Kinnity Public Water Supply

Ballyshane Bridge

Groundwater Source Protection Zones

March 2004

Prepared by:
Coran Kelly
Geological Survey of Ireland

In partnership with:
Offaly County Council

TABLE OF CONTENTS

1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for Kinnity (Ballyshane Bridge Borehole) Public Water Supply.
- To outline the principal hydrogeological characteristics of the surrounding area.
- To assist Offaly County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the well. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection scheme for the county. The maps produced for the scheme are based largely on readily available information in the area and mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 Summary of Borehole Details

GSI No.	2019NEW019
Grid reference	218519 210409 (GPS measurement 12/12/02)
Townland	Ballyshane
Owner	Offaly County Council
Well Type	Borehole
Depth	45 m (Co. Co. records)
Elevation (top of casing)	120 m OD (Malin Head) GSI staff 12/12/2002
Pumping water level	7.21 m below top of borehole (measured by GSI personnel 12/12/2002)
Piezometric level	Above ground level (observed by GSI personnel 12/12/2002)
Yield	393 $m^3 d^{-1}$ (86,400 gals/day) (Co. Co. records)
Normal consumption	140 $m^3 d^{-1}$ (30,000 gals/day) (Co. Co. records)
Maximum Abstracted	Unknown
Hours Pumping	Approximately 24 hours per day
Depth of pump	Approximately 40 m
Depth-to-rock	Approximately 10 m
Diameter	0.15 steel casing to 12 m; 0.125m slotted plastic liner to 45 m
Treatment	Chlorinated and Raw water tap available at reservoir
System	Pumps to reservoir (20,000 gallons)
Drilled	4/7/1997

3 Methodology

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

The data collection process included the following:

- Interview and site visit with council staff 12/12/2002.
- Drilling of five auger holes by GSI 30/4/2003.
- Field mapping walkovers 12/12/2002 were also carried out to further investigate the subsoil geology, the hydrogeology and vulnerability to contamination.
- Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

4 Borehole Location & Site Description

The source is located approximately four kilometres south of Kinnity, at Ballyshane Bridge. The source comprises a single borehole that pumps water to a reservoir. At the time of the GSI site visits, the system provided water for Kinnity village and the immediate area. The borehole is located a concrete chamber 1 m deep, and 1.3 m by 2 m across. The top of the chamber stands 0.15 m above ground level. Photographs are given in Figure 1 (a) and Figure 1 (b).

5 Topography, Surface Hydrology and Land Use

The borehole is situated toward the bottom of the northwestern slopes of the Slieve Bloom mountains. The elevation at the borehole is 120 m OD. There are three hills immediately east and south east of the source, the highest of which is Knocknaman (340 m O.D.). Average topographic gradients are approximately 0.13, indicating the steepness of the topography east and south east of the borehole.

There is one main stream, approximately 10 m north of the source, flowing in an northwesterly direction. This stream drains the western and northwestern sides of the hills that occupy the area around the source. There are two springs mapped on the GSI 1:10,560 archive ordnance maps located on the lower slopes of the hill directly to the south of the source: one is located approximately 800 m south of the source, which discharges into the main stream; and another, named Dominicks Well, is located approximately 1.5 kilometres to the south of the source. Apart from the stream and springs, the natural and artificial drainage density is relatively low.

The area around the source belongs to the Little Brosna subcatchment (Hydrometric area 25) of the Shannon River Basin District.

Land use in the vicinity of the source is dominated by agriculture; primarily grassland used for grazing cattle and sheep. There are a number of farms and houses within 500 m of the source.

6 Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the supply borehole. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. Geological information was taken from a desk-based survey of available data, which comprised the following:

- Gately, S., Sleeman, A.G., and G. Emo. A Geological description of Galway - Offaly, and adjacent parts of Westmeath, Tipperary, Laois, Clare and Roscommon to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 15, Galway - Offaly.
- Information from geological mapping in the nineteenth century (on record at the GSI) and subsequent mapping in the 1970's by the GSI.
- Offaly Groundwater Protection Scheme (Daly *et al,* 1998).
- Subsoil mapping by the GSI.
- Auger Drilling of 5 holes carried out by GSI (April 2003).

Figure 1 (a, b); (a) Ballyshane Bridge borehole, (b) Borehole chamber and Ballyshane Bridge

6.2 Bedrock Geology

The bedrock consists of limestones, shales and sandstones and they are described below, from oldest to youngest. An extract from the available geology map is given in Figure 2, and, a representative cross-section is given in Figure 3.

The **Silurian Metasediments and Volcanics** (Capard Formation) consists of: greenish-grey to medium and dark-grey, fine to medium-grained sandstones; medium to dark-grey or greyish-green siltstones; and, mudstones.

The **Devonian Old Red Sandstone** (Cadamstown Formation) comprises a mixture of coarse and fine grained sandstones, siltstones, shales and conglomerates.

The **Devonian Kiltorcan-type Sandstone** (Clonaslee Flagstone Member) consists of medium to coarse grained, pale, often creamy coloured sandstone with red and green siltstones and mudstones. The upper unit has been distinguished on the geology map and is named as, the Clonaslee Flagstone Member, because of its' thick flaggy nature. It is this unit in which the source borehole is located.

The **Dinantian (early) Sandstones, Shales and Limestones** (Lower Limestone Shale (LLS)) consist of thinly-bedded, dark grey calcareous mudstones and occasional thin muddy limestones.

According to the geology map, the boundary of the Clonaslee Flagstone and the younger Lower Limestone Shales is approximately 50 m to the northwest of the borehole. However, the contact is not directly seen in the area, as there are few outcrops, thus, it may be occur closer to the borehole. A sketch showing a representative cross-section through the area is given in Figure 3.

