Borrisokane Water Supply Scheme

Groundwater Source Protection Zones

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1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Borrisokane Water Supply Scheme spring 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 source is an old spring, named Poulsheshery on the O.S. 6” sheet, in the townland of Crotta, 2 km southeast of Borrisokane village, North County Tipperary. The spring is encased in a 5 m diameter concrete chamber.

The water is passed through a sand filter, chlorinated and fluoridated.

3. Summary of Spring Details

GSI no.	1719SEW061
Grid ref. (1:25,000)	19334 19279
Townland	Crotta
Owner	North Tipperary County Council
Well type	Spring
Elevation (top of casing)	~62.5 m OD
Diameter	5 m
Depth-to-rock	~ 5 m
Static water level	~61.5 m OD (at surface)
Daily Abstraction	865 m^3/d (190,500 gal/d)
Hours pumped per day	15-20
Pumping Rate	1186 m^3/d (assuming 17½ hours pumping)

4. Methodology

Desk study
Bedrock geology information was compiled from Brück (1985) and soils were compiled from Finch and Gardiner (1993). Basic source details were obtained from GSI records and County Council personnel; such details include shaft depth, elevation, abstraction rate, and 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 investigate further the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and potential hazards. Water samples were taken for analysis in the State Laboratory. Five holes were bored by continuous-flight auger to ascertain the depth to bedrock in the area.

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

5. Topography and Surface Hydrology

The Borrisokane supply is a spring that emerges in low-lying hummocky ground in a boggy pasture area. The source lies within the catchment of the River Crotta, which flows in a westerly direction immediately north of the site. Overflow from the spring is piped to the subsurface, from where it seeps into the Crotta River. The Ballyfinboy River, into which the Crotta drains, flows through low-lying flat ground approximately 500 m to the south of, and 500 m to the west of, the spring.

The Crotta River valley is surrounded by ridges of higher ground to the northeast and southwest, and by a high boggy plateau to the east-southeast. Topographic relief is approximately 10 m, rising to about 16 m difference at the top of the Scohaboy Bog, 2.7 km away. A tributary to the Crotta River rises just south of a hill (84 m elevation), 1650 m east-south east of the source.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises limestone sediments of Lower Carboniferous age (c.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 Borrisokane spring

Rock Formation	Rock Material	Thickness	Occurrence
Slevoir Limestone-Shale Formation (SV)	Muddy limestone: comprised of dark grey, shelly, argillaceous limestones and calcareous shales. Beds from a few cm to 1m thick.	c. 250 m	Underlies the source and outcrops in several places nearby, in the fields and in the Crotta river.
Lismaline Micrite Formation (LM)	Clean limestone: a homogeneous medium grey micrite (carbonate mud).	40 m	Occurs to the southeast of the spring, about 1km away. Faulted against the Slevoir Limestone-Shale Formation. Underlies the higher ground to the east.
Terryglass Calcarenite Formation (TS)	Clean limestone: a grey, thick-bedded and well-sorted calcarenite.	up to 200 m	
Oldcourt Formation (OC)	Limestone: cherty calcarenites deposited in hollows above the Waulsortian Limestone	variable	Occurs to the southeast of the spring, about 1.5km away. Enclosed by TS Formation, in the in core of an anticline. Underlies the higher ground to the southeast
Waulsortian Limestones (WA)	Clean limestone: massive, unbedded micrite.	200 - 300 m	

6.1.1 Geological Structure

The spring occurs in the Slevoir Limestone-Shale Formation on the eastern limb of a major NE-SW trending fold, the Borrisokane Syncline. Bedding dips in the immediate vicinity are very low (3^{o}) and generally to the east. Approximately 1000 m to the east of the source is a major NE-SW trending fault that juxtaposes the Slevoir Limestone-Shale Formation against the Lismaline Micrite and Terryglass Limestone Formations.

6.2 Soils and Subsoils (Quaternary) Geology

The subsoils in the area are glacial tills derived from a limestone parent material. The spring occurs very close to the mapped boundary (Teagasc, 1993) between gley soils and podzolic loam soils, i.e. between saturated (gley) and unsaturated (grey brown podzolic) soils.

Teagasc (1993) assign the unsaturated soils to the 'Patrickswell Series'. The gley soils are assigned to the 'Mylerstown Series', occupying the lower-lying, boggy areas along the section of the Crotta River near the spring point.

The five GSI auger holes (see Figures 2 & 3) encountered varying deposits. Three (TNBK 1-3) were very shallow (<2 m deep), with largely sandy subsoil. TNBK4, close to the spring, met peat, overlying grey silt, overlying bedrock at 5 m depth. This may represent a local alluvial deposit along the stream. TNBK5 met mostly clayey gravel, which is consistent with Limestone Till.

6.3 Depth-to-rock

The 19th Century GSI geological mapping indicates exposures of rock in several places around the area, as shown on Map 2. Elsewhere, the depth to rock is known at selected localities from a GSI drilling programme undertaken for this study to ascertain the thickness and type of the subsoils. The locations of the five auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Depths to bedrock range from 0.8 to 7.5 m. In the vicinity of the spring it is about 5 m.

Overall, it appears that rock is not deeply buried anywhere in the area.

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 prep.)
  County Council analyses of Public supplies (1989 – 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. Potential Evaporation (PE) is estimated from Met Éireann's national contoured map as 505 mm/yr. Actual evapotranspiration (AE), estimated by taking 90% of the potential figure to allow for soil moisture deficits, is 455 mm/yr. Using these figures, the potential recharge (R–AE) is taken as approximately 464 mm. Runoff is assumed to be 50% of available recharge, i.e. 232 mm. This assumption takes account of topography and also of the infiltration capacity of the moderately permeable sandy till subsoils which dominate the area around and uphill of the Poulsheshery site (Wright *et al.*, 1983). These calculations are summarised below:

Average rainfall (R)	919 mm/yr
Estimated P.E.	505 mm/yr
Estimated A.E. (90% P.E.)	455 mm/yr

Potential recharge (R–AE)	464 mm/yr
Surface Runoff	232 mm/yr
Recharge	232 mm/yr

7.3 Groundwater levels

In this area, borehole groundwater level data are sparse. River water level data were established from Ordnance Survey trig points and from contours. The level of the water in the cased chamber should be about 61.5 m OD. Water was encountered at a maximum of 1.5 mbgl in saturated peat in the trial borehole about 15 m from the spring (TNBK4, Figure 3).

