Louth County Council

Establishment of Groundwater Source Protection Zones

Omeath Water Supply Scheme

Lislea Cross Borehole

July 2014

Revision: D

Prepared by:
Peter Conroy
On behalf of the Geological Survey of Ireland

With contributions from:
Dr. Robert Meehan, Consultant Geologist; Jenny Deakin TCD; Natalya Hunter-Williams, GSI
And with assistance from:
Louth 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.

Louth County Council contracted GSI to delineate source protection zones for eight groundwater public water supply sources in Co. Louth. The sources comprised Ardee, Cooley (Carlingford and Ardtullybeg), Collon, Greenore, Termonfeckin, Omeath (Lislea Cross and Esmore Bridge), Drybridge and Killineer.

This report documents the delineation of the Lislea Cross Source Protection Zones.

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

TABLES, FIGURES & APPENDICES

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Lislea Cross Borehole source and reserve borehole 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 Source Protection Zone Delineation.

The Lislea Cross borehole source supplies drinking water to the town of Omeath on the Cooley Peninsula in northeast Co. Louth. The borehole abstraction supplements a surface water abstraction located 125 m south southwest of the borehole on a west to east flowing mountain stream. The stream is called the Lislea Stream in this report. There are a further two boreholes associated with the scheme in the Lislea Cross area, one of which is a reserve borehole for the Lislea Cross Borehole and the other of which is abandoned. It is not known why the latter borehole has been abandoned, however it is assumed that the borehole was low yielding and that this was the reason. Both boreholes are located approximately 370 m east of the Lislea Cross borehole.

As well as this, Omeath Water Supply Scheme abstracts groundwater from another borehole source at Esmore Bridge, adjacent to the Ryland River 1 km to the south of Omeath village centre. This borehole was constructed in 1984, independently of the Lislea Cross borehole developments. This source is dealt with in a separate report.

The nomenclature adopted for this report for the various water supply sources associated with the scheme is shown in Table 1. The locations of the various sources are shown in Figure 1.

Table 1 Nomenclature for Omeath WSS water supply sources

Source Name	**Description**
PWSBH01	Lislea Cross Borehole
PWSBH02	Esmore Bridge Borehole
PWSBH03	Lislea Cross Reserve Borehole
PWSBH04	Abandoned borehole drilled in the vicinity of Lislea Cross
PWSSW01	Surface Water abstraction point at Lislea Cross

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the source.
- To delineate source protection zones for the Lislea Cross borehole.
- To assist the Louth County Council in protecting the water supply from contamination.

Groundwater protection zones are delineated to help prioritise the area around the source in terms of pollution risk to groundwater. This prioritisation is intended as a guide in evaluating the likely suitability of an area for a proposed activity prior to site investigations. The delineation and use of groundwater protection zones is further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The maps produced are based largely on the readily available information in the area, a field walkover 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.

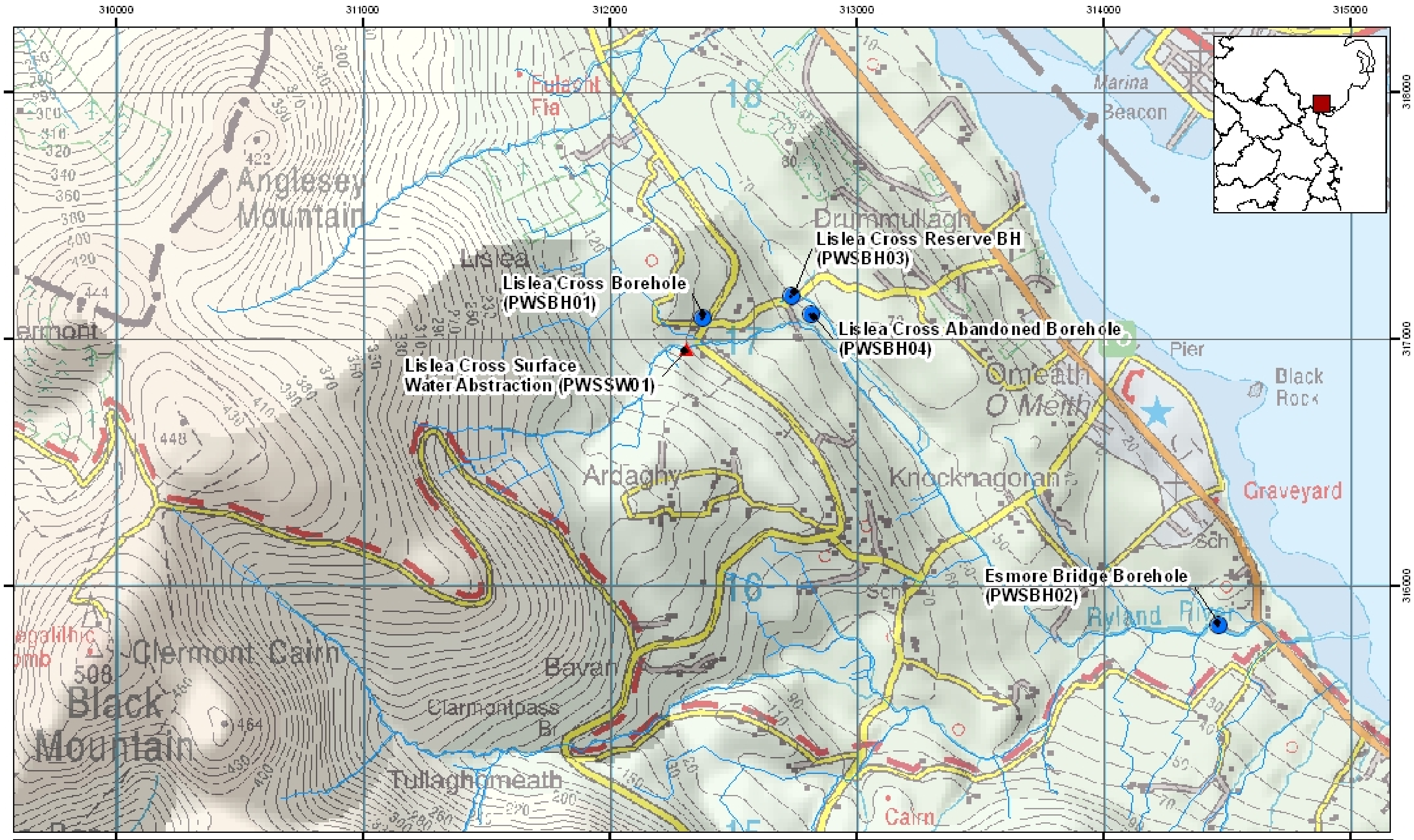


Figure 1 Omeath - Lislea Cross Site Location Map

PWS Abstraction

Stream

Surface Water Abstraction

0 0.25 0.5 0.75 km

2 METHODOLOGY

A desk study of existing data sources relevant to the source was carried out prior to a site visit. Site visits and site walk-overs and field mapping of the study area were conducted on 30/04/2010 and 29 & 30/06/2010. An interview with the source caretaker was carried out on 30/04/2010, and a 10 hour pumping test of the source borehole was conducted on 30/06/2010. A depth to bedrock drilling programme was carried out by the GSI during May 2007 to investigate the subsoil geology, the hydrogeology and vulnerability to contamination of the study area.

The locations of the point features investigated during the site visits and identified during the desk study are shown in Figure 2. A summary table of the point data collected during the site visits and field mapping is provided in Table A1.1a in Appendix 1.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

Borehole PWSBH01 is located in the townland of Lislea approximately 1.5 km west of Omeath village centre, adjacent to Lislea cross-roads on the local road between the townlands of Knocknagoran and Cornamucklagh, as shown in Figure 1. The source is located inside a small compound in the northwestern quadrant of the crossroads.

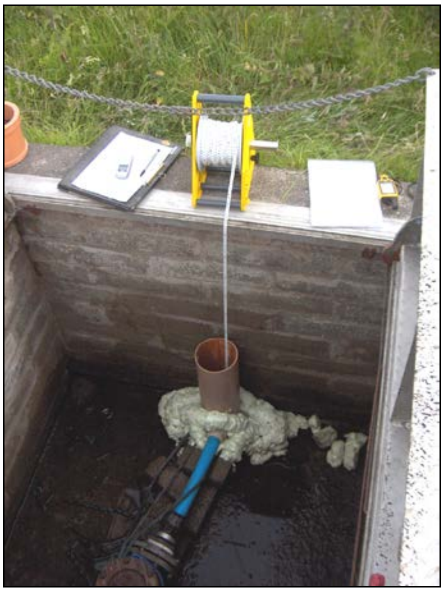
The compound surrounding the source is approximately 10 m by 10 m in area. The compound is surrounded by a 1.2 m high fence comprising a wooden post and rail fence along its southern boundary and a concrete post and wire fencing suitable for preventing access by sheep across the remaining boundary length.

The compound has a permeable, grass surface. Borehole PWSBH01 is located inside a sunken, block built chamber with a concrete floor and roof. The roof of the chamber has a lockable, hinged, steel lid, which keys down over a steel rim fixed to the chamber roof. The chamber is approximately 1.5 m by 1.5 m in area and is approximately 1.2 m deep. The roof of the chamber and the rim of the steel lid stand approximately 0.15 m above ground level. The chamber and lid provide a secure housing for the borehole. The chamber contains the borehole headworks and rising main and an adjacent valve assembly. There is no sampling tap at the borehole (or elsewhere) to allow collection of untreated groundwater samples. Untreated samples of the abstracted water are collected from the outfall of the rising main into a manifold at the water treatment works approximately 150 m east of the borehole. The site layout and borehole chamber can be seen in Photographs 1 to 3 below.

The mouth of the borehole is formed by a recently–fitted, nominal 150 mm diameter orange PVC tube, fitted over the original nominal diameter 150 mm steel casing of the borehole. The borehole is also fitted with a 125 mm diameter PVC liner which does not extend up to the mouth of the borehole. The steel casing sticks up approximately 0.15 m above the chamber floor. The orange PVC tube sticks up approximately 0.6 m above the chamber floor and is has been stuck to the steel casing using expanding foam. The orange PVC tube was fitted as a measure to prevent flooding in the borehole chamber from flowing into the mouth of the borehole. During site visits in April and June of 2010, the borehole chamber floor was wet but was not flooded. Flooding of the chamber during wet weather may occur, owing to drainage into the chamber *via* cable ducts. There is currently no drain to remove flooding from the chamber.

The borehole log records that a grout seal was not installed during the construction of the borehole.

Photograph 1 View of Site Compound from east



Photograph 3 View of borehole and borehole chamber

Photograph 2 Plan view of borehole PWSBH01

Photograph 4 Borehole PWSBH03

4 SUMMARY OF BOREHOLE DETAILS

A copy of the driller's borehole log for borehole PWSBH01 was provided by Louth County Council and is included in Appendix 1. The borehole was drilled in August 1997 by Des Meehan & Co (N.I.) Ltd on behalf of Louth County Council, as part of a contract to drill three boreholes in the vicinity of Lislea Cross. The drilling was carried out to provide a supplementary source for the nearby surface water abstraction PWSSW01, which proved insufficient to meet demand during periods of prolonged drought. The two other boreholes drilled in 1997 have been labeled PWSBH03 and PWSBH04 in this report. Borehole PWSBH01 and the other boreholes drilled in 1997 have been assigned various names over their lifetime to date. The various names used to date are detailed in Table A1.1 of Appendix 1.

Borehole PWSBH01 was drilled to a depth of 110 mbgl using a rotary percussion drilling rig and compressed air as the drilling fluid. The borehole was lined with nominal 150 mm diameter mild steel casing to 5.19 mbgl and was lined with slotted, 115mm internal diameter PVC casing from 0 to 110 mbgl. Table 2 provides a summary of the well details.

The well was developed with the drill rods at 90 mbgl for 9 hours giving rise to an estimated yield of 345 m^3/day. The borehole was not subjected to a pumping test prior to commissioning although a short pumping test at the current abstraction rate was carried out as part of this investigation which is detailed in Section 8.5. The individual abstraction rates from borehole PWSBH01 and surface water abstraction PWSSW01 are not recorded routinely. Only their combined abstraction rate is recorded routinely.

