Aglish Water Supply Scheme

Groundwater Source Protection Zones

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In collaboration with:

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1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Aglish Water Supply Scheme source.
- To outline the principal hydrogeological characteristics of the area.
- To assist North Tipperary County Council in protecting the water supply from contamination.

2. Location and Site Description

The site is situated about 3 km southeast of Aglish village, in the townland of Lisbryan. The well head consists of a 7 m diameter concrete chamber set on crushed rock. The source is fenced off, but the fence is broken in places through which cows were seen to gain access. Cows graze the fields immediately around the source. The nearest farm is approximately 250 m away.

The water is chlorinated.

3. Summary of Spring Details

GSI no.	1719SEW062
Grid ref. (1:25,000)	19571 19724
Townland	Lisbryan
Owner	North Tipperary County Council
Well type	Spring
Elevation (top of housing)	65.42 m OD
Depth	4 m
Diameter	7 m
Depth-to-rock	about 6 m
Static water level	63.6 m OD
Hours pumped per day	7 – 8
Pumping rate	514 – 529 m^3/d
Daily Abstraction	150 – 154 m^3/d

4. Methodology

Desk study

Bedrock geology information was compiled from Brück (1985); soil information was derived from Finch and Gardiner (1993). Basic public supply source details were obtained from GSI records and County Council personnel; such details include spring chamber depth, elevation, abstraction rate, pumping duration details.

Site visits and fieldwork

The second stage of investigation comprised site visits and fieldwork in the area. This included a walkover survey in order to further investigate the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and potential hazards. Water samples taken were analysed in the State Laboratory. Three auger holes were bored in the area to ascertain the depth to bedrock.

Data analysis

The assessment stage utilised analytical equations and hydrogeological mapping to delineate protection zones around the public supply well.

5. Topography and Surface Water Hydrology

The Aglish supply is a spring that emerges in low-lying ground in a boggy pasture area. Overflow from the spring feeds a small stream. Four hills lie to the northwest, north, northeast and east. Topographic relief is on the order of 15-25 m, with surface gradients ranging between 0.006 and 0.016. The steepest gradient is off the eastern hill.

Several seeps rise in an otherwise dry culvert about 30 m to the south and east of the source. The base of the culvert at the spring points is about 2–2.5 m below the source pump house floor. These springs feed into the same stream as the source overflow.

Uphill from the WSS spring, about 1000 m to the southeast, a second spring rises in a turlough that is pumped during winter into a concrete-lined culvert that terminates and drains into the ground just uphill of the WSS spring. A further 350 m southeast of the pumped turlough is a second turlough, which may or may not be in hydraulic connection with the first.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises limestone sediments of Carboniferous age (Tournasian–Visean; about 330 million years old) which were subsequently folded and faulted. The rock units of the area, which are shown in Figure 1, are summarised in Table 1.

Table 1: The bedrock geology in the vicinity of the Aglish Spring WSS.

Rock Formation	Rock Material	Thickness	Occurrence
Borrisokane Calcarenite Formation (BK)	Clean limestone: a pale grey, coarse (occasionally medium-grained), well-sorted calcarenite (carbonate sand).	120 m	Underlies the source and forms the core of the Borrisokane syncline.
Slevoir Limestone-Shale Formation (SV)	Muddy limestone: comprised of dark grey, homogenous argillaceous limestones and calcareous shales.	~260 m	Occupies the area to the south west of the spring and underlies the Borrisokane Calcarenite Formation.
Lismaline Micrite Formation (LM)	Clean limestone: a homogenous medium grey micrite (carbonate mud).	40 m	Occurs to the south-west of the spring, approximately 2km away.
Terryglass Calcarenite Formation (TS)	Clean limestone: a grey, thick-bedded and well-sorted calcarenite.	Up to 200 m	Has a faulted contact with BK Formation and occurs to the east and south east of the spring.
Waulsortian Limestone (WA)	Clean limestone: massive, unbedded micrite.	200 – 300 m	Has a faulted contact with BK Formation and occurs to the east and northeast of the spring.

6.1.1 Geological Structure

The spring occurs in the Borrisokane Calcarenite Formation on the east limb of a major NE-SW trending fold, the Borrisokane Syncline. Bedding dips in the immediate vicinity are gentle (5-15^{o}) and generally to the west. Approximately 150 m to the east of the source is a major NE-SW trending fault that juxtaposes the Borrisokane Calcarenite Formation against the Waulsortian and Terryglass Limestone formations.

6.2 Subsoils (Quaternary) Geology

The subsoils in the area comprise a mixture of fine and coarser-grained deposits: till and peat. The spring itself occurs within a gravelly till, very close to the boundary between the peat and till. The till is directly influenced by the underlying bedrock, which is limestone. The characteristics of each category are described briefly below.

6.2.1 Peat

Peat occupies the lower-lying, boggy areas to the southwest of the spring. The visible layer of peat is black, crumbly and has the appearance of being a very rich and fertile soil. Teagasc (1993) assess that the peat has a fen origin, which implies a high water table. The peat has low permeability.

6.2.2 Limestone Till

Auger hole drilling by GSI determined the glacial till subsoils to the east of the Aglish spring to be variously gravelly and silt/clay (Figure 3). Teagasc (1993) assign most of the overlying topsoils in this area to the 'Patrickswell Series'. This soil type is characteristically well drained, which implies at least a moderately permeable subsoil.

6.3 Depth-to-rock

The depth to rock is known at selected localities from a drilling programme undertaken for this study by GSI to ascertain the thickness and type of the subsoils. The locations of the three auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Depths to bedrock range from 5.5 to 6.5 m.

7. Hydrogeology

7.1 Data availability

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

- Hydrogeology

    Data such as flows, and water levels in the spring and local boreholes were gained from Co. Co. personnel, and collected by the GSI as part of this study.

- Hydrochemistry/water quality

    GSI targeted sampling (August 2000)
    EPA (March 1997 and in preparation)
    County Council analyses of public supplies (1984 – 2000)
    EC STRIDE Sub-programme Measure 1 (September 1993)

The hydrochemical data are summarised fully in the accompanying report "An assessment of the quality of public, group scheme and private groundwater supplies in North County Tipperary".

7.2 Rainfall and Recharge

Rainfall data for the area were obtained from Met Éireann. The mean annual rainfall (R) for the area (1961-90) was 919 mm/yr (the value for Borrisokane was used). Potential Evaporation (PE) is estimated from Met Éireann's national contoured map as 450 mm/yr. Actual evapotranspiration (AE), estimated by taking 90% of the potential figure to allow for soil moisture deficits, is 405 mm/yr. Using these figures, the potential recharge (R–AE) is 514 mm. Runoff is assumed to be 50% of available recharge, i.e. 257 mm. This assumption, from Wright *et al.* (1983), is an empirical standard used in GSI for moderately permeable subsoils of the sandy till type which dominate the area uphill of the site. These calculations are summarised below:

Average rainfall(R) 919 mm/yr

Estimated P.E.	450 mm/yr
Estimated A.E. (90% P.E.)	405 mm/yr
Potential recharge (R–AE)	514 mm/yr
Surface Runoff	257 mm/yr
Recharge	257 mm/yr

7.3 Groundwater levels

Water level data are sparse in this area. The level of the water in the cased chamber is 63.6 m OD. Water was encountered at a maximum of 3.5 mbgl in gravel subsoils in the trial borehole approximately 15m from the spring (TNAG2, Figure 3).

