# Kilworth Water Supply Scheme

# Downing Bridge

# Groundwater Source Protection Zones

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# 1 Introduction

Downing Bridge borehole was drilled and commissioned in 1983, in order to augment the Kilworth Water Supply Scheme.

The objectives of the report are as follows:

- To delineate source protection zones for the borehole.
- To outline the principal hydrogeological characteristics of the Downing Bridge area.
- To assist Cork County Council (Northern Division) in protecting the water supply from contamination.

# 2 Location, Site Description and Well Head Protection

Downing Bridge borehole is about 2.5 km north of Fermoy along the N8 primary route. Kilworth village is about 5-700 m to the northeast of Downing Bridge. The borehole is located inside a concrete bunker next to the pumphouse situated alongside the main road. The ground alongside the site is covered with limestone chippings. The bunker is covered by a padlocked galvanised cover. The water supply is disinfected with chlorine.

# 3 Summary of Borehole Details

| | | |
|---|---|---|
| Grid reference | : | R$^1$823 $^1$018 |
| Townland | : | Gortore |
| Well type | : | Borehole |
| Owner | : | Cork County Council (Northern Division) |
| Elevation (ground level) | : | 27.40 m OD. (90ft) |
| Depth of borehole | : | 17.37 m (57ft) |
| Diameter of borehole | : | 355.6 mm (14″) |
| Depth to rock | : | 12.8 m (42ft) |
| Static water level | : | 6 m (19.66ft) on 28/11/1983 |
| Normal consumption | : | 1000 $m^3 d^{-1}$ (220,000 gallons per day) |
| Pumping test summary | : | 72 hr test under supervision of Geoex Ltd. on 28/11/1983<br>(i) abstraction rate : 2226 $m^3 d^{-1}$<br>(ii) specific capacity : 1980 $m^3 d^{-1} m^{-1}$<br>(iii) transmissivity : 3400 $m^2 d^{-1}$ |

# 4 Methodology

## 4.1 Desk Study

Details about the borehole such as elevation, and abstraction figures were obtained from County Council personnel; geological and hydrogeological information was provided by GSI files.

## 4.2 Site visits and fieldwork

This included carrying out geophysics, depth to rock drilling and subsoil sampling. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

### 4.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

## 5 Topography, Surface Hydrology and Land Use

The borehole is located in the Funshion River valley, on the south side of the river. The area on both sides of the river is quite flat. To the south of the borehole the land rises steeply to a height of about 50 m, where there is a broad ridge before dropping steeply to the Blackwater River Valley. To the north of the Funshion the land rises steeply to well over 200 m in the Kilworth Mountains.

The Funshion, Blackwater and Araglin Rivers are the main water features in the area. The area between Fermoy and Downing Bridge is free draining with no drains or surface streams. The Funshion flows to the southeast 30 m north of the borehole and joins the Blackwater about 2 km downstream.

The land is primarily used for agricultural purposes, mainly pasture. Two farms occur within 1 km of the source, one of which is the Teagasc Moorepark Research Farm.

A primary road passes about 20 m east of the borehole (N8, Cork-Dublin). Fermoy town is 2.5 km south of the source.

## 6 Geology

### 6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the borehole. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Bedrock information was taken from a desk-based survey of available data, which comprised the following:

- Bedrock Geology 1:100,000 Map Series, Sheet 22, East Cork-Waterford. Geological Survey of Ireland. (Sleeman, A.G., *et al*, 1995).
- The Carboniferous Geology of the Fermoy and Mitchelstown Synclines, Southern Ireland. (Shearley, E.P., 1988, Unpublished PhD thesis, University of Dublin.)
- Information from geological mapping in the nineteenth century (on record at the GSI).

Subsoils information was gathered from a drilling programme that was undertaken by GSI personnel to investigate the subsoils of the area.

### 6.2 Bedrock Geology

The rocks are the result of sediments deposited during Carboniferous times (over 300 million years ago). The area is underlain entirely by the Waulsortian Limestone Formation. This rock unit is described as being a pale grey massive LIMESTONE.

The rocks have been deformed during a ‘mountain building event’, known as the Variscan Orogeny and were compressed from north and south to produce an east-west trend. The

Waulsortian rock unit in this area forms the centre of the Fermoy Syncline, a major east-west trending fold. Minor folds occur with similar orientations. Two major fault sets are widespread across the region; east-west trending (strike faults) and north-south trending (cross faults). Both fault sets are mapped at the geological contacts with other rock units several kilometres to the north and east of Downing Bridge.

### 6.3 Subsoil (Quaternary) Geology

An extensive geophysics and drilling programme was carried out by GSI personnel to investigate the permeabilities of the subsoil and the depth to rock across the domain. The geological logs of the auger holes drilled are given in Appendix 1 and the locations are given in Figure 1. The subsoils comprise a mixture of coarse and fine-grained materials, namely till, and are directly influenced by the underlying bedrock, which is made up of limestones.

Three geophysical methods were employed, namely: EM-31(electrical conductivity survey), Wenner Sounding (electrical resistivity survey) and 2-D Electrical Resistivity surveys. Further details of the geophysics are given in Motherway (1999).

#### 6.3.1 River Alluvium

This material occupies the area on either side of the Funshion River that flows past the source, and comprises fine-grained black silty clay.

