic weather stations in Co. Laois and the closest one is the Teagasc station at Oakpark, Co. Carlow where the long term mean annual potential evapotranspiration (PE) is calculated as mm (Met Eireann data). The mean annual PE for Co. Laois is estimated to vary from approximately 450 to 500 mm. Actual evapotranspiration is estimated at about 90 to 95% of the PE.

The mean annual potential recharge (rainfall minus actual evapotranspiration) values are therefore estimated to be in the range 300 to 1000 mm, with the lowest levels in the low-lying areas and the highest in the uplands. The actual annual recharge to the groundwater depends on the relative rates of infiltration and surface runoff. In many areas recharge is likely to be as low as 25% of the potential recharge.

4.4 Groundwater Usage

There are approximately 30 public, and numerous private and group water schemes in Co. Laois. In total the main public and group groundwater schemes abstract some 13000 m^3/d (based on County Council figures, 1999), which constitutes approximately 50% of total water consumption in the County Council area (OCM, 1999). The principal County Council groundwater supplies are summarised in Table 4.1. Areas not served by the County Council or group water schemes generally rely on individual private wells as their source of water.

Table 4.1. Summary of Principal Co. Council Supplies (from Co. Council data)

WATER SUPPLY	ABSTRACTION	SOURCE
Eastern Area	(m^3/d approx.)	
Arless	10	spring & borehole
Coolenaugh	6	borehole
Emo	200	borehole
Heath GWS	110	impounded spring
Portarlington WSS (Lough bh)	200	borehole
Kyle	350	impounded spring
Killenard GWS	300	borehole
Orchard	250	impounded spring
Strand	10	borehole
Newtown-Mayo WSS (Swan bh)	500	artesian borehole
Vicarstown	41	borehole
Central Area		
Ballydavis (Portlaoise WS) (3410)		2 boreholes
Darkin Well (Portlaoise WS)	4300	Spring
Derrygarron (Portlaoise WS)		2 boreholes
Derryguile (Mountmellick WS)	1160	borehole
Meelick (Portlaoise WS)	773	borehole
Rosenallis WSS (Srahleagh bh)	27	borehole
Tullamore UDC WSS	264	boreholes
Ballyroan WSS (Tullore sp)	482	Spring
Western Area		
Aughfeerish (Abbeyleix WS)		spring
Ballyglisheen (Abbeyleix WS)	910	dug well
Five wells (Abbeyleix WS)		?dug well
Cloghoe (Ballinakill WS)	100	spring
Coolfin well (Ballacolla GWS)	240	?dug well
Dairyhill (Ballacolla GWS)	142	borehole
Shanahoe (Ballacolla GWS)	366	impounded spring
Tinnaraheen (Ballacolla GWS)	240	impounded spring
Cullahill GWS	275	impounded spring
Donaghmore GWS	90	borehole
Derrin (Borris-in-Ossory WSS	173	borehole
Townparks (Borris-in-Ossory WSS)		borehole
Durrow Convent (Durrow WSS)	159	borehole
Errill GWS	725	boreholes
Durrow/Ballinakill WSS (Fermoyle bh)	300	Borehole & impounded spring
Rathdowney WSS (Whitewall Sp)	390	spring
TOTAL	13093	

(source: Laois County Council 1996)

Table 4.2. Summary of pumping tests undertaken during the project.

Public Supply	*GSI no.*	*Grid ref.*	*Depth (m)*	*Aquifer (Formation)*	*DTB[a] (m)*	*SWL[b] (m)*	*s[c] (m)*	*Q[d] test (m^3/d)*	*Q normal (m^3/d)*	*Hrs/d pumped*	*Q/s[e] ($m^3/d/m$)*	*Q/s 1 week ($m^3/d/m$)*	*KD[f] (m^2/d)*
Meelick WSS			14	Crosspatrick/AW		3.03	1.20	763	763		636	489	510
Lough WSS			71.8	Ballyadams Lst		4.305	3.285	272			94		
Fermoyle (B) WSS		24281 17910	24.4	Ballyadams Lst		3.90	0.79	168			210		
Derryguile WSS		2415 2057	45.7	Ballysteen Fm				420			18.45		
Drim WSS	2319sw		152	Cadamstown Sst		11.33		954	960	12	101.3	73	54
Rosenallis WSS		2405 2090	36.6	LLS		5.745	23.07	73	87.3	4-6	3.16		4

Notes:

a) Depth-to-bedrock below ground level
b) Static water level below ground level
c) Drawdown at end of test
d) Discharge (*Q test* refers to the rate of pumping during the pumping test. *Q normal* indicates the quantity of water abstracted daily.)
e) Specific capacity (*Q/s* is the specific capacity calculated from the pumping test data. *Q/s 1 week* is extrapolated from the pumping test data.)
f) Transmissivity

4.5 Aquifer Classification

The aquifer classification used by GSI (Daly, D. 1995) has three main aquifer categories, with each category sub-divided into two or three classes:

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

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

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

(i) Sand/gravel (**Lg**)
(ii) Bedrock which is generally moderately productive **(Lm)**
(iii) Bedrock which is moderately productive only in local zones **(Ll)**

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

(i) Bedrock which is generally unproductive except for local zones **(Pl)**
(ii) Bedrock which is generally unproductive **(Pu)**

These aquifer categories take account of the following factors:

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

Aquifers are defined on the basis of:

- Lithological and/or structural characteristics of geological formations which indicate an ability to store and transmit water. Pure limestones and clean sandstones are more permeable than muddy limestones and clayey sandstone, respectively. Areas where strong folding and faulting has produced strong joint systems has led to increased permeability.
- Hydrological indications of groundwater storage and movement e.g. the presence of large springs (indicating a good aquifer); absence of surface drainage (suggesting high permeability) or high density of surface drainage (low permeability situation usually – the main exception is in low lying areas where there is no outlet for the water); high groundwater base flows in rivers, etc.
- Information from boreholes, such as high permeabilities from pumping tests, specific capacities (rate per unit drawdown), and well yields and productivities.

Use of Borehole Yields in Defining Aquifers

Well yields are just one factor used for categorising a rock unit as an aquifer. However they are often the main type of data available and they allow the three main aquifer categories to be conceptualised. Regionally important (**R**) aquifers should 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). Poor (**P**) aquifers would generally have low yielding wells - less than 100 m^3/d.

Information from the wells throughout Laois and neighbouring counties show a wide variation in well yields, with 'excellent', 'good', 'moderate' and 'poor' wells all in close proximity. The details from some of these wells are limited and thus interpretation is difficult from the available records.

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). This Groundwater Protection Scheme is the first to have made full use of this index in defining aquifer categories.

In order to make the best use of all relevant available information, data from groundwater investigations in neighbouring counties have also been used. The data are summarised in Table 4.3.

Table 4.3 Well Productivity & Yield Categories

Formation	***Well Productivity***						***Well Yield***					**Aquifer category**
	I	***II***	***III***	***IV***	***V***	***Total***	***E***	***G***	***M***	***P***	***Total***	
Quaternary deposits (Sand/gravel)	8	10	4	6	1	29	11	7	8	3	29	Lg - Rg
Coolbaun Formation	No Data						No Data					Pl
Moyadd Coal Formation (MC)	0	0	0	1	0	1	0	0	0	1	1	Pl
Westphalian Sandstones (Clay Gall & Swan Ssts)	0	3	4	0	0	7	1	3	2	1	7	Lm
Namurian (Bregaun Sst Fm, Killeshin Siltstone Fm, Luggacurren Shale Fm	0	0	1	7	3	11	0	2	4	6	12	Pl - Ll
Clogrenan Limestone Fm (CL)	No Data						No Data					Rk
Ballyadams Limestone Fm (BM)	9	5	6	6	5	31	7	8	11	6	32	Rk
Allenwood/Rickardstown Lst Fm (AW)	7	5	1	4	3	19	10	5	3	2	20	Rk
Crosspatrick Limestone Fm (CS)	1	1	2	0	0	4	2	2	0	0	4	Lm
Calp Limestone (CD)	2	9	13	7	11	42	5	8	16	13	42	Ll
Milford Limestone Fm (MI)	0	0	2	0	0	2	0	2	0	0	2	Rk
Waulsortian Limestone (WA)	2	3	2	3	8	18	3	2	4	9	18	Ll - Rk
Dolomitised Waulsortian Lst (WAdo)	8	2	2	2	0	14	10	2	1	1	14	Rf
Ballysteen Formation (BA)	1	1	5	5	8	20	2	1	7	10	20	Ll
Dolomitised Ballysteen Formation (BAdo)	2	2	4	1	1	10	6	1	1	2	10	Lm
Lisduff Oolite member (BAld)	1	2	1	0	0	4	3	0	0	1	4	Lm
Lower Limestone Shale (LLS)	0	0	0	1	0	1	0	1	0	0	1	Pl
Clonaslee Flagstone (& equivalents)	6	6	3	2	0	17	8	8	1	0	17	Rf
Old Red Sandstone (ORS)	0	0	3	0	1	4	0	1	1	2	4	Ll
Lower Palaeozoic rocks	0	0	0	3	5	8	0	1	2	6	9	Pl
Totals	51	50	53	47	46	247	72	55	60	63	250	