Water levels in the springs in the adjacent dry channel (about 63.4 m OD; GR 19574, 19718), the turlough 1000 m away (approximately 71 m OD; GR 19666,19672) and its adjacent turlough (approximately 77.7 m OD; GR 19685, 19640) are assumed to represent true groundwater levels, either seasonal or more permanent.

There are few surface drainage features uphill (north and east) from the source. Already mentioned is the drainage culvert leading from the second spring that is pumped into it. Into this culvert, another ditch drains from Ballingarry, although for much of its length (more than 800m away from the outflow on a dry day in November 2001), it is dry. The water table is close to ground surface southwest of the source, in the boggy area.

7.4 Groundwater Flow Directions and Gradients

The water table in the northeast of the source area is assumed to broadly reflect topography with groundwater locally flowing toward the southwest and discharging to the spring, beneath the bog and also into a stream to the south west of the spring. Absence of surface drainage or water features suggests that the static water level is relatively deep in the gentle hills surrounding the source, and that the natural groundwater gradient is around 0.008 (0.8%).

To the south and southwest of the source, the water table is very close to the surface, and surface drainage is partly directed to the northeast. This semi-enclosed basin drains to the east.

7.5 Hydrochemistry and Water Quality

Field measurements in June 2001 recorded an electrical conductivity of 629 µS/cm and a temperature of 10.3^{o}C. In November 2001, the corresponding measurements had values of EC = 689 µS/cm and T = 11.3 ^{o}C.

Results of laboratory analyses of water samples are presented in Appendix 1. Data that reflect water quality are shown graphically in Figure 4. The following key points are identified from the data:

- The groundwater samples have a calcium-bicarbonate (Ca - HCO_3) hydrochemical signature.
- Groundwater hardness ranges between 'hard' and 'excessively hard' (total hardness 335–385 mg/l as $CaCO_3$).
- Nitrate concentrations range widely from 7.8-35 mg/l, with an average concentration of 19.3 mg/l (6 samples) over the period February 1985 to August 2000. The GSI threshold of 25 mg/l was exceeded once in the sampling period. The results are representative of general nitrate contamination by both diffuse (spreading of inorganic fertiliser and slurry) and point sources (septic tank systems and farmyards) in this area of relatively intensive farming. There is no trend apparent in the data.
- Chloride concentrations range between 22.5 and 35 mg/l (4 samples). Chloride is a constituent of organic wastes and (away from coastal areas) levels higher than 30 mg/l usually indicate significant contamination. On three occasions (February 1984, February 1990, and September 1993), concentrations were 34 or 35 mg/l. Chloride concentrations appear to be decreasing over time.

- Bacteriological sampling indicates faecal contamination of the source on six occasions (out of seven) in the period November 1990 to August 2000. Three of the contaminated samples were raw, and the remaining three were treated, indicating that the chlorination process at the source has sometimes been inadequate.
- Two potassium:sodium (K:Na) ratios of 0.214 and 0.314 can be calculated from the available data. Even though the source is surrounded by pasture, these values suggestthat the bacterial contamination probably originates from septic tanks rather than silage, since contamination by silage is indicated by high K:Na ratios (values of about 10). The K:Na ratio is used to help indicate (along with other parameters) if water has been contaminated and may indicate contamination if the ratio is >0.4. To provide sufficient data to assess the source, it should be measured routinely in the future.
- High manganese levels have been reported to sometimes be a problem during the summer months, and concentrations exceed the EU Drinking Water Directive maximum admissible concentration (MAC) of 0.05 mg/l twice out of five samples (in July 1990 and August 2000). On the remaining three times the source was tested for manganese levels, concentrations were very close to or below the method detection limit (MDL) of 0.002 mg/l. Manganese is not detrimental to health at the recorded concentrations but is an aesthetic problem, since it can cause spotting and marking of laundry.

7.6 Aquifer Parameters

Since the source at Aglish is a spring, it was not possible to undertake a pumping test to determine aquifer parameters. Therefore, permeability and porosity measurements are established by parameter fitting to the Thiem steady state equation for steady state unconfined flow (Thiem, 1906 in Driscoll, 1986), combined with values used for the Borrisokane Calcarenite Formation in other areas. These values are summarised in Table 2.

Table 2: Estimated aquifer parameters for the rock units at Aglish WSS

Parameter	**Data source**	**Borrisokane Calcarenite Formation (BK) parameter values**
Permeability (in upper 7.5 m)	• estimated from parameter fitting to analytical equation, and informed by regional experience	10 m/d
Porosity		0.03
Hydraulic gradient	• estimated from topography and surface hydraulic features	0.008 (0.8%)

7.7 Aquifer Category

The Borrisokane Calcarenite Formation (BK), in which the spring occurs, is classified as a Regionally Important fractured aquifer (**Rf**). The Slevoir Limestone-Shale Formation (SV), which underlies the rock unit that contains the spring, and the Terryglass Calcarenite Formation (TS), which is adjacent to the spring and faulted against the BK Formation, are classified as '**Ll**' and '**Rf**' respectively.

7.8 Conceptual Model

- The Aglish spring is located at a topographic break in slope, on the boundary between glacial till subsoils covering gentle hills in the north west, east and south east (topographic relief of between 10 and 20m) and flat fenland peat bogs to the south west.
- The permeability of the limestone aquifer depends on the development of faults, fissures and fractures.

- These rock units are largely overlain by moderately permeable limestone till with gravel. The groundwater can, therefore, be considered as unconfined or semi-confined. In the vicinity of the spring, saturated gravels were met during GSI drilling (see TNAG2, Figure 3), indicating a source of extra groundwater storage.
- To the northeast of the source, the water table is assumed to reflect the topography of the area, with hills acting as recharge mounds and groundwater flowing from these high points to the discharge point (spring) and underneath the peat bog. The groundwater gradient is approximately 0.008 (0.8%), with groundwater flowing to the southwest.
- West and southwest of the source, the water table is close to ground level causing the development of a peat bog.
- The groundwater level varies seasonally in the vicinity of the spring, as shown by movement of the spring points in the drainage culvert. The observed lateral shift in the spring point (between June [high] and November 2001 [low]) is about 130m, corresponding to a change in elevation of roughly 1 m.
- High manganese levels sometimes encountered during summer months indicate that, during times of low water level, the spring is partly taking water from the peat bog.