#### 6.3.2 Till (Boulder Clay)

Till is the dominant subsoil type in the area. ‘Till’ is an unsorted mixture of coarse and fine materials laid down by ice. Limestone fragments tend to dominate in the till. The till description varies from silty SAND with frequent/abundant gravels to angular sandy GRAVELS with clay.

#### 6.3.3 Depth to Bedrock

The depth to rock is known in certain localities from a drilling programme carried out by the GSI to ascertain the thickness and permeability of the subsoils. The geophysical methods allowed the depth to rock to be interpreted over a large part of the area around the Moorepark Research Farm. The depth to bedrock is variable ranging 0-10 m.

## 7 Hydrogeology

### 7.1 Introduction

This section presents our current understanding of groundwater flow in the area of the source. The production well is shown in Figure 1.

Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- A Study of Nitrate and Vulnerability in the Waulsortian Limestone Aquifer of North Cork, Ireland. Motherway, K., 1999. MSc Thesis, University College London.
- GSI files and archival Cork County Council data.
- Cork County Council annual drinking water returns.
- Cork County Council Nitrate monitoring programme.
- Geoex Limited 1983. Report on Drilling and Testing of Exploratory and Production Wells. Kilworth, Co. Cork, Cork County Council (Northern Division).

## 7.2 Rainfall, Evaporation and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and generally assumed to consist of an input (i.e. annual rainfall) less water losses prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as it will dictate the size of the zone of contribution to the source.

In areas where point recharge from sinking streams, etc., is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff and are listed as follows:

- Annual rainfall: 1034 mm. (Met Éireann)
- Annual evapotranspiration losses: 434 mm. Potential evapotranspiration (P.E.) is estimated to be 457 mm $yr.^{-1}$ (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.
- Potential recharge: 600 mm $yr.^{-1}$. This figure is based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for vertical downward flow to groundwater or for runoff.
- Annual runoff losses: 30 mm. This estimation assumes that 5% of the potential recharge may be lost to overland flow and shallow soil quickflow without reaching the main groundwater system.

These calculations are summarised as follows:

| | |
|---|---|
| Average annual rainfall (R) | 1034 mm |
| Estimated A.E. | 434 mm |
| Potential Recharge (R – A.E.) | 600 mm |
| Runoff losses | 30 mm |
| Estimated Actual Recharge | 570 mm |

## 7.3 Hydrochemistry and Water Quality

The hydrochemical analyses show that the water is hard, with total hardness values of 222-303 mg $l^{-1}$ (equivalent $CaCO_3$) and electrical conductivity values of 494-636 µS $cm^{-1}$, indicating that the groundwater has a hydrochemical signature of calcium bicarbonate type water. These values are indicative of groundwater from limestone rocks. The analyses are given in Appendix 2.

Nitrate concentrations range 9.7-71.2 mg $l^{-1}$ (39 samples; 1983-2000), average 40 mg $l^{-1}$. Nitrate concentrations have exceeded the EU Drinking Water Directive maximum admissible concentration (MAC) on three occasions (19/11/1991, 30/3/1993, 10/7/1995) and approached the limit in 16/4/1998 with a concentrations of 49 mg $l^{-1}$. The trend is increasing, as illustrated in the graph in Appendix 3, approaching the EU MAC. The concentrations are likely to be representative of present general nitrate contamination by both diffuse (spreading of inorganic fertiliser and slurry) and point sources (septic tank systems and farmyards)

Chloride concentrations range 18-28 mg $l^{-1}$ (9 samples; 1983-2000), average 23 mg $l^{-1}$. Chloride is a constituent of organic wastes and levels higher than 25 mg $l^{-1}$ may indicate significant contamination (in North Cork). Concentrations higher than 30 mg $l^{-1}$ usually indicates significant contamination (except in coastal areas).

Monitoring of untreated water analyses (7 samples) record the presence of total coliforms (1 out of 7) and faecal coliforms (0 out of 7). Bacteria counts are reported in 4 out of 6 samples. The borehole water was also sampled for cryptosporidium and giardia, using customised equipment provided by Inniscarra Laboratory. Subsequent analysis by City Analysts found the samples to be negative for both cryptosporidium and giardia.

Total coliforms and nitrate are the only parameters to exceed the EU MAC.

### 7.4 Groundwater levels, Flow Directions and Gradients

In general, the water table is assumed to be a subdued reflection of topography, with groundwater flowing from the watersheds and discharging into the rivers. It is assumed that the Funshion River represents true groundwater elevations as it is the lowest stream with respect to elevation in the area of Downing Bridge. In addition, electrical conductivities of the River Funshion are high (600 $\mu S\ cm^{-1}$ on 20/8/99) indicating that there is a high proportion of groundwater in the river. High permeability material overlies the bedrock, hence it is assumed that the groundwater is unconfined and that the rivers are in hydraulic connection with the groundwater. There are no surface water features between the Blackwater and Funshion rivers in the Gortore/Downing Bridge area and a broad ridge separates the two rivers. It is likely that the groundwater table constitutes a broad mound between the two rivers.