Borehole PWSBH01 is pumped continuously. Monitoring on the 30th of June 2010 during this investigation indicates that the current abstraction rate is approximately 79 m^3/day. The water is chlorinated in conjunction with water from a nearby surface water abstraction (SW01) at a treatment plant approximately 100 m downhill to the east of the source. The source caretaker indicated that iron and manganese encrustation is a problem at the borehole. As a result of encrustation, the submersible pump is replaced approximately every 18 months. The current pump abstracting 79 m^3/day has been in the borehole for more than 18 months.

The combined abstraction rate from borehole PWSBH01 and the surface water abstraction PWSSW01 generally ranges from 150 m^3/day to 220 m^3/day. During the summer of 2006, the Lislea Stream dried up reducing the PWSSW01 component to zero, such that the total abstraction at that time would have been limited to the borehole contribution. This may have exceeded the current borehole abstraction rate of 79 m^3/day if the pump in use at that time was operating at or nearer to its full specified capacity.

Borehole PWSBH03 is located in a fenced compound similar to borehole PWSBH01, approximately 370 m east of borehole PWSBH01. In theory it is considered to be a reserve PWS borehole, however when used as such in 2006 when the surface water abstraction SW01 dried up, the borehole dewatered completely and was not able to support a significant abstraction rate. An attempt was made to purge the borehole in June 2010 using the installed submersible pump, however when the pump was engaged the circuits failed and the pump failed to operate. No abstraction records are available for this borehole. It had a low yield on drilling but was subsequently subjected to hydro-fracturing, after which it was pumping tested at 105 m^3/day, resulting in a drawdown of 10.7 m. Despite the current status of PWSBH03, it has been included in the Lislea Cross Source Protection Zone delineation because it could potentially be used as a reserve borehole at some stage in the future.

Borehole PWSBH04 is located in a field approximately 200 m south of PWSBH03, has been welded shut with a steel plate and is currently not in use. There is no borehole log available for borehole PWSBH04.

Table 2 Summary of Source Details

Monitoring Code	n/a	n/a
GSI Well Database Reference No.	n/a	n/a
Borehole Name	PWSBH01	PWSBH03
Grid reference	E312383 N317093	E312741 N317174
Townland	Lislea	
Source type	Borehole	
Drilled	1997	
Owner	Louth County Council	
Elevation (Ground Level)	approx. 94.6 mAOD (i, ii)	approx 59.92 mAOD (ii)
Depth	110 mbgl (iii)	95.42 mbgl
Depth of casing	5.19 mbgl	9.14 mbgl
Depth of Well Screen	Slotted PVC casing 0 m to 110 mbgl	n/a
Diameter	150 mm nominal diameter steel casing 0 to 5.19 mbgl Drilled open hole 5.19 m to 110 mbgl Lined with 115 mm internal diameter slotted PVC 0 m to 115 m	150 mm nominal diameter steel casing 0 9.14 mbgl Open hole 0 to 9.14 m
Depth to rock	3 mbgl	4.87 mbgl
Static water level (SWL) (iv)	5.99 mbRef (v) (30/06/2010 @ 08:37)	0.81 mbRef (v)
Pumping water level (PWL)	6.4 mbRef (29/04/2010 @ approx 16:00) (vi) 8.955 mbRef (29/06/2010 @ 17:48) (vi)	n/a
Drawdown at current pumping rate (vii)	approx 2.965 m (viii)	n/a
Depth of pump	approx. 52 m	unknown
Consumption (Co.Co. records)	78 m^3/d (ix)	n/a (reserve borehole)
Borehole yield	345 m^3/d (x)	102 m^3/d (xi)
Pumping test summary (xii):		
(i) abstraction rate m^3/d	79 m^3/d (approx 1 l/s test pumping rate)	102 m^3/day (940 gallons/hr)
(ii) specific capacity	27 $m^3/d/m$ @ 79 m^3/day	12.4 $m^3/d/m$
(iii) transmissivity (T)	18.1 m^2/d	2.4 m^2/d

Note (i): mAOD = metres above ordnance datum;
Note (ii): Elevation taken from EPA 20 m grid spacing Digital Terrain Model for Co. Louth.
Note (iii): mbgl = metres below ground level.
Note (iv): Measurement based on initial water levels following overnight recovery after pump shut down on 29/06/2010.
Note (v): mbRef = metres below PWSBH01/PWSBH03 water level measurement reference datum, i.e. PWSBH01 = the top edge of the steel rim of the borehole lid directly over the borehole mouth. This is 0.63 m above the top of the orange plastic pipe fitted to the borehole mouth. PWSBH03 = top of 6-inch steel casing (this is 0.3 m below the steel rim of the chamber lid)
Note (vi): Pumping continuously for PWS abstraction at measurement, therefore assume this is a steady state level.
Note (vii): Pumping rate at time of PWL measurement = approx 78 m^3/day.
Note (viii): Drawdown estimated based on steady PWL on 29/06/2010 minus SWL after overnight recovery on 30/06/2010.
Note (ix): Average daily consumption based on spot readings of flow meter on 30/06/2010.
Note (x): Maximum proven yield based on driller's estimate of borehole yield following 9 hours of borehole development.
Note (xi): Based on driller's reported results from pumping test following hydrofracturing
Note (xii): PWSBH01 → 10 hour constant rate pumping test at 78 m^3/day started at 08:37 on 30/06/2010; PWSBH03 → 4 hour constant rate test at 102 m^3/day on 19/06/1998.

The well chamber at borehole PWSBH03 (Photo 4) is constructed identically to the one at borehole PWSBH01. The groundwater level is above the base of the chamber and floods the chamber floor, however the mouth of the 6-inch casing is 0.7 m above the water level in the chamber. A copy of the driller's borehole log for borehole PWSBH03 was provided by Louth County Council and is included in Appendix 1.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

Borehole PWSBH01 is located on the eastern lower backslope of Black Mountain, on the northern side of a broad, shallow, west to east trending channel cut by a tributary of the Ryland River as it flows off the mountain (called Lislea stream and valley here). The ground elevation decreases from west to east from 508 mAOD at the peak of Black Mountain 2.8 km to the west-southwest, to sealevel at the coast 1.3 km to the east-northeast. The steep backslope of the mountain decreases to a moderate slope approximately 400 m upgradient of the source. The topographic gradient in the vicinity of borehole PWSBH01 is approximately 0.08 while the gradient in the vicinity of borehole PWSBH03 is approximately 0.13 from west to east and 0.014 from northwest to southeast along the Knocknagoran valley.

Lislea valley continues roughly eastwards for 400 m downgradient of the borehole at which point it intersects a north-northwest to south-southeast trending valley (called Knocknagoran valley here) approximately 400 m east of the borehole. The opposite side of Knocknagoran valley is formed by a north-northwest to south-southeast trending ridge through Drummullagh and Knocknagoran townlands, which creates a topographic divide between the source and the coast. A further, northeasterly trending ridge (Lislea ridge) runs from Black Mountain through Lislea and Drumullagh townlands, and forms a topographic divide northwest of the borehole, closing off the northwestern end of Knocknagoran valley and ridge. The southern side of Lislea valley is formed by another ridge (Ardahy ridge) which forms a topographic divide between Lislea valley and further valleys to the south.

Drainage is generally to the east or east-northeast, with streams flowing off the eastern slopes of Black Mountain to the sea. The Lislea stream flows roughly east, approximately 100 m south of borehole PWSBH01, until it intersects Knocknagoran valley, where it turns southeast along the valley until it intersects the Ryland River approximately 600 m upstream of Esmore Bridge. A small tributary of the Lislea stream flows southeast approximately 100 m west-southwest of borehole PWSBH01 and intersects the stream as it crosses the local road between Ardaghy and Lislea. To the north of the Lislea Ridge, the mountain streams drain directly to the coast. To the south of the Ardaghy ridge, they flow eastwards and converge to form the Ryland river.

Drainage density is high, in excess of 1 km per 1 km^2. During site visits, artificial drainage and indicators of poor drainage conditions, such as rushes, were observed on steeper slopes with shallow (<3 m deep) subsoils. Further down the catchment, where thicker subsoils occurred, poor drainage indicators were absent.

Landuse in the vicinity of borehole PWSBH01 is primarily agricultural. Adjacent to the southern boundary of the source compound and the cross-roads, is a large farm-shed with hardcore frontage onto the cross-roads. The shed is used for storage of hay and straw. The land surrounding the source and the adjacent shed is mainly used for sheep grazing. A sheep dip compound is located approximately 60 m south of the source on the opposite side of Lislea cross-roads. Two domestic residences are located within 100 m upgradient (west) of the source, while a further two occur at approximately 100 m distant north and south respectively. Further agricultural land, housing and some areas of bog are located downgradient to the east of the borehole. The upper slopes of Black Mountain are covered in blanket peat. Domestic residences in the area are unsewered and are serviced by onsite wastewater treatment systems discharging to ground.

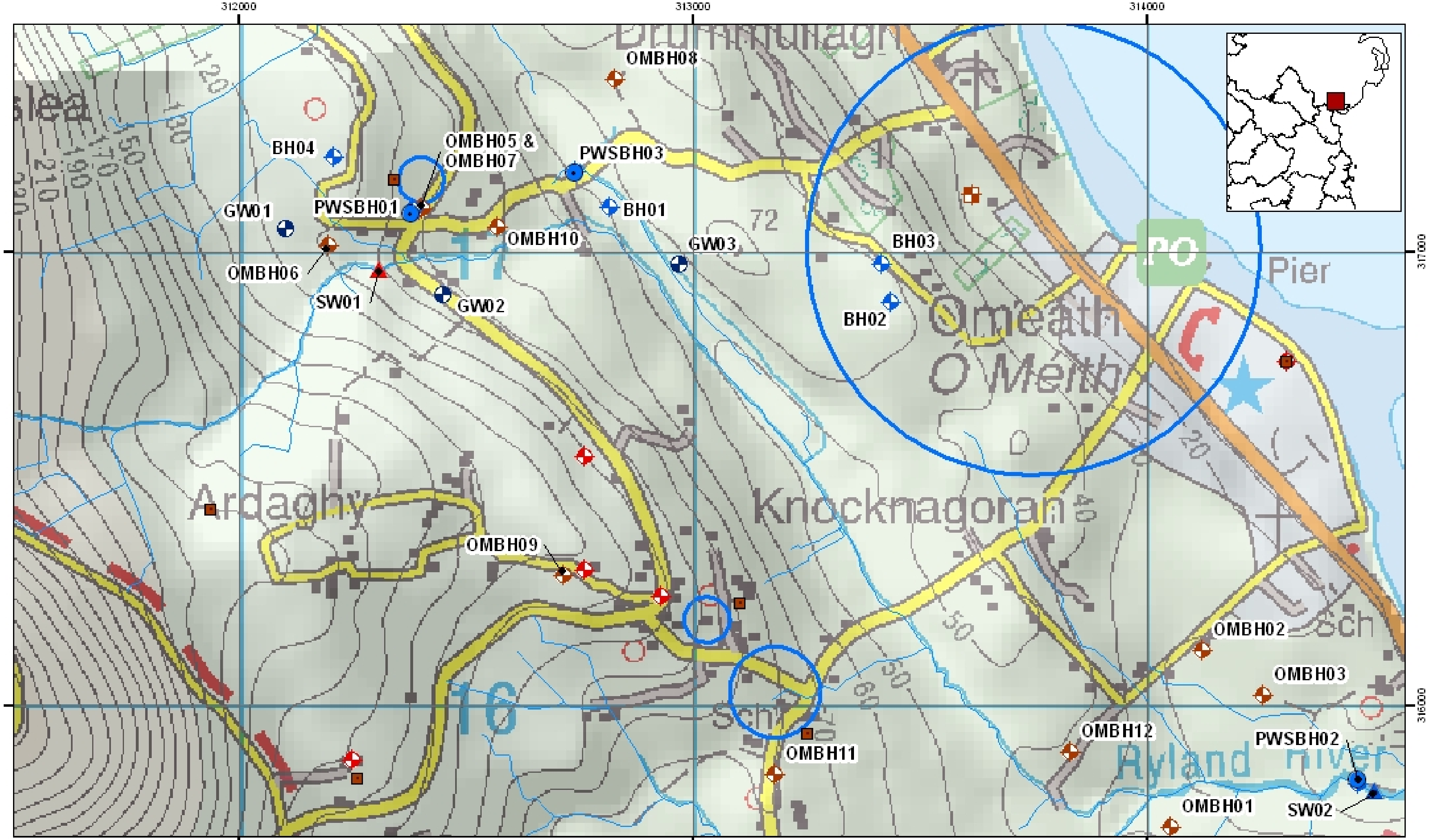


Figure 2 Datapoints in the Vicinity of Lislea Cross Borehole

PWS Abstraction
Stream
Groundwater, Borehole
Groundwater, Spring
Surface Water, Abstraction
Surface Water, Monitoring Point
GSI Well Database (0 to 50 m accuracy)
GSI Well Database (50 to 1000 m accuracy)
GSI Auger Hole
GSI - Other known DTB Data Point

0 0.1 0.2 0.3 km

6 HYDRO-METEROLOGY

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. The data source is Met Éireann.