8. Delineation of Source Protection Areas

8.1 Introduction

Two source protection areas are delineated:

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

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 delineated as the area required to support the spring flow from long-term recharge. The ZOC is controlled primarily by (a) the spring flow (b) the recharge in the area. The ZOC is delineated as follows:

i) Topographic boundaries.

ii) An estimate of the area size obtained by using the average recharge and the spring flow rate.

Daily abstraction at the site is approximately 154 m^3/d (34,000 gallons) over a pumping duration of 7-8 hours. The overflow volume from the spring (i.e. excess that is not pumped) could not be assessed. The instantaneous pumping rate, assuming a pumping duration of 7 hours, is 528 m^3/d. It can be assumed that the average flow is somewhat higher than the reliable minimum flow.

Taking the annual recharge to be 257 mm as indicated in Section 7.2, the area required to supply an average flow of 528 m^3/d (the pumping rate) is calculated to be 0.82 km^2 (82 ha). This area compares with an area of 1.58 km^2 (158 ha) estimated from topographic considerations. It can therefore be estimated that the average flow is of the order of 1000 m^3/d (11.5 litres/second).

The boundaries of the ZOC are illustrated on Figure 1 and are delineated as follows:

Western boundary: skirts the edge of the bog and runs north-northwest from a few metres south of the spring area to a topographic high at approximately 79 m aOD.

Northeast Boundary: defined by the line between two topographic highs of 79 m and 91 m, it runs from northwest to southeast, crossing the saddle between the hills at right angles to the contours.

Southern Boundary: runs almost due west from the topographic high at 91 m OD near to Lisbryan House to just south of the spring. It encompasses the farm about 300 m to the east of the spring.

These boundaries are based largely on topography and surface drainage patterns, our current understanding of groundwater conditions in the area and on the available data.

8.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) from a point below the water table to the source. It is delineated to protect from potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination (Figure 1). The 100-day ToT is estimated as follows:

Taking the permeability as 10 m/d, Effective Porosity as 0.03, and natural hydraulic gradient as 0.008, and using the Thiem steady state equation (Thiem, 1906 *in* Driscoll, 1986), the 100 day ToT is estimated as about 470 m. Appendix 2 gives details of the methodology.

The Inner Protection Area covers about 0.32 km^2 (32 ha), about 20 % of the ZOC.

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. It 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 (DoELG/EPA/GSI, 1999).

Areas of rock outcrop and where rock is less than 3 m from the surface are rated 'Extreme' vulnerability. Where subsoils are greater than 3m thick, aquifer vulnerability ranges between 'Low' and 'High', depending upon the subsoil permeability. As this is an interim study, a distinction is made only between Extreme and other vulnerability categories. Since the subsoil thickness appears not to exceed 10 m, no 'Low' vulnerability areas are believed to occur.

The groundwater vulnerability in the area is considered to be 'High to Moderate' for much of the area, and 'Extreme' in limited parts (for example, along the unlined part of the culvert). Vulnerability of groundwater in the Aglish area is shown in Figure 5.

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), i.e. by superimposing the vulnerability map on the source protection area map. Since this is an Interim GWPS, in which only the extremely vulnerable areas are delineated, there are a total of only four possible source protection zones (Table 3). Each zone is represented by a code e.g. **SO/E**, which represents an Outer Source Protection area where the groundwater is extremely vulnerable to contamination. There are three groundwater protection zones present around the Aglish source, as shown in Figure 6 and Table 3.

Table 3: Matrix of Source Protection Zones

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

11. Land Use and Potential Pollution Sources

The spring lies in very poor, boggy pastureland. Livestock grazing the adjacent land drink from the stream immediately beside the spring, and dung accumulates around the source, despite the fencing. Agriculture is the principal activity in the area. Other hazards include farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides, and possible spillages along the roads. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The spring is fed from the Borrisokane Calcarenite Formation, a regionally important fissured limestone aquifer (**Rf**).
- The area around the supply has both 'High-Moderate' and 'Extreme' vulnerability to contamination.
- The inner and outer 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.
- To this end, it is recommended that the V-notch weir that is present at the site is fitted and monitored daily. This would allow the measurement of the true spring flow rate and enable better constraint of the source ZOC.
- Chemical and bacteriological analyses of raw water rather than treated water should be carried out on a regular basis (every 3 – 6 months).
- A strategy should be established and implemented to minimise the risk of faecal bacteria entering the groundwater in the source protection zone. From site visits, the origin of the bacteria could well be from grazing animals.
- Guidelines should be drawn up for dealing with spillages along the roads in the area, especially along the part of the road that is adjacent to the culvert (at the top of the road leading from Ballylina East), and 1 km from the source along the road towards Ballingarry.

13. References

Brück, P.M. (1985) *The Geology of the Country between Slieve Aughty, the Silvermines-Devilsbit Mountains and Slieve Bloom, Central Ireland*. Department of Geology, University College Cork, Occasional Report Series RS 85/12.

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Driscoll, F. (1986) *Groundwater and Wells* (2nd Ed). Johnson Filtration Systems, Minn., USA. 1089pp.

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Hunter Williams, N. & Wright, G.R. (2001) *An assessment of the quality of public, group scheme and private groundwater supplies in North County Tipperary*. Geological Survey of Ireland.

Wright, G.R. *et al.* (1983) *Groundwater resources of the Republic of Ireland.* Report to the Commission of the European Community.

Figure 1: Bedrock geology in the Aglish area. Based on Brück (1985).