On a regional scale groundwater and surface water are flowing toward the Blackwater. However, on a more local scale, groundwater close to the River Funshion is likely to flow and discharge to the river. It is likely that the groundwater divide between the two rivers starts where the two rivers meet and heads off in a northwesterly direction, through the townlands of Mountrivers, Licklash, Lisnallagh, Ballyvoskillakeen and Boherderroge. There are only 4 wells in the area from which water levels could be measured, three of which are on the Moorepark Research Farm. Water level data are also available on the River Funshion at 3 locations upstream of the source, taken from the older edition of the 6″-inch maps. The groundwater levels in the wells on the high ground of Moorepark are deep, ranging from 18-26m below ground level. Taking into account the levels relative to ordnance datum, the water levels in the wells indicate a line of equal head, roughly north-south, suggesting that groundwater is flowing toward the River Funshion. Groundwater flow is likely to be to the northeast in the townland of Gortore, again flowing toward the River Funshion. Further west, in the townland of Loughnahilly groundwater flow direction is likely to be easterly.

The gradient of the water table is likely to be similar to the gradient of the Funshion River, which is about 0.001-0.002. There are no water level data to indicate where the groundwater divide between the two rivers is located.

### 7.5 Aquifer Characteristics

The source is located in the Waulsortian Limestone Formation which is considered a **regionally important karstified aquifer (Rk)**. 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 (Deakin *et al*, 1998).

The resistivity surveys indicate that the Waulsortian Limestone is highly fractured and karstified (Motherway, 1999). Several infilled cavities that have no surface expression have been interpreted from the geophysics. The drilling log for the production borehole indicate several cavities in the limestone. Caves, swallow holes, sluggeras (dolines) and other solution features are recorded in the Waulsortian throughout Munster.

Aquifer properties for the Waulsortian vary widely across the Munster area; generally very productive, recording very high well yields and specific capacities. Test pumping at Downing Bridge and Moorepark suggests transmissivities range 15-3400 $m^2 d^{-1}$, and permeabilities range 10-200 $m d^{-1}$. (Motherway, 1999). The porosity is considered to be about 0.025. Velocities are estimated to be about 30 $m d^{-1}$ in the vicinity of the borehole. In general, velocities range 4-2500 $m d^{-1}$ within the Waulsortian Limestone. In 1979 a tracing test was carried out by the G.S.I. at a sinkhole/swallow hole in Aghern, Fermoy. A spring 1.1 km to the southeast of the swallow hole showed a positive trace within 11 hours, indicating velocities of about 100 $m hr^{-1}$.

Groundwater flow is likely to occur in three main hydrogeological regimes within the limestone aquifer:

- An upper, shallow, highly karstified weathered zone, known as the epikarst, in which groundwater moves quickly, through solutionally enlarged conduits, in rapid response to recharge;
- A deeper zone, where groundwater flows through interconnected, solutionally enlarged conduits and cave systems that are controlled by structural deformation. It is the conduits that give the extremely high groundwater velocities.
- A more dispersed slow groundwater flow component in smaller fractures and joints outside the main conduit systems.

### 7.6 Conceptual Model

- The production well is located in the Waulsortian Limestone, a **regionally important karstified aquifer (Rk)**.

- The hydrochemical analyses show that the water is hard and has a hydrochemical signature of calcium bicarbonate type water.

- It is assumed that that the River Funshion is in hydraulic connection with the aquifer.

- On a regional scale, groundwater and surface water are flowing toward the Blackwater. However, on a more local scale, groundwater close to the River Funshion is likely to flow and discharge to the river. It is likely that the groundwater divide between the two rivers starts at where the two rivers meet and heads off in a northwesterly direction. Therefore, groundwater in the area of Gortore flows to the Funshion river where the production well intercepts some of this water.

- Groundwater flow is likely to occur through shallow, interconnected, solutionally enlarged fracture zones and along fractures and joints outside the main fracture systems.

- The geophysics, the presence of caves, test pumping and the drilling logs of the production well indicate that the aquifer is highly karstified.

# 8 Delineation of Source Protection Areas

## 8.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, and are presented in Figures 1 and 2.

Two source protection areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution;
- Outer Protection Area (SO), encompassing the zone of contribution (ZOC) of the borehole.

## 8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the rock permeability and (d) the recharge in the area.

The ZOC for the Downing Bridge production well is delineated as follows:

1) An estimate of the area size is obtained by using the average recharge and the abstraction rate. To allow for errors in the estimation of groundwater flow direction and to allow for an increase in the ZOC in dry weather, a safety margin is incorporated by assuming a higher abstraction rate than the current rate. Taking the recharge to be 570 mm, the area required to supply a pumping rate of 1500 $m^3 d^{-1}$ is calculated to be 1 $km^2$
2) The shape of the area is then derived by using hydrogeological mapping techniques and the conceptual model.

The groundwater regime in the area is complex and the available hydrogeological information does not allow a definitive understanding of the hydrogeology. The resulting ZOC catchment boundaries are discussed as follows and are shown in Figure 1:

The **southern boundary** is based on an assumed groundwater divide between the Funshion and Blackwater. The topography over karstified limestones does not provide a reliable means of delineating groundwater divides. In this instance the groundwater divide coincides with the topographic ridge that occurs in this area.
The **western and eastern boundaries** are based on estimated groundwater flow directions and the water balance.

The **northern boundary** is based on semi-analytical modelling. The maximum downgradient extent of the cone of depression is estimated using a discharge figure 50% greater than the current abstraction rate, transmissivity of 3400 $m^2 d^{-1}$ and a gradient of 0.001. This estimate is 70 m.

## 8.3 Inner Protection Area

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (ToT) to the supply. Estimations of the extent of this area are made by hydrogeological mapping, analytical modelling and conceptualisation methods. Velocities are estimated to be about 30 m $d^{-1}$ in the vicinity of the borehole and in general they can range anywhere from 4-2500 m $d^{-1}$ within the Waulsortian Limestone. Therefore the entire ZOC is included in the inner protection area.