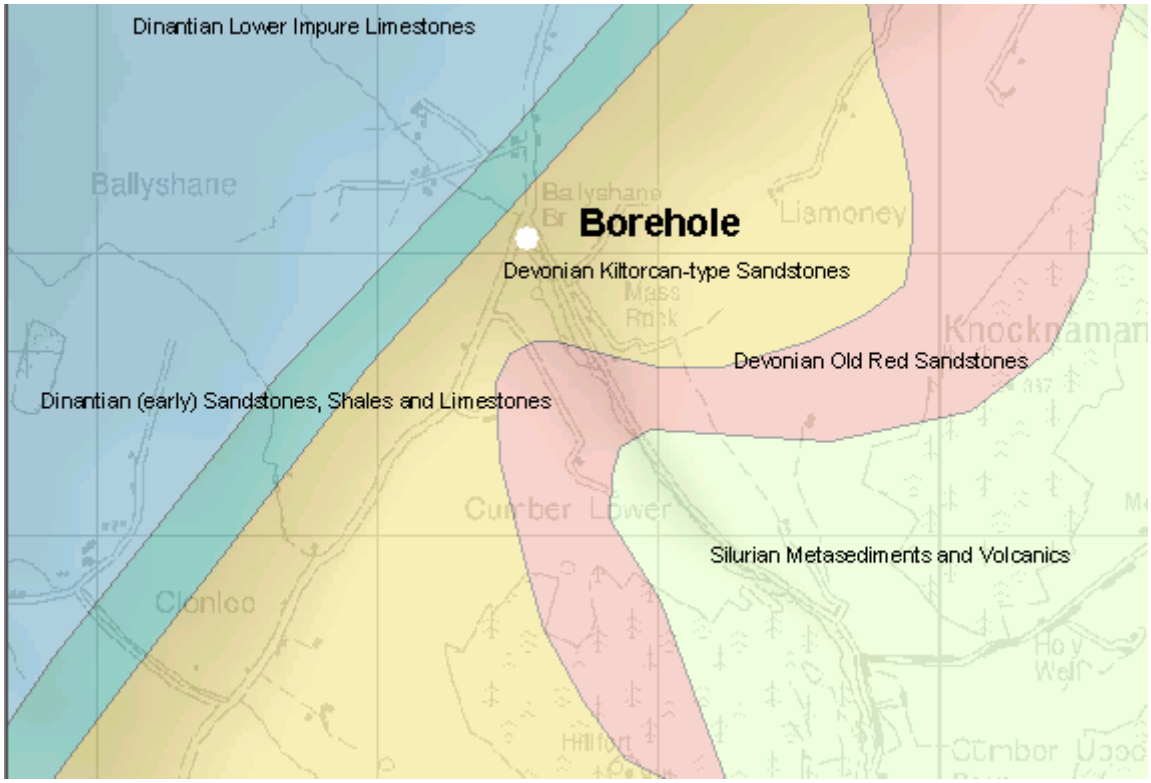

Figure 2 Geology around Ballyshane Bridge.

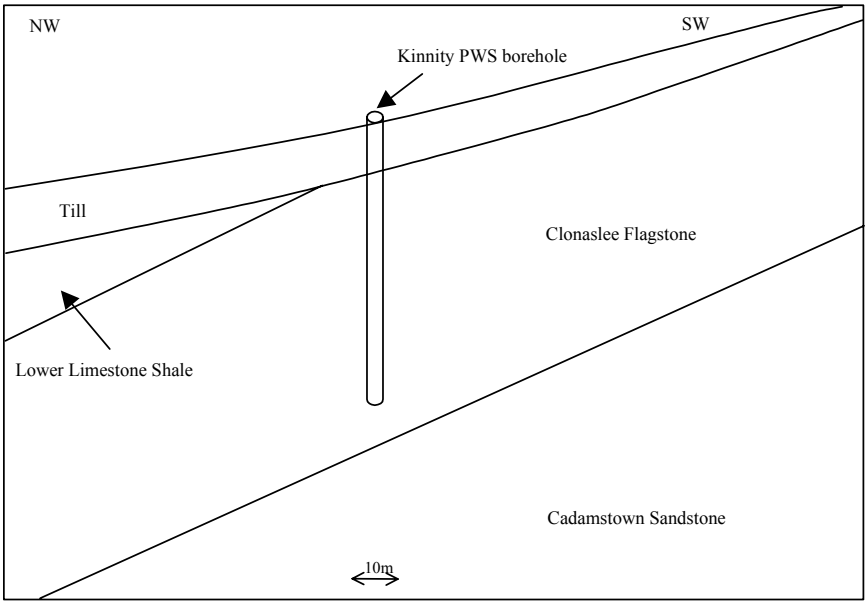

Figure 3 A cross-sectional sketch of the geology at Ballyshane Borehole (Kinnity PWS)

6.3 Subsoil Geology

Sand/gravel and till are the dominant subsoils in the area. The characteristics of each category are described briefly below:

- Sand/gravel is present along the river valley, and, on the lower slopes of the hills around the source. The extent of the sand/gravel as mapped is given in Figure 4.
- 'Till' or 'Boulder clay' is an unsorted mixture of coarse and fine materials laid down by ice. The borehole is located in till. Till occupies areas to the west and north of the borehole, and also, beyond the sand/gravel, on the higher hill slopes.
- Five auger holes were drilled in the vicinity of the borehole, which are shown in Figure 4, and further details are given in Appendix 1.
  - Till was present at auger holes 1, 4 (classified as "**SILT**" using BS 5930, 1999) and 5 (classified as "**SILT/CLAY**" using BS 5930).
  - Sand/gravel was present at auger hole 3 (classified as "**SAND**" using BS 5930).
  - Both till (classified as "**SILT**" using BS5930) and sand/gravel (classified as "**SAND**" using BS 5930) were present at auger hole 6.
- Only auger holes 1 and 3 met rock; the others went as far as 10 m without meeting rock. The subsoil thickness varies from 0 m (outcrop) to greater than 10 m at the pumping well. Shallow rock and outcrop occur in the higher areas at. The deeper areas coincide with the low lying areas covered by peat.

