Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Knockcroghery/Lecarrow Public Water Supply
Toberreeoge Spring

Groundwater Source Protection Zones

June 2010

Prepared by:
Coran Kelly (TOBIN), David Drew (TCD)

With contributions from:
Caoimhe Hickey (GSI); Jenny Deakin TCD; Orla McAlister (Tobin); Robert Meehan (Consultant Geologist)

And with assistance from:
Roscommon County Council

PROJECT DESCRIPTION

Since the 1980's, the Geological Survey of Ireland (GSI) has undertaken a considerable amount of work developing Groundwater Protection Schemes throughout the country. Groundwater Source Protection Zones are the surface and subsurface areas surrounding a groundwater source, i.e. a well, wellfield or spring, in which water and contaminants may enter groundwater and move towards the source. Knowledge of where the water is coming from is critical when trying to interpret water quality data at the groundwater source. The Source Protection Zone also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

The project "Establishment of Groundwater Source Protection Zones", led by the Environmental Protection Agency (EPA), represents a continuation of the GSI's work. A CDM/TOBIN/OCM project team has been retained by the EPA to establish Groundwater Source Protection Zones at monitoring points in the EPA's National Groundwater Quality Network.

A suite of maps and digital GIS layers accompany this report and the reports and maps are hosted on the EPA and GSI websites (www.epa.ie; www.gsi.ie).

TABLE OF CONTENTS

1 INTRODUCTION 1
2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION 1
3 SUMMARY OF SPRING DETAILS 1
4 METHODOLOGY 3
5 TOPOGRAPHY AND LANDFORMS, SURFACE HYDROLOGY AND LAND USE 4
6 GEOLOGY 4
6.1 BEDROCK GEOLOGY 4
6.2 SOILS AND SUBSOILS 4
6.3 DEPTH TO BEDROCK 5
7 GROUNDWATER VULNERABILITY 5
8 HYDROGEOLOGY 9
8.1 GROUNDWATER BODY AND STATUS 9
8.2 HYDRO-METEOROLOGY AND RECHARGE 9
8.3 SPRING DISCHARGE 10
8.4 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS 11
8.5 AQUIFER CHARACTERISTICS 12
8.6 HYDROCHEMISTRY AND WATER QUALITY 15
8.7 CONCEPTUAL MODEL 17
9 DELINEATION OF SOURCE PROTECTION AREAS (SPA) 17
9.1 OUTER PROTECTION AREA 17
9.2 INNER PROTECTION AREA 19
10 GROUNDWATER PROTECTION ZONES 19
11 POTENTIAL POLLUTION SOURCES 19
12 SUMMARY 22
13 RECOMMENDATIONS 22
14 REFERENCES 22
APPENDIX 1 OVERVIEW OF SPRINGS AROUND TOBERREEOGE AND KNOCKCROGHERY 24

TABLES & FIGURES

TABLES

Table 3-1 Summary of Source Details....3
Table 9-1 Estimations of flow, recharge and contributing area to Toberreeoge 18
Table 10-1 Source Protection Zones....19

FIGURES

Figure 1 Location Map....2
Figure 2 Bedrock Geology....6
Figure 3 Subsoil Map 7
Figure 4 Groundwater Vulnerability 8
Figure 5 Time discharge series for Toberreeoge from September 2009 to June 2010 (EPA)....13
Figure 6 Regional flow patterns and localised flow patterns around Tobereeoge 14
Figure 7 Key indicators of contamination....16
Figure 8 Source Protection Zones for Toberreeoge 21

1 INTRODUCTION

Groundwater Source Protection Zones (SPZ) are delineated for the Toberreeoge source according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

Knockcroghery/Lecarrow Public Water Supply comprises two sources feeding the overall distribution network: Toberreeoge (Local Authority Drinking Water Code: 2600PUB1003) and another groundwater source at Lecarrow (Drinking Water Code 2600PUB1019). Knockcroghery/Lecarrow PWS serves approximately 450 people (council records).

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Knockcroghery area.
- To delineate source protection zones for Toberreeoge.
- To assist EPA and Roscommon County Council in protecting the water supply from contamination.

The maps produced are based largely on the readily available information in the area, specific field work for this source and on 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, SITE DESCRIPTION AND WELL HEAD PROTECTION

Toberreeoge comprises a single spring located 1.5 km north of Knockcroghery village, 7.5 km southeast of Roscommon town, as shown in Figure 1. The spring discharges between a railway line and a narrow road. The sump is covered and overflows southeast to L. Ree. The abstraction intake is in the covered sump and the site is fenced off. The water is pumped into the Knockcroghery PWS which is also fed by the Lecarrow source.

3 SUMMARY OF SPRING DETAILS

The measured total spring outflows, including pumping range from 6.5-55 l/s, with an average of 22 l/s. The outflow estimates are based on council records of abstraction and discharge data provided by EPA. The spring discharge and abstraction is discussed in further in Section 8.3 and Table 3-1 provides a summary of the details as currently known. A photograph of the spring is given in Plate 1.