Notes:

1. These data are drawn from Co. Laois and neighbouring counties: Carlow, Kildare, Kilkenny, Offaly, & Tipperary (N)
2. These statistics may be skewed towards higher yielding sources – mainly Co. Co. and group scheme supplies.
3. From over 2100 Co. Laois well records, most have neither drawdown data (for specific capacities) nor maximum yields.
4. 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)

Karstification

The word **karst** is derived from the Serbo-Croat word **krs** and Slovenian **kras** meaning stony bare ground. The Kras is a limestone region, now a part of Slovenia and Croatia, in which the distinctive landforms of such areas are exceptionally well developed.

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. One of the consequences of karstification is the development of an uneven distribution of permeability which results from the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones.

The type of limestone strongly influences its susceptibility to karstification. Purer limestones are more susceptible than impure (shaly) limestones. The geological structure is also influential: folding of the limestone causes fracturing, which creates a network of fissures along which water can penetrate and dissolve the rock. Pure limestones tend to be brittle, allowing extensive open fractures. Impure limestones tend to be less brittle and deform more readily, sealing up the fractures and impeding water movement. Shale layers also impede water movement and hinder karstification. However, very strong deformation causes re-sealing of fractures by crystalline calcite, again impeding karstification.

The degree of karstification can vary from slight to intensive. Where it is slight, a regionally important limestone aquifer is considered to be similar to a fissured rock and is classed as **Rf**, although some karst features may occur. A regionally important aquifer in which karst features are more significant is classed as **Rk**. Locally important or poor limestone aquifers may be classed as **Lm**, **Ll** or **Pl**.

Relatively few karst features are found in County Laois. Table 4.4 lists 22 which have been recorded in the GSI Karst Database. Of these, 15 are surface features and 7 have been recorded in boreholes.

Table 4.4 Karst Features in Co. Laois

Type	Feature Name	East	North	Townland	6 inch	1:25,000	Stratigraphy
Cave	Luggacurren Cave	25866	18968	Luggacurren	25	2317NE	CL (Clogrenan Fm)
Cave	Clopook Cave	25831	19072	Clopook	19	2319SE	CL (Clogrenan Fm)
Cave	Pollaphuca	25751	19418	Aghamaddock	19	2319SE	CL (Clogrenan Fm)
Spring	Julian’s Well	25425	20462	Morett	9	2319NE	BM/CD
Spring	Fooraun Well	25443	20419	Morett	9	2319NE	BM
Spring	Toberkine	25444	20343	Morett	9	2319NE	BM/CD
Spring	Sally Well	25423	20321	Morett	9	2319NE	BM/CD
Spring	St. Brigid’s Well	25412	20411	Morett	9	2319NE	BM/CD
Spring	Tobernahinch	25455	20236	Killone	14	2319NE	BM
Borehole	Trial Well No. 1	24885	20260	Straboe	8	2319NE	WA
Borehole	Production Well No. 2	25005	20075	Derrygarran	13	2319NE	AW
Borehole	Production Well No. 3	25047	20095	Ballydavis	13	2319NE	AW
Borehole	Production Well No. 4	25037	20112	Ballydavis	13	2319NE	AW
Cave	Poulasthore Cave	25528	20090	Kilmurry	14	2319NE	CL (Clogrenan Fm)
Borehole	Killenard GWS No.3	25460	21030	Ballymorris	5	2321SE	CD
Borehole	Killenard GWS No.5	25456	21006	Ballymorris	5	2321SE	CD
Borehole	Killenard GWS No.6	25465	21041	Ballymorris	5	2312SE	CD
Spring	Toberneeve	26217	19050	Parkahoughill	19	2619SW	BM
Spring	Tobernasool	26220	19046	Parkahoughill	19	2619SW	BM
Spring	Tubbernagapple	26277	19106	Ballyadams	19	2619SW	BM
Spring	Tobernadrain	26423	19117	Cappanafeacle	20	2619SW	BM
Enclosed Depression	N/A	27006	18052	Hollymount	32	2617NW	BM

Dolomitisation

Dolomitisation is a process whereby calcium ions are replaced by magnesium ions in the crystal lattice, converting the mineral Calcite (Ca CO_3) to Dolomite (Ca Mg $(CO_3)_2$). Because the magnesium carbonate has a different crystal structure, this creates additional void space in the rock, and can enhance the development of permeability and, in some cases, karstification.

There are two different types of dolomitisation, which have significantly different effects on permeability. The first is the typical well known, highly weathered, yellow/orange/brown dolomitisation which is usually evident in boreholes as loose yellow-brown sand with significant void space. 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 of dolomitisation which is often a black colour on the surface. This type is considered to be a barrier to groundwater flow.

Aquifer Delineation

Aquifer delineation is a generalisation which reflects the overall resource potential; because of the complex and variable nature of Irish hydrogeology, there will often be exceptionally low or high yields which do not conform with the aquifer category given. It is also important to note that the top few metres of all bedrock types are likely to be relatively permeable.

The rock units in County Laois are listed in Table 4.3 above, together with a summary of the useful well data for each formation, and the aquifer category. In assessing the well data in Table 4.3, it should be noted that there will be a bias towards higher yielding wells, as only these wells are used by the County Council and group schemes. The remaining wells (>1500 in the GSI database) are mainly privately owned or site investigation boreholes and many are shown to have ‘poor’ yields; however, these wells have not been tested properly and the yields given may not be the maximum possible. Also many of the records do not have yield estimations.

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

4.6 Sand/Gravel Aquifers

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

A sand/gravel deposit is classed as an aquifer if it is over one km^2 in area and has a saturated thickness of at least 5 m. In the absence of detailed water table data (and hence saturated thickness) a deposit thickness of at least 10 m is taken as the criterion for inclusion. In general, a deposit over 10 m thick will have a saturated zone of at least 5 m. This is not the case where deposits have a high relief, for example eskers or deposits in high topographic areas, as these gravels often have a thin saturated zone. Conversely, in lowlying areas (e.g. flood plains) a slightly lesser thickness may be adequate.

There are two categories of sand/gravel aquifers – regionally important and locally important. The two differ in areal extent and estimated annual throughput (see Table 4.5).

Table 4.5 Sand/gravel Aquifer Classification

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

A regionally important gravel aquifer should have an areal extent of *at least* 10 km^2. This is to ensure that, assuming an average annual rainfall of 400 mm, there will be enough recharge to provide a supply of one million cubic metres per year from the whole aquifer. A locally important aquifer on the other hand can be expected to have enough resources to supply a group scheme or village.

Daly (1983) identified nine significant gravel aquifers in County Laois (Table 4.6), with a total areal extent of 124 km^2. The Quaternary mapping undertaken by Aoibheann Kilfeather for this project, and later subsoil mapping by Teagasc (R. Meehan) has extended and refined the area of known or inferred sand/gravel deposits in Co. Laois. The Sand/Gravel aquifers illustrated on the aquifer map (Maps 5E and 5W) were delineated by the following process:

- Identifying Sand/Gravel deposits at least 1 km^2 in area
- Discounting areas of sand/gravel less than 10 m in thickness (except in the Barrow Valley)
- Taking account of other evidence (mainly E.P. Daly's surveys, & water well data)
- Discounting small areas only tenuously connected to the main deposit

Fourteen sand/gravel aquifers are identified, listed in Table 4.7. Two are classified as Regionally Important (Rg). The remainder, ranging up to 13 km^2 in area, are classified as Locally Important (Lg). Although three of these are 10-13 km^2 in area, there is insufficient confidence in their resource capacity to classify them as regionally important. In one case only (Barrow Valley) the aquifer has been classified despite having a total thickness of less than 10 m, because (a) a high water table can be expected in the Barrow floodplain, and (b) it is a proven aquifer.