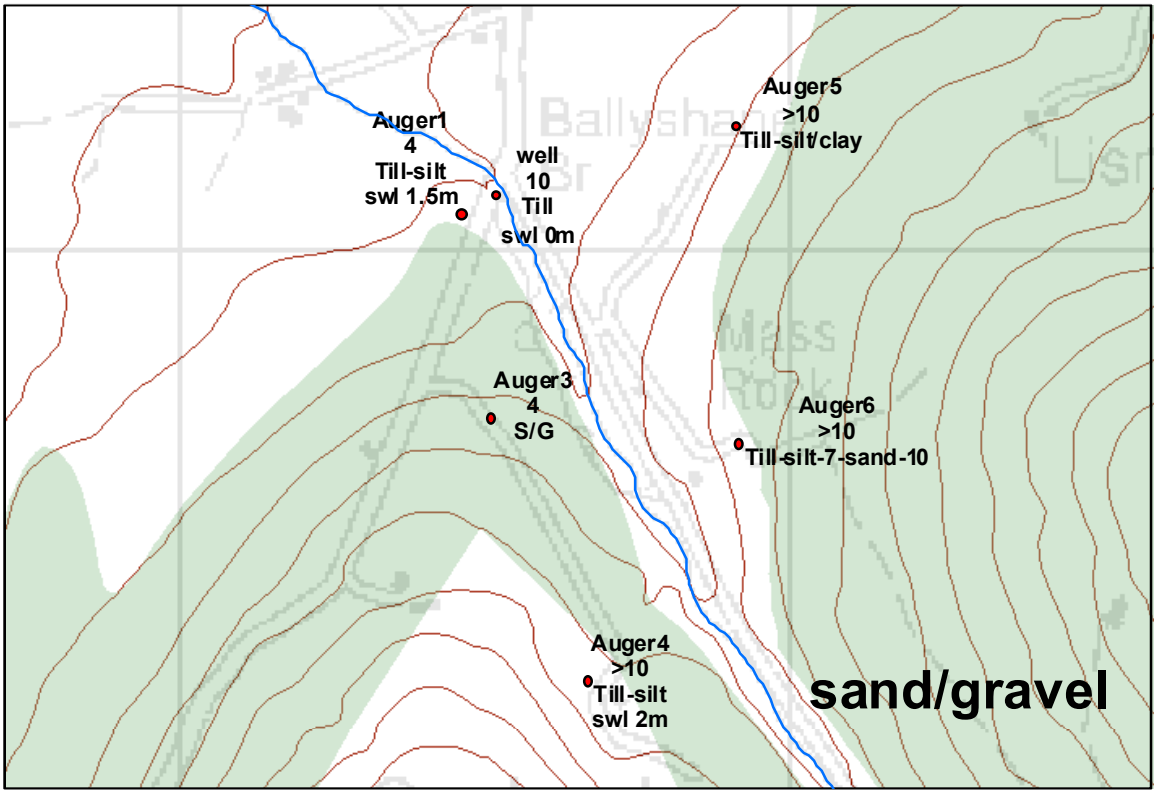

Figure 4 Location of auger holes; sand/gravel; depth to rock; water levels, streams and contours.

7 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. Consequently, vulnerability relates to the thickness of the unsaturated zone in the gravel aquifer, and the permeability and thickness of the subsoil in areas where the gravel aquifer is absent. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999), and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. (Fitzsimons, 2003).

- The source of the groundwater is the bedrock, thus for the purposes of vulnerability mapping, the "**top of the rock"** is the target.
- The permeability of the till is classed "**moderate**", and the permeability of the sand & gravel is "**high**".
- Depth to bedrock varies from being greater than 10 m beside the well to 0 m (outcrop).
- The vulnerability is classified as "**moderate**" at the well, to "**high**" and "**extreme**" across the rest of the area. The vulnerability is shown in Figure 6.

Depth to rock interpretations are based on the available data cited here. However, depth to rock varies over short distances. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. The mapping is intended as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

8 Hydrogeology

8.1 Introduction

This section presents our current understanding of groundwater flow in the area of the source. Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- GSI files and archival Offaly County Council data.
- Offaly County Council drinking water returns.
- Hydrogeological mapping carried out by GSI on 12th Dec 2002, 28-30th April 2003 and 1st May 2003.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability (five auger holes, May 2003).
- A Groundwater Protection Scheme for Co. Offaly (Daly *et al*, 1998).
- Hydrogeology of the Kiltorcan Aquifer System. Daly, E.P. (1985) Geological Survey of Ireland.
- The Kiltorcan Sandstone Aquifer. Daly, E.P. (1988). Proceedings of the Eighth Annual International Association of Hydrogeologists (Irish Branch) Seminar, Portlaoise.

8.2 Meteorology and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. 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 Kinnity, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient. The recharge is estimated as follows.

- **Annual rainfall:** 1025 mm.
  Rainfall data for gauging stations around Kinnity (from Fitzgerald, D., Forrestal., F., 1996) are as follows:

Gauging Stations	Grid reference	Elevation OD (m)	Approximate distance & direction from source	Annual precipitation 1961-1990
Kinnity Castle	N203058	143	2 km north east	1012 mm

  The contoured data map for the Offaly Groundwater Protection Scheme (Daly *et al*, 1998) show that the borehole is located between the 1050 mm and the 1000 mm average annual rainfall isohyets.

- **Annual evapotranspiration losses:** 380 mm.
  Potential evapotranspiration (P.E.) is estimated to be 400 mm $yr.^{-1}$ [on the basis of the country-wide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996)]. Actual evapotranspiration (A.E.) is estimated as 95 % of P.E., to allow for seasonal soil moisture deficits.