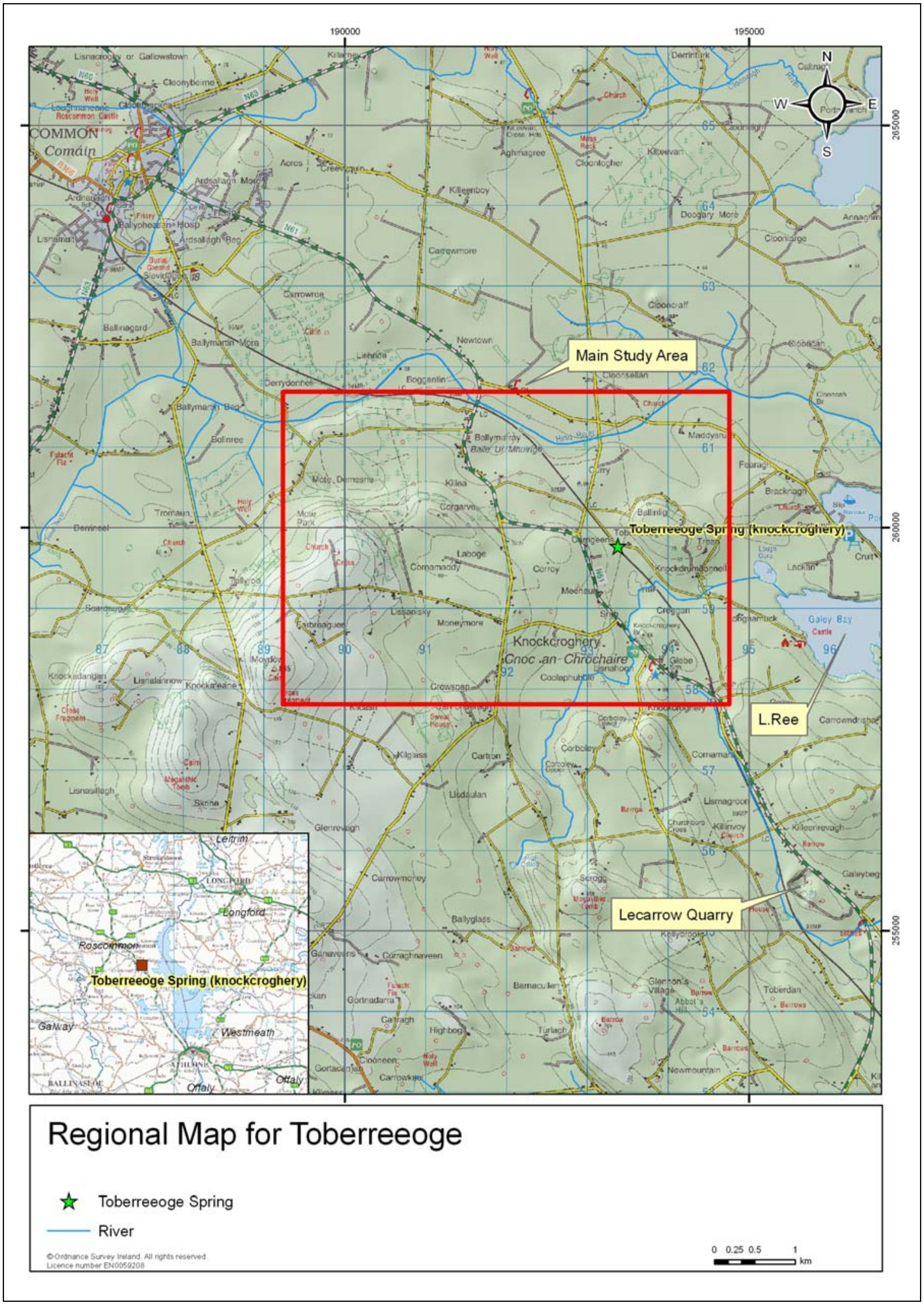

Figure 1 Location Map

Table 3-1 Summary of Source Details

EU Reporting Code	IE_SH_G_091_20_015
Drinking water code	2600PUB1003
Grid reference	E193375 N259772
Townland	Toberreeoge
Source type	Spring
Owner	Roscommon Co Co
Elevation (Ground Level)	Approximately 45 m OD
Depth to rock	Less than 3m
Static water level	Ground level
Abstraction (Co Co records)	6.5 l/s (562 m^3/day) to 9.8 l/s (847 m^3/day)
Measured discharge range (including pumping)	6 – 55 l/s Average 22 l/s
Hours Pumping (Co Co records)	Generally 24 hours /day
Depth of sump	~1m

Plate 1: Toberreeoge (EPA)

4 METHODOLOGY

The methodology comprised data collection, desk studies, site visits, field mapping, discharge/conductivity/temperature measurements at springs and water tracing. A logger was installed by EPA to assist with obtaining information on the discharge. Analysis of the information collected during the studies was used to delimit the SPZ. The water tracing was a multi-tracing experiment at separate input locations using fluorescent dyes with detection by flurometer and spectrometer.

5 TOPOGRAPHY AND LANDFORMS, SURFACE HYDROLOGY AND LAND USE

Figure 1 depicts the topography of the area. The landscape in the immediate vicinity of Toberreeoge comprises two pronounced elevated areas to the northeast and west of the spring respectively, both with an altitude of 60-70 m OD, and located in the townlands of Toberreeoge, Ballinlig, Knockdrumdonnell, Carrigeens, and Corroy. To the north west of Toberreeoge, in the townland of Curry and approximately 900 m from Toberreeoge there is also an elevated area rising to just over 50 m OD. Three to four kilometres west of Toberreeoge, the ground rises to over 160 m OD, comprising a relatively broad and high upland area oriented north south.

Glacial and karst landforms are generally absent in the elevated areas in the immediate vicinity of Toberreeoge. On the major upland area west of Toberreeoge there are numerous enclosed depressions present. Glacial deposits are present across the area but glacial landforms are not very obvious.

There are very few surface water features in the region as can be seen in Figure 1. The main river is the Hind located 1.3 km to the north of Toberreeoge and there is an unnamed stream located 600 m south of Toberreeoge, flowing through Knockcroghery. Both discharge to Lough Ree, just over 2 km east of Toberreeoge. There are seven other springs, including Lough Collog, located in the area shown in Figure 3 and details are given in Appendix 1.

Land use in the study area is principally dairying, cattle and sheep rearing.

6 GEOLOGY

6.1 BEDROCK GEOLOGY

The geological information is based the Geology of Longford and Roscommon (Sheet 12, 1:100,000 Series), Morris *et al*, 2003. The bedrock map shown in Figure 2 indicates that the area is underlain predominantly by Dinantian Pure Bedded Limestones (undifferentiated Visean Limestones). The limestones are pale grey, pure, medium to coarse grained, well bedded and thickly bedded and are almost horizontal. The rocks are best seen in Lecarrow Quarry, located 5 km southeast of Toberreeoge, located on Figure 1. The limestones may be dolomitised in the vicinity of Toberreeoge as dolomitisation has been reported in the limestones in the vicinity of Roscommon town, on the north side of the River Hind (Lee & Kelly, 2003). There are limited data on the structure of the rocks in the area.

6.1.1 Karst Features

Hydrogeological mapping included investigating for karst features in the vicinity of the spring. Figure 2 shows the karst features in the study area and includes those recorded in the GSI Karst Feature Database and those mapped during the field work in 2009 by TOBIN, David Drew (TCD) and Caoimhe Hickey (GSI). The features comprise enclosed depressions and springs. As can be seen the majority of the enclosed depressions are located on the elevated areas and the springs are in the lowest areas. The features mapped as former quarries are not karst features but are old rock quarries.

6.2 SOILS AND SUBSOILS

According to EPA web mapping, the study area is dominated by well drained Basic Mineral Deep Well Drained Soils (BMinDW).

According to the EPA and GSI webmapping the subsoils comprise limestone till (boulder clay) and 'cutover' peat with karstified bedrock outcrop (KaRck) distributed throughout the till areas, generally across the elevated portions of the landscape. Hydrogeological mapping and hand augering by TOBIN, Robert Meehan, Caoimhe Hickey in the immediate vicinity of Toberreeoge revealed a greater extent of shallow rock than previously mapped. The 'cutover' peat is mapped both southeast of Toberreeoge, extending along the overflow channel to the unnamed stream onto Lough Ree and also extensively along the flanks of the River Hind, coincident with the lowermost portions of the landscape. The subsoils, including the area now known to comprise shallow rock are depicted in Figure 3.

The till in the area is mapped as a 'moderately permeable' subsoil (Lee and Daly, 2003). No subsoil exposures were mapped during this specific SPZ study. The secondary indicators, primarily vegetation and drainage indicators for subsoil permeability suggest free draining soils and subsoils, comparing favorably with the regional mapping.

6.3 DEPTH TO BEDROCK

The majority of the upland and elevated areas are considered to comprise depth to rock of less than 3 m with rock outcrops distributed throughout. As indicated in the previous section shallow rock occupies the area to the immediate north of Toberreeoge. In the lowest portions of the landscape depth to rock is considered to be 3-10 m.

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. 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, *et al*, 2003). The Groundwater Vulnerability for the area around Toberreeoge, is dominated by '**Extreme'** to '**Moderate'** vulnerability, shown in Figure 6. The map in Figure 6 includes the additional area of '**Extreme (X) - Rock at surface**', subset of the '**Extreme'** vulnerability category recently mapped for this study.