Most of the aquifers thus identified are not significantly developed and their resource availability is therefore not proven. Until confirmatory evidence is obtained, e.g. from exploratory boreholes, they should be regarded as *Potential* gravel aquifers. Several of the aquifers also overlie bedrock aquifers, and this needs to be taken into account when developing them.

There are several other smaller deposits of gravel which have not been classed as a locally important aquifer as they do not meet the areal extent requirement, as mapped on the ground surface.

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

Table 4.6 Sand/gravel Aquifers in Co. Laois (EP Daly, 1983)

Gravel deposit	Extent (km^2)	Development	Remarks
Barrow Valley (Lg)	6.0		Overlies the dolomite aquifer; extends into counties Carlow and Kildare
Newtown (Lg)	1.9		
Stradbally (Lg)	4.5	Kyle Spring; Orchard Spring	Overlies the Ballyadams Formation
Derrygarran (Lg)	4.1	Darken Well (spring)	
Camross (Rg)	16.1		Partially overlies the Clonaslee Flagstone aquifer
Ballyfin (Rg)	13.5		Partially overlies the Clonaslee Flagstone aquifer
Clonaslee (Rg)	10.9		
Maryborough Esker (Rg)	19.2		Small parts overlie bedrock aquifers
South Laois (Rg)	48		Partially overlies various bedrock aquifers
Total	***124***		

Table 4.7 Sand/gravel Aquifers in Co. Laois (Groundwater Protection Scheme)

	Area	km^2	EPDaly's survey	Sources	Class
1	Southeast of Durrow	3	part of Middle Nore River Gravels		**Lg**
2	Northeast of Cullahill & north of Durrow	??	part of Middle Nore River Gravels		**Lg**
3	Rathdowney	2.5	Not included		**Lg**
4	West of Borris-in-Ossory	4	Not included but apparent continuation of Roscrea gravels		**Lg**
5	North, West and South of Camross	??	part of Upper Nore River Gravels		**Lg**
6	Northwest of Mountrath	3	part of Upper Nore River Gravels		**Lg**
7	Southwest of Mountrath	7.5			**Lg**
8	Northwest of Clonaslee	14			**Lg**
9	North of Portlaoise	10			**Lg**
10	South of Portlaoise	2			**Lg**
11	Northeast of Stradbally	??			**Lg**
12	Timahoe	12.5		Kyle, Orchard springs	**Lg**
13	around Abbeyleix	30.5	part of Middle Nore River Gravels	Ballinakill WSS (Cloghoe Spring); Abbeyleix WSS springs; Tullore Spring.	**Rg**
14	Barrow Valley (Lg)	6 (in Laois)		Overlies dolomite aquifer (Rf); extends into counties Carlow & Kildare	**Rg**
	Total	162			

Bedrock Formations:

Coolbaun Formation (CQ) Pl

Data are sparse for this formation, so it is classified on lithological grounds and because it acts as a confining layer to the Swan Sandstone and Clay Gall Sandstone.

Swan Sandstone (CQss) Lm

This is classified on the basis of investigations carried out in the 1970s (Daly, D. et al, 1980, Misstear et al, 1980), but some recent data tend to be supportive.

Clay Gall Sandstone Formation (CG) Lm

This is classified on the basis of investigations carried out in the 1970s (Daly, D. et al, 1980, Misstear et al, 1980), but some recent data tend to be supportive.

Moyadd Coal Formation (MC) Pl

Data are sparse for this formation, but well yields are generally poor and its lithology is unfavourable.

Bregaun Flagstone Formation (BE) Pl

Data are sparse for this formation, but well yields are generally poor and its lithology is unfavourable.

Killeshin Siltstone Formation (KN) Pl

There are few pumping tests for this formation but abundant evidence that well yields are poor.

Luggacurren Shale Formation (LS) Pu

This is classified on the basis of its predominant shale/mudstone lithology.

Clogrenan Limestone Formation (CL) Rk

No pumping test data are listed, but several karst features are recorded. The formation is considered to be essentially in continuity with the underlying Ballyadams Formation and is classified similarly.

Ballyadams Formation (BM) ***(formerly Cullahill Lst)*** **Rk**

This formation is the main productive limestone formation in the county. Nevertheless, pumping test results from 31 boreholes in the formation show a wide range of properties, which reflects the karstified nature of the formation.

Milford Formation (MI) Rk

Only two pumping tests are listed for this formation, but from these and lithological evidence, the formation is classified as Rk.

Calp Formation (CD) Ll

This formation shows a very wide range of properties within Ireland. In Galway it is a very poor aquifer, while in Meath it is good. In Laois and the neighbouring counties its properties appear to be intermediate between these extremes. Only two boreholes (out of 42) have a class I productivity, but 9 have class II and 13 have class III, while another 11 have class V. This indicates a Locally Important Aquifer which can be quite good but can also be poor (Ll).

Allenwood Formation (AW) Rk

The QSC data have 19 data points showing a wide spread across all productivity classes, but over half in the top two three classes. This suggests a Regionally Important Aquifer (Rk). Karst features have been recorded only in boreholes.

Aghmacart Formation (AG) Ll

This muddy limestone unit, regarded as equivalent to the Calp, is given the same classification – Ll.

Durrow Formation (DW) Ll

No pumping test data are listed.

Crosspatrick Formation (CS) Lm

This has limited pumping test data. The classification is based primarily on E.P. Daly's Nore Basin work.

Waulsortian Limestone (WA) Ll

Pumping test results (23) show a wide spread of values; half the yields and productivities are in the bottom two classes, confirming the Ll classification given for Co. Offaly and implied in E.P. Daly's Nore Basin work. Some of the higher yields and productivities may refelect the unrecorded occurrence of dolomite.

Dolomitised Waulsortian (WAdo) Rf

Pumping test results from two main sites (Straboe well field (Portlaoise WSS), and Lisheen Mine) confirm E.P Daly's classification of the dolomitised Waulsortian as a Regionally Important Aquifer.

Ballysteen Formation (BA) Ll

Pumping test data from 20 boreholes show a heavy predominance in the lower categories.

Dolomitised Ballysteen Formation (BAdo) Lm

As with the Waulsortian Limestone, the prevalence of dolomitisation transforms the otherwise patchy permeability of the Ballysteen Limestone, bringing about a much more consistent permeability which allows it to be classified as Lm.

Lisduff Oolite (BAld) Lm

Very limited pumping test data tend to confirm this classification, which is mainly based on E.P. Daly's Nore Basin work.

Boston Hill Formation (BN) Ll

This is included with the Ballysteen Formation and classified accordingly.

Lower Limestone Shale (LLS) Pl

Very few data points exist for this formation, so a Pl classification is given, principally on lithological grounds.

Cadamstown Formation (CW)Rf

The Cadamstown Formation is regarded as equivalent to the Kiltorcan Formation found in counties Kilkenny, Cork and Tipperary, where it is a Regionally Important fissured aquifer (Rf). Pumping test data supprt this. In Laois, this classification is supported by data from the Clonaslee wellfield (Tullamore WSS) on the north side of Slieve Bloom, although results of drilling south of Slieve Bloom have sometimes been disappointing (i.e. at Camross) although good elsewhere (i.e. at Drim).

Old Red Sandstone (ORS) Ll

Outside the Cadamstown Sandstone, there are very few pumping test results for this formation. In common with practice adopted for other counties, the formation is classified as Ll, which is in conformity with the few data points available.

Silurian slates & greywackes (SIL) Pl

In most parts of Ireland (except in the Caledonian fold belt of Counties Wexford, Wicklow and South Kilkenny) the Lower Paleozoic rocks are poor aquifers. The few data points available for Laois and surrounding counties support a classification of Pl.

4.7 Summary of Aquifer Categories

The rock units in County Laois are classified into the different aquifer categories in Table 4.8.