Annual rainfall: 1102 mm. The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the source is located between the 1000 mm and 1,200 mm average annual rainfall isohyets. The closest meteorological station to the Lislea Cross Source is Omeath G.S. in Omeath town centre, 1.8 km to the east where the average rainfall between 1961 and 1990 was 1102 mm/a (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: *451* mm. The closest synoptic weather station to the study area is Clones, situated 64 km west and inland from the source and where average annual rainfall is estimated at 928 mm and potential evapotranspiration (P.E.) is estimated at 438 mm/yr. The nearest coastal synoptic station is Dublin Airport 72 km to the south where annual average rainfall is estimated at 733 mm and potential evapotranspiration is estimated at 560 mm/yr. The contoured mean annual potential evapotranspiration for Ireland shows that Lislea Cross lies approximately midway between the 450 mm and the 500 mm/yr contours (Collins and Cummins, 1996). Based on the mean annual PE contours and the data for Clones, which has a closer annual rainfall to Omeath than Dublin Airport, annual PE at Omeath is estimated at 475 mm. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 451 mm.

Annual Effective Rainfall: 651 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 651 mm/year. See Section 8.6 on Recharge which estimates the proportion of effective rainfall that enters the aquifer

7 GEOLOGY

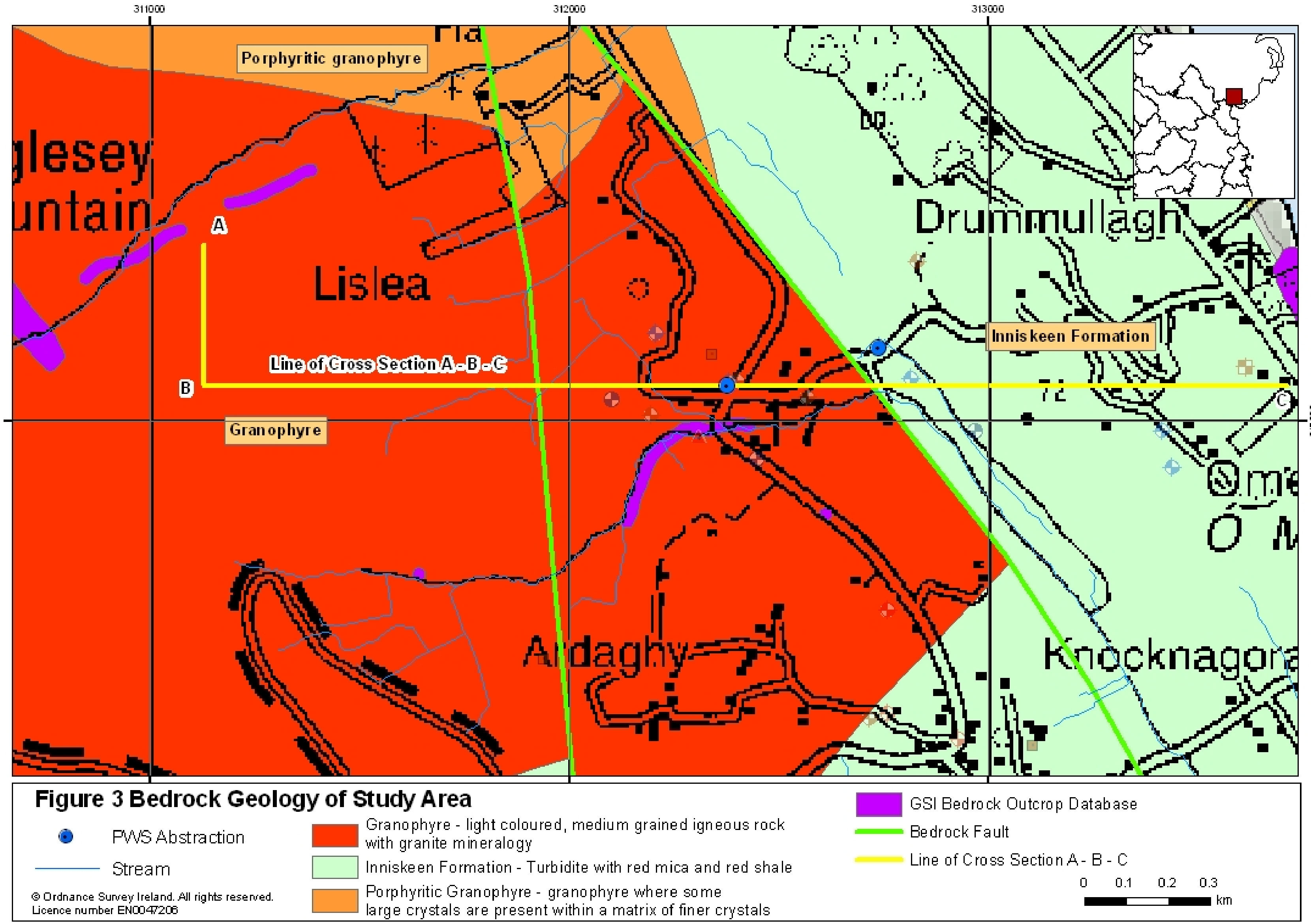
This section briefly describes the relevant characteristics of the geological materials that underlie the Lislea Cross source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based on the bedrock geological map of Monaghan - Carlingford, Sheet 8 and part of Sheet 9, 1:100,000 Series (Geraghty, 1996) and accompanying memoir (Geraghty, 1997), historical geological mapping by the GSI at the 6-inch to 1 mile scale, the GSI Well and Borehole Databases, and on bedrock outcrop and subsoil exposures encountered during site visits. The bedrock geology of the area is shown in Figure 3.

7.1 BEDROCK GEOLOGY

The bedrock map indicates that the area surrounding the source and extending to the west is underlain by igneous bedrock of Tertiary age. The igneous rocks are included in the Granites and other Igneous Intrusives Rock Unit Group. Approximately 270 m to the east of the source, the granite rocks are bounded by layered sandstone and shale bedrock (Silurian Metasediments and Volcanics). These sandstones and shales also occur approximately 1 km south of the source in Ardaghy. To the north of the Lislea ridge, the area is underlain by rock comprised of Precambrian Gniesses and Schists.

The different geological rock units in the area are described in more detail in Table 3 and can be seen in Figure 3.

A cross-section of the geology of the study area is shown in Figure 4. The line of the cross-section in Figure 4 is shown in Figure 3.


311000
312000
313000
317000
Porphyritic granophyre
Lislea
Line of Cross Section A-B-C
A
B
C
Granophyre
Innis keen Formation
Drummullagh
Ardaghy
Knocknagor
Figure 3 Bedrock Geology of Study Area
PWS Abstraction
Stream
Granophyre - light coloured, medium grained igneous rock with granite mineralogy
Inniskeen Formation - Turbidite with red mica and red shale
Porphyritic Granophyre - granophyre where some large crystals are present within a matrix of finer crystals
GSI Bedrock Outcrop Database
Bedrock Fault
Line of Cross Section A - B - C
0 0.1 0.2 0.3
km

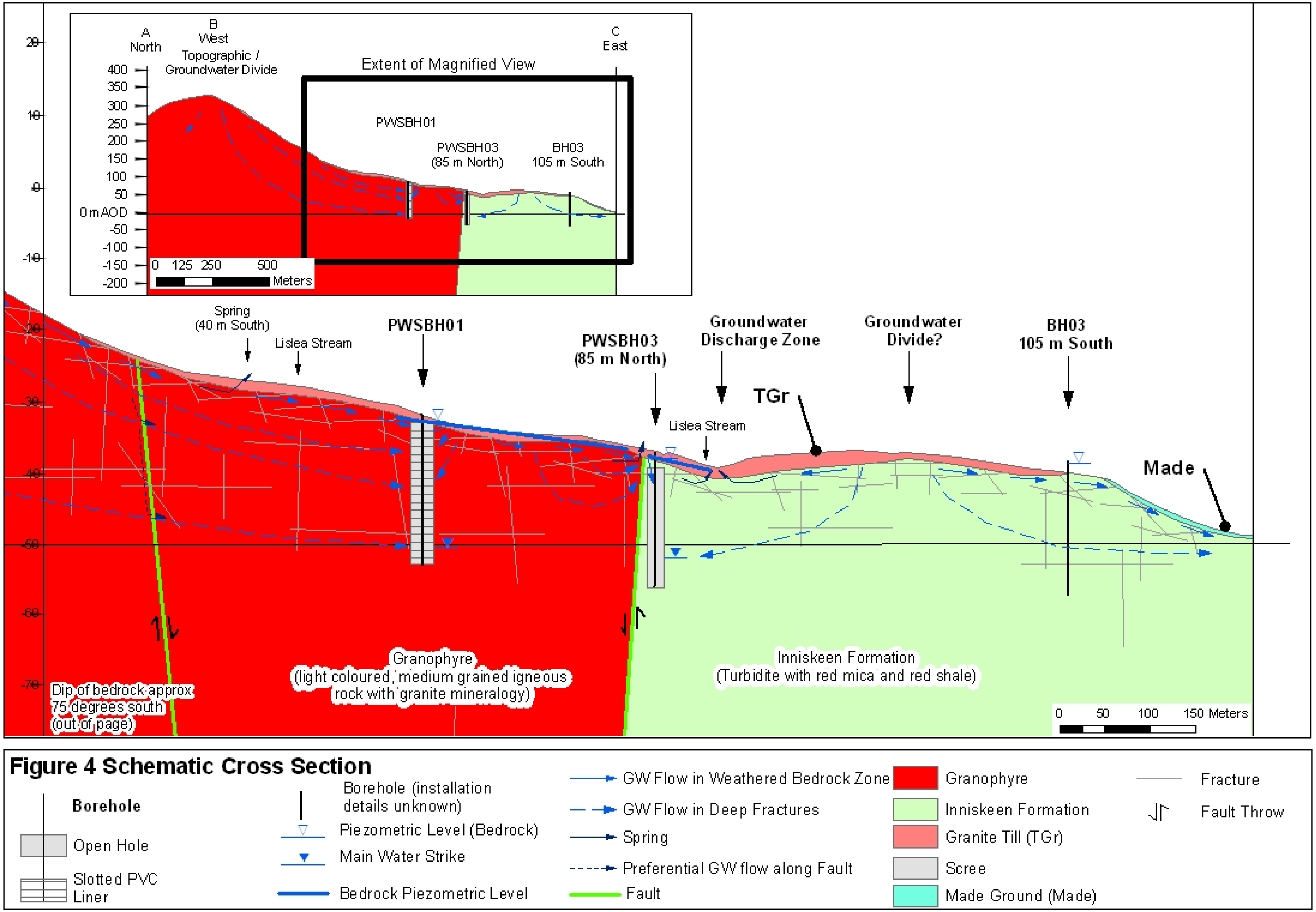


Figure 4 Schematic Cross Section

Table 3 Bedrock Geology and descriptions around Lislea Cross PWS Boreholes

Rock Unit Group	Bedrock Formation	Geological Description
Granites and other Igneous Intrusives	Granophyre	Granophyre - a light coloured, medium grained igneous rock with granite mineralogy
Silurian Metasediments and Volcanics	Inniskeen Formation (IN)	Medium to thick bedded turbiditic greywacke sandstones and minor amounts of shale, with red biotite mica and red shale
Precambrian Gniesses and Schists	Porphyritic granophyre	Porphyritic granophyre – granophyre where some large crystals are present within a matrix of finer crystals

Two roughly north to south trending faults are mapped on either side of the source. The fault to the west lies approximately 450 m away and is a regional scale feature extending from north of Newry, along the length of the Cooley peninsula. The fault to the east is approximately 250 m away and extends from near Carlingford to approximately 1.4 km north of the source. The rocks between the two faults, which underlie the source, are downthrown with respect to the adjacent rock units. GSI mapping indicates that bedrock layers are tilted south-southeast at approximately 60 to 85 degrees.

