Clonbulloge Water Supply Scheme

Clonbulloge Spring

Groundwater Source Protection Zones

March 2005

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1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the spring.
- To outline the principal hydrogeological characteristics of the Clonbulloge 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 spring. 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 (Daly, *et al*, 1998). 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 Location and Site Description

The source is located 2 m from the eastern bank of the Figile river, approximately 35 m upstream from the confluence of the Philipstown and Figile Rivers, on the western outskirts of Clonbulloge Village, Co. Offaly.

The source was commissioned in 1968, and consists of a spring with a large diameter concrete pipe installed around the spring, with a sump 1.55 m deep. A small pumphouse has been built next to the chamber, which has a padlocked door as shown in Figure 1. The chlorination tank and chemicals are stored in the pumphouse and there is a raw water tap available. A flow meter is positioned beneath a second manhole cover beside the pumphouse. The scheme serves approximately 450 people and there are approximately forty farms on the scheme (Burns, 1993). The water is pumped to a reservoir with a storage capacity of approximately 365 m^3 (80,000 gallons).

It is relatively easy to remove the manhole cover from the top of the chamber, there is no fence or wall around the spring chamber or the site, and vegetation can get in through cracks in the walls of the chamber as can be seen in Figure 1. The chamber is also susceptible to being flooded by the Figile River at times of heavy rainfall and high flows.

3 Summary of Spring Details

GSI No.	2621NWW001
Grid reference	26070 22368
Townland	Clonbulloge
Owner	Offaly County Council
Well Type	Spring (warm – 14.6-14.9^{o}C)
Elevation (ground level)	Approximately 68 m OD. (Malin Head)
Static water level	Ground level, 0.7m above river level
Depth to rock	Approximately 5.5 m
Normal consumption/abstraction	300-320 m^3d^{-1} (65,000-70,000 gallons per day) (Caretaker 29/1/03)
Maximum Abstraction	510 m^3 d^{-1} (112,000 gallons per day)
Maximum Yield	510 m^3 d^{-1} (measured by GSI staff 29/1/03)
Maximum Drawdown	0.76 m below ground level (29/1/03); approximately 0.3 m above river level
Hours Pumping	17-24 hours per day (caretaker, 29/1/03)
Depth of sump	1.55 m below ground (measured by GSI staff 29/1/03)

Figure 1 Views of Clonbulloge Village Spring

4 Methodology

Details about the spring 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 with the caretaker 29/1/03.
- Field mapping walkovers to further investigate the subsoil geology, the hydrogeology and vulnerability to contamination.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability May 2003.
- 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 spring is located at approximately 68 m OD, in an expansive area of low-lying, relatively flat land. Approximately 10 km to the west there are two relatively large hills (over 100 m OD) and approximately 5 km to the north there is another relatively large hill (109 m OD). In a northerly direction, the topographic gradient is 0.02.

The natural and artificial drainage densities in the vicinity of the spring are high. In the higher relief areas, upgradient of the spring, the drainage density is lower. The Philipstown and Figile rivers are the two main rivers that drain the area, and both are part of the River Barrow catchment. The area to the west of the spring is drained by the Philipstown River and the area to the north and east of the spring is drained by the Figile river. The low-lying area in the vicinity of the source is drained by an extensive network of natural and artificial drains. According to archival six inch Ordnance Survey maps, the area around the spring is liable to flooding and this is supported by the caretaker. The drainage pattern follows the subcatchments of the Figile and Philipstown rivers to the confluence at Clonbulloge, after which the regional drainage is southerly. The spring is located in the South Eastern River Basin District.

Industrial peat cultivation by Bórd na Móna is the dominant land use in the region. To the west of the spring there are some areas of forestry. Clonbulloge Village occupies the land immediately to the east of the spring. To the north of the spring, land use consists of cattle/sheep rearing and some tillage.

6 Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie Clonbulloge. 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:

- Bedrock Geology 1:100,000 Map Series, Sheet 16, Kildare-Wicklow, Geological Survey of Ireland (Mc Connell, B. *et al*, 1995).
- Offaly Groundwater Protection Scheme (Daly *et al,* 1998).
- Information from geological mapping in the nineteenth century (on record at the GSI).
- Subsoil mapping by the GSI.
- Studies into the Peat Stratigraphy and Underlying Mineral "Soils" of a Raised Bog in Ireland (Hammond, R.F., 1968).
- Auger Drilling of one hole carried out by GSI (2/5/2003) beside the spring.

6.2 Bedrock Geology

- The area underlying the spring is occupied by limestones, predominantly, the Upper Impure Bedded Limestone (Calp Limestone) and the Pure Bedded Limestone (Edenderry Limestone). There is also an area occupied by the Pure Unbedded Limestone (Waulsortian Limestones) According to the geology map, the spring is located in the Upper Impure Bedded Limestone, approximately 200 m to the east of a faulted contact between the two rock units. There are very few outcrops in the area.
- The **Pure Bedded Limestone** is a pale grey, poorly-bedded limestone, that is frequently dolomitised, making them often difficult to distinguish in cores (McConnell, 1995). They occupies the area to the west of the spring.
- The **Upper Impure Bedded Limestone** is dark grey and fine grained, occupying the area to the east of the spring, and, according to the geology map of the area, the spring is located in this rock unit.
- The **Pure Unbedded Limestone** is a pale grey limestone.
- There is a large NE-SW fault mapped approximately 200 m to the northwest of the spring. This fault is the mapped contact between the two limestone units and is shown as the dashed red line in Figure 2. The exact position and direction of the fault is not known with certainty as there are few rock outcrops in the area, thus, the precise location of the fault may be closer to or at the spring.