Fig 2 – location map

Fig 3 - driller logs

Fig 4 - chemistry

Fig 5 -ZOC and TOT map

Fig 6 – vulnerability map

Fig 7 – source PZ

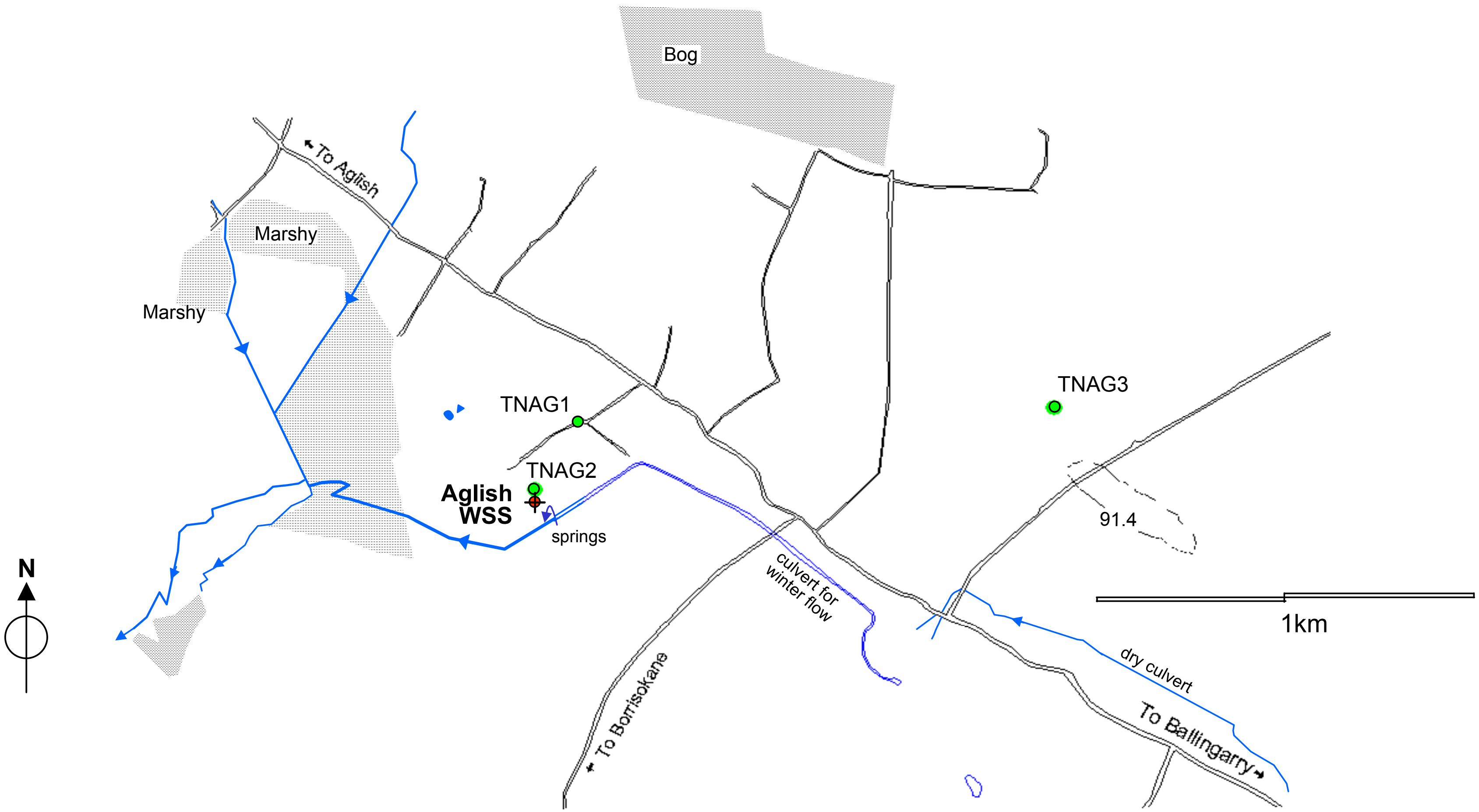
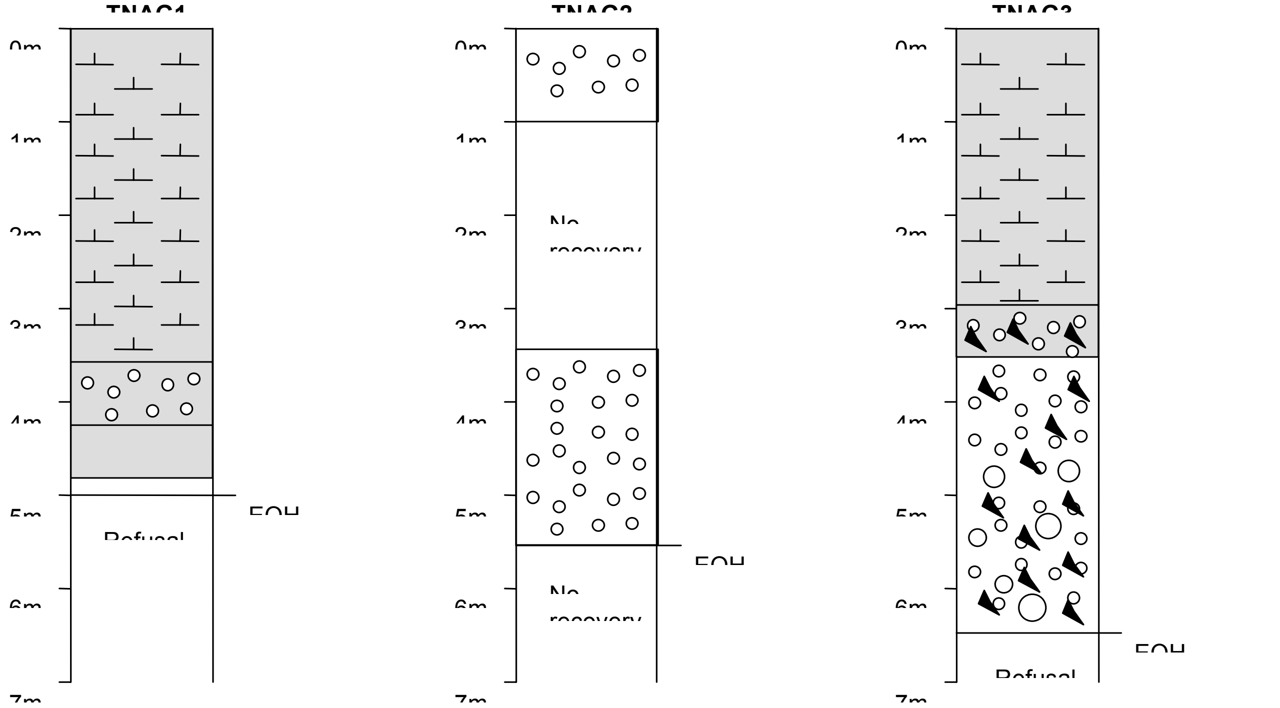


Figure 2: Location map of Aglish WSS spring
Showing auger holes drilled by GSI to determine depth to bedrock nearby (TNAG1 to TNAG3) and other hydrogeological features discussed in the text.



TNAC1

GSI hole name: 1719SEW054

1m SILT/CLAY

2m SILT/CLAY

3m SILT/CLAY

3.5m CLAY with some Gravel

4.0m CLAY with some Gravel

4.2m CLAY

4.8m Less Dense Drilling

5.0m REFUSAL

TNAC2

GSI hole name: 1719SEW055

1.0m GRAVEL

2.0m No Recovery

3.0m No Recovery

3.5m WET GRAVEL

5.5m EOH no Recovery

Wet gravel from 3.5m

TNAC3

GSI hole name: 1719SEW056

1.0m Grey/Brown SILT/CLAY

2.0m Grey/Brown SILT/CLAY

3.0m Black Rock fragments with some gravelly CLAY

3.5m Angular Rock Fragments and some GRAVEL

4.0m Angular Rock Fragments & some GRAVEL up to 50mm

6.5m REFUSAL

Hole dry all the way

Figure 3: Summary logs and lithological descriptions of auger holes drilled to assess depth to bedrock near Aglish spring.
See Figure 2 for the locations of the auger holes.