- **Effective Rainfall:** 630 mm.
  The effective rainfall is calculated by subtracting actual evapotranspiration from rainfall.

- **Recharge coefficient:** 70%.
  The slopes and the nature of the deposits around the source need to be considered in order to give a representative value for the recharge coefficient during rainfall events. In general, the subsoils are free draining and the slopes are moderately steep. A representative value for the recharge coefficient is estimated to be in the order to 70%.

These calculations are summarised as follows.

average annual rainfall	1025 mm
estimated P.E.	400 mm
estimated A.E. (95% of P.E.)	380 mm
effective rainfall	630 mm
recharge coefficient	70%
Recharge	**440 mm**

8.3 Groundwater levels, Flow Directions and Gradients

Groundwater levels were measured at a site visit (12/12/02). The pumping water level was recorded at approximately 7.21 m below ground (approximately 113 m O.D.). The static water level (piezometric head) of the groundwater is above ground level, indicating that the groundwater is confined in the area of the borehole, and is an "artesian" borehole.

The static water level is greater than 3 m above the water level in the nearby river. The pumping water level is approximately 4 m below river level. It is assumed that the borehole does not draw water from the river.

Water level data is poor in the area. However, it is generally assumed that the water table is a subdued reflection of the topography. It is expected that the groundwater flow directions will be to the northwest and west.

The groundwater gradients are unknown, but are assumed to be less than the topographic gradient (0.13), and, are estimated to be in the order of 0.02 (Daly, 1988).

8.4 Hydrochemistry and Water Quality

The following key points are identified from the data.

- The hydrochemical analyses show that the water is slightly hard, with total hardness values of 116-136 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 341-571 µS cm^{-1}. The hydrochemistry indicates that the groundwater feeding the borehole is derived from the sandstones.
- Nitrate concentrations are low, ranging from 6.1-13.7 mg l^{-1}, and have not exceeded the EU Drinking Water Directive maximum admissible concentration (MAC) of 50 mg l^{-1}. There is no apparent trend in the data.
- Chloride is a constituent of organic wastes and levels higher than 25 mg l^{-1} may indicate significant contamination, with levels higher than the 30 mg l^{-1} usually indicating significant contamination. Chloride data range from 13 to 19 mg l^{-1} (average is 14 mg l^{-1}), suggesting that there is little or no contamination.
- One raw water sample (14/7/1997) indicates no faecal coliforms.
- In summary, there appears to little human impact on the groundwater quality.

8.5 Aquifer Characteristics

The Devonian Kiltorcan-type Sandstone (Clonaslee Flagstone) is the main rock unit that is providing groundwater to the borehole. According to the well driller, a fissure is present at 36 m below ground, and that the major inflow is from this fissure.

A constant rate test was undertaken at the borehole by council staff from 27th August 1997 to 4th September 1997. The reported yield was 327 m^3 d^{-1} (3000 gallons per hour), and the maximum drawdown was 15.48 m (50 feet). The specific capacity[1] is estimated to be 21 $m^3 d^{-1} m^{-1}$. Transmissivity is estimated from the specific capacity to be approximately 25 m^2 d^{-1}. Permeability is estimated from the transmissivity, to be approximately 0.6 m d^{-1}. Available data for Devonian Kiltorcan-type

[1] Specific capacity is the rate of abstraction per unit drawdown: units are $m^3 d^{-1} m^{-1}$

Sandstone elsewhere in the country, indicate that permeability ranges from 0.5-2.0 m d^{-1}. Porosity is assumed to be approximately 2%.

The Devonian Kiltorcan-type Sandstone has relatively high fissure permeability, and, in areas where the sandstone is friable due to weathering, it may have an intergranular permeability. Artesian conditions occur where the Devonian Kiltorcan-type Sandstone aquifer passes under confining beds of the Dinantian (early) Sandstones, Shales and Limestones. The static water level indicates that the groundwater is confined in the vicinity of the borehole. The till is the main reason that the groundwater is confined in the vicinity of the borehole. Groundwater flow is assumed to be unconfined on the upper slopes, where the other rock units do not overlie the Devonian Kiltorcan-type Sandstone, and where it is overlain by sand/gravel.

The Devonian Kiltorcan-type Sandstone is bounded on the uphill and downhill sides by relatively poor aquifers and covered by a mixture of till and sand/gravel. The hydrogeological setting of the aquifers described above, has been studied and described by E.P. Daly (Daly 1985; 1988). There are four subdivisions, shown in Figure 5; each comprising different hydraulic and flow characteristics. The Ballyshane borehole is located at the boundary of zones II and III.

The main recharge areas are where the Devonian Kiltorcan-type Sandstone is exposed. Sand/gravel is likely to provide additional storage where it is overlying the Devonian Kiltorcan-type Sandstone. It is possible that some additional recharge occurs to the Devonian Kiltorcan-type Sandstone, close to the boundary with the Old Red Sandstone.

The Silurian Metasediments (Capard Formation) and the Old Red Sandstone (Cadamstown Formation) generally have low permeabilities, low transmissivities and poor storage. Groundwater flow paths are expected to be short. Therefore, it is considered that recharge to these rocks, is transmitted to nearby surface water features, as evidenced by the spring at Cumber Lower, occurring on the steep slopes overlying the Cadamstown Formation.

The Devonian Kiltorcan-type Sandstone is classified as a **Regionally Important Fractured Aquifer (Rf)**.

Table 1 Aquifer parameters for the Devonian Kiltorcan-type Sandstone at Ballyshane Bridge.