7.4 Groundwater Flow Directions and Gradients

The water table in the area is assumed to broadly reflect topography with groundwater flowing northwest towards, and discharging into the Crotta and Ballyfinboy Rivers, and to the other streams in the area.

In the higher elevation areas further east, the soil cover is very thin (e.g., auger holes TNBK2 and TNBK3, Figure 2 and Figure 3). This indicates that the Ballyfinboy and other rivers in the area either incise into the aquifer, or have only a thin layer of soil material between the stream and the aquifer, giving the elevation of the water table where it intersects with the ground surface

As evidenced by the extensive development of marsh ground, the water table intersects with the ground surface in the Ballyfinboy and Crotta valley reaches between the spring and the town of Borrisokane.

The average hydraulic gradient in the area is estimated to be 0.03 (3%) as flow approaches the spring (<200 m), and 0.008 (0.8%) further away from the spring (>500 m away).

7.5 Hydrochemistry and Water Quality

Field measurements indicated an electrical conductivity of 682 μS/cm and a temperature of 10.1^{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 indicate a calcium-bicarbonate (Ca - HCO_3) hydrochemical signature.
- Groundwater hardness is classed as 'very hard' (total hardness 353–403 mg/l as $CaCO_3$).
- Nitrate concentrations ranged between 12.4 and 37.9 mg/l (as NO_3), with an average concentration of 25.6 mg/l (23 samples) over the period June 1989 to August 2000. The GSI guide level of 25 mg/l was exceeded in more than half of the samples. 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 appears to be a slight upward trend in the data.
- Chloride concentrations ranged between 24.2 and 33 mg/l (3 samples). On one occasion (March 1991), the chloride concentration was greater than 30 mg/l. Chloride is a constituent of organic wastes and (away from coastal areas) levels higher than 25 mg/l may indicate contamination, and higher than 30 mg/l usually indicate significant contamination.
- Bacteriological sampling indicated faecal contamination of the source on three occasions (out of seven) in the period March 1991 to August 2000. Two of the contaminated samples were untreated, with the status of the third unknown. Of the four negative samples, three were non-source (i.e. treated), with the status of the remaining sample unknown. Problems at the source with both faecal and total coliform occurrences and concentrations appear to have decreased over the monitoring period.
- Three potassium:sodium (K:Na) ratios, ranging between 0.26 and 0.32, can be calculated from the available data. Even though the source is surrounded by pasture, these values indicate that the

bacterial contamination may originate from septic tanks rather than silage, since contamination by silage is indicated by high K:Na ratios (values of about 10).

- During mid-September 1993, very high manganese and iron levels were recorded that significantly exceeded the EU Drinking Water Directive maximum admissible concentrations (MACs) of 0.05 mg/l and 0.2 mg/l respectively. On the remaining 15 times the source was tested, concentrations were very close to or below the method detection limits (MDLs) of 0.005 mg/l (iron) and 0.002 mg/l (manganese). Neither metal is detrimental to health at the recorded concentrations but can cause aesthetic problems and deterioration in well performance.

7.6 Aquifer Parameters

In the absence of any relevant measurements on site (e.g. from pumping test data), the aquifer parameters are estimated from analogous situations elsewhere, and are tuned to the specific location by using analytical flow equations (Thiem, 1906 in Driscoll, 1986, see Appendix 2) calibrated with water level and flow data. The values are given in Table 2.

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

Parameter	**Data source**	**Slevoir Limestone-Shale Formation (SV) parameter values**
Permeability (in upper 10 metres)	• Estimated from parameter fitting to analytical equation, and informed by regional experience	18.5 m/d
Effective porosity		0.05 (5%)
Hydraulic gradient	• estimated from topography and surface hydraulic features	0.03 (3%) (near to spring) 0.008 (0.8%) (away from spring)

Away from the zone of flow convergence at the spring, it is likely that the permeability and porosity are lower than the values given above, as the rocks will have experienced lower flow velocities and probably less dissolution of the limestone.

7.7 Aquifer Category

The Slevoir Limestone-Shale Formation (SV), from which the spring emerges, is classified as a Locally Important aquifer (moderately permeable only in local zones) (**Ll**). The zone of contribution (ZOC, Figure 5) to the spring encompasses several other rock types: the Lismaline Micrite Formation (LM), the Terryglass Calcarenite Formation (TS), the Oldcourt Formation (OC), and Waulsortian Limestones (WA). These are classified as, respectively, **Lm**, **Rf**, **Lm** and **Ll**.

7.8 Conceptual Model

The Borrisokane spring emerges from the Slevoir Limestone-Shale Formation. The permeability of this muddy limestone aquifer depends on the development of faults, fissures and fractures. The permeability and resulting groundwater velocities are likely to be high as the water approaches the spring.

The spring is located in a topographic low area – the River Crotta valley – close to the boundary between glacial till and gley (saturated) subsoils.

The subsoil is moderately permeable till and very thin in many places; therefore, the aquifer is considered to be unconfined.

Groundwater flow is topographically driven, mainly from the upland area to the east (topographic relief of up to 20m), but also from the gentle (10 m height difference) slopes to the north east and southwest of the Crotta valley.

The water table is assumed to reflect broadly the topography of the area, and the rivers and streams in the area are assumed to record the elevation of the water table in their vicinity and to be in good hydraulic communication with the aquifers that they cross.