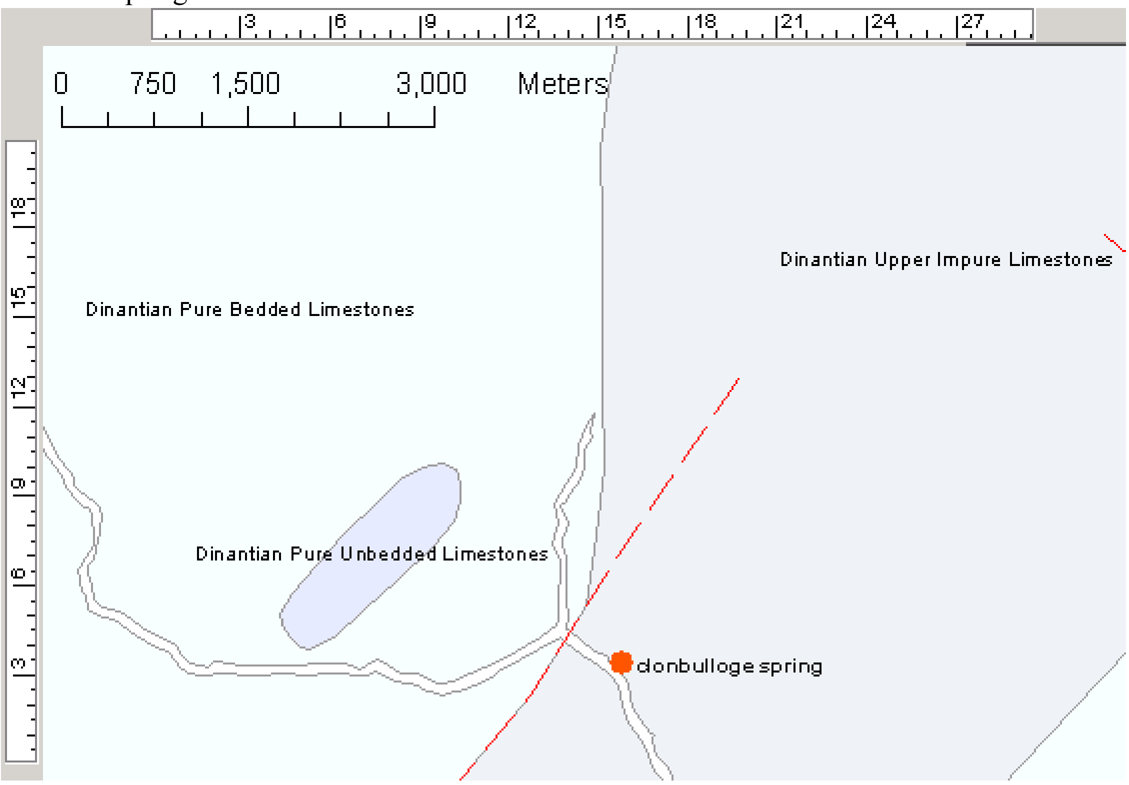

Figure 2 Geology around Clonbulloge Spring

6.3 Subsoil Geology

Limestone tills, peat and till with gravel are the dominant subsoils in the area. The characteristics of each category are described briefly below:

- 'Till' or 'Boulder clay' is an unsorted mixture of coarse and fine materials laid down by ice. Till dominates the area to the south of the spring. It also occupies, approximately circular areas of higher ground to the west of the spring, centred around Cloncreen and Clonad. Field investigations by Hammond (1968) indicate that the till underlies the peat areas to the east of spring and it assumed that the situation extends westwards. An auger hole was drilled approximately 40 m north of the spring into the till, classed as "**SILT/CLAY**" using BS 5930, (British Standards Institute, 1999) and the water table was met at 4m below ground level.