Parameter	*Source of data*	*Value/range*
Transmissivity (m^2 $d^{-1)}$	Local	25
Specific Capacity (m^3 $d^{-1}m^{-1}$)	Local	21
Permeability (m d^{-1})	Local & regional (Clonaslee)	0.6
Porosity	Regional	0.02
Hydraulic Gradient	Regional	0.02

8.6 Conceptual Model

- The Ballyshane Bridge borehole abstracts approximately 140 m^3 d^{-1} from the Devonian Kiltorcan-type Sandstone, which is a **regionally important fissured aquifer (Rf)**.
- It is bounded by relatively poor aquifers on both the uphill and downhill sides of the borehole.
- The static water level is above ground level at the well, thus groundwater is confined at the source, due to the till around the borehole The subsoils are moderately to highly permeable, thus groundwater is unconfined uphill from the borehole.
- The hydrochemistry indicates that the groundwater is derived from the sandstone.
- The Devonian Kiltorcan-type Sandstone has high fissure permeability and groundwater flow is predominantly via fractures and fissures, although there may be intergranular permeability present.
- Groundwater is assumed to flow in a northwesterly direction.
- Groundwater recharging the Devonian Kiltorcan-type Sandstone is likely to occur where it is exposed at the surface and where it is covered by sand/gravel and moderately permeable till. The recharge is estimated to be in the order of 440 mm per year.
- Groundwater recharging the poorer aquifers to either side of the Devonian Kiltorcan-type Sandstone is expected to transmit to nearby surface water streams, although some recharge may be transmitted to the Devonian Kiltorcan-type Sandstone at the boundary with the Devonian Old Red Sandstone.

- Sand/gravel overlies the Devonian Kiltorcan-type Sandstone in places, providing extra storage for the bedrock aquifer.
- Groundwater quality is relatively good at the source.

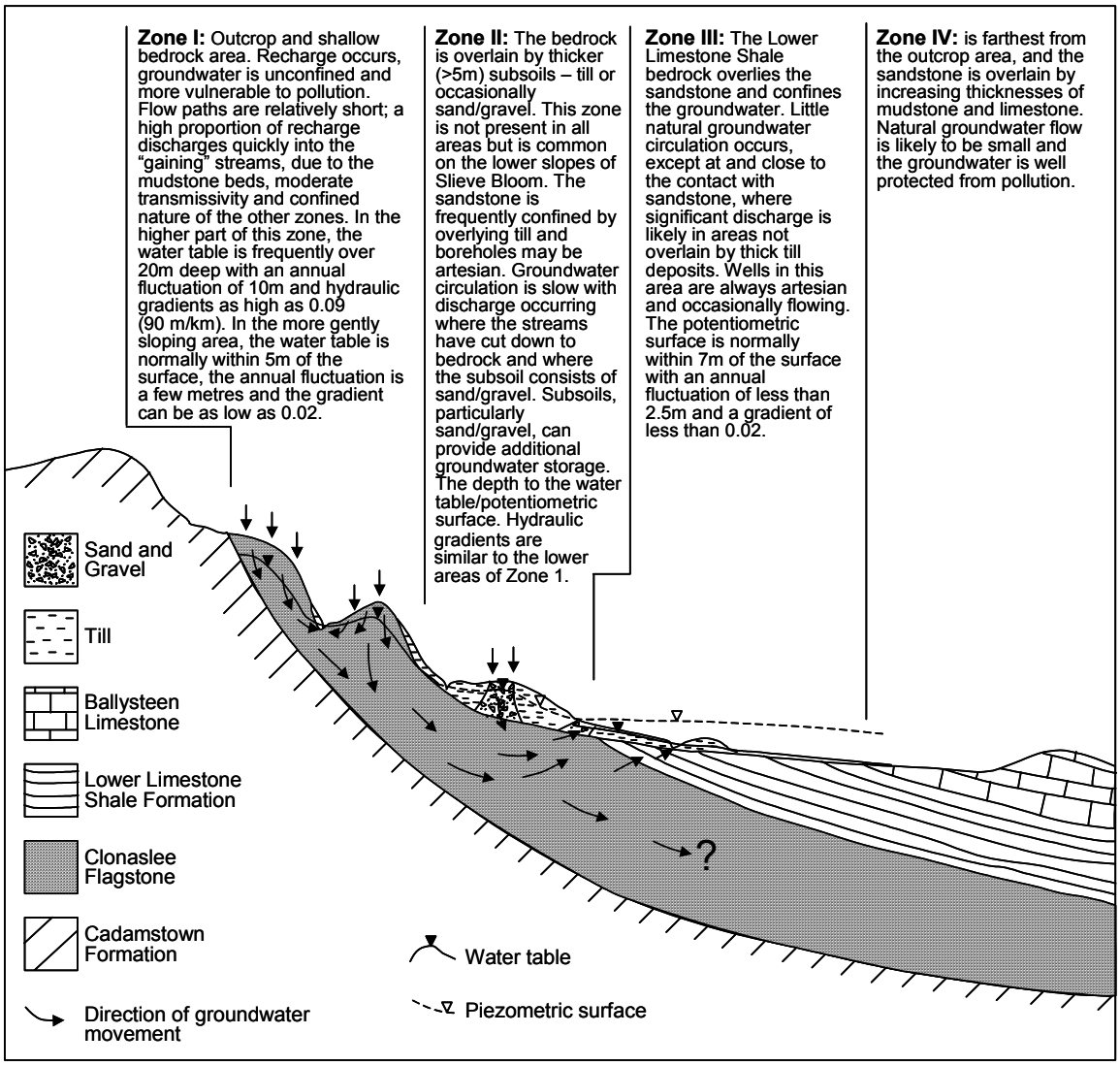

Figure 5 Conceptual model of groundwater flow in the Devonian Kiltorcan-type Sandstone, in the Slieve Bloom area. (after Daly, 1988; Hunter-Williams, 2002)

9 Delineation of Source Protection Areas

9.1 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 7 and 8.