Table 4.8 Bedrock aquifer classifications

Aquifer Category	Subdivision	Rock Unit
Regionally important (R) **(35%)**	Sand/gravel (**Rg**) (5%)	Two deposits (Table 4.7)
	Karst – conduit flow dominant (**Rk**) (17%)	Clogrenan Limestone Formation; Ballyadams Limestone Formation; Milford Limestone Formation; Allenwood Limestone Formation;
	Fissure flow (**Rf**) (13%)	dolomitised Waulsortian Limestone; Cadamstown Formation (Clonaslee Flagstone);
Locally important (L) **(47 %)**	Sand/gravel (**Lg**) (4.5%)	Nine deposits (see Table 4.7)
	Bedrock which is generally moderately productive (**Lm**) (3.5%)	Westphalian sandstones (Swan Sandstone, Clay Gall Sandstone); Crosspatrick Limestone; Lisduff Oolite; dolomitised Ballysteen Limestone;
	Bedrock which is moderately productive only in local zones (**Ll**) (39%)	Calp Limestone; Aghmacart Limestone; Durrow Limestone; Waulsortian Limestone; Ballysteen Limestone; Boston Hill Formation; Old Red Sandstone;
Poor (P) **(18 %)**	Bedrock which is generally unproductive except for local zones (**Pl**) (17%)	Coolbaun Formation; Moyadd Coal Formation; Bregaun Sandstone Formation; Killeshin Siltstone Formation; Lower Limestone Shale; Silurian;
	Bedrock which is generally unproductive (**Pu**) (1%)	Luggacurren Shale Formation

Note: The percentages refer to the proportional areal extent of each aquifer category in Co. Laois.

4.8 Potential for Future Groundwater Development in County Laois

Sand/gravel

Carefully located wells would be capable of supplying large quantities of water. These aquifers could be particularly important in areas not supplied or unlikely to be supplied by regional schemes. Site investigations are required to design the wells for optimum yield and protection of the zone of contribution. The water quality of the sand and gravel deposits will depend strongly on the composition of the deposit, its depositional history and the degree of natural protection in the area.

Bedrock Aquifers

Regionally Important Aquifers: the clean limestone aquifers, Ballyadams, Allenwood, Clogrenan and Milford formations, and the dolomitised Waulsortian Formation, are capable of yielding substantial quantities of water for regional or local supplies. As with all such limestones, permeability can be very variable, and there may be failures as well as successful wells. The Clonaslee Flagstone; and the locally important (Lm) Swan and Clay Gall Sandstones, should be more consistent. The Clonaslee Flagstone has proved very productive on the north side of Slieve Bloom, but less so on the south side. It remains to be seen if this contrast is real or apparent, and if real, the hydrogeological cause of the difference.

The locally important limestone aquifers: Crosspatrick Formation, dolomitised Ballysteen Formation, and Lisduff Oolite, can be expected to give moderate to good yields. The Old Red Sandstone will give good yields only where particular fracture zones can be tapped.

In all cases, the chances of a successful well will be improved by careful attention to the geological environment, the topographic location, and often by employing a geophysical survey to identify a fracure zone.

Remaining Rock Units

None of the remaining rock units (see Table 4.7) has the potential to provide sufficient yield to satisfy the likely needs of the Council. While an occasional high yielding well is always possible in view of the folded and faulted nature of bedrock in Ireland, yields are generally low and may reduce further in dry weather. Also, wells in some of these rocks frequently have high iron concentrations and also associated high manganese.

5 Hydrochemistry and Water Quality

5.1 Introduction

An assessment of the quality of groundwater in County Laois is given in a report to Laois County Council by the Geological Survey of Ireland (Fitzsimons & Wright, 2000). This chapter gives the main conclusions of that report.

5.2 Overall Assessment

The hydrochemistry of groundwater in County Laois is primarily influenced by the nature of the subsoil and bedrock that it passes through.

Of 50 public and group water supply sources sampled, 49 have a 'calcium-bicarbonate' chemical signature, i.e. calcium and bicarbonate are the dominant major ions (Table 5.1). This signature is typical of groundwater in Ireland – especially in limestone areas or areas of limestone-rich subsoils.

The remaining supply, at The Swan, has a more unusual 'calcium-magnesium-bicarbonate' signature, diagnostic of 'ion exchange' in the layered bedrock sequence of the Castlecomer Plateau (Misstear et al., 1980). Evidence of this process is rare in Ireland, and usually indicates much less vulnerable groundwater with slower, longer flow paths. Note that The Swan is the only source studied with undetectable nitrate levels, although elevated ammonia levels (regularly 0.1-0.15 mg/l) indicate a readily available source of nitrogen, probably the shales and coals of the Castlecomer succession.

Of the 50 supplies sampled, waters in 60% are 'very hard', 30% 'hard', 4% 'moderately hard', 4% 'slightly hard' and 2% (i.e. 1 source) 'moderately soft'.

Iron concentrations ranged from 0.3 mg/l to undetectable (∗ 0.005 mg/l). Typical concentrations were around 0.01 mg/l. Results from 8 out of the 50 sources were undetectable in both sampling rounds.

Sulphate concentrations ranged from 4 mg/l to 61 mg/l, but were typically 15 to 20 mg/l.

Chloride concentrations ranged from 8 mg/l to 37 mg/l, but were typically 15 to 20 mg/l.

Table 5.1: Typical Major Ion Concentrations in each Rock Unit Category

Rock Unit Category	Median Concentration for each Rock Unit Category (mg/l)[1]										
	Ca	Mg	Na	K	Alk	SO_4	Cl	EC	Fe	Mn	NH_x
Upper Carboniferous sandstones & mudstones	120	10	9	2	310	10	20	620	0.02	<0.005	<0.015
Clean or dolomitised Carboniferous limestones	110	10	9	2	300	20	20	610	0.01	<0.005	<0.015
Muddy Carboniferous limestones	130	10	10	3	350	30	20	680	0.01	<0.005	<0.015
Devonian sandstones & mudstones	40	3	6	2	120	8	12	270	0.01	<0.005	<0.015
Total (including the eleven non-classified sources)	120	10	9	2	330	20	20	650	0.01	<0.005	<0.015

The waters in the limestones are 'hard' or 'very hard' and have a chemical signature typical of Irish groundwaters. The groundwaters in the Devonian sandstones generally have a similar chemical signature, but are slightly softer than the limestone waters. There is potential for longer, slower groundwater flow patterns and for higher 'natural' levels of iron in the Upper Carboniferous sandstones and mudstones.

[1] Ca: Calcium. Mg: Magnesium. K: Potassium. Na: Sodium. Alk: Alkalinity (as $CaCO_3$). SO_4: Sulphate. EC: Conductivity (µS/cm). Fe: Total Iron. Mn : Manganese. NH_x: Ammonia.

5.3 Summary of 'Natural' Groundwater Characteristics

The data from two sampling rounds, encompassing 50 water sources in Laois, suggest the following:

- The dominant chemical signature in the 50 sources under consideration is 'calcium-bicarbonate'. This is typical of Irish groundwaters.
- Waters in the limestone sources are hard or very hard, so lime scale is likely to be a problem. Waters in the Devonian sandstones are moderately hard to moderately soft.
- Sulphate and chloride concentrations are typical of Irish groundwaters in the Midlands.
- Iron, potassium, manganese and ammonia concentrations are generally low, but may cause problems in specific sources, especially in the Upper Carboniferous sandstones and mudstones.

5.4 Groundwater Quality Problems

General Groundwater Quality Assessment of Supply Sources

The supply sources were divided into four groups 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 following GSI threshold levels:

Parameter	**GSI Threshold (**mg/l)	**EU MAC** (mg/l)
Nitrate	25	50
Potassium	4	12
Chloride	30	250
Ammonia	0.15	0.4
K/Na ratio	0.3	
Faecal bacteria	0	0

- **Group 1:** Sources in which one or more contaminant indicators in the available data set exceeded the MAC and which are therefore considered to have been polluted at the time of sampling.
- **Group 2:** Sources which show concentrations of the contaminant indicators chloride, nitrate, ortho-phosphate, iron, manganese and potassium:sodium ratio in excess of the GSI threshold levels. Some interpretation is required as levels in excess of these thresholds can reflect natural conditions in some cases (e.g. elevated potassium and/or iron can occur naturally in sandstone groundwaters).
- **Group 3:** Sources with slight anomalies in the analyses which may be naturally induced or indicative of some slight contamination. These are, however, inconclusive with the current data set.
- **Group 4:** Sources showing no evidence of contamination from the analyses carried out for the project.