7.2 SOILS AND SUBSOILS

7.2.1 Soils

GSI and EPA web mapping indicate that the soils underlying the source and across the majority of the study area are classified as deep, well drained mineral soils (AminDW) derived from mainly non-calcareous parent materials. An area of deep, poorly drained mineral soils (AminPD) derived from mainly non-calcareous parent materials runs in a west to east band approximately 100 m wide along the southern side of the Lislea stream from upstream of the site as far as the Knocknagoran valley. The soils on the upper slopes of Black Mountain are predominantly comprised of deep poorly drained mineral soils with peaty topsoil and derived from mainly non-calcareous parent materials (AminPDPT) (Teagasc, 2004b).

7.2.2 Subsoils

According to GSI and EPA web mapping, a number of different subsoil units underlie the areas around the Lislea Cross water supply. Drilling and permeability mapping carried out by Tobin Consulting Engineers for the National Vulnerability Mapping Programme, and by the GSI for this project, provide additional information on the subsoils. The subsoil map of the area is shown in Figure 5.

The subsoils around the source comprise till derived from granite bedrock (TGr). Till is an unsorted mixture of coarse and fine materials laid down by ice. Tills are often over consolidated, or tightly packed, unsorted, unbedded and possess many different particle and clast (stone) sizes. They commonly have sharp, angular clasts. The till in the vicinity of the source is categorised according to its dominant lithological component.

Blanket peats are present along the floor of the Knocknagoran valley, and in places on the upper slopes of Black Mountain. Large parts of the upper slopes of Black Mountain host scree slopes or bedrock outcrop. Bedrock outcrop is also mapped along the Lislea stream in the vicinity of and upstream of the source, along the Drummullagh – Knocknagoran ridge, and in Ardaghy at a break in slope running roughly along the local road between Ardaghy and Lislea.

7.2.3 Subsoil Permeability

Eleven auger holes were drilled in the granite till deposits in the areas surrounding the Lislea cross and Esmore Bridge groundwater sources by GSI in May 2007. Subsoil samples from the auger holes were logged in accordance with BS5930. The data from the auger holes drilling are summarised in Table 4. The auger holes locations are shown on Figure 2.

The subsoils across County Louth have been classified with respect to their permeability in the preparation of a Groundwater Vulnerability map for Louth County Council. The permeability of the granite till in the study area has been classed as '***Moderate Permeability'***.

Table 4 Subsoil data from Auger Drilling samples taken in Vicinity of Lislea Cross Public Supply

Location[1]	Easting	Northing	DTB (m)	BS5930 Result	Subsoil Permeability	Subsoil Unit from Map
OMBH01	314054	315732	8	None	n/a	TGr
OMBH02	314123	316123	3.5	Very dense, coarse grained sandy GRAVEL.	Moderate	TGr
OMBH03	314258	316023	6	Very dense becoming soft, very silty GRAVEL.	Moderate	TGr
OMBH05	312397	317094	4.5	Very sandy, GRAVEL.	Moderate	TGr
OMBH06	312196	317014	2.9	Rck Close	Moderate	TGr
OMBH07	312403	317096	4.5	Loose, sandy GRAVEL.	Moderate	TGr
OMBH08	312829	317381	1	Rck Close	Moderate	TGr
OMBH09	312716	316289	1.5	Rck Close	Moderate	TGr
OMBH10	312568	317057	4	Very dense SAND.	Moderate	TGr
OMBH11	313179	315849	7	Sandy, coarse GRAVEL.	Moderate	TGr
OMBH12	313832	315897	2	Rck Close	n/a	TGr

Auger holes OMBH05 to OMBH10 were drilled in the vicinity of borehole PWSBH01. In three of the auger holes the subsoil thickness exceeded 3 m and sandy GRAVEL subsoils were recorded. Two of the three are located adjacent to the source while the third (OMBH10) is located 200 m east of the source adjacent to the Lislea stream. Given the acidity of the soil there are likely to be iron pans in pockets in this area. Some rushes were observed in the vicinity of the three auger holes, particularly at OMBH10 which suggests poor drainage conditions and may be related to iron pan pockets. Overall the indicators suggest that the bulk subsoil permeability in the vicinity of the source is moderate, in line with the regional interpretation.

The widespread plant indicators of poor drainage on the steep, upper slopes of the study area where subsoils are thin is interpreted to be due to rejected recharge from the low permeability bedrock overwhelming the storage capacity of the thin subsoils and resulting in saturated conditions up to the ground surface and overland flow (Robbie Meehan, pers comm., 2010). Where the subsoils are thicker, they have sufficient storage and permeability to transmit the rejected bedrock recharge downgradient to surface water courses without giving rise to saturated topsoil conditions, such that plant indicators of poor drainage are largely absent.

7.3 DEPTH TO BEDROCK

Depth to bedrock (DTB) has been interpreted across the study area based on bedrock outcrops mapped by the GSI, outcrops mapped during site visits, areas mapped as extreme groundwater vulnerability under the GSI Groundwater Protection Scheme (GWPS), DTB data from the GSI Well Database and logged evidence from drilling of GSI auger holes in the vicinity of the source.

[1] Note: There was no auger hole labelled "OMBH04" drilled during the investigation.

The subsoil map of Louth indicates that areas of outcropping rock are found on large parts of the upper slopes of Black Mountain, along the Lislea stream in the vicinity of and upstream of the source, a small area 200 m east-northeast of the source, along the Drummullagh – Knocknagoran ridge, and in Ardaghy at a break in slope running roughly along the local road between Ardaghy and Lislea.

DTB point data for the area are shown in Figure 4, and DTB data from GSI auger holes are shown in Table 4. DTB data from other sources are shown in Tables A1.1a to A 1.1c in Appendix 1.

The data indicate that in the vicinity of the source, DTB is generally between 3 m and 5 m. The borehole log for borehole PWSBH01 indicates a depth to bedrock of 3 m, while auger holes OMBH05 and OMBH07 adjacent to the source both record DTB of 4.5 m.

On the south side of the Ardaghy ridge and along the southeastern end of the Knocknagoran valley an area of thicker subsoils with DTB greater than 5 m has been mapped, with DTB of 7 m encountered at auger hole OMBH11.

7.4 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. In this area this means that vulnerability relates to the permeability and thickness of the subsoil. 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 map is shown in Figure 6. The field investigations for this report have confirmed that the draft county scale groundwater vulnerability map is accurate at the local scale in the vicinity of the source.

The vulnerability map indicates areas of extreme vulnerability on the upper slopes of Black Mountain and along the areas of outcrop in the Lislea stream in the vicinity of the source, the small outcrop 200 m east-northeast of the source, along the local road between Ardaghy and Lislea, and along the crest of the Drummullagh – Knocknagoran ridge.

The majority of the remainder of the study area surrounding the source is classified as high vulnerability due to the combination of moderate permeability subsoils and 3 to 5 m DTB. An area of moderate vulnerability has been delineated south and southwest of the Ardaghy ridge where subsoil thickness exceeds 10 m.

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 Databases
- ⇨ County Council Staff
- ⇨ Local Authority Drinking Water returns and monitoring of untreated groundwater quality,
- ⇨ Hydrogeological mapping by Peter Conroy and Robert Meehan (April 2010)
- ⇨ Local hydrogeological mapping carried out by the GSI and Tobin Environmental Ltd as part of the National Vulnerability Mapping Programme;
- ⇨ Drilling and permeability mapping carried out by GSI in May 2007
- ⇨ Met Éireann rainfall and evapotranspiration data