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) to the borehole.

9.2 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 subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. They are described as follows.

The **Northwestern boundary** is estimated using the uniform flow equation, which allows the downgradient distance that the well can draw water from to be estimated. It takes account of the estimated transmissivity, gradient and abstraction. Accordingly the boundary is 80 m to the northwest of the borehole.

The **Northern boundary** is constrained by topography. It is assumed that there is a groundwater divide between Ballyshane bridge and Lismoney.

The **Southern boundary** is delineated using the geological boundary with the Devonian Old Red Sandstone. It is assumed that groundwater will discharge quickly to the surface water features via short flow paths; thus it is assumed that groundwater, in general will not be fed into the Devonian Kiltorcan-type Sandstone from the Old Red Sandstone. However, it is possible that; at the boundary, some groundwater may discharge across the boundary into the sand/gravel and/or the Devonian Kiltorcan-type Sandstone. Hence, the boundary is extended 100 m into the Devonian Old Red Sandstone. The distance is arbitrary but is expected to be longer than the general flow paths for the Devonian Old Red Sandstone.

The **Western boundary** is delineated using topography. It is assumed that there is a groundwater divide along the ridge in Cumber Lower.

The area delineated is approximately 0.4 km^2. As a cross check, a water balance was used to estimate recharge area required to supply groundwater to the source. The recharge is estimated to be 440 mm, therefore, an area of 0.3 km^2 is required to provide 400 m^3d^{-1}. Thus, the area delineated appears to be a good match for the area required.

9.3 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 contamination and it is based on the 100-day time of travel (ToT) to the supply.

Using the "Well Head Protection Area" modelling programme (Blandford, T.N., 1991, 1993), the 100 day time of travel is estimated around the borehole. The estimated values for the gradient, porosity, transmissivity, permeability for the volcanics (0.02, 0.02, 25 m^2 d^{-1}, 0.6 m d^{-1}, respectively), given in Section 8.5, are used in the calculation of the inner protection area. In addition, the estimated yield (400 m^3d^{-1}) is taken into account.

Accordingly, the boundary of the inner protection area (SI) is 170 m on the upgradient side and 80 m on the downgradient side from the well.

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.

Four groundwater protection zones are present around the source. The final groundwater protection zones are shown in Figure. The matrix of source protection zones is given below.

Table 2 Matrix of Source Protection Zones.

VULNERABILITY RATING	SOURCE PROTECTION	
	Inner	***Outer***
Extreme (E)	Not present	**SO/E**
High (H)	**SI/H**	**SO/H**
Moderate (M)	**SI/M**	Not present
Low (L)	Not present	Not present

11 Potential Pollution Sources

Agriculture is the principal activity in the area. Potential hazards include farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides.

12 Conclusions and Recommendations

- The source comprises a borehole located in a **regionally important fissured aquifer (Rf)**.
- The groundwater feeding the source is moderately to extremely vulnerable to contamination.
- Available data suggests that there is limited contamination at the source.
- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data.
- It is recommended that:
  1. The potential hazards in the ZOC should be located and assessed.
  2. A full chemical and bacteriological analysis of the **raw** water is carried out on a regular basis.
  3. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well.

13 REFERENCES

British Standards Institution. 1999. BS 5930:1999, Code of practice for site investigations. British Standards Institution, London.

Cronin, C., Daly, D. (1999). An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly. Geological Survey of Ireland and Offaly County Council.

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

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

Daly, D. (1996). Groundwater in Ireland. Course notes for Higher Diploma in Environmental Engineering, UCC.

Daly, D., Cronin, C., Coxon, C., Burns, S.J. (1998). *Offaly Groundwater Protection Scheme*. Geological Survey of Ireland. 78pp.

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

Fitzgerald, D. and Forrestal, F. (1996). Monthly and Annual Averages of Rainfall for Ireland 1961-1990. Meteorological Service, Climatological Note No. 10, UDC 551.577.2(415).

Fitzsimons, V., Daly, D. and Deakin, J. (2003). GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. Geological Survey of Ireland.

Gately, S., Sleeman, A.G., and G. Emo. A Geological description of Galway - Offaly, and adjacent parts of Westmeath, Tipperary, Laois, Clare and Roscommon to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 15, Galway - Offaly.

SUMMARY LOGS OF THE AUGER HOLES

Site 1 2019NEW014 218462 204059
Ballyshane bridge, field on the other side of the road to the borehole.
0-4 m Till; frequent angular fragments, very gritty, i.e., very difficult to get most of the gravel component out of sample.
Matrix: SILT
BS: 2 rolls, 70-80 ribbons, Slow dilatancy. Firm grey brown.

Site 3 Cumber Lower 2019NEW015 218511 203723
0-4 m Sand/gravel; reddy brown, abundant gravel, subrounded.
Matrix: SAND
BS: 0rolls, 30cm ribbon, Dilatant, very gritty
4 m EOH, refusal, assumed to be bedrock

Site 4 2019NEW016 218670 203290
0-10 m Till; Abundant angular gravels:
Matrix: SILT
BS: Dilatancy obvious.
EOH: 10 m, bedrock not met.

Site 5 Lismoney. 2019NEW017 218914 204203
0-10 m Till; Frequent angular gravels
Matrix: SILT/CLAY
BS: 3-4 rolls; 80cm; slow Dilatancy
EOH: 10 m, bedrock not met.