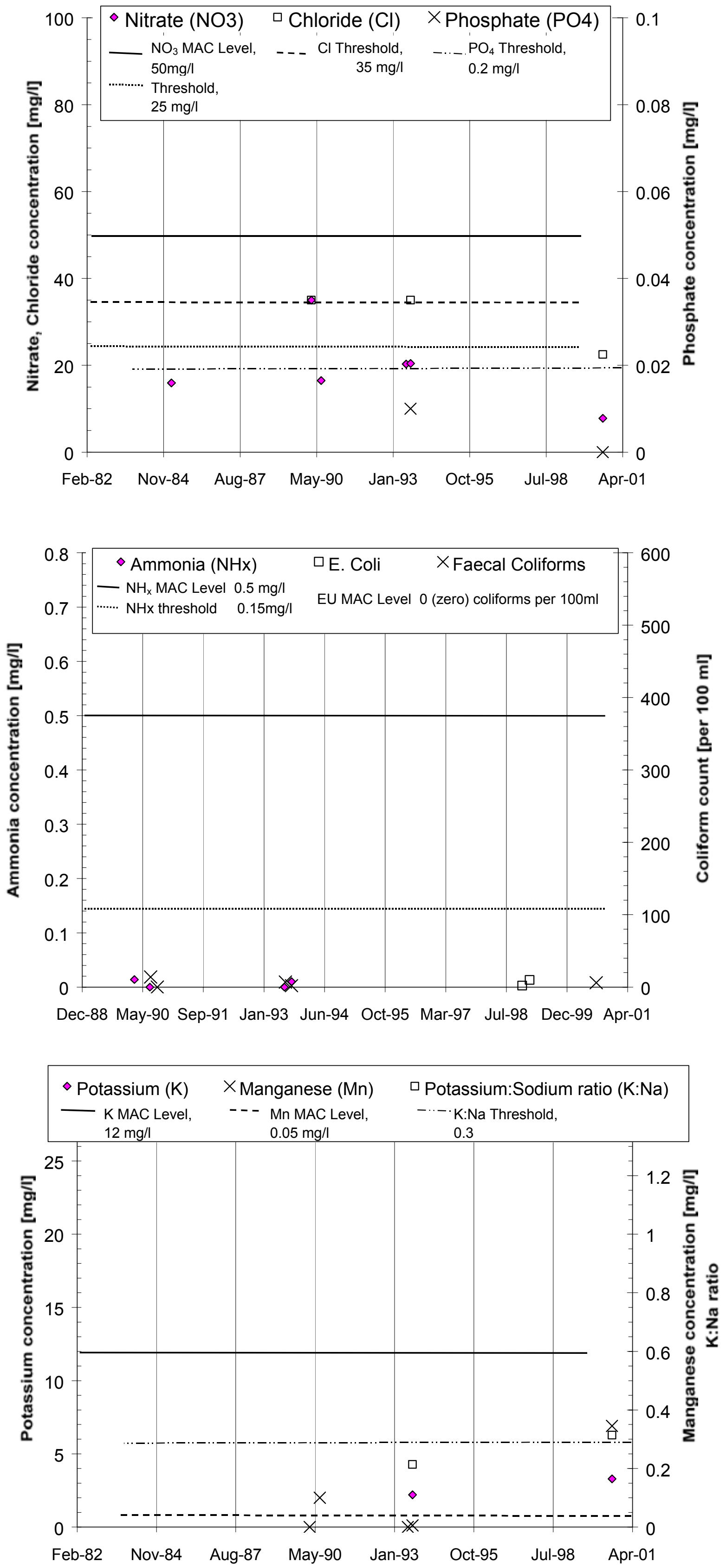


Figure 4: Key indicators of agricultural and domestic groundwater contamination at Aglish spring

Appendix 1: Laboratory Analyses of Groundwater at Aglish WSS

Parameter	**Results of Laboratory Analyses**															
Laboratory	State Lab.		North Tipperary Co.Co.							Regional Water Lab	Tipp (NR) Co.Co.				Tipp (NR) Co.Co.	State Lab
Sample treatment		-	-	-	NS	NS?	S	-	NS?	S	S	NS	NS	NS	NS	S
Date	24/02/84	25/02/85	26/02/90	04/07/90	11/07/90	24/07/90	04/09/90	19/07/93	27/07/93	15/09/93	03/08/94	19/04/95	01/12/98	01/02/99	09/02/99	03/08/00
EC (µS/cm)				736				740		711						752
TDS (mg/l)	403															
pH (lab.)	7.3		7.4	7.7				7.07		7.4						
Total Hardness (mg/l $CaCO_3$)	322		335							384.2						346.825
Total Alkalinity (mg/l $CaCO_3$)	282		292							296						354
Calcium (mg/l)	174.8									122						115.73
Magnesium (mg.l)	8.75									19						13.8
Chloride (mg/l)	*34*		*35*							*35*						22.5
Sulphate (mg/l)	1.0		22							< MDL						11.4
Sodium (mg/l)	8.3									10.3						10.5
Potassium (mg/l)	2.8									2.2						3.3
K:Na	0.34									0.21						0.31
Nitrate (mg/l NO_3)	15.72	15.94	*35*	16.5				20.3		20.4						7.8
Iron (mg/l)	< MDL		0.1	< MDL				< MDL		0.019						0.013
Manganese (mg/l)			< MDL	**0.1**				< MDL		0.006						**0.345**
E/F coli per 100 ml.				**14**		0		**7**	**2**				**2**	**10**		**6**
Total *coli* /100ml					14		0		7	2	8		6	11		46
Total Ammonia (mg/l NHx)	**0.784**		0.014	< MDL				< MDL		0.01						
Comments	Probably substantially contaminated. On-going monitoring should take place, especially of faecal bacteria, nitrate and chloride levels.															