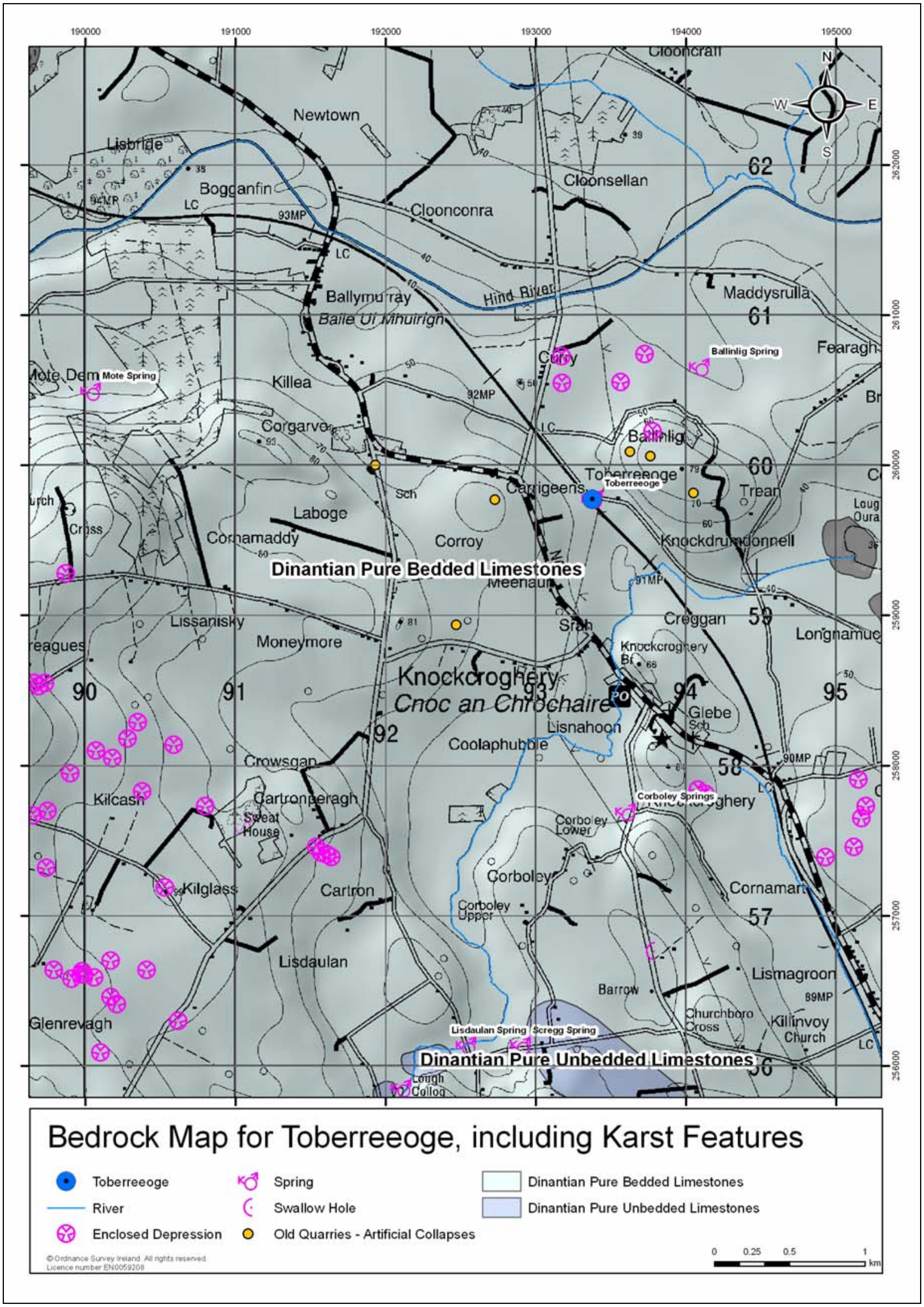

Figure 2 Bedrock Geology

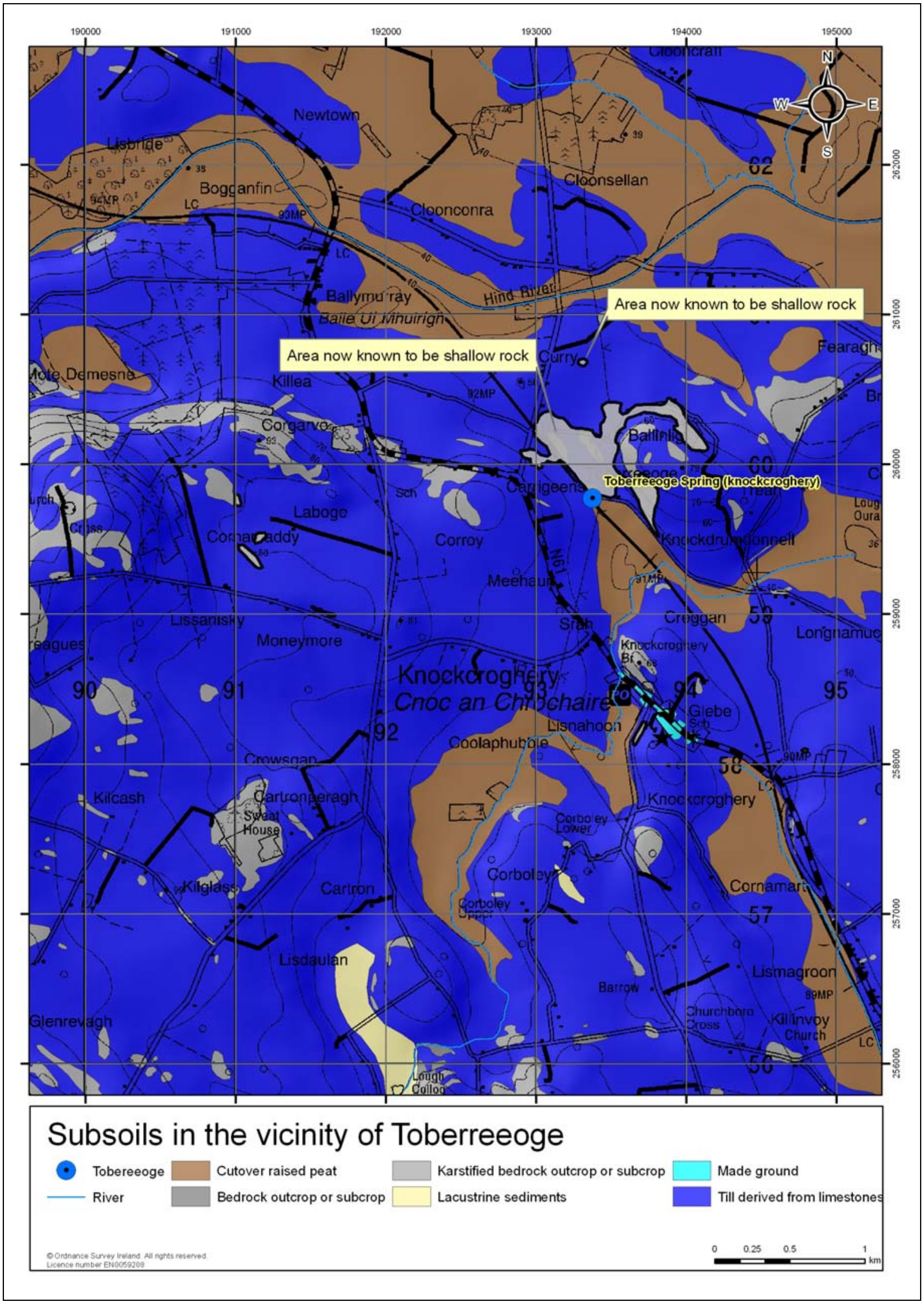

Figure 3 Subsoil Map

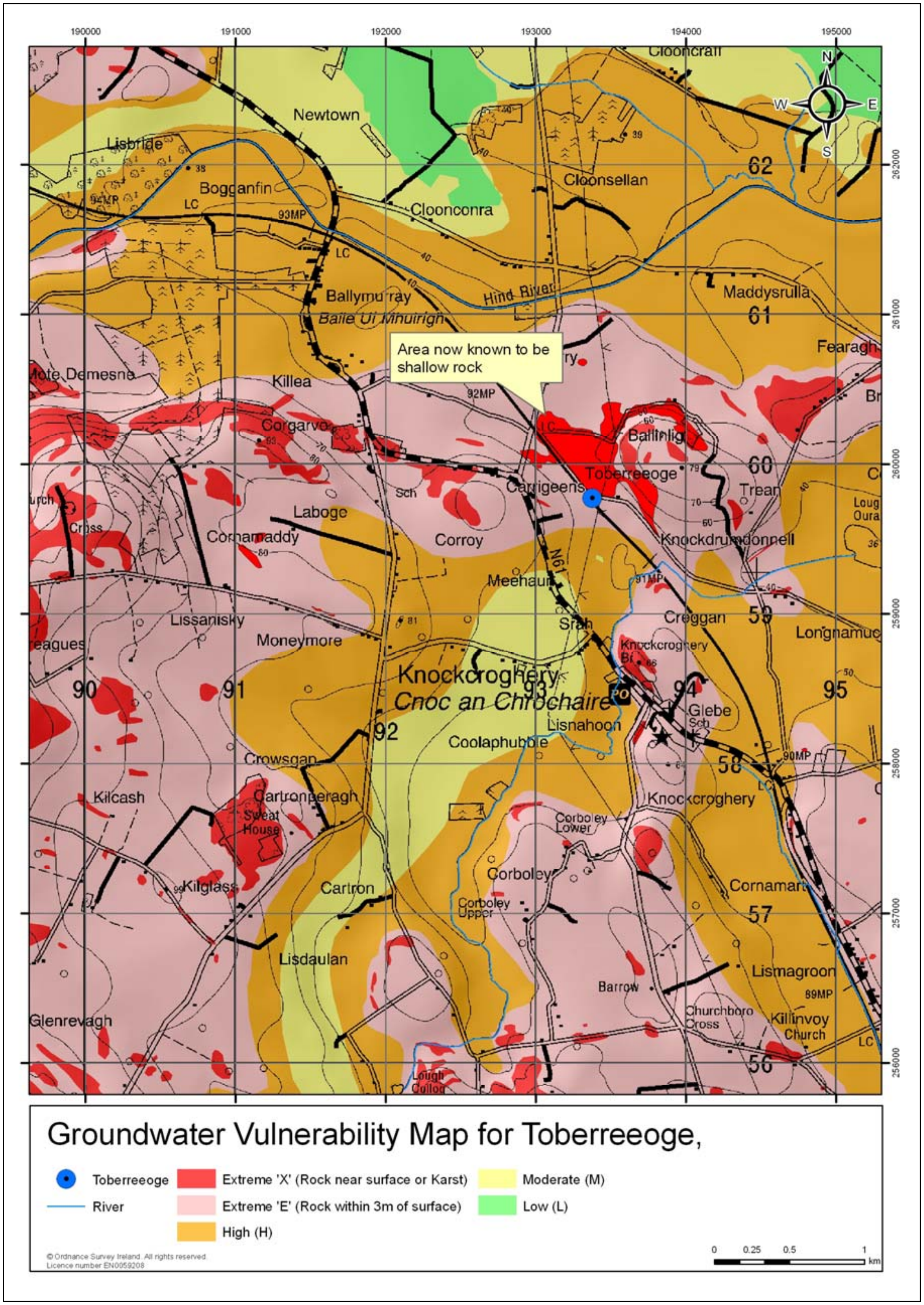

Figure 4 Groundwater Vulnerability

8 HYDROGEOLOGY

This section describes the current understanding of the hydrogeology in the vicinity of the source. Hydrogeological and hydrochemical information was obtained from the following sources:

- ⇨ GSI Website and Database (karst, well)
- ⇨ County Council Staff
- ⇨ EPA website (soils, subsoils mapping)
- ⇨ Local Authority Drinking Water returns
- ⇨ County Roscommon Groundwater Protection Scheme. (Lee and Daly, 2003)
- ⇨ EPA spring discharge data
- ⇨ Hydrogeological mapping by TOBIN, Trinity College Dublin, Geological Survey of Ireland and Robert Meehan in September, October and November 2009.
- ⇨ Tracing by TOBIN, Trinity College Dublin and the Geological Survey of Ireland January 2010.

8.1 GROUNDWATER BODY AND STATUS

The area is included in the Funshinagh Groundwater Body. The overall status is currently classed as Poor Status, due to failure of the Surface Water Quality Test, however, the Groundwater Quality tests currently indicate that the groundwater has Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the following website: www.wfdireland.ie .

8.2 HYDRO-METEOROLOGY AND RECHARGE

Establishing groundwater source protection zones requires an understanding of general hydro-meteorological data for the area of interest. The data source is Met Éireann and is based on the long term available dataset – 1961-1990.

Annual rainfall: taken to be 1100 mm. The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the spring and potential zone of contribution is located between the 1000 – 1200 mm average annual rainfall isohyets.

Annual evapotranspiration losses: taken to be 437 mm. Potential evapotranspiration (P.E.) is estimated to be 460 mm/yr (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.

Annual Effective Rainfall: 663 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to 663 mm/year. See section on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient which takes account of the hydrogeological setting – mainly the groundwater vulnerability. Guidance Document GW5, Groundwater Working Group (2005), provides the information on the appropriate recharge coefficient, which is refined based on the hydrogeological field mapping.

The Groundwater Vulnerability map for the area around Toberreeoge, is dominated by 'Extreme to Moderate' as shown in Figure 6. The hydrogeological mapping indicates that the area is free draining, with large areas of rock close to surface and runoff is therefore considered to be very low.

The bulk ***recharge coefficient*** for the area is therefore estimated to be 95%.

These calculations are summarised as follows:

Average annual rainfall (R)		1100 mm
estimated P.E.		450 mm
estimated A.E. (95% of P.E.)		437 mm
potential recharge		663 mm
runoff	5%	30 mm
Bulk recharge coefficient	95%	
Recharge		**630 mm**

8.3 SPRING DISCHARGE

Figure 2 shows the location of all the outflows mapped in the area and Appendix 1 provides spot flow measurements. They comprise both simple and complex discharge points, located in lowest areas east of the main upland area oriented north – south and are listed as follows:

- Corboley Springs comprises four individual outflows in close proximity, presumed to be linked;
- Ballinlig Spring is clearly dominated by one single outflow though there may be additional smaller outflows close by;
- Scregg Springs comprises two individual outflows;
- Lisdaulan Spring is a single point outflow;