## 9 Groundwater Vulnerability

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities and depends on the thickness, type and permeability of the subsoils. A detailed description of the vulnerability categories can be found in the "Groundwater Protection Schemes" document (DELG/EPA/GSI, 1999).

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 1. Outcrop, areas of shallow rock, auger holes, geophysics and topography are used to contour depth to rock and are used along with the permeability classifications to develop the vulnerability zones. There are several outcrops and areas with subsoil thickness <3 m, giving rise to a vulnerability classification of 'Extreme' (E) over parts of the area, most of which are on the high ground. The subsoil thickness over the rest of the area is considered mostly less than 5 m and almost certainly less than 10 m. The results of the geophysics indicate that areas of conductivities <10 mS $m^{-1}$ are areas of shallow rock (<3m). Conductivities of 10-15 mS $m^{-1}$ are interpreted to represent areas of <5 m. The highest conductivity was 34 mS $m^{-1}$ and this anomaly was drilled into and a depth to bedrock of 7.8 m was recorded.

An average buffer of 100 m is used around areas of outcrop to produce a 3 m depth to bedrock contour, i.e., the limit of the 'Extremely' vulnerable zones. This buffer incorporates topography and known points of depth to bedrock and is based on calculations made by measuring the distance along the ground between outcrops and known points of depth to rock. An average figure of 100 m was calculated and represents the average distance from outcrop to a point where the depth to bedrock is about 3 m.

## 10 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. Two groundwater protection zones are present as given in Table 1 and illustrated in Figure 2.

Table 1 Matrix of Groundwater Protection Zones around Downing Bridge.

| VULNERABILITY RATING | SOURCE PROTECTION | |
|---|---|---|
| | ***Inner*** | ***Outer*** |
| ***Extreme (E)*** | SI/E | absent |
| ***High (H)*** | SI/H | absent |
| ***Moderate (M)*** | absent | absent |

| | | |
|---|---|---|
| ***Low (L)*** | absent | absent |

## 11 Potential Pollution Sources

Land use in the area is described in Section 5. The land near the source is largely grassland-dominated and is primarily used for grazing. Agricultural activities are the principal hazard in the area. The main potential sources of pollution within the ZOC are farmyards, runoff from the roads, and landspreading of organic fertilisers. Road spillage also presents a threat to the water quality at the borehole and also to the River Funshion. The main potential pollutants are faecal bacteria, viruses and road spillage.

## 12 Conclusions and Recommendations

- The borehole source is located in the Waulsortian Limestone rock unit, which is a **regionally important karstified aquifer (Rk)**.

- The area around the supply is generally highly or extremely vulnerable to contamination.

- Farmyards, landspreading, runoff from the road and road spillage pose a threat to the water quality at the source.

- It is recommended that:

1) A full chemical and bacteriological analysis of the **raw** water is carried out on a regular basis.
2) particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well.
3) the potential hazards in the ZOC should be located and assessed.

- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.

- A more definitive understanding of the hydrogeology would require a site investigation that would include drilling and geophysics. Geophysics and drilling would also improve the accuracy of the vulnerability boundaries. Drilling would improve considerably the information on the water table, thus delineation of the boundaries could be improved.

## 13 References


Deakin, J., Daly, D. and Coxon, C. 1998. *County Limerick Groundwater Protection Scheme*. Geological Survey of Ireland, 61 pp.

Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland (1999) *Groundwater Protection Scheme*. DELG/EPA/GSI report.

Geoex Limited 1983. *Report on Drilling and Testing of Exploratory and Production Wells. Kilworth, Co. Cork*. Cork County Council (Northern Division).

Motherway, K., 1999. *A study of nitrate and vulnerability in the Waulsortian Limestone Aquifer of North Cork, Ireland.* Unpublished MSc thesis. University College London.

Sleeman, A. G., Mc Connell, B., Claringbold, K., O' Connor, P., Warren, W.P. and Wright, G. 1995. *A Geological description of East Cork, Waterford and adjoining parts of Tipperary and Limerick to accompany the bedrock geology 1:100,000 scale map series, Sheet 22, East Cork-Waterford.* Geological Survey of Ireland, 66 pp.

Trayner, P., 1985. *The stratigraphy and structure of parts of east County Cork and west County Waterford.* Unpublished PhD thesis. National University of Ireland.

**Appendix 1 Geological Logs of the Auger Boreholes.**

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It assumed that the auger has reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

| ***Borehole No.*** | ***Depth (m)*** | ***BS5930 Description*** | ***Permeability*** |
|---|---|---|---|
| DBR1 | 0-1.5<br>1.5-2.4 | Sandy CLAY with cobbles (TILL)<br>Sandy SILT with cobbles (TILL) | LOW<br>MODERATE |
| DBR2 | 0-7.8 | Silty SAND with gravel (TILL) | HIGH |
| DBR3 | 0-3<br>3-3.5 | Clayey SAND with gravel (TILL)<br>Sandy CLAY with gravel (TILL) | MODERATE<br>LOW |
| DBR4 | 0-2 | Sandy silt CLAY with gravel (TILL) | LOW |
| DBR5 | 0-8.5 | Silty SAND with gravel (TILL) | HIGH |