The public supply sources are listed under each of the four groups in Table 5.2, which aims to:

- Summarise the large amount of water quality data available.
- Identify those parameters where exceedances of drinking water limits or GSI threshold limits have occurred most commonly.
- Prioritise supply sources for remedial action.

Table 5.2 Groundwater Quality Classification of Co. Laois Groundwater Supply Sources

Group [2]	Supply Source	Exceedances by Key Indicators of Contamination[3]								
		NO_3	Cl	PO_4	NH_x	E.coli[4]	K	K:Na Ratio	Fe	Mn
1	Arless.	*Excess threshold*	*Excess threshold*			**excess MAC**	**excess MAC**	*Excess threshold*		
	Emo.	*Excess threshold*				**excess MAC**		*Excess threshold*	**excess MAC**	
	Shanahoe (Ballacolla), Cloghogue (Ballinakill) , Cullahill.	**excess MAC**				**excess MAC**		*Excess threshold*		
	Darkin Well, 5 Wells.	*Excess threshold*				**excess MAC**			**excess MAC**	
	Errill B., Shanbeg (Rosenallis), Dairyhill (Ballacolla), Coolfin (Ballacolla).	*Excess threshold*				**excess MAC**		*Excess threshold*		
	Killeaney.	**excess MAC**				**excess MAC**				
	Attanagh.	**excess MAC**						*Excess threshold*		
	Killenard, Tinraheen (Ballacolla), Kyle.	*Excess threshold*				**excess MAC**				
	Cavanagh's (Borris-in-Ossory).					**excess MAC**		*Excess threshold*		
	Barrow House, Fermoyle (Ballinakill).	**excess MAC**								
	Rosenallis.				**excess MAC**	**excess MAC**				
	Lough (Ballybrittas), Mountsalem, The Heath, Derrin (Borris-in-Ossory), The Orchard (Timahoe).					**excess MAC**				
	Ballinabranagh, Donaghmore.					**excess MAC**			**excess MAC**	
	Knocks Spring (Mountrath), Aughfeerish (Abbeyleix).							*Excess threshold*	**excess MAC**	
2	Ballydavis 1 and 2[5], Durrow Convent, Max Well, Ralish, Tullore (Ballyroan).	*Excess threshold*								
	Fermoyle (Durrow).	*Excess threshold*						*Excess threshold*		
	Roundwood, Knock Bore (Mountrath).							*Excess threshold*		
	Coolenaugh.			*Excess threshold*						
3	Ballypickas, Byrnes (Borris-in-Ossory), Errill A, Derryguile, Drim (Mountrath), Lough (Portarlington), Meelick, Rathdowney, Townspark, The Swan[6], The Strand.									
4	None.									

[2] Selenium was detected slightly above the MAC in June 1999 samples from the following sources: Byrnes (Borris-in-Ossory), Dairyhill (Ballacolla), Errill A, Errill B, Ralish, Derrin (Borris-in-Ossory), and Townspark (Borris-in-Ossory). Cadmium was detected slightly above the MAC in June 1999 samples from Ballydavis 2, and Five Wells (Abbeyleix). Fluoride was detected above the detection limit in a sample from the Lough (Portarlington). 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 in Table 3.

[3] NO_3: Nitrate. Cl: Chloride. PO_4: Phosphate. NH_x: Ammonia. K: Potassium. K:Na ratio: potassium:sodium ratio. Fe: Total Iron. Mn : Manganese. NH_x: Ammonia.

[4] These figures represent untreated samples and treated samples where e.coli or faecal coliforms were detectable. As such, though useful in terms of identifying contamination sources, they are not necessarily indicative of human health concerns.

[5] Ballydavis 1 has both available nitrate results close to, or in excess of the GSI threshold. Nitrate levels in Ballydavis 2 are 10-15 mg/l lower in both available samples, but both manganese results are in excess of the MAC. As the supplies are close together, it is assumed that these results reflect a common contaminant origin and, consequently, they are grouped together.

[6] The Swan has levels of manganese and iron consistently in excess of the MAC. The Strand has one of the two available manganese data points in excess of the MAC. However, levels of nitrate, chloride, untreated E.coli and the potassium:sodium ratio are otherwise low and it is thought that the iron and manganese levels are naturally-derived, or derived from borehole casing materials. As such, both supplies have been 'downgraded' from Group 1 to Group 3.

The main groundwater quality problems in County Laois are:

- high iron (Fe) and manganese (Mn);
- bacteriological pollution;
- nitrate (NO_3) contamination

- 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, muddy limestones, the Old Red Sandstone and the Namurian and Westphalian rocks, 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 County Laois is the presence of faecal bacteria in public and private water supplies. A significant proportion of the public groundwater supplies (10 out of 15) contained faecal bacteria during GSI sampling of raw waters. In certain areas, a high proportion of private wells (>50%) are also likely to be polluted, at least intermittently. 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.
- The bacteriological pollution of a relatively high proportion of groundwater supplies in Laois 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.
- Nitrate concentrations are generally above 'background' levels and often give cause for concern..

5.5 Overall Assessment and Conclusions

- The hydrochemistry of groundwater in Co. Laois is primarily influenced by the dominant limestone lithologies in both the bedrock and the subsoils. The groundwater throughout most of County Laois is hard and can be classed as a calcium-bicarbonate water type. Softer waters are found in the Upper Carboniferous and Devonian Sandstones and Mudstones.
- Of the 50 supply sources studied , the most contaminated supplies are considered to be:

Arless	Cloghogue
Cullahill	Emo
Darkin Well	Five Wells
Shanahoe	

  These sources require the highest priority for corrective action, having at least two contaminant indicators above the MAC and at least two indicators above the GSI threshold (Table 5.2).
- Twenty-nine supply sources are 'polluted', i.e. at least one indicator compound is, or has been, above the drinking water MAC. A further ten 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 12 sources:

Barrow House	Killeaney
Aughfeerish	Fermoyle (Ballinakill)
Tinraheen	Emo
Attanagh	Cullahill
Shanahoe	Cloghogue, Ballinakill
Durrow Convent	Fermoyle, Durrow

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 Durrow Convent and Fermoyle (Ballinakill).

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 13 supplies (26% of the total). This suggests that farmyard point sources or septic tank systems 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. Of these 13 supplies, 8 are group schemes (42% of the group schemes) and 5 were public supplies (16% of the public supplies).
- Levels of iron and/or manganese were identified above the EU MAC in ten supply sources (20% of the total). Levels in at least two of these (Strand and The Swan) are likely to have a 'natural' origin.

5.6 Recommendations

- 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.

- The 12 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
- All supply sources require regular analysis of raw water as well as treated water samples, including full analyses (including all major ions). The frequency of sampling at each source should be influenced by the degree of concern at each source. The following is recommended:

Group	Number of Supply Sources	Recommended Sampling Frequency
Group 1A	2	At least *fortnightly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then down-grade to Group 3 sampling frequency.
Group 1B	8	At least *monthly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then down-grade to Group 3 sampling frequency.
Group 2B	2	At least *monthly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then down-grade to Group 3 sampling frequency.
Groups 1C, 1D, 2C, 2D.	28	At least *quarterly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then down-grade to Group 3 sampling frequency.
Groups 3 and 4	10	At least twice yearly.

- Indicators of organic compound contamination, including petroleum, pesticides, sheep dip and herbicides, should be included twice yearly. One approach is to undertake a 'semi-volatile organic carbon' scan on selected samples. These analyses are relatively cheap and suitably-accredited laboratories should be able to identify indicator compounds of all the above substances from such scans (e.g. certain phenols and permethrin, when found together, can indicate sheep dip contamination). Such analyses cannot measure the precise concentrations required for drinking water analyses, but they can identify the indicator compounds, where they occur, to a level comparable with the detection limits specified in drinking water criteria. Once detected in a sample, more specific compounds can be examined. For example, if hydrocarbon compounds are detected, analysis of total petroleum hydrocarbons can be requested for additional samples.