The average hydraulic gradient in the area is estimated to be 0.03 (3%) as flow approaches the spring (<200 m), and 0.008 (0.8%) further away from the spring (>500 m away).

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 an abstraction from long-term recharge. The ZOC is controlled primarily by a) the pumping rate or spring flow, b) the groundwater flow direction and gradient, c) the rock permeability and d) the recharge in the area. The ZOC is delineated as follows:

i) An estimate of the area size is obtained by using the average recharge and the spring discharge rate.

ii) The estimated total spring discharge, rather than the daily abstraction, is used in estimating the ZOC.

Taking the recharge to be 232 mm/yr as indicated in Section 7.2, the area required to supply a spring flow of 1186 m^3/d is calculated to be 1.87 km^2 (187 ha). This compares with an area of 1.97 km^2 estimated on topographic and hydrogeological considerations.

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

Northern/Northeastern Boundary: this boundary is defined by the flow line of water that is captured by the spring and by the line of the Crotta River.

Southern Boundary: this local groundwater divide runs west-northwest from around Ballynavin Castle, between two streams (Crotta River in the north and a tributary to the Ballintotty River in the south) and along a local ridge of high ground that runs just south of the Borrisokane road.

Western Boundary: defined by the down-stream extent of the flow that is captured by the spring.

Eastern Boundary: the edge of Scohaboy Bog and the local topographic highs 1650 m east-southeast of the spring define this boundary.

These boundaries are based largely on topography, 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, and 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. The 100-day travel time distance is estimated as 560 m, by using the Thiem equation (Thiem, 1906 in Driscoll, 1986) for unconfined steady state flow; it is shown on Figure 1. The parameters used to compute the 100 day ToT are included in Appendix 2.

The Inner Protection Area covers about 0.15 km^2 (15 ha), and constitutes approximately 7.5 % 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. Since subsoil depths do not appear to exceed 10 m in the area, no 'Low' vulnerability areas are believed to exist.

The groundwater vulnerability in the area is considered to be 'Extreme' for much of the area, and 'High-Moderate' in parts of the ZOC furthest away from the source. Vulnerability of groundwater in the Borrisokane spring 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 Groundwater Protection Scheme, in which only the extremely vulnerable areas are delineated, there are a total of only four possible source protection zones (see the matrix in the table below). 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 four groundwater protection zones present around the Borrisokane source (see Figure 6), as shown in the matrix below.

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

Agriculture, both livestock rearing and crop-growing, 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 and into the Crotta River or its tributaries. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The spring is fed from a locally important (**Ll**) limestone aquifer (Slevoir Limestone-Shale Formation). The zone of contribution to the spring also encompasses several other rock types that are classified as **Lm**, **Ll** and **Rf** aquifers (section 7.7).
- The area around the supply includes both 'Extreme' and 'High to Moderate' 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.

- In addition, chemical and bacteriological analyses of raw water rather than treated water should be carried out on a regular basis (every 3 - 6 months)
- Guidelines should be drawn up for dealing with spillages along the roads and in the streams in the area, especially the road at Crotta Bridge, and the Crotta river and its tributaries.

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.

DoELG/EPA/GSI (1999) *Groundwater Protection Schemes*. Department of Environment & Local Government, Environmental Protection Agency & Geological Survey of Ireland.

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

EPA (March 1997 and in preparation) *Nitrates in Groundwater County Tipperary (NR)*. EPA, Regional Inspectorate, Dublin

Finch, T.F. & Gardiner, M.J. (1993) *Soils of Tipperary North Riding*. Soil Survey Bulletin No. 42, National Soil Survey of Ireland, Teagasc, Dublin.

Hunter Williams, N. & Wright, G.R. (2001) *An assessment of the quality of public, group scheme and private groundwater supplies in North Tipperary County*. 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 Borrisokane area. Based on Brück (1985).