**Appendix 2 Hydrochemical Analyses for Downing Bridge Borehole.**

Table 1 of 2

| **Parameter** | 10/11/83 | 28/11/83 | 29/11/83 | 30/11/83 | 1/12/83 | 1/12/83** | 2/4/91 | 19/11/91 | 27/5/92 | 20/7/92 |
|---|---|---|---|---|---|---|---|---|---|---|
| Conductivity (μS/cm) | 390 | | | | | 550 | 607 | 600 | 645 | 636 |
| Temperature (°C) | | | | | | | 9.0 | 11 | 10.0 | |
| pH | 7.68 | 7.4 | 7.51 | 7.63 | | 7.2 | 7.2 | 7.2 | 6.9 | 7.0 |
| Total Hardness (mg $l^{-1}$ $CaCO_3$) | 213 | 308 | 304 | 311 | | 312 | | | | |
| Total Alkalinity (mg $l^{-1}$ $CaCO_3$) | 234 | 270 | 270 | 275 | | 260 | | | | |
| Calcium | | | | | | 126 | | | | |
| Magnesium | | | | | | - | | | | |
| Chloride | 25 | 18 | 21 | 20 | 20 | 24 | | | | |
| Sulphate | | | | | | 13 | | | | |
| Sodium | | | | | | 11 | | | | |
| Potassium | | | | | | 1 | | | | |
| Aluminium | | | | | | | | | | |
| Ammonium | <0.01 | | | | | 0.09 | 0.04 | 0.01 | 0.02 | 0.02 |
| Nitrate (as $NO_3$) | 9.7 | 12.0 | 14.0 | 12.0 | 22.0 | 26.58 | 33.82 | 62.30 | 35.6 | 36.85 |
| Nickel | | | | | | | | | | |
| Cadmium | | | | | | | | | | |
| Chromium | | | | | | | | | | |
| Copper | <0.02 | | | | | 0.002 | | | | |
| Iron | <0.02 | 0.12 | | 0.17 | 0.29 | 0.02 | | | | |
| Lead | <0.02 | | | | | 0 | | | | |
| Manganese | <0.02 | | | | | 0.005 | | | | |
| Zinc | <0.01 | | | | | 0.04 | | | | |
| O-PO4-P | <0.01 | | | | | | | | | |
| Total Coliforms per 100 ml | 10 | 0 | 0 | 0 | | <1 | 0 | 0 | 0 | 0 |
| Faecal Coliforms per 100 ml. | 0 | 0 | 0 | 0 | | <1 | 0 | 0 | 0 | 0 |
| Bacteria count 22°C | | 36 | 12 | 14 | | 56 | 0 | 1 | 5 | 2 |
| Bacteria count 37°C | | 2 | 0 | 1 | | 37 | 1 | 1 | 0 | 5 |

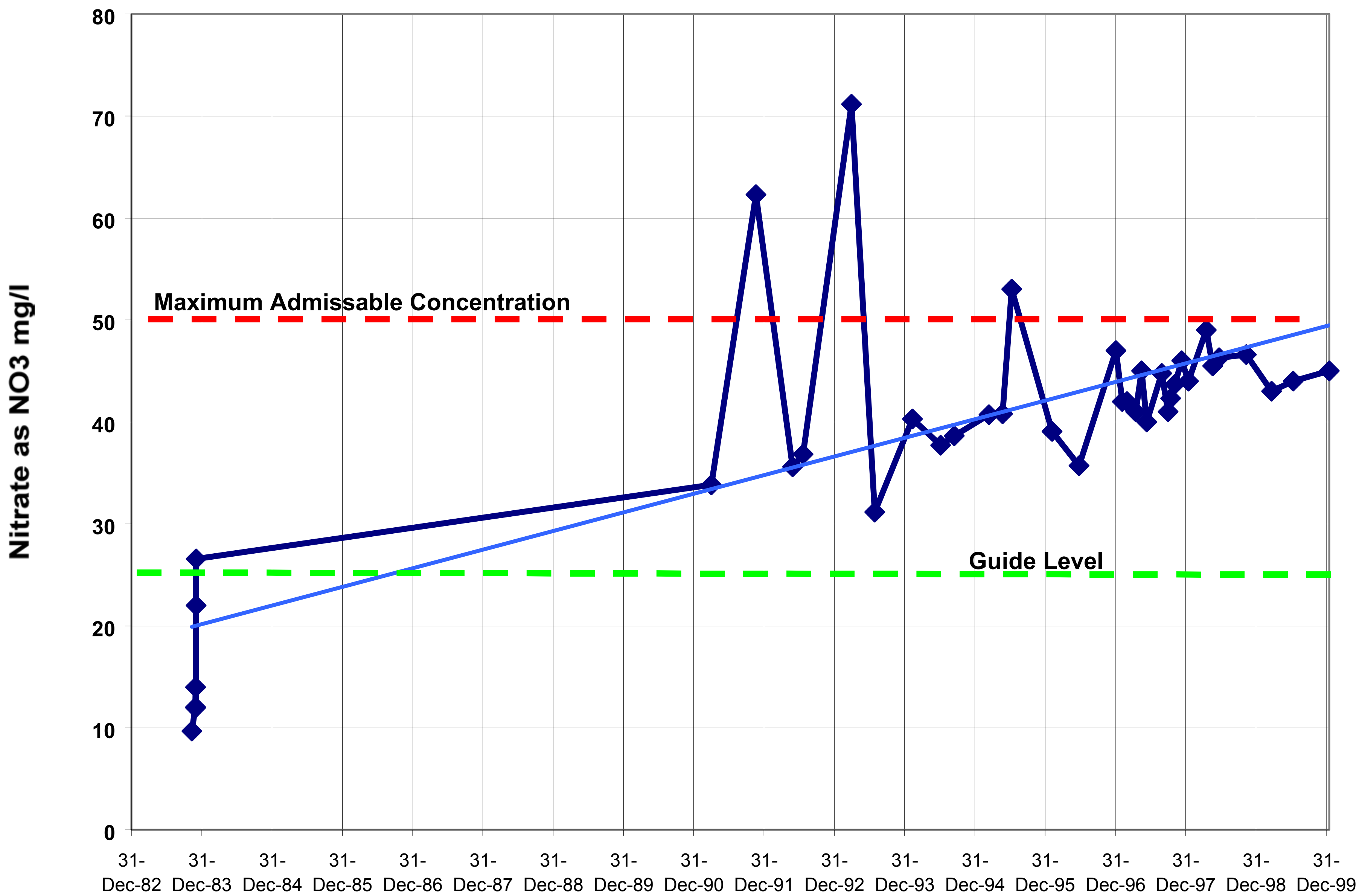
** Consult-Ltd., the rest of the samples were analysed by Cork County Council.