- Lough Collog is considered to be an outflow;
- Mote Spring a single point outflow; and,
- Toberreeoge is a single point outflow.

A crude approximation of the outflows using the data in Appendix 1 indicates a total ranging from 120-350 l/s. The approximate topographic area that could recharge the springs, estimated to be the area on the east side of the plateau is in the order of 15-16 km^2. A recharge figure of 630 mm/yr could potentially generate over 320 l/s, thus suggesting spring discharges account for a considerable proportion of the groundwater flow.

Toberreeoge:
A water level logger was put into the sump by EPA Hydrometric Staff at Toberreeoge to provide continuous discharge data, and data was obtained from 18th September 2009 to 2nd June 2010. Figure 5 displays a hydrograph for Toberreeoge. It also includes rainfall and abstraction. The time discharge series shown in Figure 5 shows that the response of Toberreeoge to rainfall is very rapid and flashy. The data for April appears to be an error as the discharge would have been expected to respond to the rainfall events at the start of April 2010. The data are supplemented with spot measurements taken twice in 2008, 2005 and once in 2004 and 2003 by Hydrometric Staff, EPA. A longer data record is required to establish a fully calibrated rating curve.

Abstraction from Toberreeoge:
The mean abstraction represents about one third of the total outflow. According to the caretaker, abstraction ranges from 6.5 l/s (562 m^3/day) to a maximum of 9.8 l/s (847 m^3/day) depending on demand, variation in pressure across the network including the distribution at Lecarrow, and weather. Highest abstraction rates generally occur from April to August at 7.4-9.8 l/s and lowest abstraction rates occur from October to February at 6.5-6.9 l/s. The uppermost abstraction of 9.8 l/s is infrequent and the usual upper rate is 9.1 l/s. The average abstraction is 7 l/s (605 m^3/day). A summary of the discharge is given below, which is based on the data provided in Appendix 2.

Summary Total Discharge (overflow and abstraction) Statistics for Toberreeoge:

- Range: 6-55 l/s (560 – 4,750 m^3/day)
- Median: 17.2 l/s (1,483 m^3/day)
- Modal Value: 17.9 l/s (1,542 m^3/day)
- Arithmetic mean: 22.3 l/s (1,860 m^3/day)

With respect to the range, there was no spring overflow in November 2003 and October 2005, both very dry weather periods, thus the value corresponds to the abstraction on that day. An exceptionally high overflow was measured in November 2005 – a total flow of 189 l/s, however, there is anecdotal evidence indicating that the flow had a significant contribution from road runoff, therefore this data is ignored in estimating the outflow. Subsequent work on the sump and the road has ensured that road runoff cannot enter the sump.

Recent daily rainfall data was obtained from Met Éireann for Claremorris Weather station, approximately 50 km northwest of Toberreeoge, and is shown in the spring hydrograph in Figure 5. It can be seen the spring reacts quickly to rainfall. The hydrograph, albeit relatively short with respect to typical river hydrographs indicates two relatively low 'dry' periods bounding a very wet period from mid-November through to February 2010 – a period of 74 days, also a period of very little if any evapotranspiration. The total rainfall amount over that period is equal to 554.2 mm. The total outflow from Toberreeoge is approximately 296556 m^3. Applying the rainfall to the ZOC described above generates a flow of 554200 m^3. Comparing the two figures suggests that the flow from Toberreeoge accounted for 60% of the rainfall over that period.