- Peat occupies the low-lying areas around Clonbulloge. They have been extensively developed by Bord na Mona and has lead to the development of the Industrial Peat Series, known as the Clonast and Boora complexes. The original peat thickness was approximately 3-8 m, which has been altered, and only the basal peat layers are remaining, the thickness of which is variable, depending on the depth of the original organic profile and the underlying topography (Conroy, *et al*, 1970). In Ballydermot (on the eastern side of Clonbulloge) the peat thickness (after cultivation) is approximately 2-4 m (Hammond, R.F., 1968).
- Till with gravel is mapped to the north and north east of the spring. The reconnaissance work in Offaly has shown that many of the sand/gravel units are small and are interbedded with tills. In many places it is not possible to map out separately the sand/gravel units and the till units during a reconnaissance mapping project. This has led to the term "till with gravel" being employed to categorise the sediments over relatively large areas (Daly *et al*, 1998).
- Alluvium occupies zones along the Figile and Philipstown Rivers and occupies the immediate vicinity to the spring. The thickness of the alluvium varies from 0.3 m to 1.3 m (GSI Field notes). It is grey in colour with occasional yellow mottles. The areas mapped as alluvium coincide with the areas marked as areas "liable to flooding" on the archival six inch ordnance maps.
- In general, the subsoil thickness vary from 0 m (outcrop) to greater than 10 m. Shallow rock and outcrop occur in the higher relief areas, such as Cloncreen and Clonad. The deeper areas coincide with the areas covered by peat and along the river networks. The depth reached in the auger hole was 5.5m below ground level, where it is assumed that bedrock is present.

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 alluvium, till and till with gravel is classed as "**moderate** to **low**", and the permeability of the peat "**low**".
- Depth to bedrock varies from being 5.5 m near the source to less than 1 m to the west of the source.
- The groundwater vulnerability is classed as "**moderate**" to "**high**", as shown in Figure 4 with the "**moderate**" area to west of the spring, while the area to the east and north of the spring is mainly "**high**".

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

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:

- Offaly Groundwater Protection Scheme (Daly *et al,* 1998).
- GSI files and archival Offaly County Council data.
- Offaly County Council drinking water returns.
- County Council personnel.
- Hydrogeological mapping carried out by GSI.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability May 2003.

8.1 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 Clonbulloge, 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: 825 mm.
Rainfall data for gauging stations around Clonbulloge is given in the table below (from Fitzgerald, D., Forrestal., F., 1996).

Gauging Stations	**Grid reference**	**Elevation OD (m)**	**Approximate distance & direction from source**	**Annual precipitation 1961-1990**
Clonast	N535160	73	5 km south west	800 mm
Edenderry	N644316	81	10 km north	853 mm

The contoured data map for the Offaly Groundwater Protection Scheme (Daly *et al*, 1998) show that the spring is located approximately at the 825 mm average annual rainfall isohyet.

Annual evapotranspiration losses: 450 mm.
Potential evapotranspiration (P.E.) is estimated to be 475 mm $yr.^{-1}$ (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E., to allow for seasonal soil moisture deficits.

Effective Rainfall: 375 mm.
The effective rainfall is calculated by subtracting actual evapotranspiration from rainfall.

Recharge coefficient: 55%.
Recharge is expected to be relatively low across the area due to low and moderate permeability subsoils and relatively impermeable bedrock. Thus, a representative value for the recharge coefficient is estimated to be in the order of 55%.

The calculations are summarised as follows:

Average annual rainfall (R)	825 mm
estimated P.E.	475 mm
estimated A.E. (95% of P.E.)	450 mm
effective rainfall	375 mm
recharge coefficient	55%
Recharge	**200 mm**

8.2 Groundwater Levels, Flow Directions and Gradients

Water level data are poor for the area. An important feature is that the water level in the river is approximately 0.7 m lower than the spring level despite the fact the Philipstown River is only 2 m distant. The spring overflows to the river when the pumps are turned off and during pumping the water level is approximately equal to the river level.

The water table was met at 4 m below ground in the auger hole drilled beside the spring. Water levels in the wells in the area and the rivers in the area, such as the Figile, Philipstown are, in general, assumed to represent true groundwater levels. However, Clonbulloge spring is artesian, as the groundwater issuing from the spring is confined.

The spring is located on the eastern side of the Figile, thus groundwater issuing at the spring is most likely to be coming from a northerly direction.

Groundwater gradients cannot be estimated from the available data but are generally assumed to be less than the topographic gradient. Gradients in the Calp are in the order of 0.01, which is less than the topographic gradient in the vicinity of the spring, and is used in later sections in the report.

8.3 Hydrochemistry and water quality

Data on trends in water quality are summarised graphically in Figure 3. The following key points are identified from the data.

- The temperature of the groundwater issuing from the spring is almost 15^{o}C (measured field values are given in Table 1), which is considered to be warm for a typical Irish spring, as warm springs are considered to have a mean temperature of equal to or greater than thirteen degrees (Burdon, 1983). A geothermal project carried out in the early 1980s, characterised the warm springs of Ireland. Thirteen warm springs are located and reported on in Leinster (Burdon, 1983). The Clonbulloge spring was not investigated as part of the project as it was found after the investigations had been concluded. It is situated relatively close to the other warm springs of Leinster, one of which is located at Toberdaly [GSI Well number 2323SEW002] and in a similar hydrogeological setting.
- The water is "hard" with an average total hardness of 290 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 485-596 µS cm^{-1}. These values are typical of groundwater from limestone rocks and typical of groundwater across Co. Offaly (Cronin, 1999). As would be expected, pH of the groundwater is generally neutral (an average of 7.2).
- Nitrate concentrations in available samples from the last 20 years range 9-15 mg l^{-1} (average is 11 mg l^{-1}). There are no reported exceedances above the EU Drinking Water Directive maximum admissible concentration of 50 mg l^{-1}. A slight upward trend is identified 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 (Daly, 1996). Chloride data range from 13-24 mg l^{-1} (average (17 mg l^{-1}), and there is no trend in the data.
- There are no raw water analyses available for inspection. There are two reported detections (18/1/1993 and 22/1/1993) of *E.coli* in the treated water analyses. It is likely that these two detections were caused by the same contamination event. Ammonia levels have never exceeded the GSI threshold.
- In summary, apart from possibly one isolated incident of faecal contamination (which may be attributable to poor well head protection), it would appear that there is no significant contamination at the source. The chemistry and quality suggest that the water at the spring is a mixture of shallow and deep groundwater. The elevated temperatures suggest a deep groundwater component. The nitrates, chlorides and the lack of mineralisation indicate a shallow component.