Table 2 of 2

| **Parameter** | 30/3/93 | 29/7/93 | 9/2/94 | 6/7/94 | 14/9/94 | 14/3/95 | 24/5/95 | 10/7/95 | 5/2/96 | 24/6/96 | 9/7/99 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conductivity (µS/cm) | 649 | 731 | 684 | 644 | 501 | 625 | 594 | 589 | 601 | 592 | 806 |
| Temperature (°C) | | | 7.0 | 15.2 | 15.0 | 8.5 | 14.0 | 17.0 | 6.5 | 16.0 | 11.2 |
| pH | | 6.8 | 7.2 | 7.3 | 7.1 | 7.2 | 7.3 | 7.3 | 7.2 | | 7.2 |
| Total Hardness (mg $l^{-1}$ $CaCO_3$) | | | | | 354 | 339 | | | | | 370 |
| Total Alkalinity (mg $l^{-1}$ $CaCO_3$) | | | | | 124 | 305 | | | | | 280 |
| Calcium | | | | | | | | | | | 118.6 |
| Magnesium | | | | | | | | | | | 9.9 |
| Chloride | | | | | 28 | 26 | | | | | 24.3 |
| Sulphate | | | | | 13 | 14 | | | | | 15.1 |
| Sodium | | | | | | | | | | | 10.2 |
| Potassium | | | | | | | | | | | 1.6 |
| Aluminium | | | | | | 0.05 | | | | | |
| Ammonium | 0.02 | 0.02 | 0.001 | 0.013 | 0.013 | 0.010 | 0.012 | 0.052 | 0.01 | 0.013 | <0.026 |
| Nitrate (as $NO_3$) | 71.16 | 31.15 | 40.28 | 37.71 | 38.64 | 40.7 | 40.8 | 53.01 | 39.08 | 35.69 | 41.3 |
| Nickel | | | | | 0.05 | 0.05 | | | | | |
| Cadmium | | | | | 0.0 | 0.003 | | | | | |
| Chromium | | | | | 0.002 | 0.010 | | | | | |
| Copper | | | | | 0.02 | 0.10 | | | | | |
| Iron | | | | | 0.01 | 0.10 | | | | | <0.1 |
| Lead | | | | | 0.003 | 0.010 | | | | | |
| Manganese | | | | | 0.025 | 0.025 | | | | | <0.05 |
| Zinc | | | | | 0.050 | 0.050 | | | | | |
| O-PO4-P | | | | | 0.010 | 0.010 | | | | | |
| Total Coliforms per 100 ml | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Faecal Coliforms per 100 ml. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bacteria count 22°C | 11 | 8 | 1 | 19 | 0 | 21 | 0 | 0 | 0 | 0 | |
| Bacteria count 37°C | 6 | 6 | 0 | 9 | 0 | 16 | 2 | 0 | 0 | 1 | |