Site 6 2019NEW018
0-6 m Till, few-frequent angular fragments
Matrix SILT
BS: 2 rolls, 50-70cm ribbons, Slow dilatancy.
7-10 m Till, coarse angular gravels
8-10 m Sand/gravel, coarse sand.
Matrix: SAND

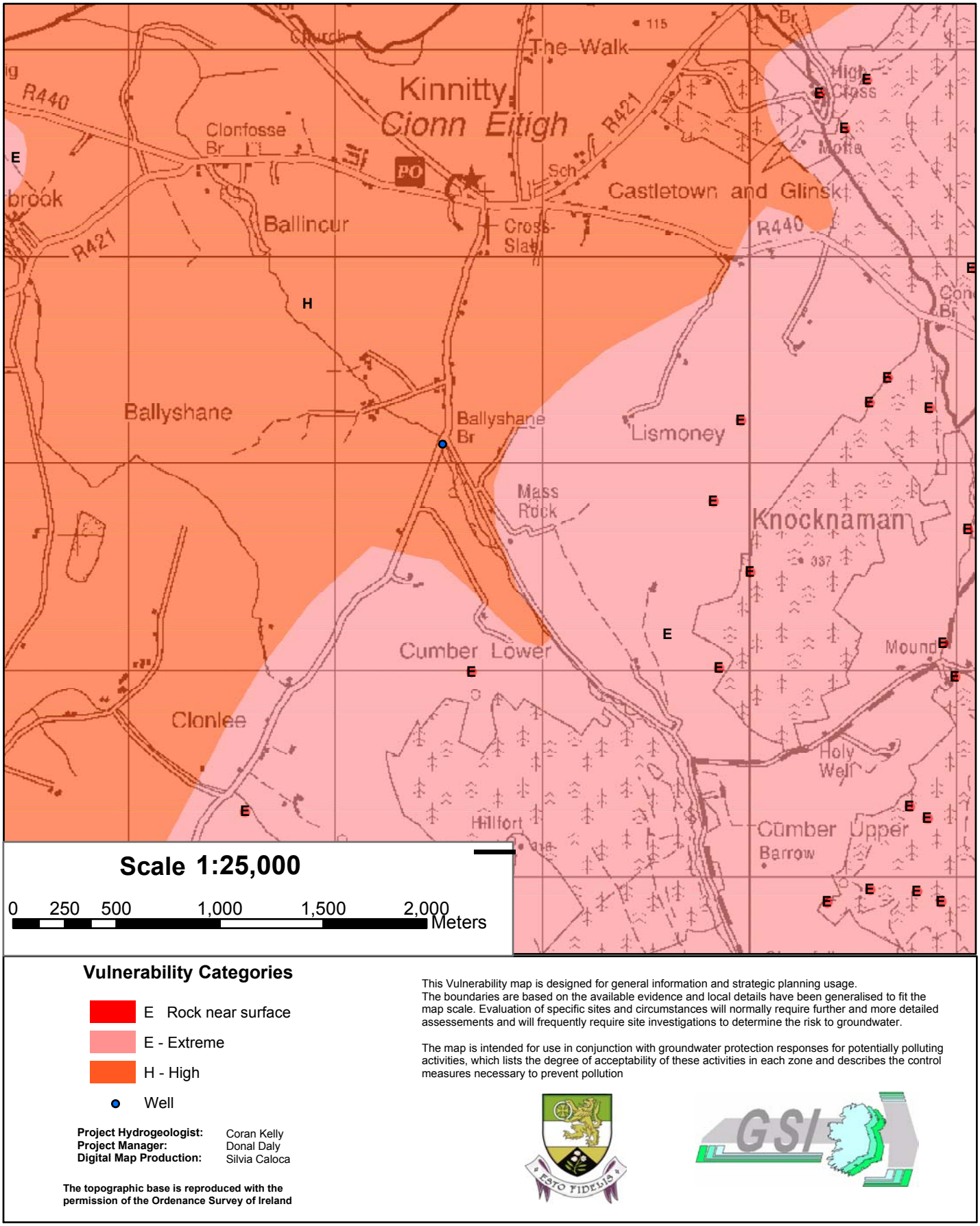