Table 1 Temperature Data For Clonbullogge Spring

Date	Water Temperature °C	Air Temperature °C	River Temperature °C
4/2/1986 GSI	14.8	6.5	?
10/3/1986 GSI	14.9	2.5	?
29/1/2003 GSI	14.6	?	5.0

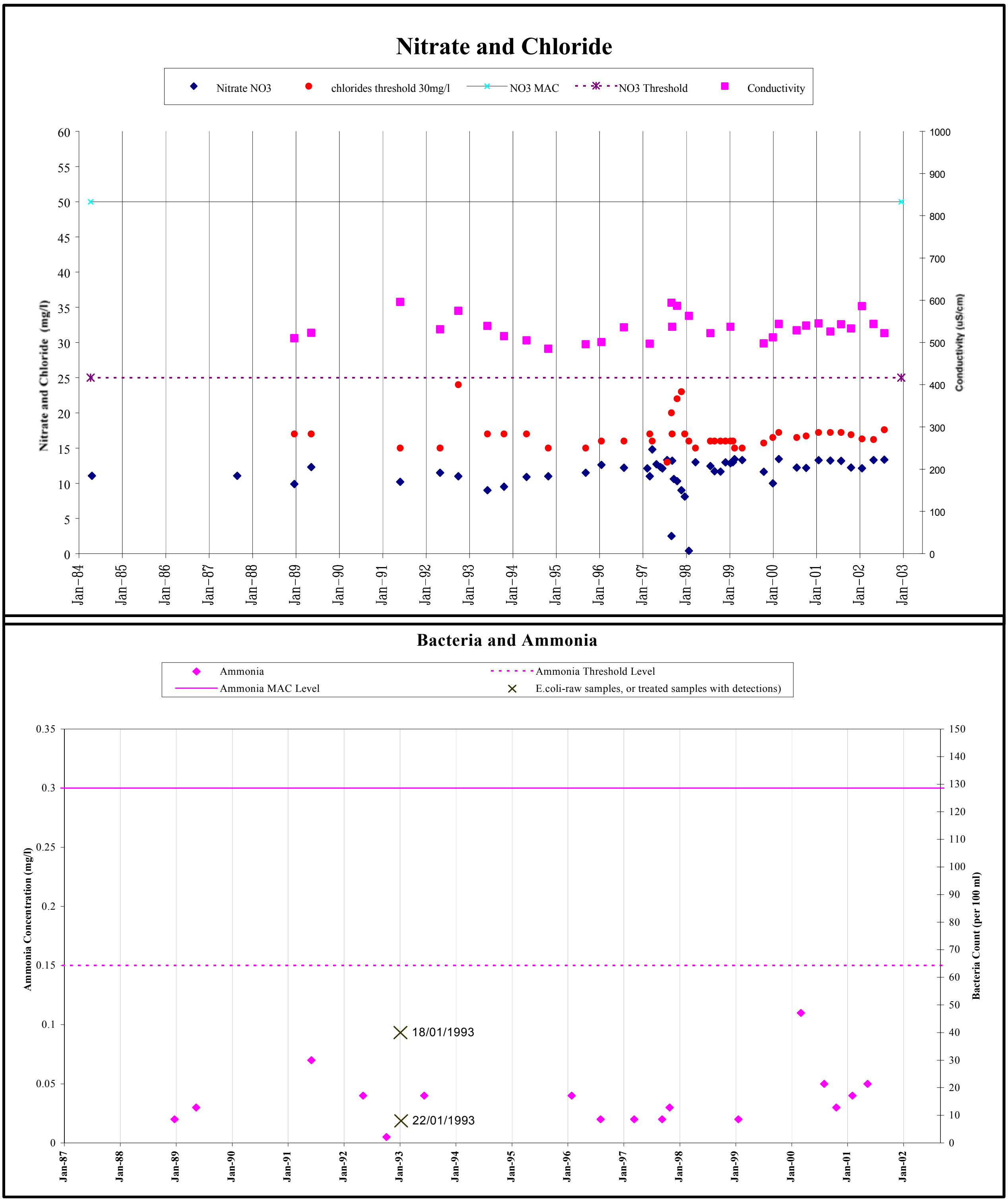

Figure 3 Key Indicators of agricultural and domestic groundwater contamination at Spring

8.4 Aquifer Characteristics

The spring issues from the Upper Impure Bedded Limestone in the vicinity of a NE-SW trending fault. There are no outcrops around the spring, thus there is a possibility that the fault could actually be at the spring. It is considered that most of the groundwater is coming from a northerly and northeasterly direction, from the townland of Ballinowlart North. The fault passes through this area.