** Consult-Ltd., the rest of the samples were analysed by Cork County Council.

**Appendix 3 Graph of nitrate levels at Downing Bridge.**



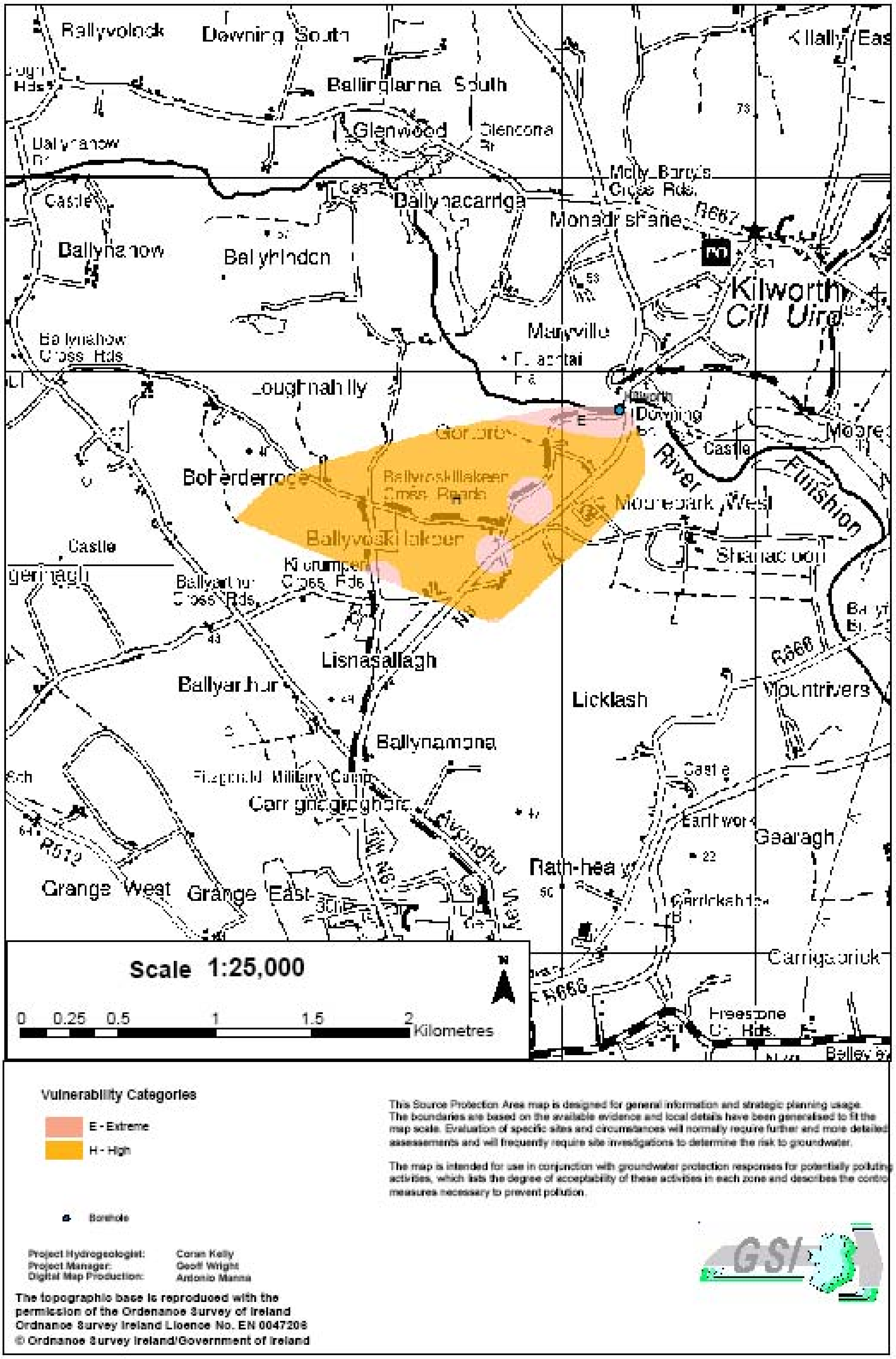



**Figure 1 Groundwater Vulnerability around