Note: **Bold type denotes E.U. MAC exceedances.** *Italic type denotes GSI threshold exceedances* 'NS'/ 'S' denotes Non-source (treated) or Source (raw) water samples

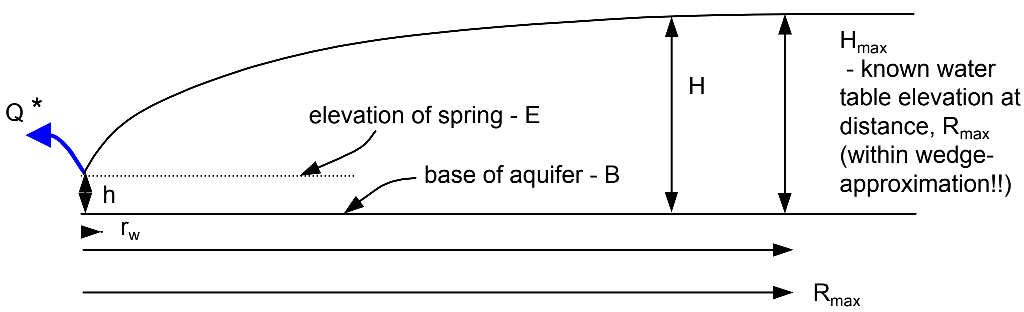
Appendix 2: Calculation of 100 day Time-of-Travel (TOT) to a spring by using the Thiem equation and approximating the zone of contribution (ZOC) to the spring by a wedge

The Thiem equation for unconfined flow is:

$$Q = \frac{1.366\ K\ (H^2 - h^2)}{\log_{10}(R/r_w)} \qquad \text{solving for H:} \qquad H = \sqrt{\frac{Q\ .\ \log_{10}(R/r_w)}{1.366\ .\ K} - h^2}$$

This equation is for radial flow to a well (i.e., flow from all sides around a cylinder), so the flow Q has to be multiplied by a factor to account for the wedge-like shape of a ZOC to a spring. This gives Q*.

In cross section, the water table has the following shape and the system is defined by these parameters:



Model parameters and predicted water table elevation at Aglish WSS

$Q^* =$ 1800 m^3/d (550 m^3/d x $110^o/360^o$)

K = 10 m/d, effective porosity = 0.03

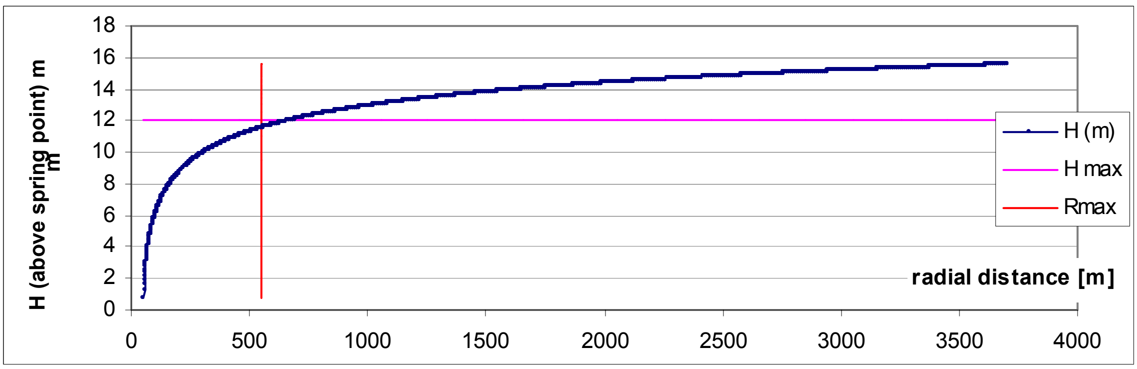
r_w = 20 m

R_{max} = 550 m; H_{max} = 70 m (average groundwater gradient of 0.008)

E = 65.42 m (the elevation of the spring);

B = 57.92 m (the base of the effectively flowing aquifer at the spring)