Fig 2: Site map,

Fig 3: Auger hole logs

Fig 4: Hydrochemistry

Fig 5: ZOC and TOT map

Fig 6: Groundwater Vulnerability Map

Fig 7 – Source Protection Zones

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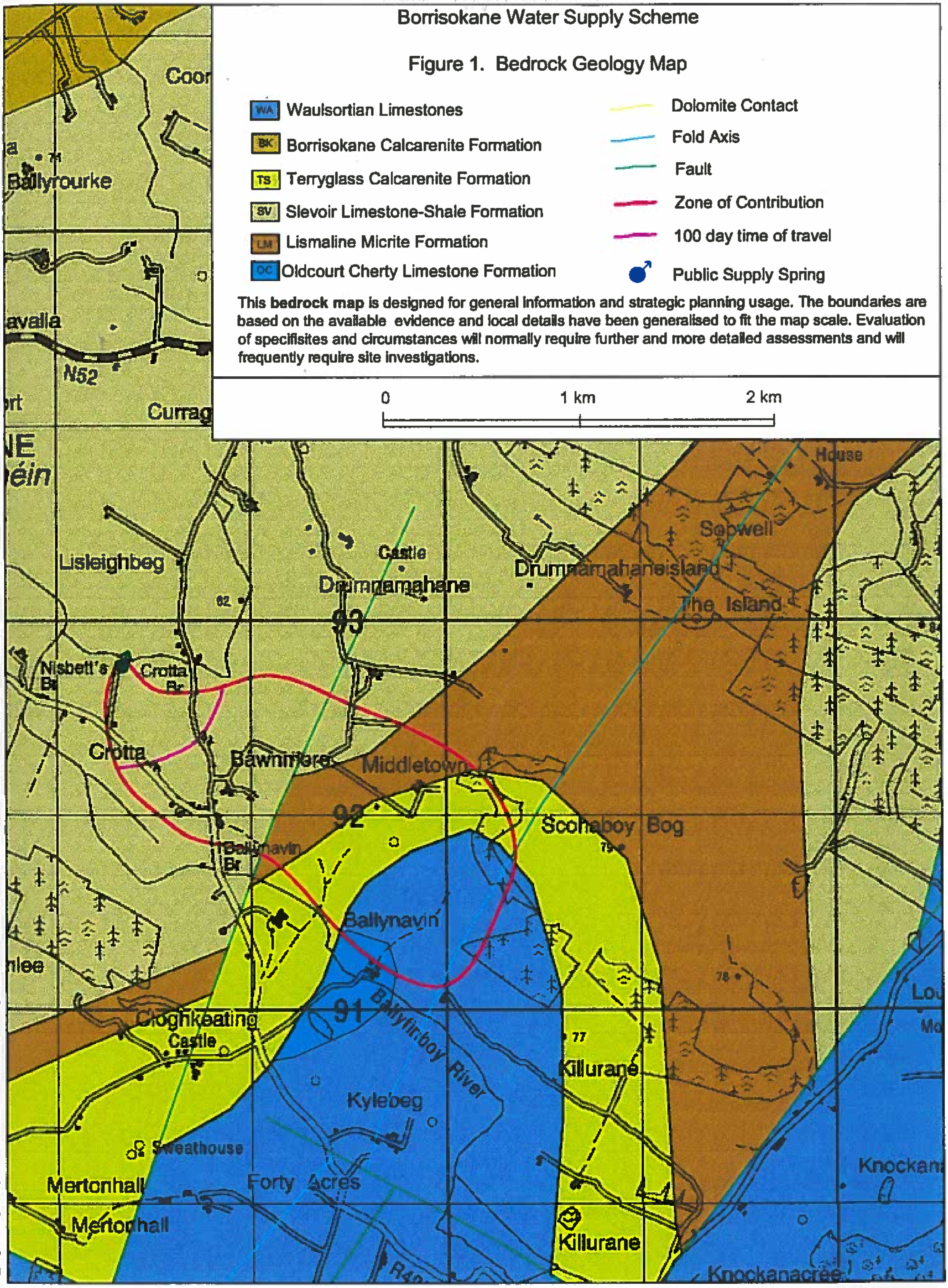
Borrisokane Water Supply Scheme

Figure 1. Bedrock Geology Map



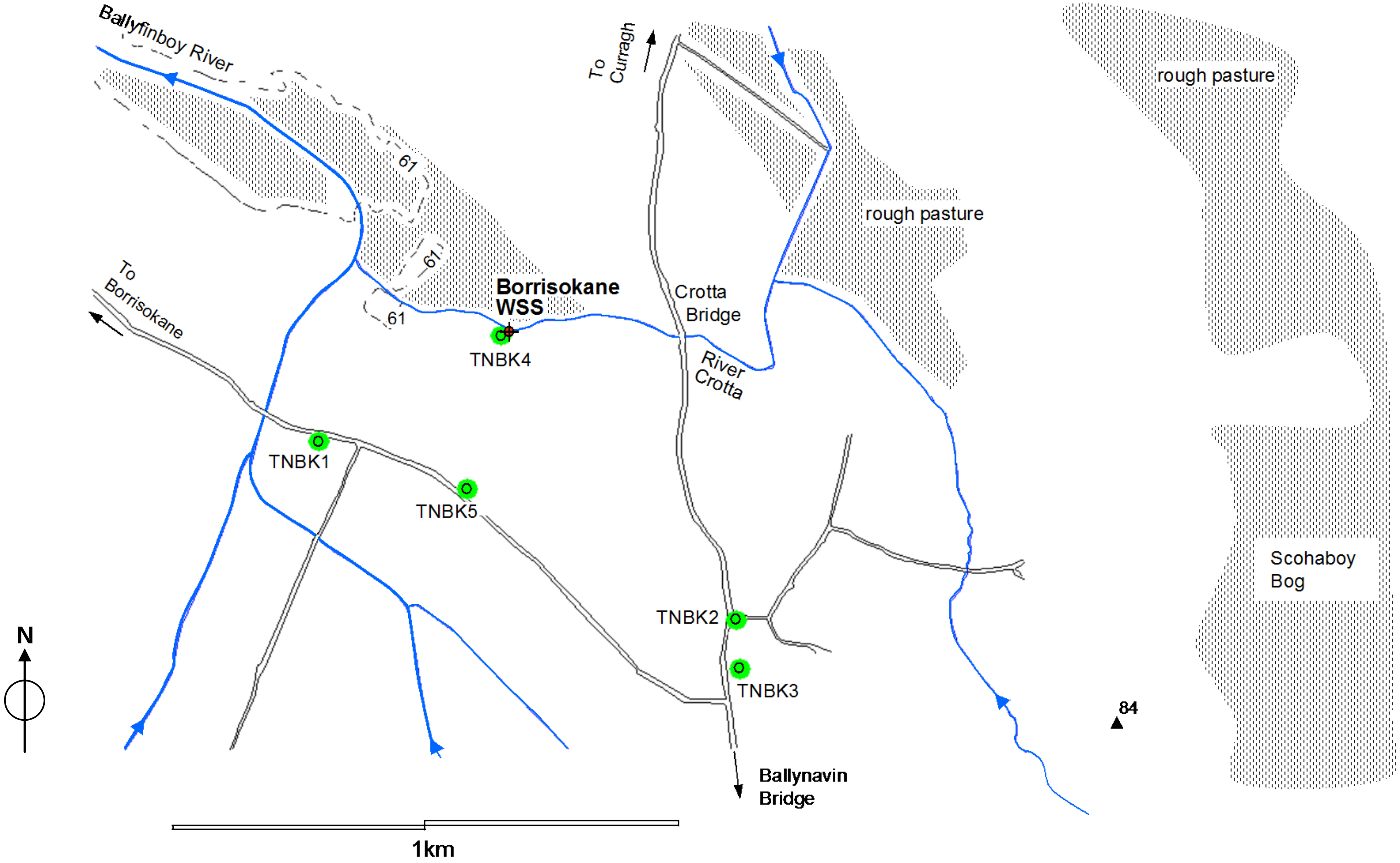
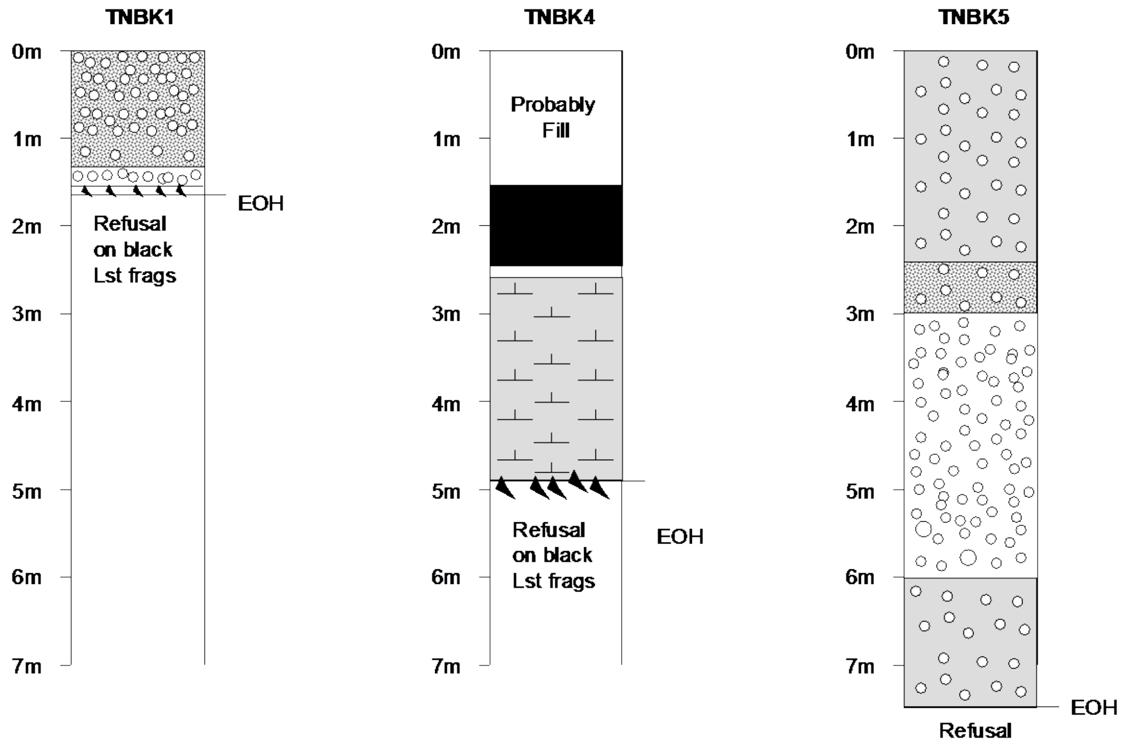