- Full analyses (including all major ions) should be carried out on at least some samples from each source to enable a fuller picture of groundwater quality and contaminant movements to be obtained.
- 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 DELG/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.

6 Groundwater Vulnerability

6.1 Introduction

The term 'Vulnerability' is used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (DELG/EPA/GSI, 1999).

The vulnerability of groundwater depends on:

- the time of travel of infiltrating water (and contaminants)
- the relative quantity of contaminants that can reach the groundwater
- the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is 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
(iii) the recharge type – whether point or diffuse

Details of the hydrogeological basis for vulnerability assessment can be found in the DELG/EPA/GSI publication 'Groundwater Protection Schemes' (DELG/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. The vulnerability 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. 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 sites where point recharge occurs (e.g. swallow holes) the vulnerability depends on the type, permeability and thickness of the subsoils. Each subsoil type described in Chapter 3 is assessed here in terms of its permeability. The vulnerability map is then derived by overlaying the permeability categories with the depth to rock. 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 6.1.

6.2 Sources of Data

Specific vulnerability field mapping and assessment of data collected during the subsoils mapping programme were carried out. Fieldwork focused on assessing the permeability of the different deposit types, as depicted on the subsoils map, so that they could be subdivided into the three permeability categories. This involved:

- describing selected exposures/sections according to the Subsoil description and classification method (adapted from BS5930:1981), taking account of the new draft revised standard (Norbury, 1998).
- taking additional samples for full particle size analysis in complex permeability boundary areas. (Hydrometer tests, which separate the silt and clay particles, are expensive. Most particle size analyses are derived from sieving, where the silt and clay are grouped together as "fines".)

- assessing the recharge characteristics of selected sites using drainage, vegetation and other secondary indicators.
- specific work at Murglash in association with two concurrent joint GSI/TCD MSc. research projects on vulnerability mapping, where two boreholes were drilled to carry out permeability measurements, and recharge assessments were made in the surrounding area.

Table 6.1 Geological and Hydrogeological Conditions Determining Vulnerability Mapping Categories

Subsoil Thickness	Hydrogeological Requirements				
	Diffuse recharge Subsoil permeability and type			Point Recharge	Unsaturated Zone
	high permeability (*sand/gravel*)	moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	*(swallow holes, losing streams)*	(*sand & gravel aquifers only*)
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

Notes: (i) N/A = not applicable.
(ii) Permeability classifications relate to the material characteristics as described by the subsoil description and classification method.
(iii) Release point of contaminants is assumed to be 1–2 m below ground surface.

(adapted from DELG/EPA/GSI, 1999)

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

- the subsoils data and maps, and the contoured depth to bedrock data produced during the 3 year mapping programme (see subsoils chapter)
- the soils map produced by An Foras Talúntais (Conry, 1987)
- the bedrock geology map (see bedrock chapter)
- the GSI karst database
- the GSI well database
- experience gained from the two MSc research projects both of which included parts of Co. Laois in their study areas (Lee, 1999; Swartz, 1999)

6.3 Permeability of the Subsoils

6.3.1 Methodology

The permeability categories, and resulting vulnerability categories depicted on the vulnerability map (Maps 6E and 6W), are qualitative regional assessments of the subsoils based on how much potential recharge is infiltrating and how quickly potential contaminants can reach groundwater. The permeability of subsoils is largely a function of (a) the grain size distribution; (b) the amount (and sometimes type) of clay size particles present; and (c) how the grains are sorted and packed together. It can also be influenced by other factors such as discontinuities (fissures/cracks, plant roots, pores formed by soil fauna, isolated higher permeability beds or lenses, voids created by weathering of limestone clasts) and density/compactness. In poorly sorted sediments, which are the most common subsoils in Laois, these characteristics also determine the engineering behaviour of the materials (Swartz, 1999) as described using the subsoil description and classification method, derived from BS5930:1981 and the draft revision (Norbury, 1998). This method is therefore used to assess the permeability of the subsoils at each exposure, supported by recharge and drainage observations in the surrounding area for a regional, three-dimensional classification.

Each of the approaches used in assessing the permeability is discussed briefly here. Some of these are described in more detail in the research theses (Lee, 1999 and Swartz, 1999):

1. *Subsoil description and classification method (derived from BS5930).* Using this method, 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 which 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. *Particle size analyses.* The particle size distribution of the sediments describes the relationships between the different grain sizes present. Evaluation of the grain size analyses for the county have shown that each glacial till type has a number of distinct grain size characteristics which have in turn influenced the permeability. Samples with less than 35% silt and clay for example have a moderate permeability. Samples with more than 35% fines are more variable and the permeability depends on the amount of clay present and the distributions of the silt and sand grains. Once the general characteristics and variations have been identified, these can be extrapolated to other similar areas where vulnerability observations may be lacking.
3. *Parent material.* The parent material, in this case the bedrock, plays a critical role in providing the particles which have created the 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. It is also useful to know the direction of movement of the glaciers and the modes of deposition of the sediments as these will dictate where the particles have moved to, how finely they have been broken down, and what the relative grain size make up and packing are. Understanding the processes at work enable predictions to be made where observations are lacking.
4. *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 are ruled out. Well-drained land suggests a moderate or high permeability once artificial drainage is taken into consideration (Lee, 1999).
5. *Soils map.* The soil map of Co. Laois was used to assess drainage characteristics where specific site recharge observations were not available. Poorly drained soils such as gleys can often be related to underlying low permeability subsoils, while the more free draining soils such as the brown earths and grey brown podzolics are more typical of the sandy and silty moderate permeability subsoils.
6. *Quantitative analysis.* The boundary between moderate and low permeability is estimated from limited piezometer data over the country to be in the region of 10^{-9} m/s at the field scale (Swartz, 1999). The moderate to high boundary has not yet been looked at in detail and there are no equivalent measured data available. However, permeability measurements are highly scale dependent: laboratory values, for example, are often up to two orders of magnitude smaller than field measurements which in turn are smaller than regional assessments measured from large scale pumping tests. A qualitative assessment incorporating the engineering behaviour of the subsoils and recharge characteristics is more appropriate for regional vulnerability mapping, than specific permeability measurements.

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. Each subsoil type and the range in permeabilities in Co. Laois is discussed, and is summarised at the end in Table 6.2.

6.3.2 Tills

Till deposits in County Laois have a widespread distribution and are derived from a number of different bedrock types. As tills are poorly sorted sediments, often with a high percentage of fines (silt and clay), they usually fall into either the 'moderate' or the 'low' permeability category. The till on Maps 2E and 2W is undifferentiated, that is, it has not been classified on the basis of the dominant clast lithology or matrix composition.

During the last ice age, the Midlandian, glaciers initially moved south across Laois. During the later stages of this glaciation, the ice moved southeast bringing midland limestone and even Galway granite right up and over the Slieve Bloom Mountains. As the ice decayed it was no longer able to move over the higher ground and was forced around the Slieve Bloom Mountains (Conry, 1987).

The till permeabilities are discussed with respect to several areas:

Slieve Bloom

The till around and on Slieve Bloom in County Laois has been derived from Silurian siltstones, mudstones and slates as well as Old Red Sandstone which is dominated by clean sandstones but also contains siltstones, mudstones and slates. There are till deposits found in the valleys south of Clonaslee. Drainage in these areas is variable with better-drained soils found nearer Clonaslee and less well drained gleys towards the top of these valleys. Using the subsoil description and classification method the till in the upper parts of the valleys is classed as firm pinkish brown sandy CLAY with grey mottles which implies to a low permeability. The drainage density, soil types, free draining grey brown podzolics, and vegetation in the lower parts of the valleys near Clonaslee indicate that these tills have a moderate permeability. Particle size analyses show that a relatively high amount of fines in the till but the percentage of clay (5%) is low, supporting a moderate permeability classification. The boundary between the two permeability classes was drawn where the well drained soil (Patrickswell, a grey brown podzolic) meets the less well drained soils (Mylerstown, a gley, and the Clonin, a complex) and on the basis of vegetation and drainage density.