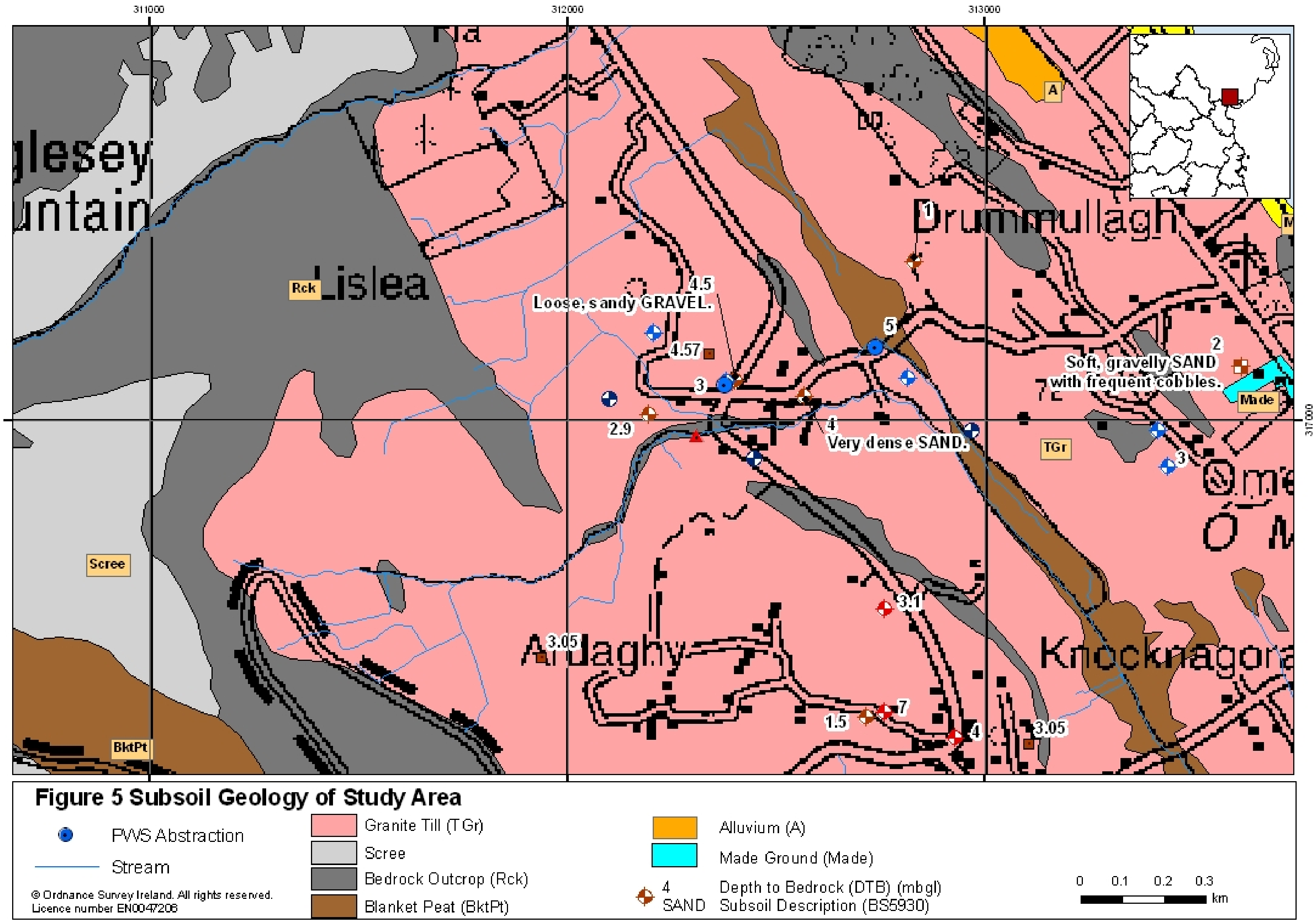


Figure 5 Subsoil Geology of Study Area

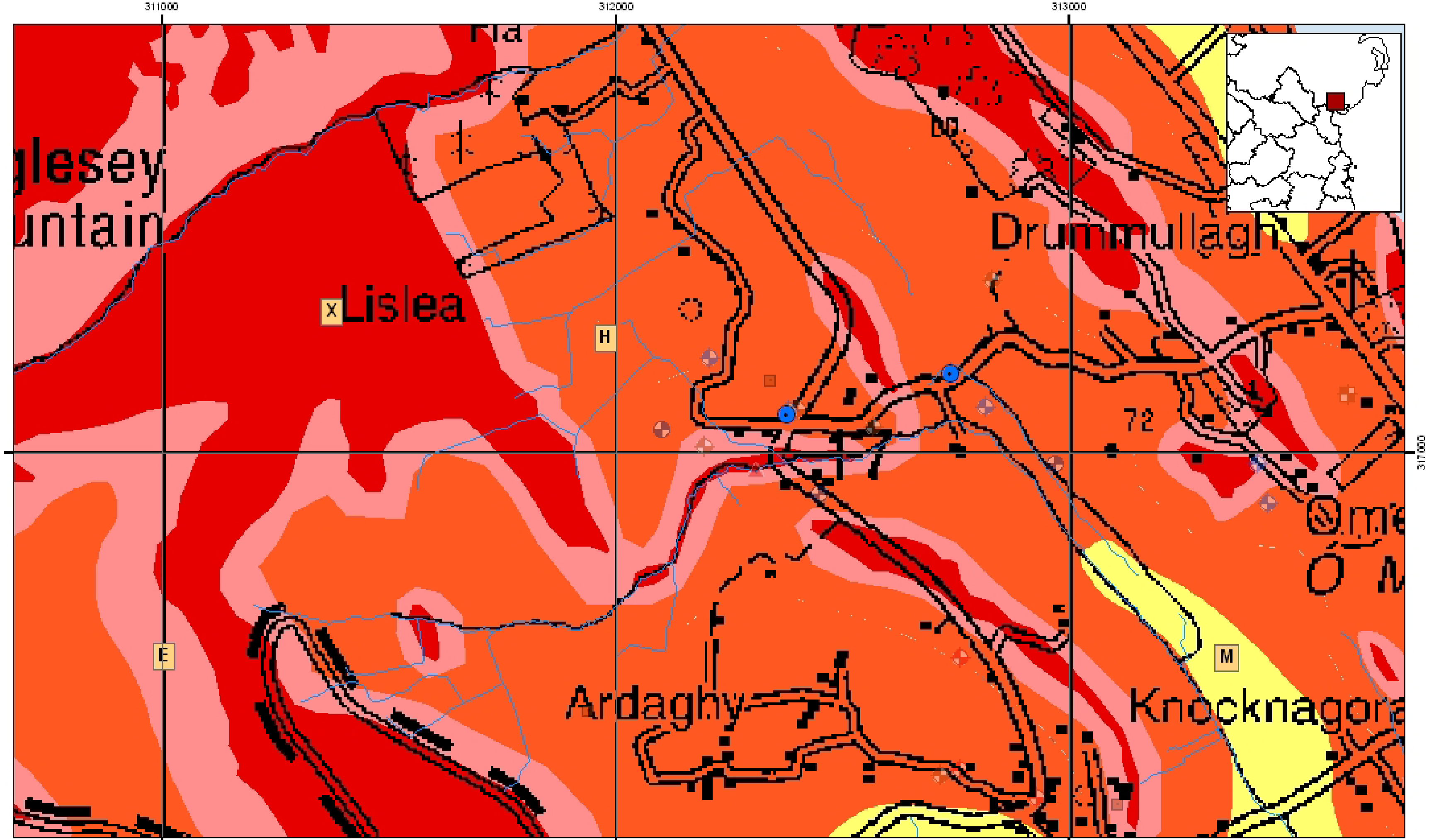


Figure 6 Groundwater Vulnerability of the Study Area

PWS Abstraction
Stream
Extreme - Rock Close to Surface (X)
Extreme (E)
High (H)
Moderate (M)

0 0.1 0.2 0.3 km

8.1 GROUNDWATER BODY AND STATUS

The source and the surrounding area form part of the Louth groundwater body (GWB), which extends across the majority of the Cooley peninsula and Co. Louth and as far west as Castleblaney and Carrickmacross in Co. Monaghan, and into parts of northeast Co. Meath.

The Water Framework Directive (WFD) reporting tool WaterMaps indicates that the status of the Louth GWB is "*Good*". The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie .

The Louth GWB is composed primarily of low transmissivity rocks. Most of the groundwater flow is likely to be in the uppermost part of the aquifer comprising: a broken and weathered zone typically less than 3 m thick; a zone of interconnected fissuring typically less than 10 m thick; and a zone of isolated fissuring typically less than 150 m thick. Recharge occurs diffusely through the subsoil and rock outcrops, although it can be limited by thicker till and the low permeability bedrock. Therefore, most of the effective rainfall is not expected to recharge the aquifers. Flow paths are likely to be short (30–300 m) with groundwater discharging rapidly to the streams crossing the aquifer, and to small springs and seeps. Overall, the flow direction is expected to be to the east, as determined by the topography.

8.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

The rest ground water level in borehole PWSBH01 was measured at 5.99 mbtc on 30th June 2010. Based on the estimated ground level at the borehole in Table 2, this equates to a groundwater elevation of 88.79 mAOD. The pumping water level in the borehole was measured at 6.4 and 8.96 mbtc on 30 April and 29 June 2010 respectively. Full details of the water level data collected are provided in Table A1.1 in Appendix 1.

The groundwater elevations recorded in boreholes BH04, PWSBH01 and PWSBH03 decrease from west to east in the direction of the topographic slope, indicating that ground water flow is in an east to east-southeasterly direction in the vicinity of the source. Flow paths are likely to be short (30-300 m) with groundwater discharging rapidly to nearby streams and small springs (GSI, 2004).

Springs were recorded by the GSI at locations GW01 and GW02 at breaks in the slope in the vicinity of borehole PWSBH01, suggesting that a component of groundwater flow goes to discharge and is directed towards springs and surface water courses. Downslope of the source in Knocknagoran Valley the GSI 6-inch historical geological mapping records the presence of numerous springs in the valley floor at approximately 56 to 57 mAOD. This suggests that groundwater flow to the west is intercepted by the valley and that the Lislea stream forms the main discharge zone for shallow groundwater flow in the Lislea – Ardaghy area.

The springs in the valley floor may also be related to the mapped geological fault running along the length of the valley. The fault may serve to impede lateral groundwater flow from the granite bedrock into the layered sandstone and shale bedrock on the opposite side of the fault, resulting in groundwater discharge via springs on the uphill side of the fault. The hydrochemistry data suggest that this may be the case; boreholes PWSBH01 and PWSBH03 lying on opposite sides of the fault and having different hydrochemical signatures (See Section 8.4). The failure of borehole PWSBH03 to sustain a significant yield when called into use in 2006 also suggests that the fault acts as a barrier to flow and prevents water from being drawn to the borehole from west of the fault.

The groundwater levels in boreholes BH02 and BH03 on the eastern side of the Drummullagh – Knocknagoran ridge were estimated at 52.94 and 60.12 mAOD respectively, *i.e.,* below and above the level of the spring discharges in the valley on the western side of the ridge. As such it is unclear whether or not the ridge acts as a groundwater divide between the groundwater flow from the Lislea – Ardaghy area and the sea. It is possible that shallow flow paths discharge to springs in the valley while deeper flow paths continue on to the east. Assuming that the groundwater divide is present, groundwater flow on the western side of the ridge will be to the west, and within the study area, towards PWSBH03. This component of flow towards the borehole from the east is likely to be the dominant component of flow to the borehole, given the likely curtailment of flow from the west by the bedrock fault.

The available groundwater level data relate to locations in bedrock aquifers which appear to be separated by a low transmissivity fault zone. As such the data cannot be used to estimate hydraulic gradients in the separate aquifers. The hydraulic gradient in the vicinity of the boreholes is likely to mirror the local topography. This suggests that the hydraulic gradient in the vicinity of borehole PWSBH01 will be approximately 0.08 from west to east. In the vicinity of PWSBH03 the dominant flow component towards the borehole is considered to be from the east. The gradient from this direction is therefore estimated to be between 0.05 and 0.13 giving an average of approximately 0.09.

8.3 HYDROCHEMISTRY AND WATER QUALITY

Four samples of untreated groundwater have been collected from borehole PWSBH01 between April 2009 and April 2010. Three of the samples, collected in April, May and November of 2009, were analysed for a limited suite of parameters. The sample from April 2010 was analysed for an extended suite of parameters including major ions, physico-chemical parameters and the parameters listed in the Drinking Water Regulations (SI No. 278 of 2007). There is no untreated water sampling tap at borehole PWSBH01. As such, samples are collected at the outlet of the rising main where it discharges into a manifold at the water treatment works 100 m downslope from the borehole. The samples were analysed by the EPA on behalf of Louth County Council. A further sample was collected from borehole PWSBH03 on 29 June 2010 and analysed for major ion parameters. On the same date, a surface water sample was collected from the Ryland River at location SW02 (adjacent to borehole PWSBH02 at Esmore Bridge). The analyses for borehole PWSBH03 and location SW02 were carried out by STL laboratories in the UK.

The resulting data are presented in Table 5 and in Table A1.2 in Appendix 1. Field water quality data (pH, conductivity and temperature) were collected from borehole PWSBH01, PWSBH03 and surface water location SW02 during the site visits of 29 and 30/04/2010. The field data are presented in Table A1.3 in Appendix 1.

Overall, borehole PWSBH01 has a low to moderate level of mineralization as indicated by the average electrical conductivity (265 µS/cm), alkalinity (102 mg/l as $CaCO_3$) and hardness (103 mg/l as $CaCO_3$). The hydrochemistry is dominated by the calcium and bicarbonate ion pair, which is likely to be the result of dissolution of calcite in the subsoil deposits. The pH of the groundwater is approximately neutral with a measured average of 7.1 [range 6.7 to 7.4]. Heavy metal concentrations have generally been low when measured. The source caretaker indicated that iron and manganese precipitation occurs in the borehole and the submersible pump requires regular maintenance and cleaning. The sample from April 2010 did not detect iron or manganese, however it may be that dissolved iron and manganese had come out of solution in the rising main between the borehole and the sampling point at the treatment works.

Table 5 Hydrochemistry data for boreholes PWSBH01 and PWSBH03 and the Ryland River at SW02

				PWSBH01				PWSBH03	SW02
	Date			02-Apr-09	07-May-09	18-Nov-09	26-Apr-10	29-Jun-10	29-Jun-10
	Units	EPA Threshold	DWS (S.I. 278 of 2007)						
Calcium	mg/l Ca						28.30	51.00	9.40
Sodium	mg/l Na	150	200				15.82	14.00	8.10
Magnesium	mg/l Mg						5.47	6.40	2.50
Potassium	mg/l K						1.13	0.76	0.970
Ammonium	mg/l NH4	0.23	0.3	< 0.039	< 0.039	< 0.039	<0.039	0.065	0.015
Alkalinity	mg/l $CaCO_3$			137	133	67	70.00	148.00	30.9
Chloride	mg/l Cl	24	250	17	18	22	24.00	13.30	10.7
Sulphate	mg/l SO_4	187.5	250				18.00	11.20	6.21
Nitrate	mg/l NO3	37.5	50	6.51	6.86	9.83	11.78	0.66	1.28
Iron	ug/l Fe		200				<10		
Manganese	ug/l Mn		50				<1		
pH	deg C		>6.5 & < 9.5	7.4	7.4	6.7	6.70	7.01	7.80
Conductivity	uS/cm	800	2500	361	355	66	277	318	98.0
Total Coliforms	No./100ml		0				0.00		
Fecal Coliforms	No./100ml		0				0.00		
Hardness	mg/l $CaCO_3$						103.00		
K/Na Ratio (using meq)	[-]	0.4					0.04	0.03	0.12

At borehole PWSBH03, the available data suggest a slightly different water chemistry. Calcium and bicarbonate concentrations are higher; chloride, nitrate and sulphate are lower; and ammonium is detectable. The pH and conductivity are above the averages for borehole PWSBH01 but within the same observed range.

The difference in hydrochemistry suggests that the groundwater flow regimes in the two different bedrock types which host the boreholes (PWSBH01 in Granophyre and PWSBH03 in Inniskeen Formation) have largely separate groundwater flow regimes. This suggests that the fault separating the two bedrock rock types may be largely un-transmissive in the study area and that groundwater flow across the fault from borehole PWSBH01 to borehole PWSBH03 is minimal.

The hydrochemistry of the Ryland River at location SW02 suggests a third unique hydrochemical signature in the surface water of the study area. The river water has a low level of mineralisation as indicated by the very low electrical conductivity (98 µS/cm) and alkalinity (30.9 mg/l as $CaCO_3$), as well as low concentrations of the dominant major ions. This suggests that at the time of sampling the river hydrochemistry comprised a dominant surface runoff component which significantly diluted any groundwater baseflow inputs. Surface runoff and river flow have short residence times which result in low levels of mineralisation compared to groundwater. The nitrate, ammonium and potassium concentrations of the river water are within the range detected in the groundwater samples which suggests that surface runoff to streams is also affected by sources of these contaminants, such as organic matter from agricultural land use.