8.4 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

There are few direct hydrogeological data on groundwater levels. The lakes and rivers are assumed to be the regional hydraulic boundaries and the main upland area is assumed to be the main control on groundwater flow direction. Thus the regional groundwater flow directions are assumed to be principally from the elevated areas towards the River Hind, the unnamed stream to which Toberreeoge discharges to and Lough Ree. Figure 6 shows the regional flow patterns.

The springs, shown in Figure 2 and 6, including Toberreeoge occur on the lowermost portions of the landscape, generally at 40 to 50 m OD. The springs (Mote and Ballinlig) on the northern side of the hills discharge to the River Hind. Toberreeoge and the springs south of Knockcroghery discharge to the unnamed stream which flows to Lough Ree. It is considered that the River Hind, the unnamed stream and Lough Ree are the main groundwater discharge zones, whilst the springs are focal points for localized groundwater subcatchments. Thus at Toberreeoge it is considered that the main groundwater flow direction to Toberreeoge is from the northeast, north and northwest, i.e, the hilly ground in the immediate vicinity drive groundwater toward Toberreeoge, shown in Figure 6.

Groundwater gradients are estimated to range from 0.01 to 0.001 using the tracer input sites and the springs and the unnamed stream to which Toberreeoge discharges to. The elevation of the input sites is expected to higher than the water table except in wet weather periods, therefore the true groundwater gradients are likely to be closer to 0.001.

8.5 AQUIFER CHARACTERISTICS

The Dinantian Pure Bedded Limestones (undifferentiated Visean Limestones) that are mapped across the area are classified as a Regionally Important Karst Aquifer (Rk^c) – dominated by conduit flow. Karstification is the process whereby limestones are slowly dissolved away by acidic waters moving through them. This most often occurs in the upper bedrock layers and along some of the pre-existing fissures and fractures in the rocks, which become slowly enlarged. One of the consequences of karstification is the development of an uneven distribution of permeability which results from the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones.

These karstified limestones provide the groundwater to Toberreeoge. Karst springs generally indicate very high transmissivities, permeabilities and velocities in the vicinity of springs. However, as with most karstic systems, permeability and transmissivity data are very variable. Large scale test pumping carried out in the limestones at Roscommon indicate that transmissivity ranges from 60 m^2/day to 180 m^2/day (Lee and Kelly, 2003). Tracer testing carried out in the vicinity of Roscommon town for the Ballinagard PWS indicates velocities of 25 m/hr or 600 m/d (Lee and Kelly, 2003).

Karst mapping undertaken in the Toberreeoge area identified enclosed depressions and springs and there are numerous enclosed depressions on the main upland area west of Toberreeoge. A tracing test was carried out during January and February 2010 to attempt to characterise dominant flow directions, typical flow rates and distinguish the likely zone (s) of contribution to Toberreeoge Spring. Fluorescein was recovered approximately 70 hours at Ballinlig Spring (NGR 194085 260653) after injection into enclosed depression (NGR 193779 260226) approximately 520 m to the northeast of Ballinlig Spring, shown in Figure 6. This gives a velocity of 7.5 m/h or 180m/d. Further, anecdotal evidence suggests that there is a rapid underground connection between the land at Curry and Toberreeoge.

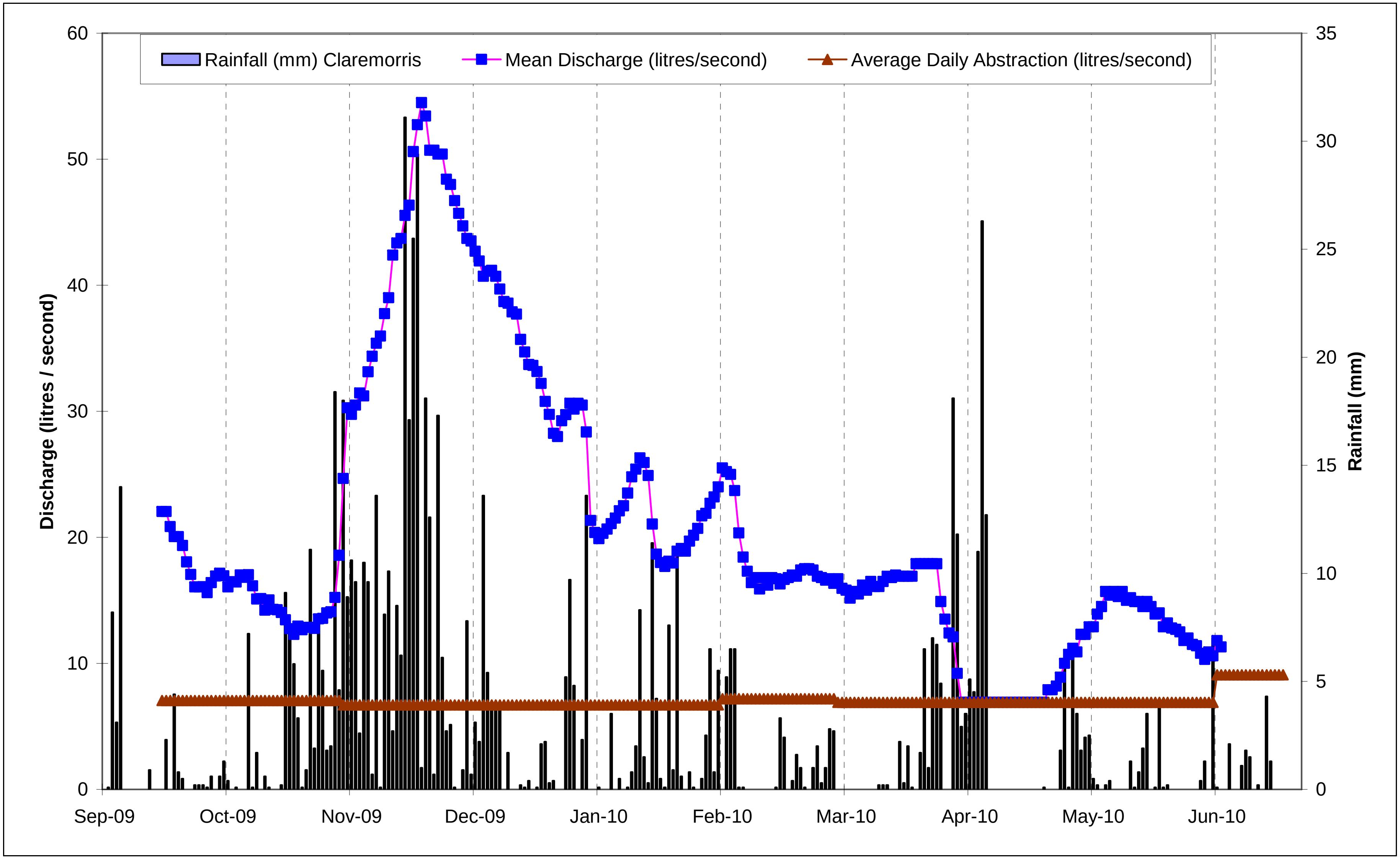

Figure 5 Time discharge series for Toberreeoge from September 2009 to June 2010 (EPA)