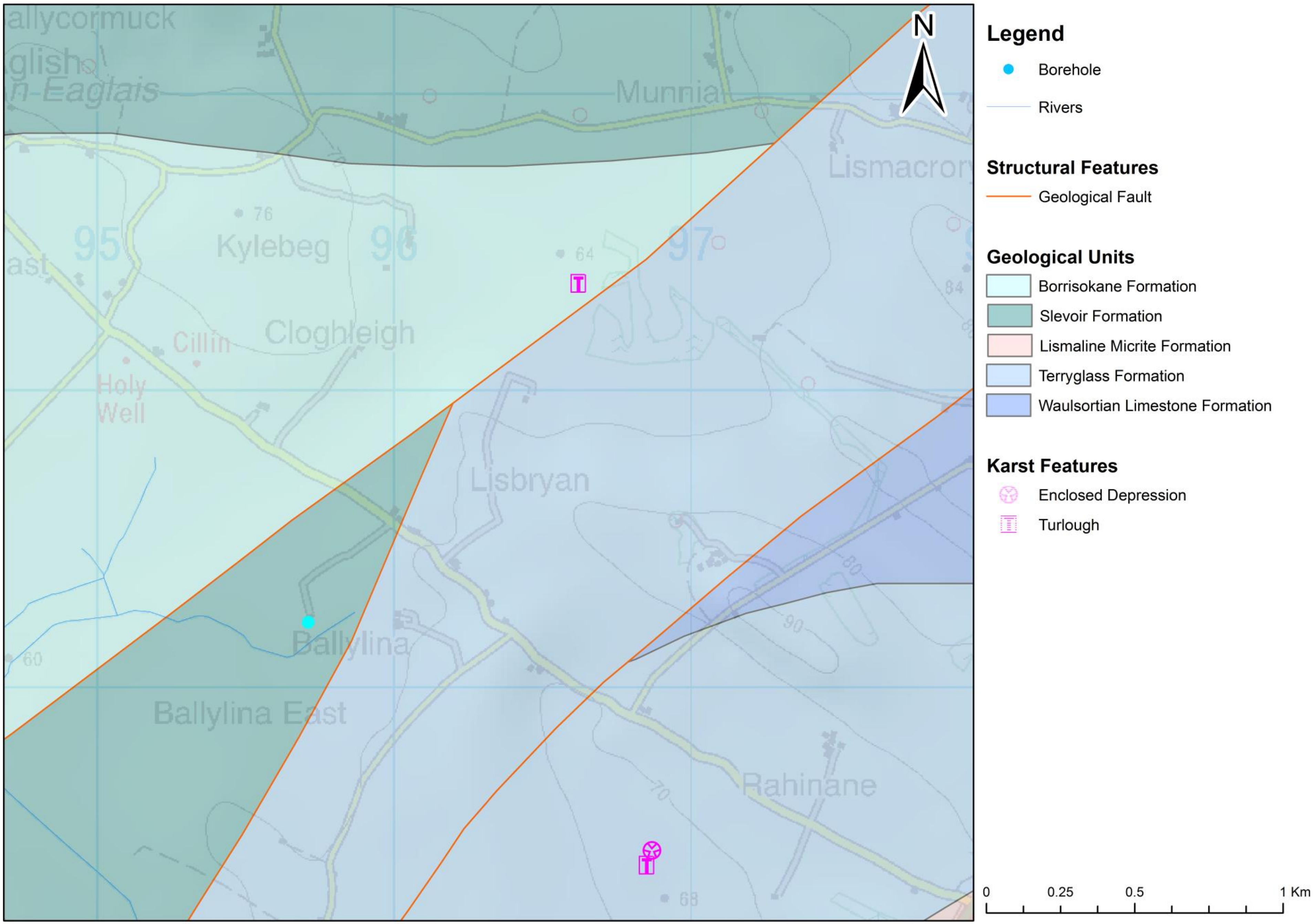
s



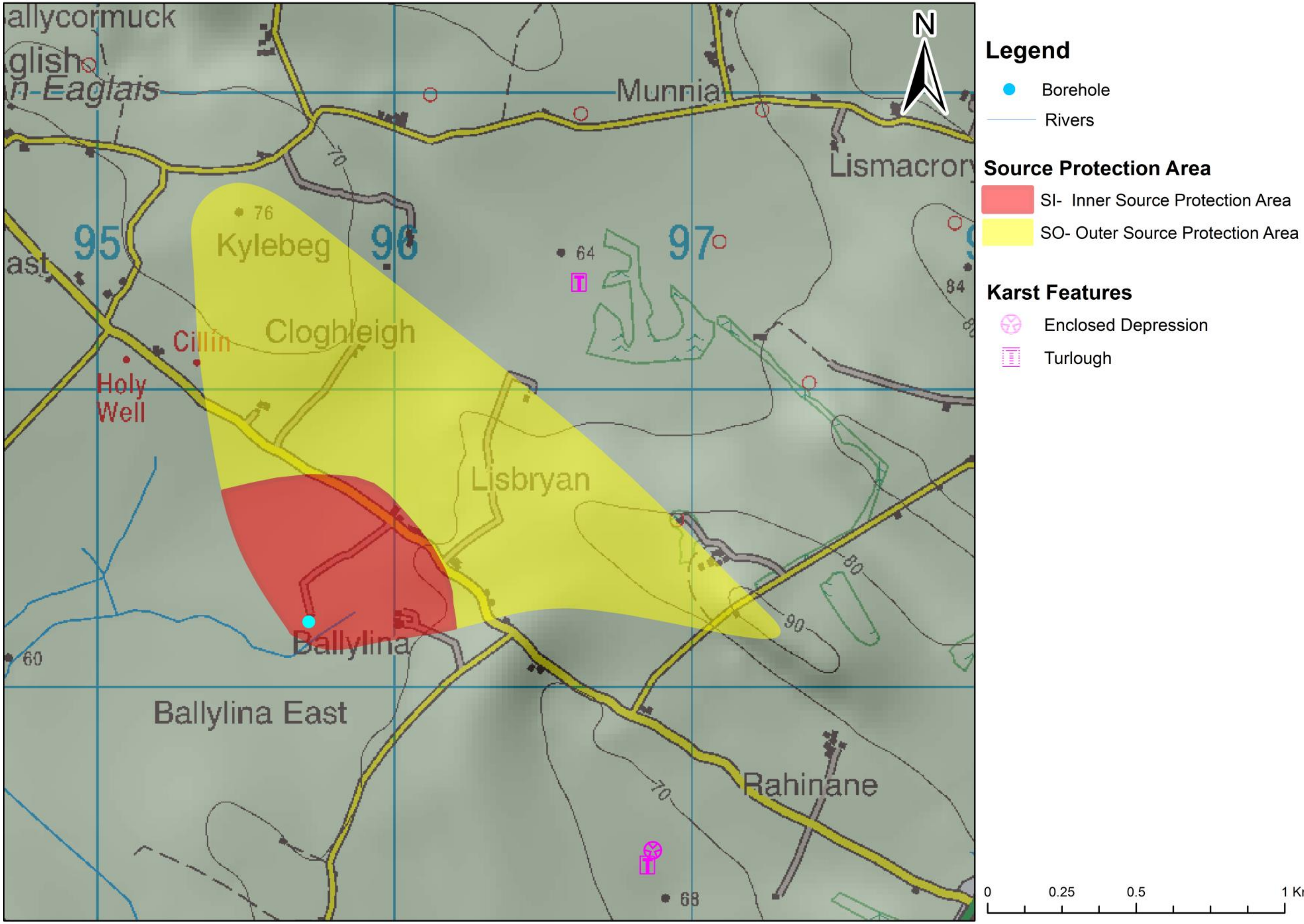
The 100 day ToT is estimated by computing travel times at incremental distances away from the spring by using the local groundwater gradient (i*) in the equation:

Pore or fracture velocity (m/d) = K i*/ effective porosity

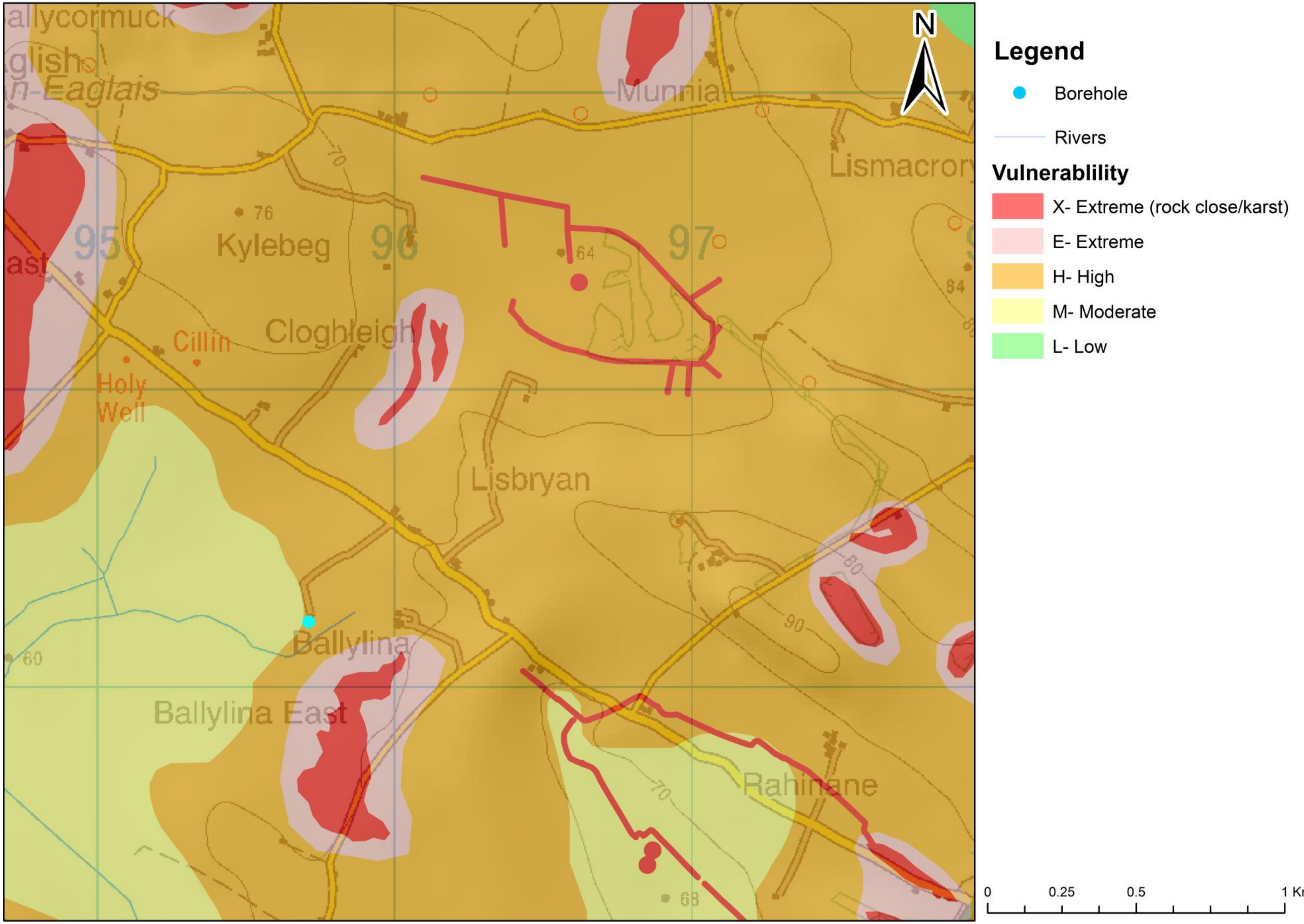
100 day ToT = Pore or fracture velocity (m/d) x 100 days