Figure 7a shows the EPA measured concentrations of faecal and total coliforms and ammonium at boreholes PWSBH01 and PWSBH03. No coliform bacteria have been detected in the untreated water samples. Ammonium concentrations are not detectable at the borehole. The ammonium concentration at borehole PWSBH03 on 29 June 2010 was 0.065 mg/l as NH_4, which is well below the EPA threshold of 0.23 mg/l as NH_4.

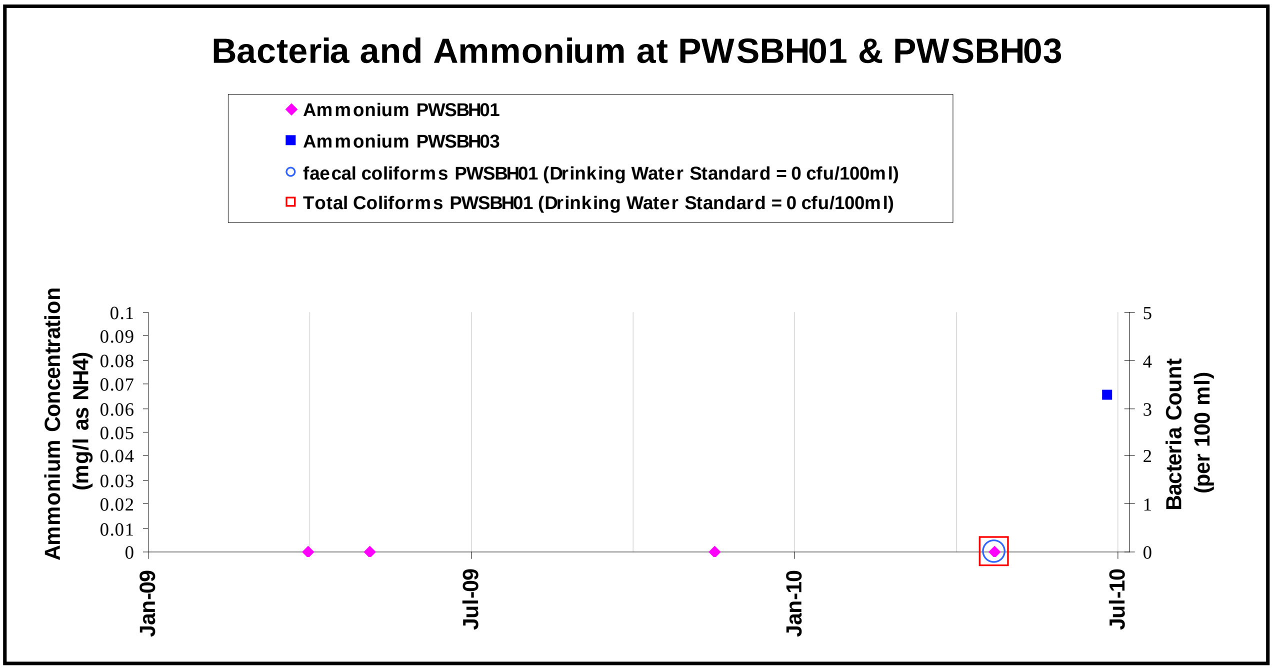


Figure 7a Graph of Bacteria and Ammonia Concentrations at Borehole PWSBH01

Figure 7b shows the measured concentrations of nitrate and chloride at borehole PWSBH01. The average nitrate concentration over the monitoring period was 8.7 mg/l as NO_3, which is below the EPA threshold of 37.5 mg/l as NO_3. Average chloride concentrations measured 20.3 mg/l which is below the EPA threshold of 24 mg/l, however, the chloride concentration on 26/04/2010 did reach 24 mg/l. This concentration may be within the natural range of chloride concentrations at the borehole which is likely to receive additional chloride inputs from sea spray due to its coastal location. The available nitrate and chloride data suggest that concentrations of both parameters are subject to a rising trend. If the rising trend effect continues, the chloride concentration in the borehole would be expected to exceed the EPA threshold in 2011. This would suggest that the chloride concentrations are beginning to exceed their natural range. A rising trend in nitrate and chloride concentrations could be the result of the onset of contamination of the groundwater by organic matter from discharge of treated wastewater or from agriculture.

Table 5 shows that the chloride and nitrate concentrations at borehole PWSBH03 on 29 June 2010 were 13.3 mg/l and 0.66 mg/l as NO_3 respectively, which are well below their respective EPA thresholds.

Table 5 also shows the EPA measured concentrations of manganese and potassium, as well as the Potassium:Sodium ratio, at boreholes PWSBH01 and PWSBH03. None of these parameters exceeded their respective thresholds.

The remaining parameters measured do not exceed their respective drinking water standard and have average concentrations less than their respective EPA thresholds.

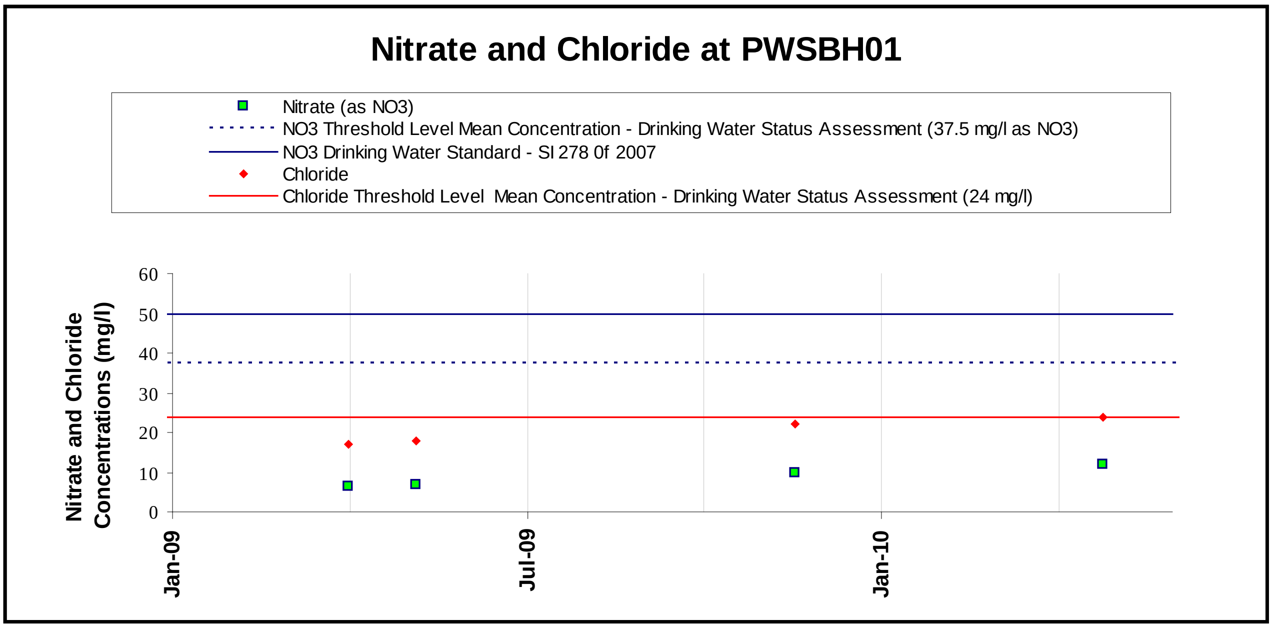


Figure 7b Graph of Nitrate and Chloride Concentrations at Borehole PWSBH01

In summary, the limited data suggest that both boreholes are currently unpolluted. Given the possible rising trend in nitrate and chloride at borehole PWSBH01, and the agricultural setting with sheep grazing and domestic on-site wastewater treatment systems in the vicinity of the source, it would be prudent to continue monitoring the untreated water quality lest the source be impacted by contamination in the future.

8.4 AQUIFER CHARACTERISTICS

The GSI bedrock aquifer map of the area classifies the rock units in the vicinity of the boreholes as a *Poor Aquifer – Generally Unproductive Except in Local Zones (Pl).* The bedrock aquifer map of the area is shown in Figure 8. Groundwater flows through fissures and fractures within the rock. The majority of groundwater flow in the bedrock is likely to be in the uppermost part of the aquifer comprising a broken and weathered zone typically less than 3 m thick, a zone of interconnected fissuring approximately 10 m thick, and a zone of isolated poorly connected fissuring typically less than 150 m thick (GSI 2004). The main water strike in borehole PWSBH01 occurred at 94 mbgl, which suggests that the deeper pathway is active in the vicinity of the borehole.

Owing to the poor productivity of the Pl aquifers in the Louth GWB, baseflow to rivers and streams is expected to be relatively low (GSI 2004). Very shallow groundwater from the transition zone will discharge into streams and seeps, however. This agrees with the low mineralisation of the Ryland River surface water in the study area.

A pumping test at a constant discharge of 79 m^3/day was carried out on borehole PWSBH01 on 30 June 2010. The details of the pumping test are presented in Appendix 2. Analysis of the pumping test data suggests that the aquifer transmissivity in the vicinity of the borehole is 14.9 m^2/day. The specific capacity of the borehole at its steady state drawdown is 27 m^3/d/m. The Groundwater Body report for the Louth GWB suggests aquifer transmissivity in the Silurian and granite Pl aquifers is typically low (20 m^3/day) to moderate (20 to 80 m^3/day) (GSI 2004).

Data from a pumping test on borehole PWSBH03 carried out by the GSI on 18 & 19 June 1998 indicate that the Pl aquifer transmissivity in the Silurian bedrock in the vicinity of PWSBH03 is approximately 2.4 m^2/day. The abstraction rate during the test was 102 m^3/day for a drawdown of 8.24 m, giving a specific capacity of 12.4 m^3/day. The pumping test duration was 4.5 hours and steady state was not achieved, such that it is not known whether or not this yield is sustainable in the long term.

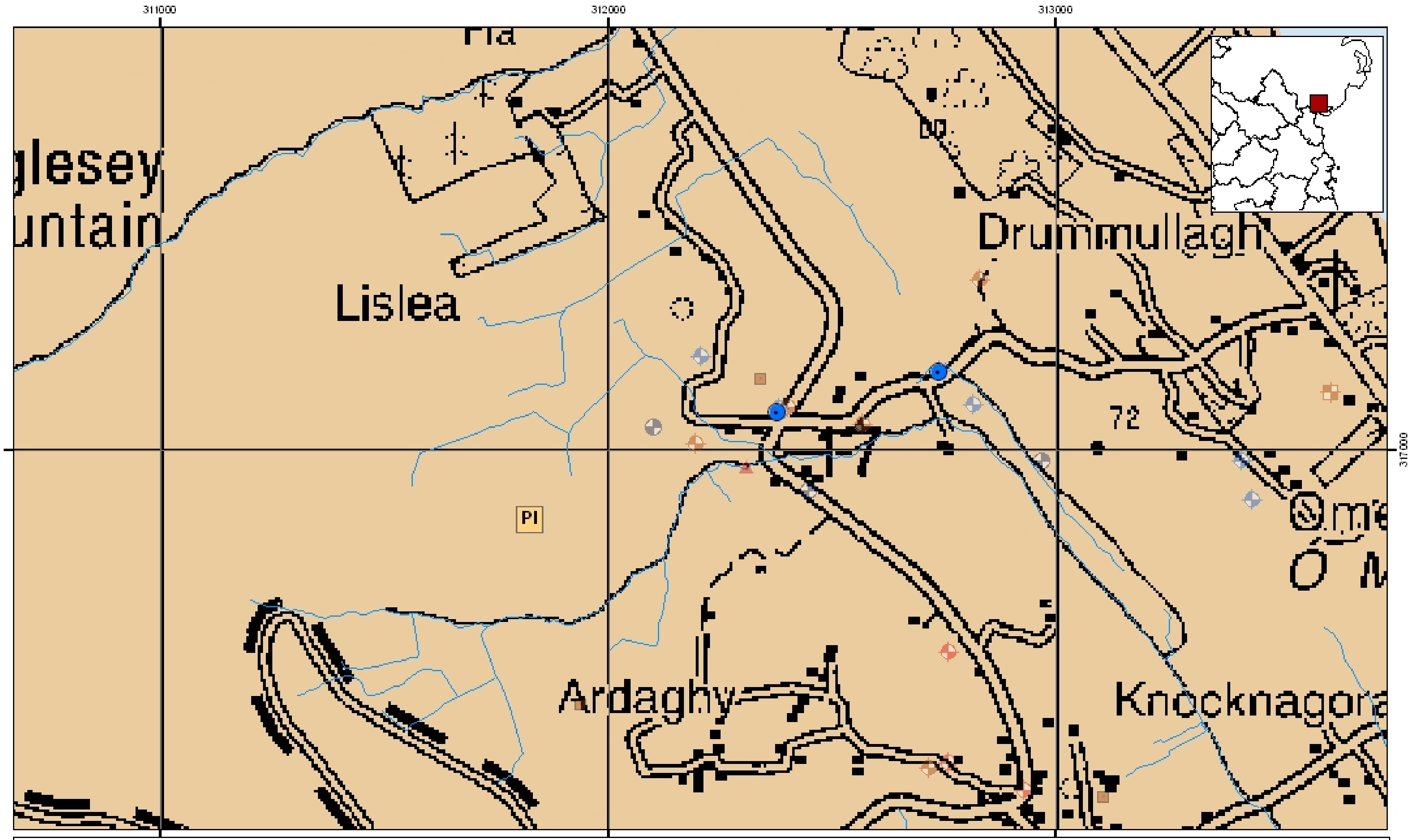


Figure 8 Bedrock Aquifer Map of Study Area

PWS Abstraction

Stream

Poor Aquifer – Generally Unproductive Except in Local Zones (PI)

0 0.1 0.2 0.3 km

Based on the estimated PI bedrock aquifer transmissivity and the aquifer hydraulic gradients, the groundwater flow velocity can be estimated based on the equation:

$$v = \frac{T \cdot i}{b \cdot n_e}$$

where: v = average groundwater velocity (m/day);
T = aquifer transmissivity (m^2/day); n_e = effective porosity (dimensionless)
i = hydraulic gradient; and, b = aquifer thickness.