Figure 2: Location map of Borrisokane WSS spring
Showing auger holes drilled by GSI to determine depth to bedrock nearby (TNBK1 to TNBK5) and other hydrogeological features discussed in the text.



TNBK1

1.0m	Gravelly SAND
1.3m	Sandy GRAVEL
1.5m	GRAVEL
1.6m	EOH on very tough Limestone Rock Fragments

TNBK4

0-1.5m	Very Hard Going (Probably Fill)
2.0m	Saturated Peat
2.5m	Water /No Recovery
2.6m	Grey SILT. Easy going
4.2m	Sounding Rough. Easy Going
4.9m	REFUSAL on Black Limestone Frags

TNBK5

1.0m	Clayey GRAVEL
2.0m	Clayey GRAVEL
2.5m	Sandy GRAVEL
3.0	More Gravelly
5.5	Wet GRAVEL returns
6.0m	Clayey GRAVEL
7.5m	REFUSAL

TNBK2 0.9m Refusal on probably Bedrock

TNBK3 0.8m Refusal on BR after SANDY overburden

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

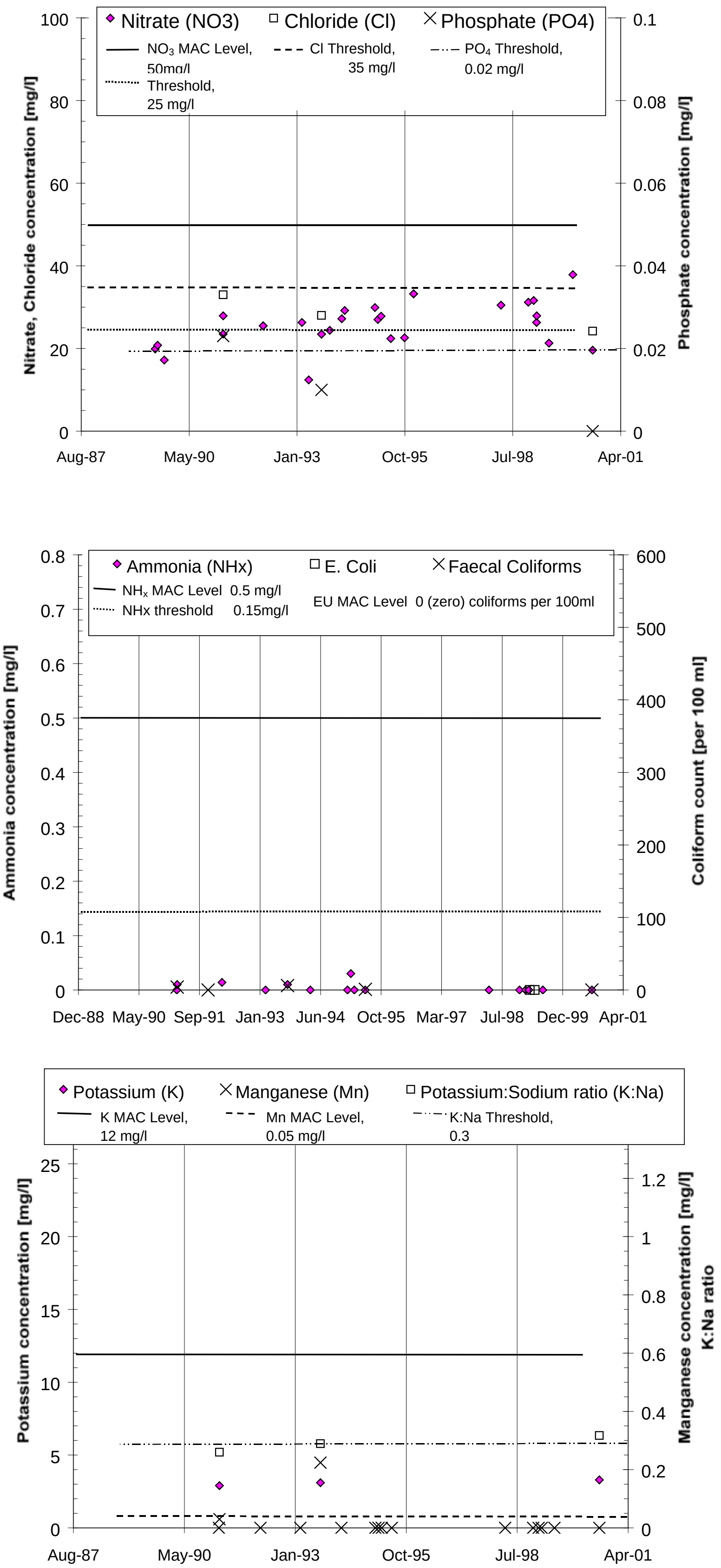
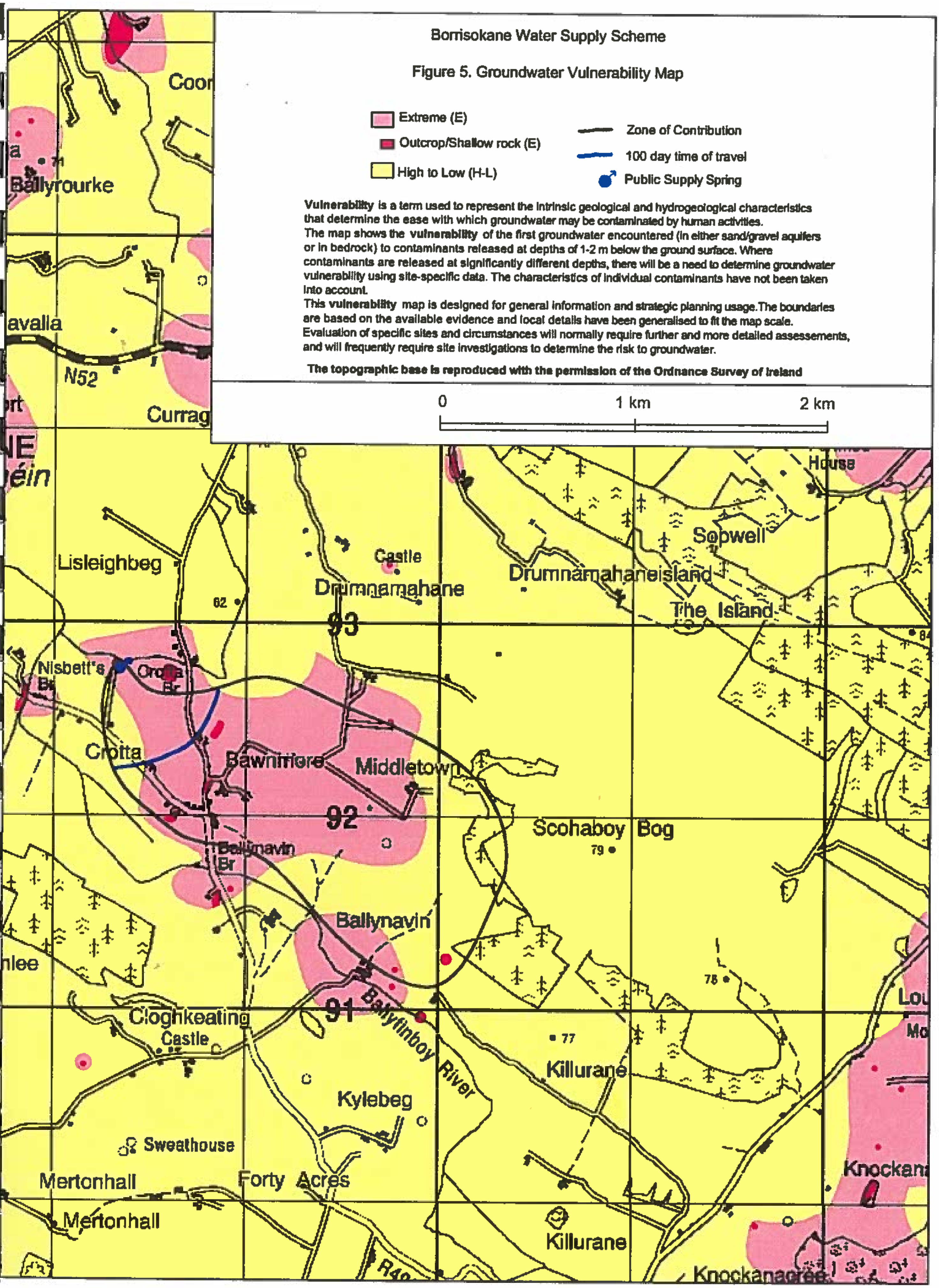
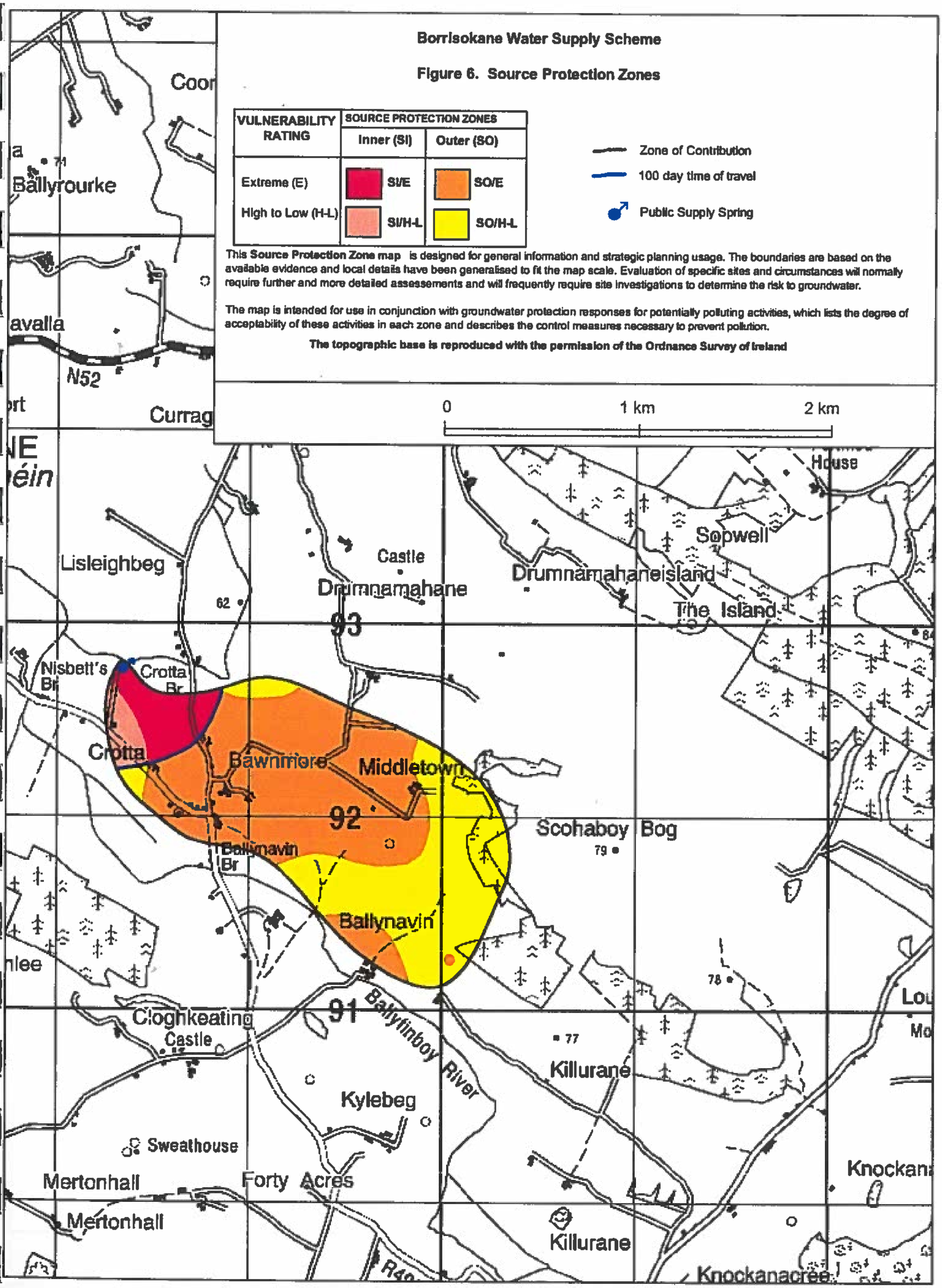