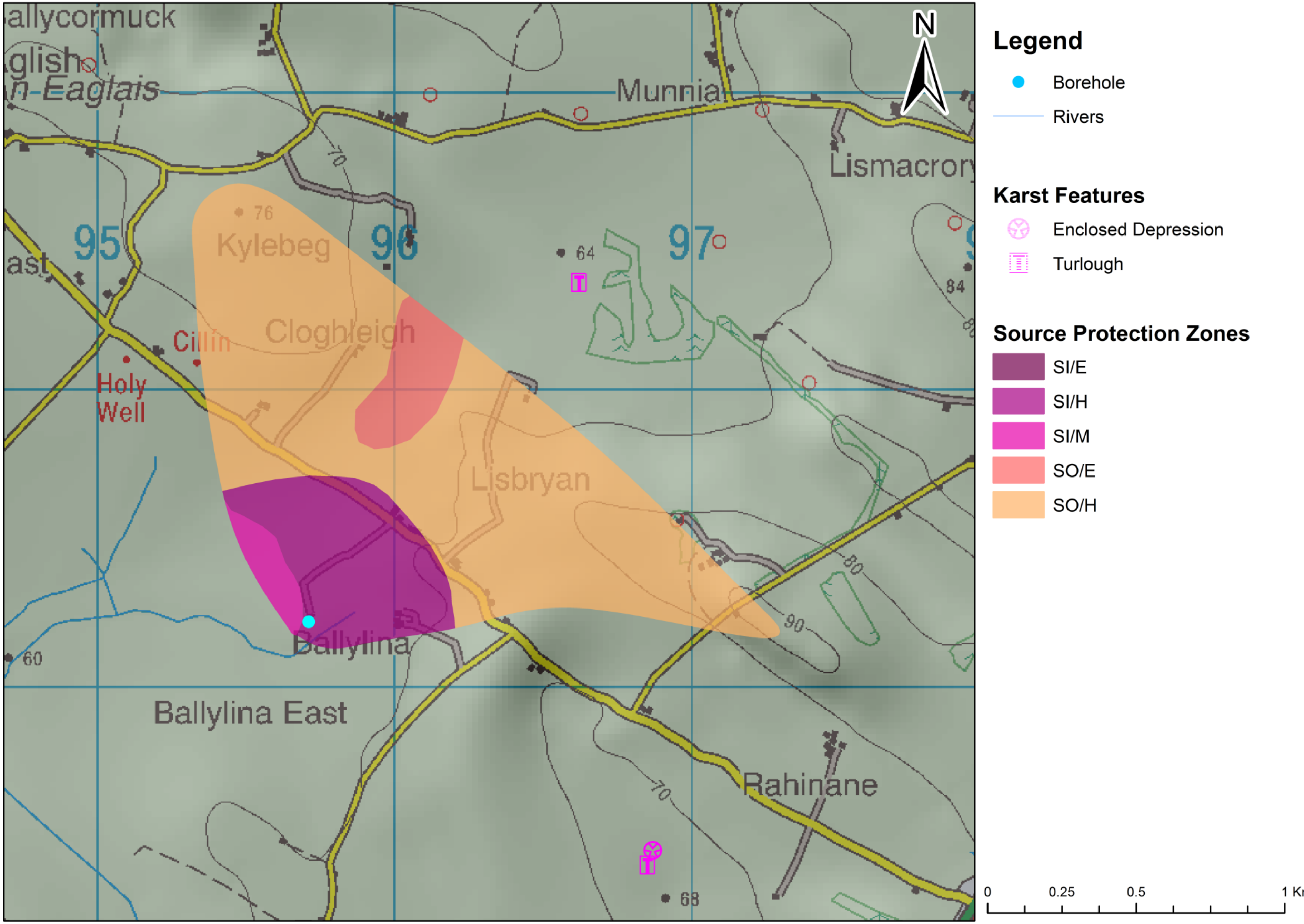
Legend
Borehole
Rivers
Structural Features
Geological Fault
Geological Units
Borrisokane Formation
Slevoir Formation
Lismaline Micrite Formation
Terryglass Formation
Waulsortian Limestone Formation
Karst Features
Enclosed Depression
Turlough
0
0.25
0.5
1 Km
N
Munnia
Lismacrory
Kylebeg
Cloghleigh
Cillín
Holy Well
Lisbryan
Ballylina
Ballylina East
Rahinane



N
Legend
Borehole
Rivers
Source Protection Area
SI- Inner Source Protection Area
SO- Outer Source Protection Area
Karst Features
Enclosed Depression
Turlough
0
0.25
0.5
1 Km
Ballycormuck
Munnia
Lismacrory
Kylebeg
Cloghleigh
Cillín
Holy Well
Lisbryan
Ballylina
Ballylina East
Rahinane
95
96
97
76
64
84
80
90
70
60
68



allycormuck
glish
n-Eaglais
Munnia
Lismacrory
Kylebeg
76
95
96
97
64
84
Cloghleigh
Cillín
Holy
Well
Lisbryan
80
90
Ballylina
Ballylina East
Rahinane
70
60
68
N
Legend
Borehole
Rivers
Vulnerablility
X- Extreme (rock close/karst)
E- Extreme
H- High
M- Moderate
L- Low
0
0.25
0.5
1 Km



Legend
Borehole
Rivers
Karst Features
Enclosed Depression
Turlough
Source Protection Zones
SI/E
SI/H
SI/M
SO/E
SO/H
0
0.25
0.5
1 Km
N
Munnia
Lismacrory
Kylebeg
Cloghleigh
Cillín
Holy Well
Lisbryan
Ballylina
Ballylina East
Rahinane
95
96
97