The Upper Impure Bedded Limestone generally has poor potential for water storage and abstraction and is classified in this region as a **Locally Important** aquifer which is **moderately productive** only in **local zones (Ll)**. Groundwater flow tends to be concentrated in the upper fractured and weathered zone, along fractured fault zones and in more permeable beds. Consequently, groundwater throughput is low and groundwater circulation is shallow and localised, often with short flow paths (Daly et al, 1998). There is a slight possibility that recharge in higher relief areas, for example at Cloncreen, located on the Pure Bedded Limestone, could also enter the fault zone and reach the spring.

The assumed conventional groundwater flow system is that recharge to the Upper Impure Bedded Limestone is quickly fed back into the surface system; however, it is likely that a proportion of recharge reaches the fault, enters a deeper flow system before returning to the surface at the spring. It is likely that a major fracture system in the vicinity of the spring allows groundwater to circulate to depths deeper than is normal, which could account for the warmer temperatures observed. Burdon (1983) suggests that geothermal springs appear to be situated in the vicinity of major faults, and has estimated that the groundwater reaches depths of 500-800 m.

For the purposes of calculating the groundwater velocity, the permeability is estimated to be approximately 0.5 m d^{-1}, based on data for the Upper Impure Bedded Limestone in Co. Offaly; and effective porosity is estimated to be approximately 0.01 (1 %). However, the velocity of groundwater approaching the spring is likely to increase, as a relatively large amount of water discharges through a narrow area. Thus, the permeability in the immediate vicinity of the spring, presumably along the fault network is likely to be higher than the general permeability of the Upper Impure Bedded Limestone. There are no data to quantify this permeability. Considering the high velocity at the spring, the permeability is assumed to be 2 m d^{-1} in the vicinity of the spring. As the groundwater comes through a narrow, relatively deep area in the subsoil, the gradient is assumed to be 0.01 in the vicinity of the spring.

Burdon (1983) concludes that the origin of water for all the warm springs in Ireland is rainfall. It would appear given the warm temperature of the spring and the location near a NE-SW trending fault that the Clonbulloge spring fits the characterisation (setting) of the other warm springs of Ireland, for example, Toberdaly.

The depth to rock in the vicinity of the spring is 5.5 m, the topography is low-lying and flat, the subsoils comprise till, peat and alluvium. It is unclear why precisely the spring issues where it does. It may be that the there is a increase in subsoil permeability at the spring, allowing groundwater reach the surface at that point. While there is some uncertainty about the source of the groundwater that issues from this spring, the evidence indicates that the groundwater is a mixture of deep and shallow water, generally derived from the groundwater flowing from the north, probably in association with the fault.

8.5 Spring Discharge

The total spring discharge (abstraction and overflow volumes) is not well characterised. There are no records of the overflow, although there are daily records of the abstraction quantity. The caretaker indicates in interviews that there is never an overflow when the pumps are turned on. The pumps were turned off and the water levels in the chamber recovered and an overflow was observed, however, it was not possible to measure it. The maximum abstraction of 510 m^3 d^{-1} indicates that the spring is an "**intermediate**" spring according to the GSI classification.

8.6 Conceptual Model

- Clonbulloge PWS abstracts approximately 320 m^3 d^{-1} from a warm spring that issues in the vicinity of a major fault between the Upper Impure Bedded Limestone and the Pure Bedded Limestone.
- The Upper Impure Bedded Limestone is classified as a **Locally Important** aquifer which is moderately productive only in local zones (**Ll**).
- A major NE-SW fault is mapped 200 m north of the spring, however, it is possible that the fault is at the spring. This fault is assumed to be the mechanism that allows deep groundwater circulation in the area that causes the increased temperatures observed at the spring.
- Groundwater flow is assumed to be from the north and north east, along the direction of the fault.
- A "window" in the subsoils, perhaps due to the presence of a localised sand/gravel unit, in association with the fault network, may have allowed groundwater to reach the surface at the spring.
- The chemistry and quality indicate that the groundwater at the spring is a mixture of shallow and deep groundwater.
- The spring issues next to the Figile river, in a low-lying flat area, dominated by peat and alluvium, where the natural and artificial drainage density is high.
- Diffuse recharge occurs over the catchment and the annual average recharge is estimated to be 280 mm per year.

9 Delineation of Source Protection Areas

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 Figure 5 and 6.

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 spring.

9.1 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 the conceptual understanding of groundwater flow in the area.

The boundaries and the uncertainty associated with them are described as follows:

The **Northern**, **Eastern** and **Western boundaries** are all based on topography, as the water table is expected to mirror topography. The fault passes through the middle of the area toward Ballinowlart north. A degree of uncertainty is associated with these boundaries, as the precise location of the fault is unknown. A surface water divide runs subparallel to the R401, running north through Clonbulloge. Groundwater to the west of the divide is assumed to flow southwest. The western boundary divides groundwater discharging to the Figile River and groundwater flowing to the spring. The boundaries come together in Ballinowlart North, which is the highest point upgradient of the spring.