Figure 4: Key indicators of agricultural and domestic groundwater contamination at Borrisokane WSS


Borrisokane Water Supply Scheme
Figure 5. Groundwater Vulnerability Map
Extreme (E)
Outcrop/Shallow rock (E)
High to Low (H-L)
Zone of Contribution
100 day time of travel
Public Supply Spring
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.
The map shows the vulnerability of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants have not been taken into account.
This vulnerability map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessements, and will frequently require site investigations to determine the risk to groundwater.
The topographic base is reproduced with the permission of the Ordnance Survey of Ireland
0
1 km
2 km
Ballyrourke
N52
Lisleighbeg
Castle
Drumnamahane
Drumnamahaneisland
Sopwell
The Island
93
Nisbett's Br
Crotta
Bawnmore
Middletown
92
Scohaboy Bog
Ballynavin Br
Ballynavin
Cloghkeating Castle
91
Ballyfinboy River
Killurane
Kylebeg
Sweathouse
Mertonhall
Forty Acres
Knockanacree


Borrisokane Water Supply Scheme
Figure 6. Source Protection Zones
VULNERABILITY RATING
SOURCE PROTECTION ZONES
Inner (SI)
Outer (SO)
Extreme (E)
SI/E
SO/E
High to Low (H-L)
SI/H-L
SO/H-L
Zone of Contribution
100 day time of travel
Public Supply Spring
This Source Protection Zone map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessements and will frequently require site investigations to determine the risk to groundwater.
The map is intended for use in conjunction with groundwater protection responses for potentially polluting activities, which lists the degree of acceptability of these activities in each zone and describes the control measures necessary to prevent pollution.
The topographic base is reproduced with the permission of the Ordnance Survey of Ireland
0
1 km
2 km
Ballyrourke
N52
Lisleighbeg
Castle
Drumnamahane
Drumnamahaneisland
Sopwell
The Island
House
Nisbett's Br
Crotta Br
Crotta
Bawnmore
Middletown
Ballinavin Br
Scohaboy Bog
Ballynavin
Cloghkeating Castle
Ballyfinboy River
Killurane
Kylebeg
Sweathouse
Mertonhall
Forty Acres
Knockanacree
93
92
91
62
79
78
77