South and Southeast of Slieve Bloom

There is an extensive till deposit on the lower slopes of Slieve Bloom, extending to the east and southeast. Comprehensive research was carried out on the till on the lower slopes of Slieve Bloom as part of two concurrent joint GSI/TCD MSc. research projects on vulnerability mapping. Two piezometers, GWBH6 and GWBH7, were installed in the till and falling head tests were carried out to obtain permeability values (Swartz, 1999). A vulnerability assessment study, using drainage density, vegetation and other secondary indicators, was also carried out (Lee, 1999). The till at GWBH 6 is classified as sandy CLAY as is that at GWBH 7 and this, combined with the results from the falling head tests (6.3×10^{-10} m/s and 1.6×10^{-9} m/s respectively) implies that the till has a low permeability. There is further evidence, from vegetation and drainage density and another sandy CLAY subsoil section, that the till in the southwestern part of this area has a low permeability. However, the tills to the east of GWBH 6 and 7 are classified as silty SAND, sandy SILT and SAND, which equate to a moderate permeability, which is again supported by recharge indicators in the area. There are two main soil types in the area, namely the Slieve Bloom gley and the Mountrath complex, which is also typically poorly drained. A boundary was drawn within this till unit to delineate the low and moderate permeability tills, using the classification descriptions from the till sections and their locations within the till unit, soil type and vegetation.

Mountrath Area

The till around and to the northeast of Mountrath has been derived from bedrock of the Clonaslee Flagstone, the Ballysteen Formation and the Lower Limestone Shale. These subsoils are described as stiff pale red brown sandy SILT, grey brown silty SAND and firm/stiff grey silty SAND using the subsoil description and classification method. They are associated with both poorly-drained and well-drained soils. These tills have been assigned a moderate permeability rating, using both the site descriptions and the % fines from particle size analyses. There are isolated areas of low permeability till, one being in the Ballyfin area, within this moderate permeability till, but they are not mappable.

Southwest Laois

A large area of till extends southwards from Borris-in-Ossory to the county boundary and eastwards towards Rathdowney. This till has been derived from limestone bedrock - the Waulsortian Limestone and the Ballysteen Formation. Both free draining soils (e.g. the Patrickswell and Elton) and gley soils (Mylerstown Gley) are associated with this subsoil, although there is a much higher proportion of the more free-draining soils overlying this till unit. The till in this area has been described as dark grey sandy SILT with frequent gravels (GWBH8). The percentage of fines in this subsoil is relatively low, generally less than 35%, which indicates a moderate permeability. This classification is supported by the overlying predominantly free draining soils, which are grey brown podzolics, and the low drainage density. Where gley is present, recharge does not occur as easily as in other areas, and the gley soil may indicate that the till beneath is of lower permeability than that elsewhere. There is insufficient information available to delineate these areas of potential low permeability.

Clogh area

The till around Clogh has been classified as having moderate permeability. The area is predominantly covered by a free draining soil, the Patrickswell, although a small amount of gley (Mylerstown) is also present. The vegetation and drainage density support a moderate permeability classification. Of the two available particle size analyses for the area, one has a high percentage of fines (52%). This sample was taken from an area that has between 1m and 3m thickness of subsoil, which indicates that the till is likely to be immature. Since a free draining soil is developed over the till, it is felt that silt must make up the major component of the fines, and that a moderate permeability rating is justified.

Northeast Co. Laois

There are extensive till deposits in the northeast of the county, from Portarlington in the north to Portlaoise and Vicarstown in the south. These tills have been derived from a number of bedrock types, ranging from the massive Waulsortian Limestone, through the shaly Calp Limestone, to the coarse-grained fossiliferous Ballyadams Formation. This variation in bedrock source material has resulted in the formation of tills with a wide range of matrix compositions. In general, a till that is derived from the Calp has a higher percentage of clay in the matrix than a till formed from the Waulsortian Limestone. Various soil types have developed over these tills, ranging from thick peat in the lower lying areas, the Allen, to free draining grey brown podzolics, the Fontstown and Stradbally, with the free draining soils occupying the higher percentage land cover. Although the fines content in many of the particle size analyses was greater than 35%, few approached 50% and so, based on this, predominant soil type and vegetation type, the tills in this area are attributed a moderate permeability. There are small isolated areas of low permeability, such as around the Great Heath of Maryborough, but due to time constraints and their small area they are not represented on the map.

Castlecomer Plateau

The Castlecomer Plateau occupies most of the southeastern part of County Laois. It comprises Carboniferous sandstones, siltstones and shales with numerous interbedded coal measures. Many of these bedrock units are relatively impermeable, leading to the development of the Abbeyfeale gley soil over much of the plateau. Many of the tills in this area have a high percentage of fines and often the clay component is over 15%. These tills are classified as dark grey very stiff CLAY and grey sandy CLAY using the subsoil description and classification method. However the tills to the north and northeast have been derived from different bedrock types, namely the Clogrenan and Ballyadams formations, respectively cherty and coarse grained, fossiliferous limestones. More free-draining soils have developed over these tills, which are described as soft grey brown sandy SILT and brown silty SAND. The percentage of fines within the tills sampled ranges from 33% to 48%. Where known, the clay percentage has a wide range, from 2% to 12%. On the basis of particle size analyses, vegetation, drainage and soil types, the till on the Castlecomer Plateau has been assigned a low permeability and the till to the northeast and north a moderate permeability. The boundary between the two types appears to follow the boundary between the more freely draining (Knockbeg, Howardstown) soils and the gley soils (Abbeyfeale, Raheenduff), and also the boundary of the cleaner limestones, so these were used to draw the permeability boundary.

6.3.3 Alluvial Deposits

These range from highly permeable sandy gravelly deposits to low permeability clayey silty deposits and they also vary depending on their topographic location. In most instances in Laois there is minimal information to enable this distinction to be made based on field observations. In general, the alluvial deposits are relatively thin so detailed investigations were not carried out. For the purposes of this study, alluvial deposits in upland and lowland areas are considered separately.

Upland areas:

Alluvium is classed as of high permeability as it is likely to be coarser grained and more gravel-rich than in lowland areas.

Lowland areas:

1. Alluvium is generally classed as of moderate permeability, i.e. as a sandy silty deposit.
2. Alluvial deposits are normally less than 10 m thick. Where depth-to-rock is more than 10 m in an area mapped as alluvium, the *composite* vulnerability must be considered, i.e. the combined properties of the alluvium and the likely underlying deposit. Larger alluvial flood plains, where deposits are likely to be thicker, are exceptional. In these areas the alluvium is given more weighting in the composite vulnerability and is assumed to be a sandy silty deposit of moderate permeability. Undoubtedly there are substantial areas where alluvium is silty/clayey, but in the absence of better quality data a more conservative assumption of the permeability is taken.
3. Where alluvium is bounded by sand/gravel, it is assumed that the alluvium is also underlain by sand/gravel. Therefore, the permeability of the sand/gravel, which is high, is assigned to this area.
4. Where alluvium is bounded by till, the permeability assigned to the alluvium depends upon the permeability classification of the till deposit.

6.3.4 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, which has accumulated in a waterlogged environment. Peat has an extremely high water content averaging over 90% by volume. Two main types of peat bog are distinguished: blanket bog, which is characteristic of upland areas with excessive rainfall, and raised bogs, which are characteristic of lowland areas with impeded drainage. Blanket bog, as found on Slieve Bloom, is typically quite thin (less than 2m), whereas raised bogs may be much deeper.

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

There are extensive areas of peat in Laois especially in the west and northwest part of the county. There are large tracts of blanket peat development on the Slieve Bloom Mountains. This blanket bog is generally thin (less than 2 metres thick) and overlies bedrock. Along the northern and western Laois/Offaly borders and in the central part of the county, raised bog deposits can be found. Sections of these bogs have been exploited commercially.

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

Although peat has a relatively low permeability, each peat deposit is considered separately as in places it is just a thin cover over a different underlying subsoil or is located where the water table is high. The soils map was used in these instances to determine the type of peat and to give an indication of the hydrogeological situation present. The underlying/surrounding subsoils in this instance determine the composite permeability, as was the case with the Banagher Series.

6.3.5 'Till with Gravel'

'Till with gravel' deposits are complex subsoils comprising intermixed tills and sand/gravel and they therefore often have a wide range in grain size distribution. In County Laois they are very extensive to the immediate and farther south of the Slieve Bloom Mountains and along the Carlow border. There are also scattered patches to be found on the central lowlands. These deposits are generally more than 3 m thick and in many instances more than 10 m.