The **Southern boundary**: It is assumed that groundwater cannot flow upgradient to the spring, or in this instance from the other side of the river.

The area delineated above is approximately 0.9 km^2. As a cross check, a water balance was used to estimate the recharge area required to supply groundwater to the source. Assuming an annual recharge of 200 mm, a recharge area of approximately 0.9 km^2 is required to provide enough groundwater to supply 500 m^3d^{-1}.

9.2 Inner Protection Area

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area (SI) is required to protect the source from microbial contamination and it is based on the 100-day time of travel (ToT) to the supply.

Estimations of the extent of this area are done by using Darcy's Law, which can be used to estimate groundwater velocities.

Velocity = (gradient x permeability) ÷ porosity

Using the estimated values for permeability, gradient and porosity in the vicinity of the spring (2 m d^{-1}, 0.01, 1%, respectively), the calculated velocity is 2 m d^{-1}. Accordingly, the boundary of the inner protection area (SI) is 200 m from the spring on the upgradient side.

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.

Three groundwater protection zones are present around the source as illustrated in Table 2. The final groundwater protection zones are shown in Figure 6.

Table 2 Matrix of Source Protection Zones at Clonbulloge

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

11 Potential Pollution Sources

Land use in the area is described in Section 5. Agricultural activities and septic tanks are the principal hazards to the water quality in the area. The main potential sources of pollution within the ZOC are the village, farmyards, septic tank systems, landspreading of organic and inorganic fertilisers.

12 Conclusions and Recommendations

- The source at Clonbulloge is an "**intermediate**" warm spring located in the Upper Impure Bedded Limestone - a **locally important** aquifer which is **moderately** productive only in **local zones** (**Ll**).

- A major fault occurs 200 m west of the spring and it is assumed that some of the groundwater reaching the surface at the spring is associated with the fault network. However, most of the groundwater is recharged to the aquifer in the higher areas to the north of the source.

- The groundwater feeding the source is moderately to highly vulnerable to contamination.

- Available data suggests that there is no significant contamination at the source, however there are isolated incidents of faecal bacteria.

- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. There is a high level of uncertainty with some of the boundaries. Reducing the level of uncertainty would require a drilling and, possibly, a geophysical programme to be undertaken. In view of the pressure magnitude in the area, this is probably not needed at present.

- The well head protection is poor, as there is no fence or wall around the spring itself, the manhole cover is relatively easy to move and there are cracks in the concrete walls of the spring chamber, therefore, the spring is susceptible to contamination or vandalism at the well head. There is also a risk of possible flooding at the well head.

- It is recommended that:
  1. Well head protection is improved.
  2. The potential hazards in the ZOC should be located and assessed.
  3. A full chemical and bacteriological analysis of the **raw** water is carried out on a regular basis. In addition, "spot" temperature reading should be recorded to increase the data on the high temperatures at the spring.
  4. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well.

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Appendix 1 Log of auger hole.

Auger 1. 40 m from the spring.
Grid reference 260756 223666

0-5.5 m Till: Black/grey. Angular fragments (0.2 m) BS: 5930: SILT
5.5 m End of Hole. Refusal, assumed to be bedrock.
Water table approximately 4 m below ground level.