Appendix 1: Laboratory Analyses of Groundwater at Borrisokane WSS

Parameter	**Results of Laboratory Analyses**																				
Laboratory	Tipp (NR) CC	Reg Water Lab	North Tipperary Co. Co.				Reg Water Lab	North Tipperary Co. Co.													State Lab
Sample treatment	-	S	NS?	NS?	-	-	S	-	-	-	-	-	NS	-	-	-	-	NS	NS	-	NS
Date	15/03 /91	19/03 /91	19/03 /91	29/11 /91	23/03 /92	18/03 /93	15/09 /93	22/03 /94	23/01 /95	20/02 /95	21/03 /95	19/06 /95	20/06 /95	06/04 /98	15/12 /98	02/02 /99	02/03 /99	09/03 /99	19/04 /99	25/06 /99	03/08 /00
EC (µS/cm)	725	746			704	758	766	747	739	736	763	750		756	768	760	767			757	772
pH (lab.)	7.6	7.8			7.7	7.5	7.4	7.6	7.7	7.7	7.6	7.8		7.7	7.8	7.7	7.8			7.7	
Total Hardness (mg/l $CaCO_3$)		376					407														354
Total Alkalinity (mg/l $CaCO_3$)		310					339														342
Calcium (mg/l)		128					131														119
Magnesium (mg.l)		13.6					19														13.7
Chloride (mg/l)		*33*					*28*														24.2
Sulphate (mg/l)		16					<MDL														18.9
Sodium (mg/l)		11					10.7														10.4
Potassium (mg/l)		2.9					3.1														3.3
K:Na		0.26					0.29														0.32
Nitrate (mg/l NO_3)		*27.9*			*25.5*	*26.3*	23.5	*27.2*	*29.9*	*27*	*27.8*	22.4		*30.5*	*31.2*	*31.6*	*26.3*			21.3	19.6
Iron (mg/l)	<MDL	<MDL			<MDL	<MDL	**1.167**	<MDL	<MDL	<MDL	<MDL	0.057		<MDL	<MDL	<MDL	<MDL			<MDL	<MDL
Manganese (mg/l)	<MDL	0.03			<MDL	<MDL	**0.224**	<MDL	<MDL	<MDL	<MDL	<MDL		<MDL	<MDL	<MDL	<MDL			<MDL	<MDL
E/F coli per 100 ml.		**4**		0			**6**						**1**					0	0		0
Total *coli* /100ml		8	600	50			11						1					0	0		0
Total Ammonia (mg/l NHx)	<MDL	0.01			0.014	<MDL	0.01	<MDL	<MDL	<MDL	<MDL	<MDL		<MDL	<MDL	<MDL	<MDL			<MDL	<MDL
Comments	Probably substantially contaminated														Coliform contamination indeterminate because of sample treatment. Other parameters less than MACs but should have on-going monitoring						

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

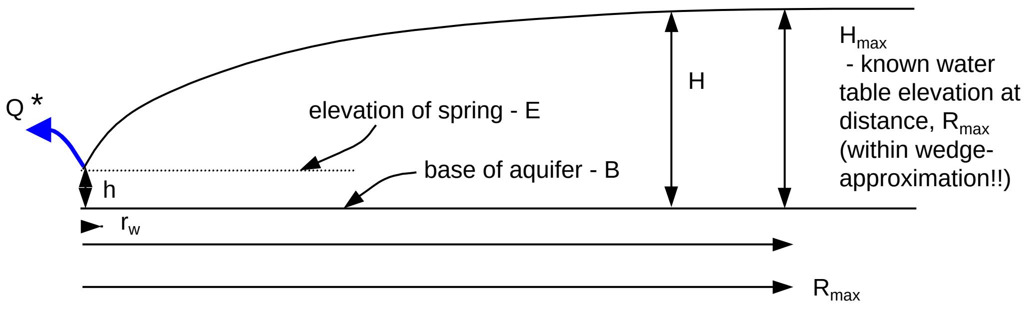
Appendix 2: Calculation of 100 day Time-of-Travel (TOT) to a spring by using the Thiem equation and approximating the zone of contribution (ZOC) to the spring by a wedge.

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 Borrisokane WSS

Q^* = 5405 m^3/d (1186 m^3/d x 80°/360°)

K = 18.5 m/d, effective porosity = 0.05

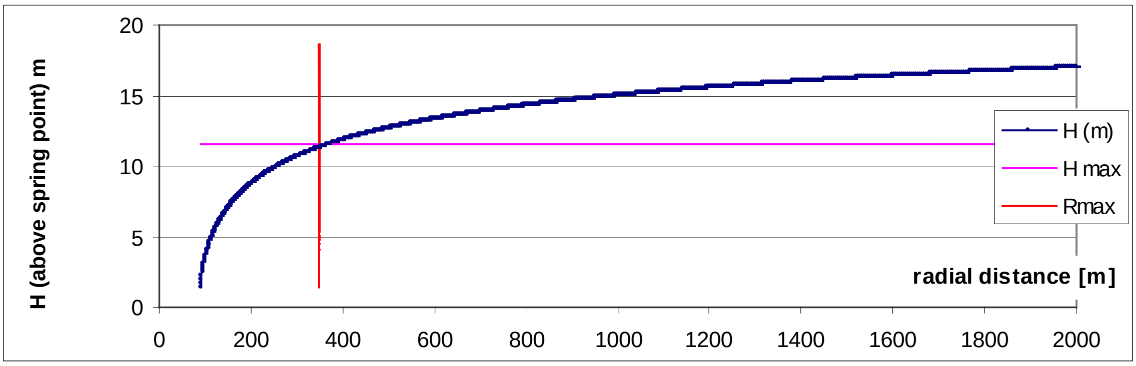
r_w = 30 m

R_{max} = 350 m; H_{max} = 64 m (the elevation and distance of the Crotta River)

E = 62.5 m (the elevation of the spring);

B = 52.5 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