These deposits were not studied in detail and there is very little information available to assess the connectivity of the sand and gravel lenses within the till. They are classed tentatively as of moderate permeability, due to the range of grain sizes present. Site specific investigations may prove high or low permeability classifications would be more appropriate in places.

6.3.6 Marl

Marl deposits are of very limited extent in County Laois. This sediment has an intrinsic low permeability. However, the vertical extent of the deposit is unknown and it is likely to be relatively thin, and be underlain by till. Therefore, the permeability of the surrounding till is taken to dictate the overall permeability and this area was assigned a moderate permeability.

6.3.7 Lake deposits

There is an extensive area of lake deposits to the north of Monasterevin and two small pockets, one near Rathdowney and the other near Garryduff. These comprise well-sorted layers of interbedded silts and clays, and have an inherent low permeability. The deposit near Monasterevin, of limestone origin (Conry, 1987), is overlain by river alluvium. The other two areas are overlain by peat soils.

These deposits were not studied in detail and there is little information available on the vertical thicknesses of these deposits. It is likely that they are relatively thin and are underlain by till. The underlying/surrounding subsoils in this instance determine the composite permeability.

6.3.8 Made Ground

Due to the uncertainty and likely variability of the composition of this deposit, a conservative approach was taken and a high permeability was assigned.

6.3.9 Distribution of Subsoil Permeability

Table 6.2. Permeability and Distribution of Subsoils in County Laois

Subsoil	Inferred Permeability	Distribution
Till	Moderate	Extensive throughout the county. Overlying clean limestone bedrock, free draining soils and areas which have sections with <35% fines (or near) and described as moderate permeability using the subsoil description and classification method
	Low	In the valleys and foothills of the Slieve Bloom mountains and on part of the Castlecomer Plateau.
Till-with-gravel	Moderate	Extensive in the southeast near Carlow, south of the Slieve Bloom Mountains and scattered patches in the central and northern lowlands.
Sand and Gravel	High	Extensive in the southwest, to the north of the Slieve Bloom Mountains and to the east and northeast of Portlaoise.
Alluvium	Variable	Usually depends on the surrounding deposits.
Peat	Low	Slieve Bloom Mountains, northwest Laois, scattered patches in the lowlands and on the Castlecomer plateau.
Lake sediments	Low	Near Monasterevin, Garryduff and Rathdowney, permeability usually depends on the surrounding deposits.
Marl	Low	Near Ballylynan, permeability usually depends on the surrounding deposits.

6.4 Thickness of the Unsaturated Zone

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

6.5 Depth to Bedrock

Along with permeability, the subsoil thickness (depth to bedrock) is a critical factor in determining groundwater vulnerability to contamination. A brief description of subsoil thicknesses is given in Section 3. The guidelines used in contouring the depth to bedrock data are listed in Appendix 1.

6.6 Groundwater Vulnerability Distribution

The vulnerability maps (Maps 6E and 6W) are derived by combining the contoured depth to bedrock data with the inferred subsoil permeabilities (see Section 1). Areas are assigned vulnerability classes of low, moderate, high or extreme. The general classification scheme is outlined in Table 6.3.

It is emphasised that the boundaries on the vulnerability map are based on the available data and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments, and will frequently require site investigations in order to assess the risk to groundwater. A combination of detailed mapping of the subsoils, assessment of surface drainage and permeability measurements would reduce the area of high vulnerability and would probably reduce the area of extreme vulnerability. However, the vulnerability maps are a good basis for decision-making in the short and medium term.

Table 6.3. Summary of Vulnerability Classification Scheme

Vulnerability Rating	Hydrogeological Setting
Extreme 26% of County Laois	Where rock is at the ground surface or where the subsoil is known or interpreted to be <3m thick above bedrock. Where the unsaturated zone in sand/gravel is less than 3 m thick.
High 60% of County Laois	Where *high* permeability subsoil is known or interpreted to be >3m thick Where the unsaturated zone in sand/gravel is over 3 m thick Where *moderate* permeability subsoil is known or interpreted to be 3-10m thick. Where *low* permeability subsoil is known or interpreted to be 3-5m thick.
Moderate 11% of County Laois	Where *moderate* permeability subsoil is known or interpreted to be >10m thick. Where *low* permeability subsoil is known or interpreted to be 5-10m thick.
Low 3% of County Laois	Where *low* permeability subsoil is known or interpreted to be >10m thick.

A large proportion of the county is classed as having either extreme or high vulnerability while areas of moderate and low vulnerability are much less common. The 3 m contour, which influences the extreme and high vulnerability categories, is based on outcrop information, Quaternary mapping and borehole data. The presence or absence of 5 m and 10 m contours, which influence the moderate and low categories, is reliant solely on borehole data and uses the shallower contours as a guide for their interpretation. Where relevant borehole data to suggest greater depths are not available, these contours cannot be drawn and there are probably more areas of moderate and low vulnerability than are currently depicted on the map. As more information becomes available, the maps should be up-dated.

The large areas of extreme vulnerability where rock is generally at or close to surface include upland areas which have little development or potential for development. When these are excluded, the proportion of the county's groundwater that is extremely vulnerable is significantly reduced.

There are few areas of low vulnerability, found only where the till subsoils have a low permeability and the depth to bedrock information indicates thicknesses of over 10 metres. However such thick deposits may not be a uniform till but may have interbedded sands and gravels in places; further confirmation by site investigation is essential to verify the vulnerability for specific developments.

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

7 Groundwater Protection Zones

7.1 Introduction

The general groundwater protection scheme guidelines were outlined in Chapter 1, and in particular, the sub-division of the scheme into two components – land surface zoning and codes of practice for potentially polluting activities – was described (see also Appendix A). Subsequent chapters described the different geological and hydrogeological land surface zoning elements as applied to County Laois. 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. Two such responses have been published: **Groundwater Protection Responses for Landfills** and **Groundwater Protection Responses for Landspreading of Organic Wastes** (DELG/EPA/GSI, 1999), and further responses will be prepared in the future.

7.2 Groundwater Protection Maps

The Groundwater Protection Zones Map (Map 7) was produced by combining the vulnerability map (Map 6) with the aquifer map (Map 5). Each protection zone on the map is defined by a code which represents both the vulnerability of the groundwater to contamination and the value of the groundwater resource (aquifer category). Not all of the possible hydrogeological settings are present in County Laois; those which are present are given in Table 7.1.

Table 7.1 Matrix of Groundwater Resource Protection Zones

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

Table 7.2 highlights the proportion of the county in each zone.

Table 7.2 Proportion of County (%) in Each Zone

VULNERABILITY RATING	RESOURCE PROTECTION ZONES					
	Regionally Important Aquifers (R)		Locally Important Aquifers (L)		Poor Aquifers (P)	
	Rk	Rf/Rg	Lm/Lg	Ll	Pl	Pu
Extreme (E)	3.36	2.89	1.38	7.47	10.19	0.53
High (H)	10.11	12.26	6.28	25.08	5.13	0.38
Moderate (M)	3.42	2.64	0.12	4.04	0.58	0
Low (L)	0.17	0.21	0.02	2.06	0.11	0

7.3 Groundwater Source Protection Reports and Maps

Source protection zones have been delineated around five public water supply sources in Co. Laois: Durrow, Fermoyle, Kyle, Lough, and The Swan. These have been produced as separate source reports.

7.4 Conclusion

This groundwater protection scheme will be a valuable tool for Laois County Council in helping to achieve sustainable water quality management as required by national and EU policies. It will enable the County 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 considering a scheme, it is important to remember that: (a) a scheme is intended to provide guidelines to assist decision-making in County Laois 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. Laois County Council will apply the scheme in decision-making on the basis that the best available data are being used. The maps have limitations because they generalise (according to availability of data) 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 certain 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 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.

The scheme has the following uses for Laois County Council:

- it provides a hierarchy of levels of risk and, in the process, assists in setting priorities for technical resources and investigations
- it contributes to the search for a balance of interests between groundwater protection issues and other special and economic factors
- it acts as a guide and provides a 'first-off' warning system before site visits and investigations are made
- it shows generally suitable and unsuitable areas for potentially hazardous developments such as landfill sites and piggeries
- 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 ensure that the pollution acts are not contravened

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