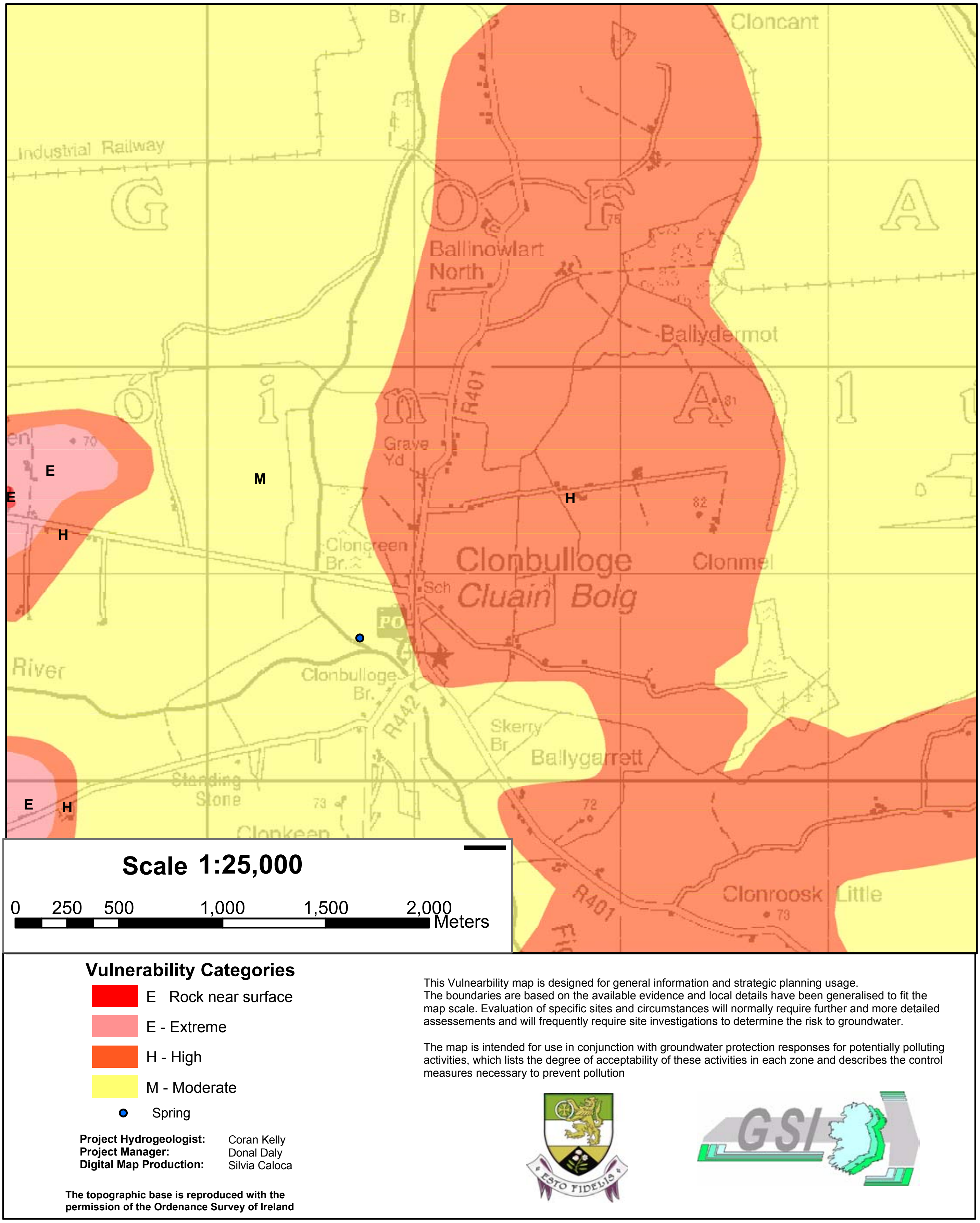

Figure 4 Vulnerability around Clonbulloge

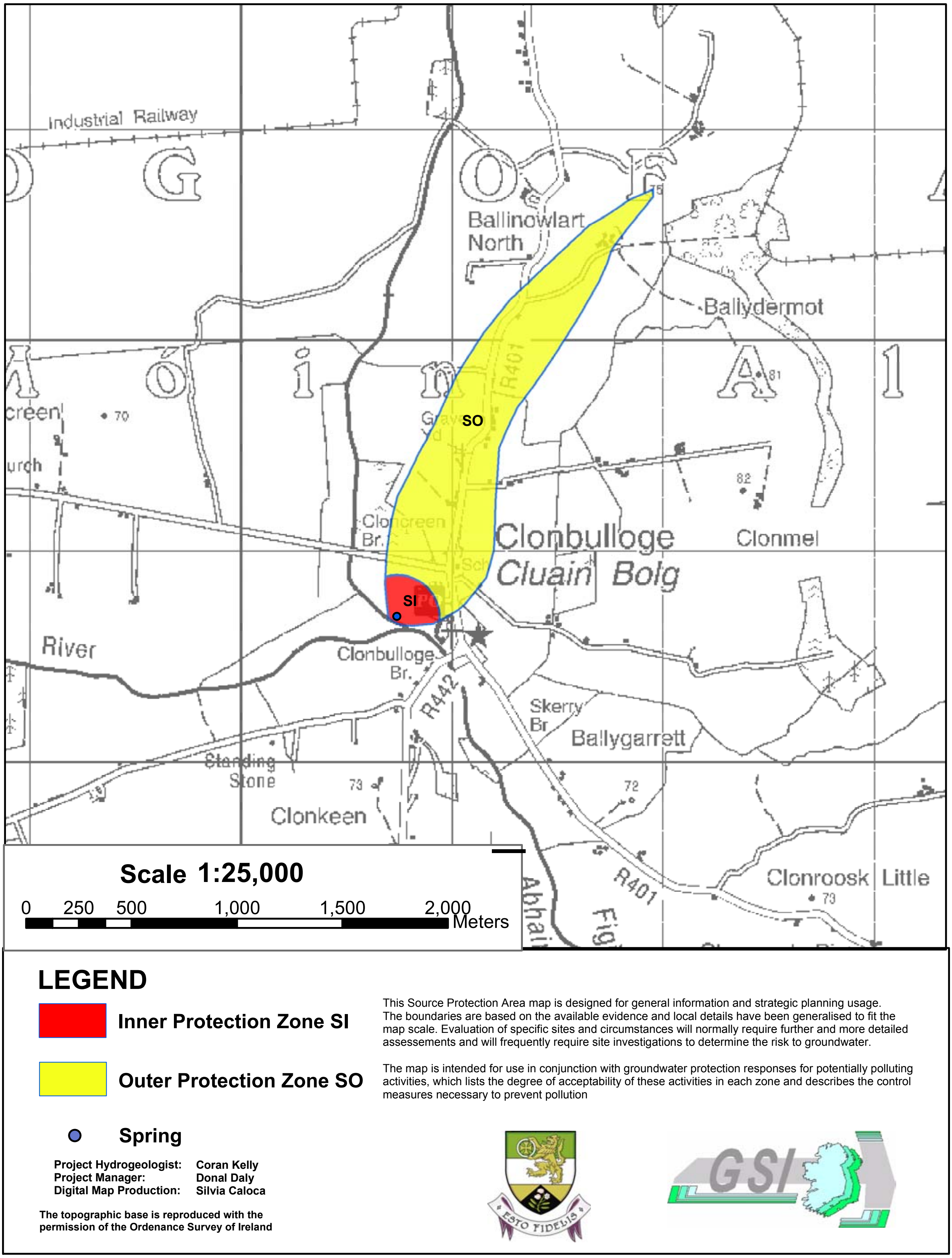