Figure 6 Vulnerability around Ballyshane Bridge Borehole

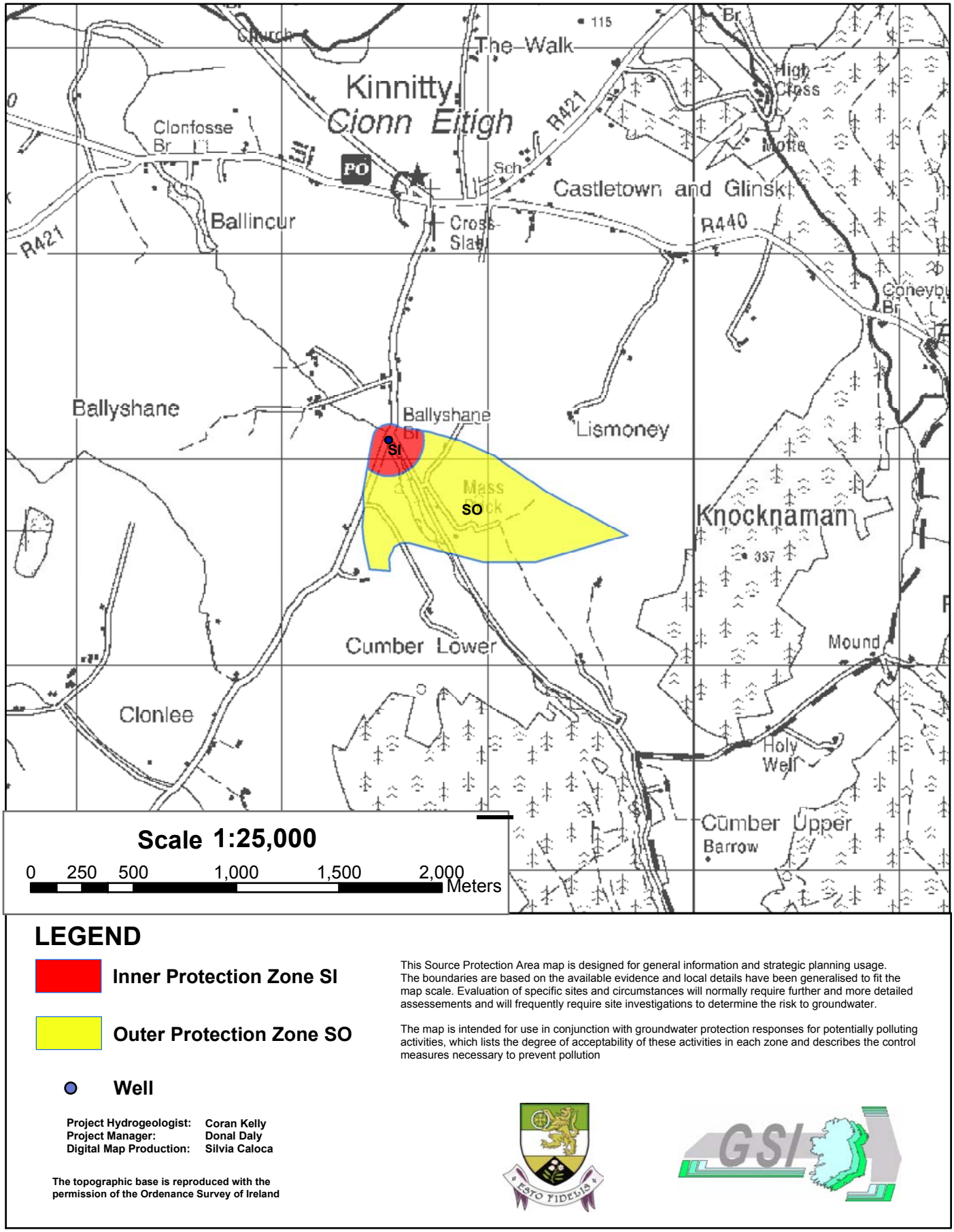

Figure 7 Source Protection Areas for Ballyshane Bridge Borehole

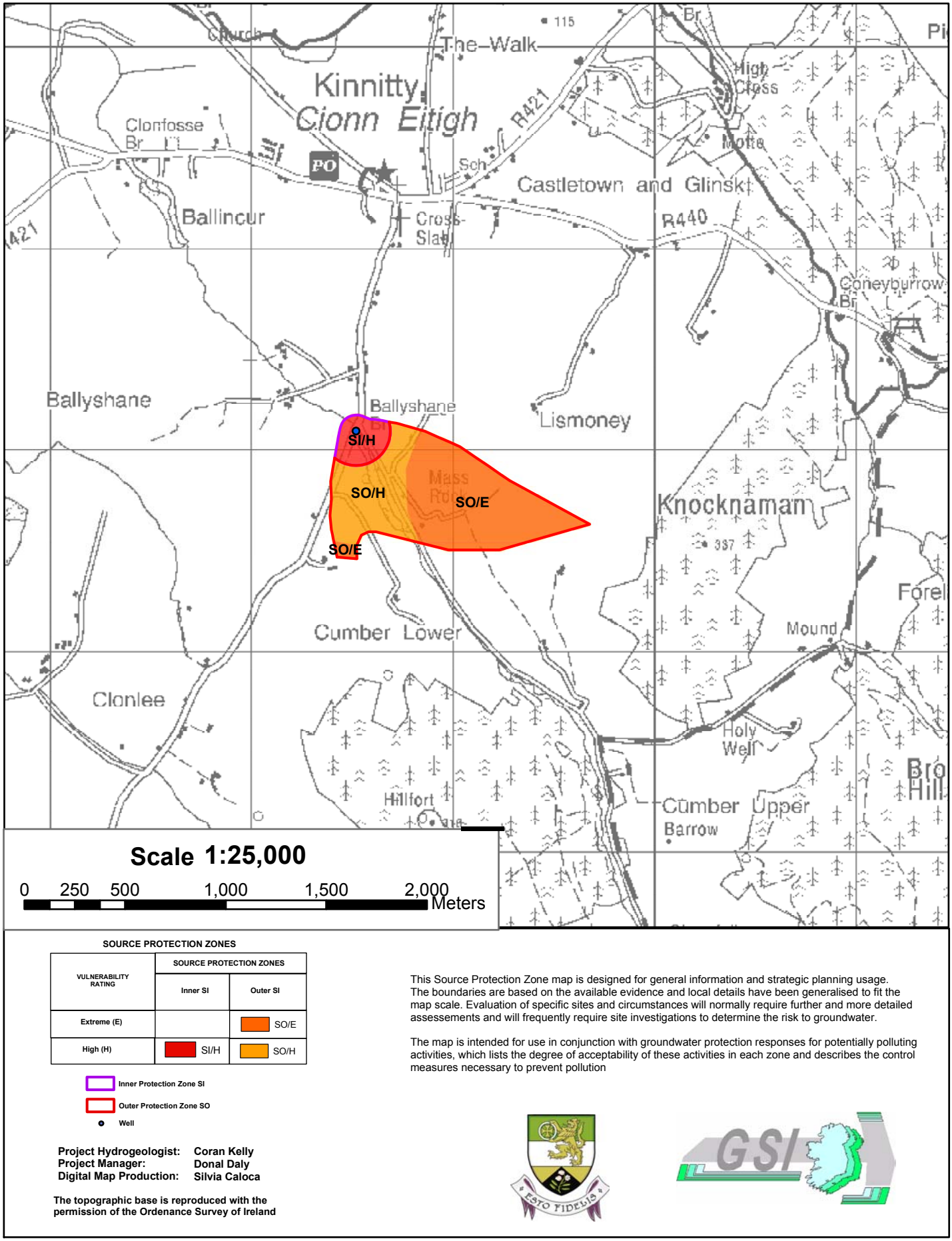

Figure 8 Source Protection Zones for Ballyshane Bridge Borehole