The estimated groundwater velocities in the bedrock aquifers on either side of the fault zone, based on the available data from boreholes PWSBH01 and PWSBH03 are shown in Table 8-2. The resulting groundwater velocity values represent an average velocity for the aquifer in question. Velocities in individual fissures or conduits may greatly exceed the calculated values.

Table 6 Estimated Groundwater Velocity at boreholes PWSBH01 and PWSBH03

Parameter	Units	PWSBH01	PWSBH03	Data Source
T	m^2/d	14.9	2.4	Pumping Tests on borehole PWSBH01 and PWSBH03
i	[-]	0.08	0.09	Estimated gradients at PWSBH01 and PWSBH03 based on topography
b	m	90	90	PWSBH01 borehole log
n_e	[-]	0.01	0.01	Typical fractured aquifer porosity
v	m/d	1.32	0.24	

9 ZONE OF CONTRIBUTION

The Zone of Contribution (ZOC) is the complete hydrologic catchment area to the source, or the area required to support an abstraction from long-term recharge. The size and shape of the ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. This section describes the conceptual model of how groundwater flows to the source, including uncertainties and limitations in the boundaries, and the recharge and water balance calculations which support the hydrogeological mapping techniques used to delineate the ZOC.

9.1 CONCEPTUAL MODEL

A schematic cross section illustrating the conceptual model is shown in Figure 4. The current understanding of the geological and hydrogeological setting is given as follows:

- The source under consideration in this report is comprised of one operating borehole (PWSBH01) and one reserve borehole (currently inoperative) in the Lislea Cross area of Omeath, located in granites (active borehole) and layered sandstones and shales (reserve borehole), both of which are classified as Poor Aquifers (PI).

- Abstraction rates from the borehole PWSBH01 currently average 79 m^3/day, however the borehole has a reported yield of 375 m^3/day and the current low abstraction rate may be due to encrustation of the pump with iron and manganese sediment. The borehole is pumped continuously.

- Borehole PWSBH03 is not currently in use but has a reported yield of 102 m^3/day. The borehole was used as a backup supply in summer 2006, but the borehole dewatered completely when brought into use and failed to supply the required demand.

- Depth to bedrock is considered to be less than 3 m on the upper slopes of Black Mountain, along the Lislea stream in the vicinity and upstream of the source, a small area along the Drummullagh – Knocknagoran ridge, and in Ardaghy. Elsewhere the DTB is 3 to 5 m, except in an area on the southwest side of the Ardaghy ridge where DTB in excess of 5 m is encountered. Where bedrock is deeper within the study area, it is overlain by subsoils of till derived from granite (TGr), which are considered to have a moderate permeability.

- Areas where DTB is less than 3 m are mapped as extreme groundwater vulnerability. The remainder of the study area is mapped as high vulnerability, except for the pocket of thicker subsoils on the southwest side of the Ardaghy ridge, which is mapped as moderately vulnerable.

- Recharge coefficients in the study area are estimated at 0.15 following application of the Pl aquifer recharge cap of 100 mm. As a result, bulk recharge for the area contributing recharge to the boreholes is estimated at 15% of potential recharge, which gives an annual actual recharge of 100 mm/yr.

- Groundwater elevation decreases from west to east from Black mountain towards the coast. The groundwater elevations at boreholes PWSBH01 (on 30/06/2010) and PWSBH03 (on 29/06/2010) were 88.79 m and 59.92 mAOD respectively. Based on the topographic gradient in the vicinity of the source boreholes, the hydraulic gradient in the vicinity of borehole PWSBH01 is estimated to be approximately 0.08, while in the vicinity of borehole PWSBH03 it is estimated to be approximately 0.013. It is unclear from the data whether or not there may be a north-northwest to south-southeast groundwater divide downgradient of the source boreholes under the Drummullagh-Knocknagoran ridge. Such a divide would direct groundwater recharge on the western side of the ridge back towards the west, away from the coast and towards the Knocknagoran valley and borehole PWSBH03.

- Groundwater flow in the Pl aquifer is expected to be largely in a shallow weathered zone and underlying relatively shallow zone of fracturing. Deeper groundwater flow may occur in isolated deeper fractures and fissures, which are generally less well interconnected than fractures in the shallow zones. Where fault zones are present, the deeper fracture zones may be more developed and interconnected in the vicinity of these.

- Groundwater flow is generally from west to east, downslope and towards the coast. Flow paths in the Pl aquifer are likely to be short and groundwater recharge is likely to discharge relatively rapidly to nearby surface water features. A component of the shallow flow is diverted to deeper flow paths, such as the deep flow intersected by borehole PWSBH01. The main discharge area for the aquifer in the study area is likely to be *via* springs and seepage into the Lislea stream along the length of the Knocknagoran valley.

- Transmissivity in the vicinity of borehole PWSBH01 in the granite bedrock is estimated to be 15 m^2/day. In the layered sandstone/shale bedrock, the transmissivity is estimated to be 2.4 m^2/day. The aquifer thickness intersected by boreholes PWSBH01 and PWSBH03 is approximately 90 m.

- The groundwater has a low to moderate level of mineralisation and is of calcium bicarbonate type. The pH of the groundwater is slightly approximately neutral. The available data suggest that there is a difference in hydrochemistry between boreholes PWSBH01 and PWSBH03, as well as between the groundwater and the surface water.

- The limited available data suggest that the untreated groundwater water quality is currently unpolluted. Nonetheless, a possible rising trend in nitrate and chloride has been observed at borehole PWSBH01 in data from 2009 and 2010. The borehole is reported to suffer from iron and manganese encrustation. No dissolved iron or manganese was detected in borehole PWSBH01 when measured in April 2010, however it may be that the metals precipitated out in the long rising main before the sampling point was reached.

9.2 BOUNDARIES OF THE ZOC

The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and the conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

The water balance approach calculates the recharge area footprint required to supply a recharge volume equal to the public water supply abstraction. Long term abstraction records for borehole PWSBH01 are not available. The current abstraction rate for borehole PWSBH01 is 79 m^3/day, however the maximum yield for the borehole is 345 m^3/day. The source caretaker indicated that the borehole abstraction is at a maximum when a new pump is installed and declines over time as iron and manganese encrustation affect the pump efficiency. The current combined abstraction from borehole PWSBH01 and the surface water abstraction at SW01 is 150 m^3/day. In order to provide a safety margin to account for increased abstraction from the borehole when a new pump is installed and to cover the potential abstraction in the event of the abstraction at SW01 going dry, the ZOC for borehole PWSBH01 has been delineated for an abstraction rate of 150 m^3/day, which is approximately double the current abstraction rate. The recharge area required to supply the borehole at this rate, based on an annual recharge of 100 mm, is 0.55 km^2. This is shown in Figure 9.

The maximum pumping tested yield from borehole PWSBH03 is 102 m^3/day, however it is not thought that this yield is sustainable in the long term. When used to supplement the supply in 2006, the borehole dewatered completely. The abstraction rate on that occasion was not recorded. Furthermore the installed pump failed to operate in June 2010. Despite these issues, a ZOC has been delineated for the borehole for an abstraction of 102 m^3/day. This does not guarantee that the borehole can supply this volume of water, but rather identifies the recharge area that would require protection were the borehole to be pumped in a sustainable manner at this rate. The recharge area required to supply the borehole at this abstraction rate, based on an annual recharge of 100 mm, is 0.37 km^2. The ZOC for each borehole, based on the water balance and constrained by the source conceptual model, has been delineated as follows.

Active Borehole (PWSBH01)

The northwestern / northern boundary is the upgradient boundary of the ZOC and follows the topographic divide of Lislea ridge, which runs northeast and then east through Lislea to the west and north of the source. Groundwater recharge to the north and west of the boundary is expected to follow flowlines away from the source, towards the northeast. Groundwater recharge on the eastern side of the boundary, within the ZOC footprint is expected to follow flowlines to the borehole. The width of the upgradient boundary perpendicular to the easterly groundwater flow direction is estimated to be of the order of 130 m using the uniform flow equation and the aquifer parameter values for borehole PWSBH01 from Table 6. In order to obtain a ZOC recharge footprint equivalent to 150 m^3/day, the width of the ZOC was delineated as approximately 500 m, which is of the same order of magnitude as the calculated value. The uniform flow equation gives the half-width of the upgradient boundary as (Todd, 1980):

Figure 9 Zone of Contribution

PWSS Abstraction (active borehole)

PWSS Abstraction (reserve borehole)

Zone of Contribution for Lislea Cross PWSS

Fault Zone in Bedrock

$Y_L = Q / (2 * T * i)$ where

Q is the daily pumping rate +/- X%

T is Transmissivity (based on the aquifer hydraulic characteristics)

i is background non-pumping hydraulic gradient.

The eastern boundary is the downgradient boundary of the ZOC. This delineates the maximum downgradient distance (X_L) that the borehole can pump water from. Using the uniform flow equation together with the parameter values for borehole PWSBH01 from Table 6, X_L is estimated to be of the order of 20 m. In order to obtain a ZOC recharge footprint equivalent to 150 m^3/day the distance to the downgradient boundary was delineated as approximately 40 m which is of the same order of magnitude as the calculated value. The uniform flow equation gives X_L as:

$X_L = Q / (2\pi * T * i)$ where Q, T and i have the same meaning as above.

The southern and northeastern boundaries are taken as groundwater flow lines from the upstream limit of the ZOC, which meet downhill of the borehole at the point defined by X_L. In the absence of water table elevation contours these flow lines are assumed to run roughly perpendicular to the ground surface elevation contours.

The resulting ZOC captures a 0.53 km^2 ZOC (see Figure 10) with a recharge footprint of approximately 150 m^3/day. This is less than the recorded maximum yield of 345 m^3/day for the borehole, which was measured immediately after drilling and development of the borehole. Borehole encrustation may have reduced the maximum yield compared to the post-drilling situation. In addition, the PWS abstraction has never approached this level and it is not demonstrated that an abstraction of 345 m^3/day is sustainable in the long term. As such, the maximum likely demand on the borehole of 150 m^3/day has been used to delineate the ZOC. If the borehole were pumped at a consistently higher rate, the effect would be to expand the ZOC as it is currently delineated.