Figure 5 Source Protection Areas for Clonbulloge spring

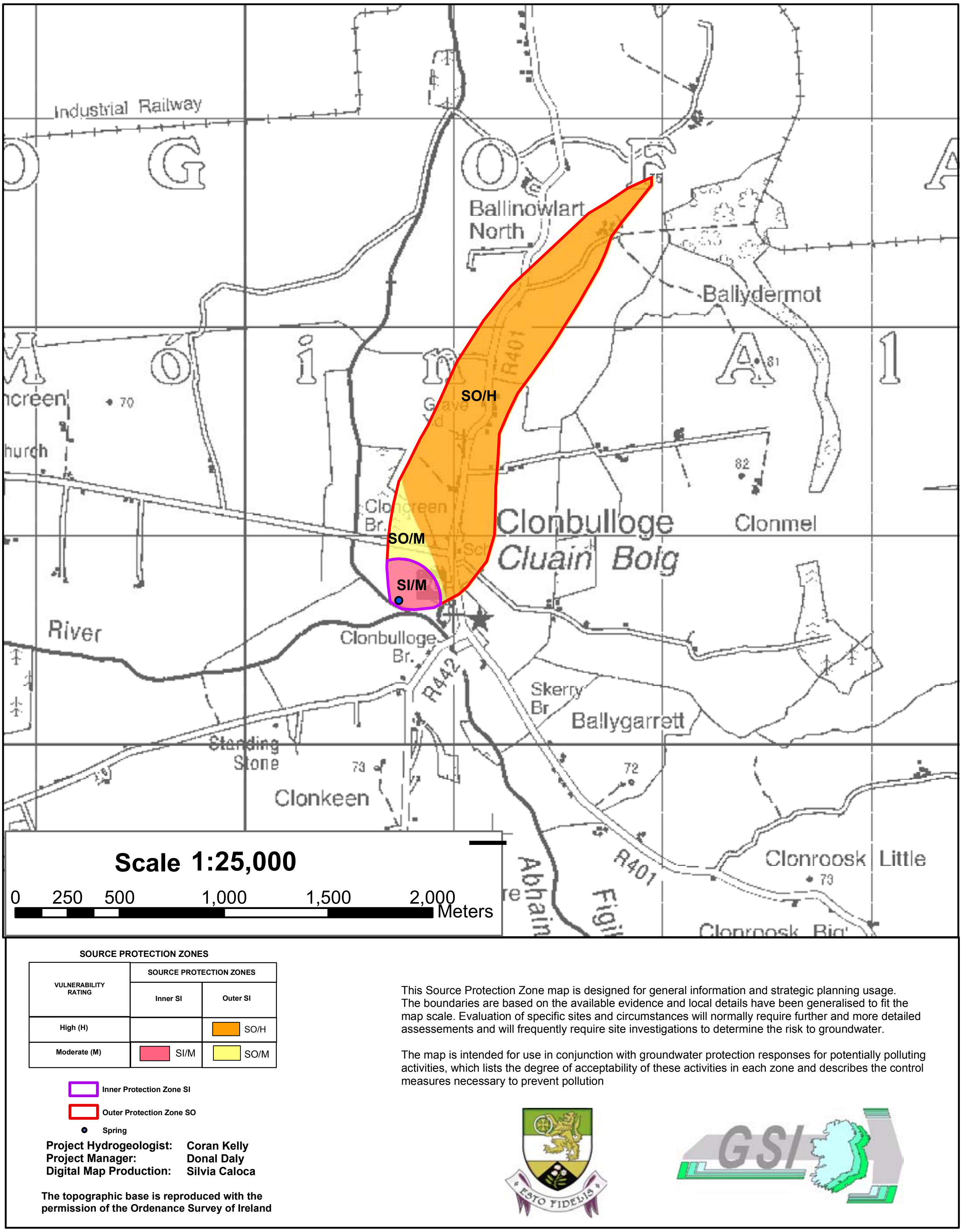

Figure 6 Source Protection Zones for Clonbulloge spring