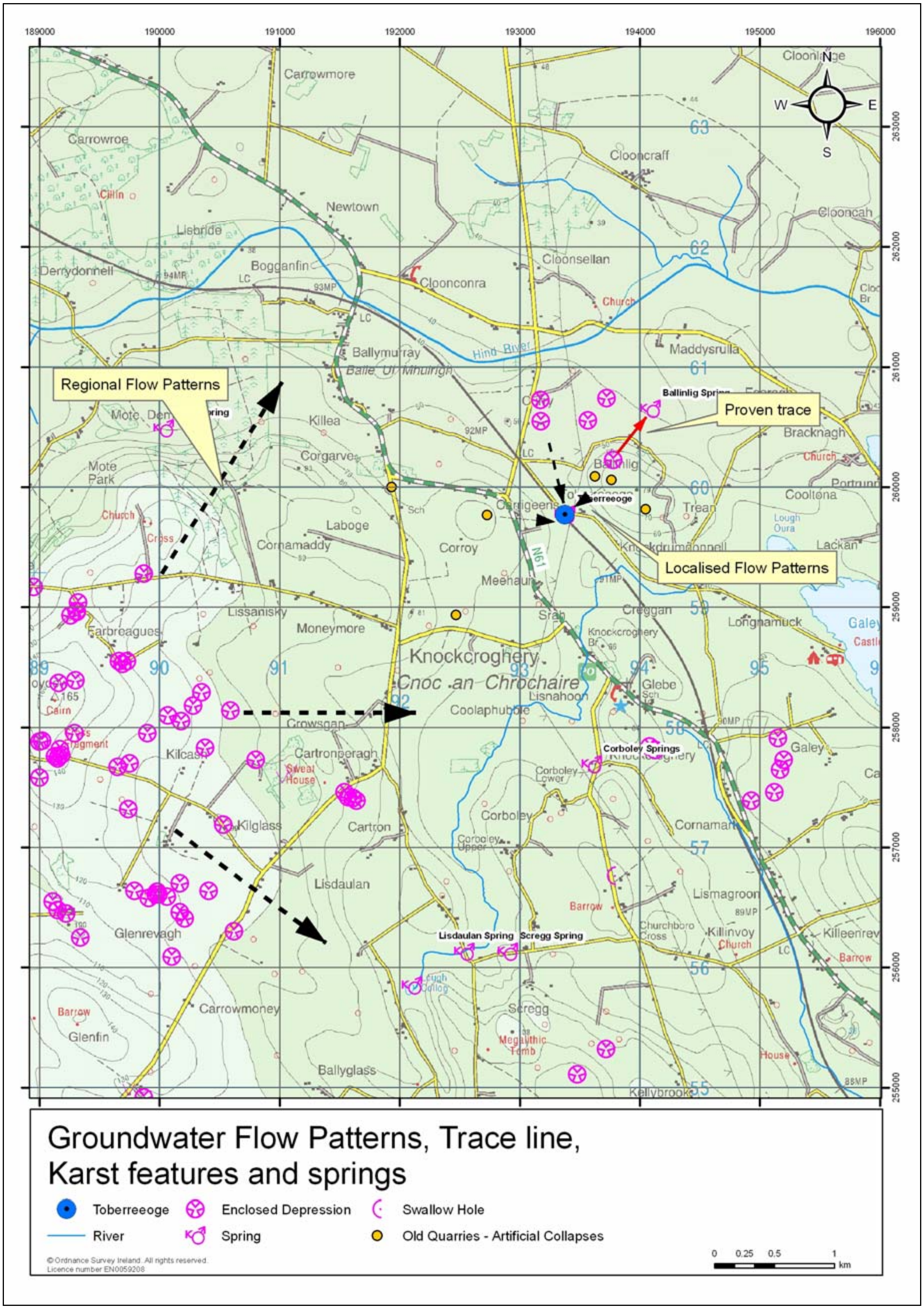

Figure 6 Regional flow patterns and localised flow patterns around Tobereeoge

8.6 HYDROCHEMISTRY AND WATER QUALITY

The hydrochemical analyses of 32 untreated samples show that the water is hard to very hard, with total hardness values of 204-372 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity (EC) values of 558-646 µS cm^{-1}, (average 613 µS cm^{-1}) indicating that the groundwater has a calcium bicarbonate hydrochemical signature (EPA data). The coefficient of variance of electrical conductivity of approximately 10% is relatively low compared to other karst springs suggesting diffuse and point recharge exist (Doak 1995).

Figure 7 shows the data for the key indictors of contamination and the main points are as follows:

- Nitrate concentrations range from 5-17.5 mg/l with a mean of 13 mg/l from 32 samples. There are no reported exceedances above the EU Drinking Water Directive maximum admissible concentration (MAC) of 50 mg/l, or the groundwater threshold value (Groundwater Regulations, S.I. No 9 of 2010). A trend line plotted through the entire dataset shown in Figure 7 is relatively flat, indicating that Nitrate concentrations are neither rising or falling over the 1995-2008 period. However, there is a seasonal trend, rising concentrations during the autumn and early winter, generally peaking in January / February. The increase in sampling from 2007 onwards should provide further information on the trends and peaks.

- Chloride concentrations range from 14-19 mg/l with a mean of 16 mg/l. No samples are above the groundwater threshold value for saline intrusion test (Groundwater regulations S.I. No 9 of 2010) of 24 mg/l.

- The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated along with other parameters and may indicate contamination if the ratio is greater than 0.035-0.4. From 32 analyses, the ratio exceeded 0.035 on two occasions: 23/11/1995 and 4/10/2008.

- The average concentration of Molybdate Reactive Phosphorous (MRP) is 0.039 mg/L P, which exceeds the Groundwater Threshold Value (Groundwater Regulations S.I. No 9 of 2010) of 0.035 mg/L P.

- Faecal coliforms counts were exceeded on 18 occasions out of 31 samples, with 5 records of gross contamination. Total coliform counts were exceeded on 29 occasions out of 31 samples. Ammonia concentrations are generally less than 0.01 mg/l, though twice have exceeded the groundwater threshold value of 0.065 mg/l (Groundwater Regulations S.I. No 9 of 2010) on 20/7/2007 and 14/10/2008, both coinciding with an exceedance of both faecal and total coliforms and once with elevated MRP.

- Iron and manganese concentrations are generally low but on two occasions 26/9/2000 and 10/10/2005 (LA records), Iron concentrations were recorded at 0.631 mg/l and 0.259 mg/l, greater than 0.2 mg/l (EU MAC).

In summary, bacteriological exceedances, occasionally elevated ammonia, iron, potassium sodium ratios, regularly elevated MRP suggest contamination from an organic waste source. The shallow bedrock and Extreme Groundwater Vulnerability provide a quick ‘pathway’ for MRP, ammonia and bacteria to get to Toberreeoge. Anecdotal evidence suggests a very rapid response to pollution events from areas dominated by shallow rock and outcrop at the surface. The water quality suggests a rapid throughput to the spring with very little protection from the thin subsoils.