Kilworth**

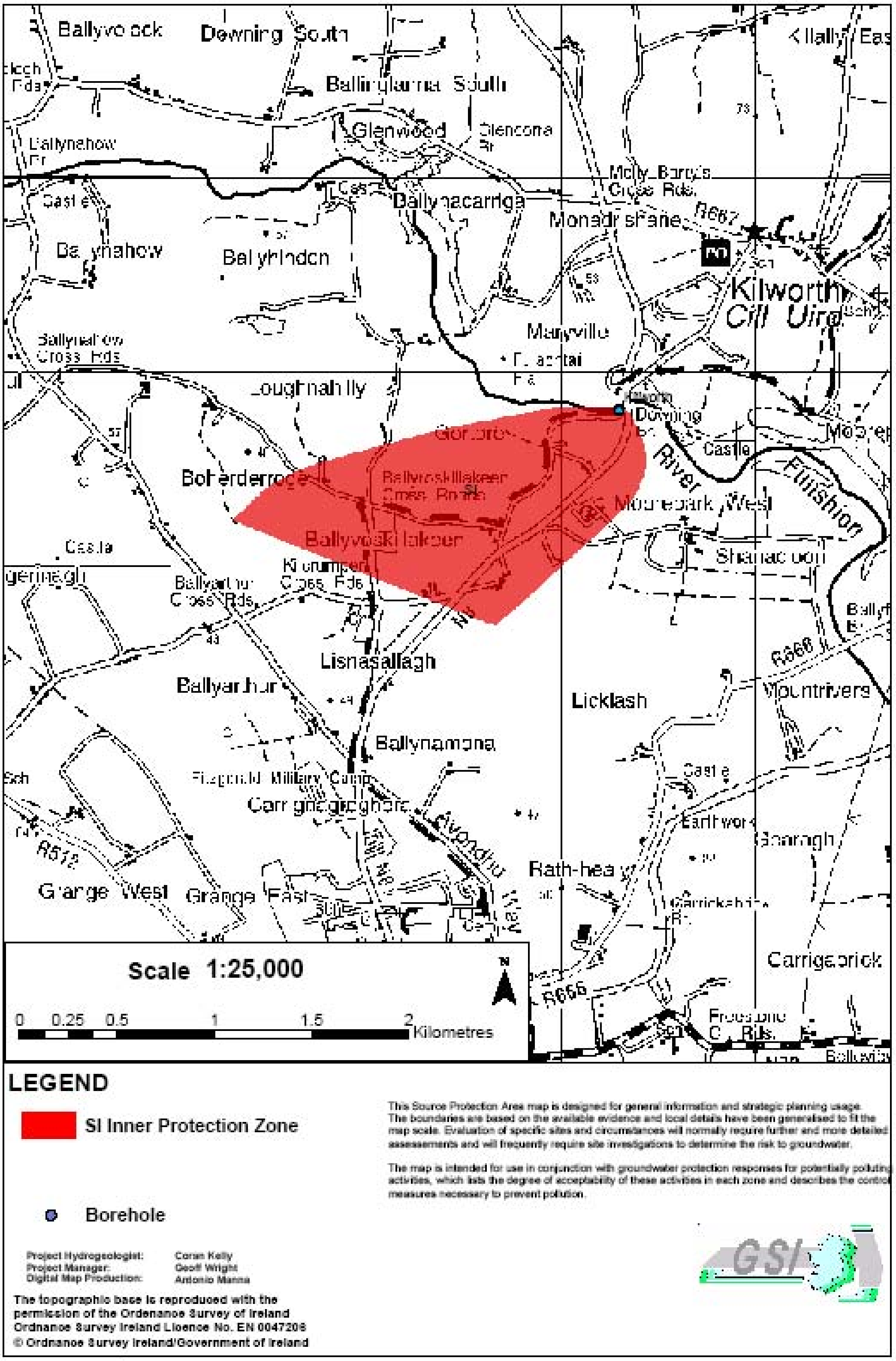



**Figure 2 Groundwater Source Protection Areas for Kilworth**

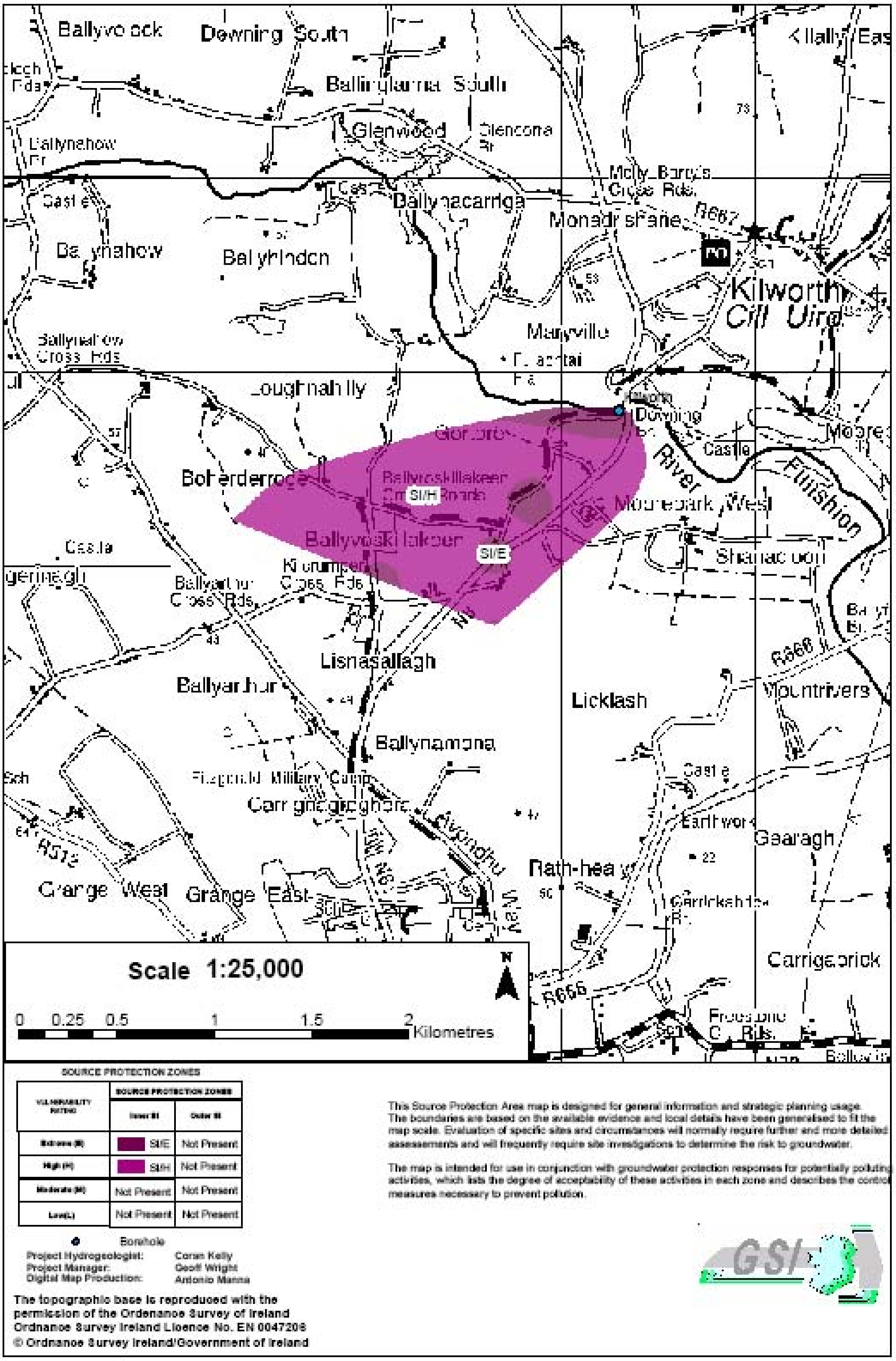



**Figure 3 Groundwater Source Protection Zones for Kilworth**