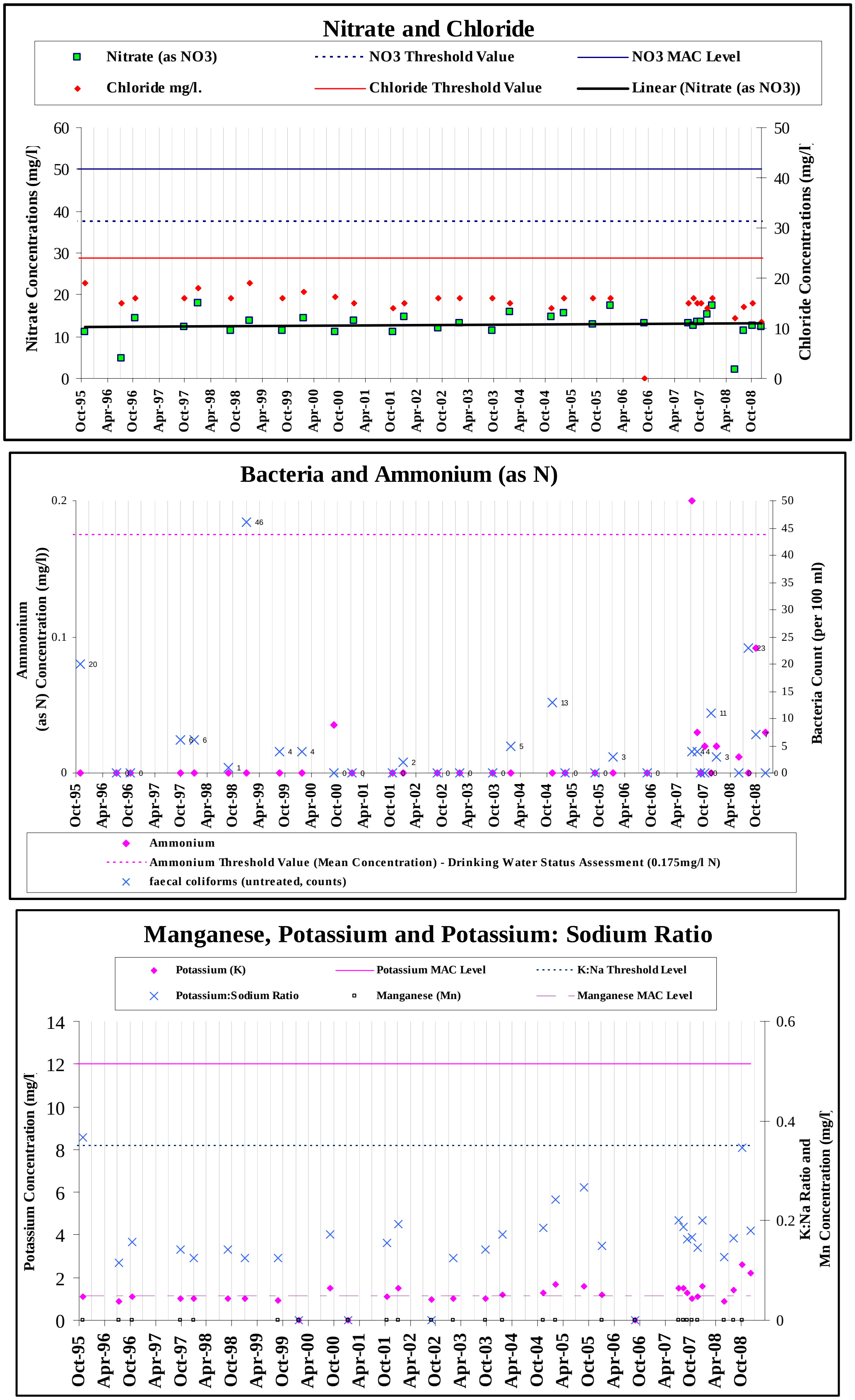

Figure 7 Key indicators of contamination

8.7 CONCEPTUAL MODEL

- The region is underlain by karstified limestones with little surface drainage and the study area is dominated by the main north-south oriented plateau area which forms the regional topographic and groundwater divide. The broad regional model is groundwater flow is radially outwards – on the eastern side of the plateau to the several springs on the lowest areas of the landscape and ultimately to the assumed regional hydraulic boundaries of the River Hind and Lough Ree.

- Toberreeoge is a single outflow located to the northeast of the main plateau between the River Hind and Lough Ree. It occurs at a topographic break in slope on the edge of the low land area. It is considered that the elevated ground in the immediate vicinity channels and funnels groundwater towards the spring, occupying a subcatchment between the plateau and the main regional hydraulic divides.

- Due to the presence of thin moderately permeable subsoils and free draining soils the groundwater feeding Toberreeoge is 'Extremely' Vulnerable; evidenced by bacteriological exceedances, occasionally elevated ammonia, iron, potassium sodium ratios, regularly elevated MRP - suggesting contamination from an organic waste source.

- The response of Toberreeoge to rainfall is very rapid and flashy. A water trace connecting an enclosed depression at the top of the hill immediately north east of Toberreeoge to Ballinlig Spring (on the opposite side of the hill to Toberreeoge) indicates velocities in the order of 7.5 m/h or 180m/d and also suggests that the hill acts as a local groundwater divide. Further anecdotal evidence of a pollution event in the vicinity of the spring indicates very rapid groundwater velocities.

- Limitations to the conceptual model mainly lie with a lack of information on the following:

  ⇨ Detailed water levels.

  ⇨ Uncertainty in groundwater flow directions, and therefore the boundaries.

  ⇨ Long term flow data.

9 DELINEATION OF SOURCE PROTECTION AREAS (SPA)

This section describes the delineation of 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 to the source, as described in the Conceptual Model.

Two source areas are delineated:

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

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 supporting the total outflow from long-term recharge.

The size of the ZOC is a function of:

- the total outflow
- the recharge in the area.

The location of the ZOC is a function of:

- the groundwater flow direction and gradient
- the subsoil and rock permeability.

The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

In the study area there is limited information on groundwater flow patterns and flow data from Toberreogoe and the other springs. Therefore to delineate the true contributing area is difficult. The following table summarises estimations for deriving the zone of contribution to Toberreeoge. It is considered the most likely area is in the region of 1 km^2.

Table 9-1 Estimations of flow, recharge and contributing area to Toberreeoge

Max Flow (l/s)	55
Min Flow (l/s)	6.5
Likely representative Flow (l/s)	**21**
Min recharge %	60
Max recharge %	100
Likeliest recharge %	**95**
Max probable ZOC (km^2)	2.6
Min probable ZOC (km^2)	0.3
Most likely ZOC (km^2)	**1.0-1.5**

Primarily based on topography, hydrogeological mapping and groundwater flow assumptions the most likely zone of contribution is delineated as follows and is shown in Figure 8.

The **Eastern and Northeastern** boundaries are constrained by a topographic ridge and water tracing. The successful trace to Ballinlig Spring on the other side of the hills provides considerable confidence in delineating the northern element of the ridge as the boundary. There is uncertainty regarding the **eastern** boundary – it is based on hydrogeological mapping. The tracing programme was unsuccessful in enabling greater confidence in delineating this boundary. Whilst the topographic grain at the eastern end of the hill at Knockdrumdonnell suggests flow direction to the south the karst terrain is topographically higher than the spring and potentially flow could be against the grain to northwest.

The **Southern** boundary is based on the location of Toberreeoge itself; it is assumed that groundwater cannot flow back up to the spring. Joining this boundary with the eastern boundary is difficult, and is based on hydrogeological mapping and is conservative. Similarly extending this boundary westwards is difficult.

The **Western and Northern** boundaries are difficult to delineate; they are based primarily on topography. The tracing programme was unsuccessful in enabling greater confidence in delineating this boundary. Evidence of a pollution event linking the area to the north of Toberreeoge to the spring shows groundwater flow direction and therefore provides confidence to the northern portion of the ZOC.

The area delineated by the boundaries described above is approximately 1.12 km^2, and is considered to conservative and captures the most likely contributing area.

9.2 INNER PROTECTION AREA

The Inner Source Protection Area is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the source is calculated from the velocity of groundwater flow in the bedrock. The velocities are normally based on the results of the hydraulic test programme, however, in this instance, the Regionally Important Karst aquifer category, suggests that very rapid groundwater velocities are likely in this area due to karstification of the limestones. Groundwater flow can be focused and travel very fast. Results from tracing programmes indicate velocities in the order of hundreds of metres/day. On this basis, all of the ZOC is designated as part of the inner protection area to the source.

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Figure 8 and are based on an overlay of the source protection areas on the groundwater vulnerability. There are two source protection zones (SPZ) defined: SI/E and SI/X (a subset of SI, where rock is close to surface).

Table 10-1 Source Protection Zones

Source Protection Zone	Area (km^2)	% of total area (1.12 km^2)
SI/X (Rock close)	0.26	24
SI/Extreme	0.86	76

11 POTENTIAL POLLUTION SOURCES

Though detailed assessments of hazards have not been carried out as part of this study, it is noted that there are many houses and farmyards within the ZOC. Land use in the vicinity of the source is described in Section 5; within the ZOC, livestock and pasture is the main land use.

The hydrochemical data indicate significant contamination or pollution of the spring source by nitrate, with chloride also relatively high. Coliforms, many of these faecal, are often present in the untreated water.

The main hazards associated with the ZOC are considered to be agricultural (farmyard leakage, landspreading of organic and inorganic fertilisers) and potential oil/petrol spills. Though domestic septic tank and other treatment systems are not a major problem as is, the installation of any new systems should be monitored closely. The location of any of these activities in any part of the ZOC categorised as ‘extremely’ vulnerable presents a potential risk, given rapid travel time through the underlying bedrock and lack of attenuation by subsoils. These are delineated as red zones on Figures 5 and 8, and the main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and Cryptosporidium.

As well as this, there are some private home heating fuel tanks located within the catchment area. The main potential contaminants from this source are hydrocarbons. There is currently no evidence of any contamination from hydrocarbons at the source.

Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

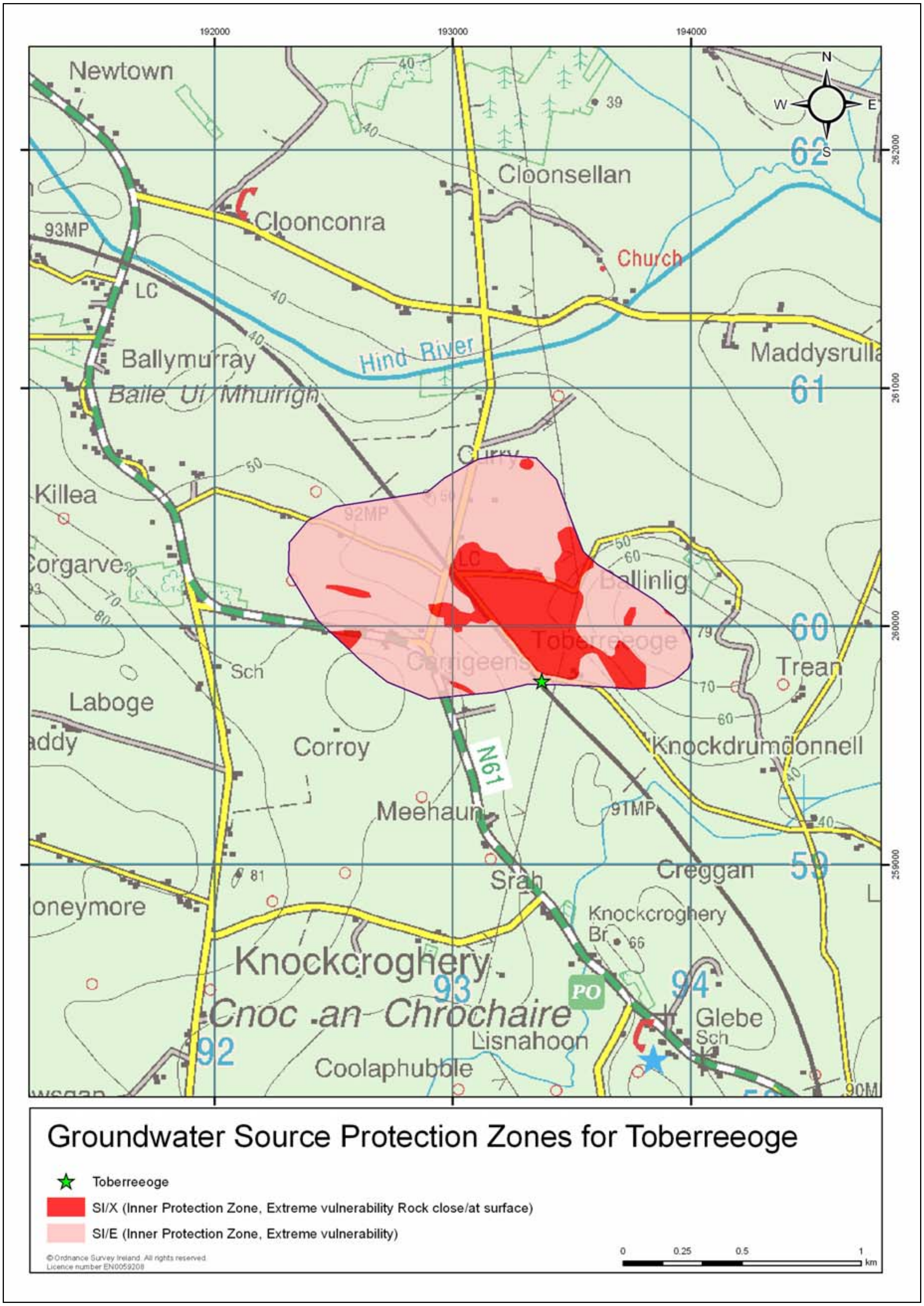

Figure 8 Source Protection Zones for Toberreeoge

12 SUMMARY

- Toberreeoge is located in the Dinantian Pure Bedded limestones which is a Regionally Important Karstified Aquifer.
- The Source Protection Area has been delineated using hydrogeological mapping techniques and water tracing and is considered to represent the most likely contributing area. There are inherent uncertainties with the boundaries, in particular the western boundary is difficult to delineate.
- Due to the rapid groundwater velocities, it is considered that groundwater in any part of the ZOC could potentially reach the source within 100 days. Therefore the entire ZOC is classified as the Inner Protection Area.
- The groundwater vulnerability in the Source Protection Area is 'Extreme' and there is a significant proportion with rock at or very close to the surface.
- Available data shows the intermittent presence of faecal coliforms in the untreated water. This suggests contamination from an organic waste source, and also provides evidence on the extreme vulnerability and rapid velocities and lack of natural attentuation.
- The Source Protection Zones delineated in this report are based on the current understanding of groundwater conditions and on the available data. Additional data obtained in the future might indicate that amendments to the boundaries are necessary, and the conclusions should not be used as the sole basis for site-specific decisions. Sources of error are due to limited discharge data, lack of trace data and groundwater level data.

13 RECOMMENDATIONS

1. Continued measuring of flow data should be carried out to develop a real-time database of hydrogeological information allowing better estimates of representative discharge.
2. High resolution water quality sampling of the **untreated** water should be carried out.
3. The entire Source Protection Area comprises **'Extreme'** Groundwater Vulnerability with a component with rock at or close to surface. It is recommended therefore that an adequate barrier to Cryptosporidium must be installed as part of the water treatment system for the supply.
4. The potential hazards in the ZOC should be located and assessed, especially given the number of farmyards and houses up-gradient of the source in the ZOC.
5. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the spring or adversely affect the spring (for example groundworks or excavations).

14 REFERENCES

DELG/EPA/GSI (1999) Groundwater Protection Schemes. Department of the Environment and Local

Government, Environmental Protection Agency and Geological Survey of Ireland.

Doak, M. 1995. The Vulnerability to pollution and hydrochemical variation of eleven springs (catchments) in the karst lowlands of the west of Ireland. M Sc. Thesis, Sligo RTC, 52 pp.

Groundwater Regulations (S.I. 9 OF 2010): European Communities Environmental Objectives (Groundwater) Regulations 2010.

Lee, M. and Daly, D. County Roscommon Groundwater Protection Scheme. 2003. Geological Survey of Ireland, pp84.

Lee, M. and Kelly, C. 2003. Groundwater Source Protection Zones for Ballinagard Spring and proposed production boreholes. Roscommon Central Regional Water Supply Scheme. Geological Survey of Ireland, pp21.

Morris, J.H., Somerville, I.D., and C.V. MacDermot. Geology of Longford and Roscommon: A Geological Description, with accompanying Bedrock Geology 1:100,000 Scale Map, Sheet 12, Longford – Roscommon. Geological Survey of Ireland.

APPENDIX 1 OVERVIEW OF SPRINGS AROUND TOBERREEOGE AND KNOCKCROGHERY

Spring Name	Coord	Height mOD	Low flow (l/s)	High flow (l/s)	Spot Flows
Toberreeoge	193376 259773	48	22.4	~40?	22 l/s on 15/10/09 22 l/s on 29/10/09 38 l/s on 18/01/10 (snow melt and ground thaw) 32 l/s on 25/01/10 (during trace injection) Conductivity 600; temp 10^{o}C
Scregg Springs	192897 256133	59	6		6 l/s on 26/08/09 Not visited on 15/10/09 9 l/s on 29/10/09
Lough Collog and Lisdaulan spring	At road 192534 256133	63 At road	22.9		High Flows 135 l/s 26/08/09 (where it's combined under road) 43 l/s on 15/10/09 23 l/s on 29/10/09
Corboley Springs	193596 257691	48	50	99	Comprises four springs ~ total estimate 25 l/s on 26/08/09 50 l/s on 29/10/09 99 l/s on 18/01/10 (snow melt and ground thaw) Conductivity 580; temp 9^{o}C (downstream of springs)
Ballinlig Spring	194085 260653	36	??	??	3.6 l/s on 26/08/09 No discharge on 15/10/09
Mote Spring	190032 260490	50	8.5	45?	13 l/s on 1/10/09 9 l/s on 15/10/09 10 l/s on 29/10/09 45 l/s on 18/01/10 (snow melt and ground thaw) 39 l/s on 25/01/10 (during trace injection) Conductivity 678; temp 9^{o}C (downstream of spring)