<u>Reserve Borehole (PWSBH03)</u>

Borehole PWSBH03 is situated in the trough of the Knocknagoran valley in an area of groundwater discharge. As indicated in Section 8.2, it is unclear from the data whether there is a groundwater divide underneath the Knocknagoran / Drummullagh ridge. If present, the groundwater divide would mean that groundwater recharge to the western side of the ridge would flow west to discharge in the trough of the Knocknagoran valley. In the vicinity of the borehole this westerly flow could be intercepted by borehole PWSBH03. In this scenario the easterly extent of the ZOC would extend to the groundwater divide underneath the Knocknagoran / Drummullagh ridge. The delineation presented below conservatively assumes that the groundwater divide is present and that groundwater flow in the area is predominantly from the east, northeast and southeast. Groundwater flow to the borehole from the west is curtailed by the low transmissivity fault immediately west of the borehole. This results in a dominant easterly extent for the ZOC.

Given the converging nature of the groundwater flow from the north and east, and the minor flow component from the west, all three of these boundaries are considered to be upgradient of the source.

The **northwestern** boundary follows the topographic divide of Lislea ridge, which runs northeast through Lislea and Drummullagh to the northwest of the source. Groundwater recharge to the northwest of the boundary is expected to follow flowlines away from the source, towards the northeast. All groundwater recharge on the southeastern side of the boundary, within the ZOC footprint is conservatively expected to follow flowlines to the borehole, ignoring any possible discharge to surface water *via* springs or seepages.

The **eastern** boundary follows the topographic divide of Knocknagoran / Drummullagh ridge to the east of the source. The southern extent of the boundary has been delineated based on topographic divides along the ridge to conservatively give the maximum likely extent to the ZOC. Groundwater recharge to the east of the boundary is expected to discharge at the coast. Groundwater recharge on the western side of the boundary is expected to discharge at the base of the Knocknagoran valley and, within the ZOC footprint, is expected to follow flowlines to the borehole.

The **western** boundary is taken as the mapped bedrock fault to the west of the borehole, which is the maximum possible western extent of the ZOC. The boundary extends northwest along the fault from a point directly southwest of the borehole to intersect the northwestern boundary. The ZOC includes a buffer zone 100 m wide on the western side of the fault to account for potential uncertainty in the mapped position of the fault. The western boundary also extends to the southeast from the fault zone to intersect the eastern boundary, at the Knocknagoran / Drummullagh ridge.

The Lislea stream is considered to be the main groundwater discharge feature in the vicinity of borehole PWSBH03. It is unlikely that it would but, if the ZOC boundary were to extend as far as the stream, the stream might act as a recharge boundary for the borehole and, in theory, allow the borehole to abstract water from the stream. Given that the borehole yield is only moderate, any flow of stream water to the borehole is likely to be limited. In 2006 when the stream dried out, and when the borehole was brought into use it dewatered completely. This suggests that when the stream is dry the borehole ZOC cannot extend beyond the stream to draw in significant volumes of water from southern side of the stream. The difference between the groundwater hydrochemistry and the stream hydrochemistry also suggests that any borehole – stream interaction is negligible. As such, the southeastern reach of the western boundary has been delineated to the north of the stream.

The resulting ZOC captures an area of 0.33 km^2 (see Figure 9), with a recharge footprint of approximately 82 m^3/day. It is not clear from the available data whether or not the borehole is capable of supporting an abstraction equal to the reported yield of 102 m^3/day in the long term. The delineated ZOC, based on the conceptual model, suggests that an abstraction in excess of 82 m^3/day would be unsustainable. The delineated ZOC reflects the recharge footprint that would be required to support an abstraction of 85 m^3/day, but does not guarantee that the aquifer is sufficiently interconnected and transmissive to deliver the recharge to the borehole and provide a sustainable supply in the long term.

Surface water intake

The surface water intake at this source is not specifically part of this study. A zone of contribution has not been delineated for it. However, since the stream is thought to contribute water to the Esmore Bridge water supply borehole, the stream has been buffered and incorporated within the Esmore Bridge ZOC. As such, it is incorporated with the Omeath PWSS combined ZOC.

9.3 RECHARGE & WATER BALANCE

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 is assumed to consist of the rainfall input (*i.e*. annual rainfall) minus 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 this dictates the size of the zone of contribution to the source (*i.e*. the outer Source Protection Area).

The main factors involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient. The recharge coefficients chosen for the different subsoil settings across the study area, based on Guidance Document GW5 (IWWG, 2005), are detailed in Table A2.1 in Appendix 2.

The actual recharge is given by the potential recharge multiplied by the recharge coefficient. The potential recharge for the area is calculated as 651 mm/yr (see Section 6). For PI aquifers where the calculated potential recharge exceeds 100 mm/yr, the Water Framework Directive Guidance Document GW5 recommends that actual recharge should be capped at 100 mm/yr. This is because PI aquifers are generally unable to accept, and transmit from recharge area to discharge area, volumes of recharge in excess of the cap. The excess recharge overwhelms the storage capacity of the aquifer such that the aquifer fills up to the brim and the excess effective precipitation runs off to surface water. Instances where a recharge cap has been applied are indicated in Table A2.1. Table A2.1 also details the area occupied by each recharge setting as a percentage of the total area contributing recharge to the source boreholes. The selected coefficients apply to the areas around both borehole PWSBH01 and PWSBH03. The percentage areas shown in the table refer to the percentage of the combined ZOC area for the two. In all cases except for the peat subsoil setting, the PI aquifer recharge cap of 100 mm was applied. An actual recharge value of 100 mm/yr equates to a recharge coefficient of 0.15. After application of the recharge cap, the bulk runoff losses from the total recharge area are estimated at 85% of potential recharge.

The bulk recharge coefficient for the area is therefore estimated to be 0.15. The recharge calculations are summarised in Table 7.

Table 7 Recharge Calculation Summary

Parameter	**Coefficient**	**Rate**
Average rainfall (R)		1102 mm/yr
Estimated P.E.		475 mm/yr
Estimated A.E. (95% of P.E.)		451 mm/yr
effective rainfall		651 mm/yr
Potential recharge		651 mm/yr
Recharge cap for PI aquifer		100 mm/yr
Averaged runoff losses	0.85	585mm/yr
Bulk recharge coefficient	0.15	
Recharge		100 mm/yr

10 GROUNDWATER SOURCE PROTECTION ZONES

The Source Protection Zones (SPZs) are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an amalgamation of source protection areas and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. Two source protection areas have been delineated:

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

The delineated source protection areas are shown in Figure 10.

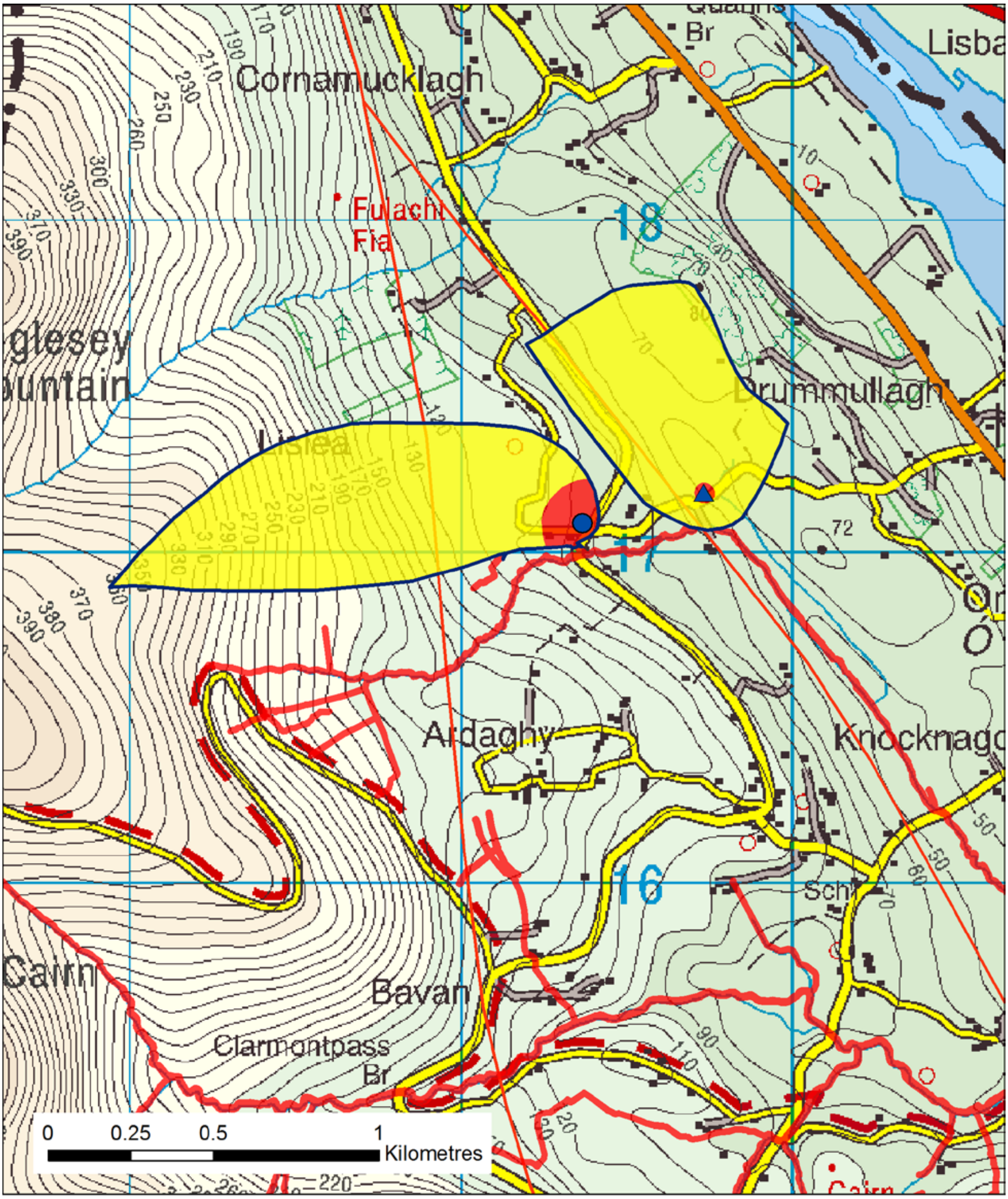


Figure 10 Source Protection Areas

PWSS Abstraction (active borehole)

PWSS Abstraction (reserve borehole)

Inner Source Protection Zone (SI)

Outer Source Protection Zone (SO)

NB - also shown are the SPAs for Esmore Bridge PWSS

Zone of Contribution for Lislea Cross PWSS

Fault Zone in Bedrock

10.1 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)**, as described in Section 9.2. As mentioned above, the surface water intake has not been specifically considered as part of the Lislea Cross report. However, the stream has been buffered and incorporated within the Esmore Bridge ZOC. As such, it is incorporated with the Omeath PWSS combined ZOC.

10.2 INNER PROTECTION AREA

The Inner Source Protection Area (SI) is the area defined by the horizontal 100 day time of travel from any point below the water table 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 velocity multiplied by the 100 day time period gives the distance travelled by the groundwater during the TOT. This distance gives the lateral extent of the buffer which must be applied around the source to form the SI.

For borehole PWSBH01, an estimated groundwater velocity of 1.32 m/day results in an SI extending up to 132 m. The SI has been delineated on this basis and occupies the area downgradient of the borehole and an area extending 132 m northwest of the borehole.

For borehole PWSBH03, the groundwater velocity in the vicinity of borehole PWSBH03 is calculated as 0.24 m/d. This gives an SI extent of 24 m, which has been delineated as a circular area around the source in all directions.

Groundwater protection zones are shown in Figure 11 and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/E, SI/H, SO/E, and SO/H.

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- Direct microbial contamination of the source from ponded water within the well head chamber. The ponded water may derive from drainage along service ducts. This water may be contaminated by animals and birds. The main potential contaminants from these sources are faecal bacteria, viruses and cryptosporidium. This does not appear to be a problem at present.
- Effluent discharge to ground from domestic onsite wastewater treatment systems. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium.
- Agricultural land use occupies a significant component of the zone of contribution and is dominated by sheep grazing activities. It is possible that some landspreading of organic matter from agricultural sources (*e.g*. cattle slurry) takes place within the lower, managed ground within the ZOC delineated for borehole PWSBH03. The steep slopes of the ZOC delineated for borehole PWSBH01 are unlikely to be suitable for landspreading activities. Runoff from farmyards may also be contaminated by organic matter. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium.
- Private home heating fuel tanks are likely to be located within the catchment area. The main potential contaminants from this source are hydrocarbons.
- Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals, and illegal dumping/flytipping.

Figure 11 Source Protection Zones

PWSS Abstraction (active borehole)

PWSS Abstraction (reserve borehole)

Zone of Contribution for Lislea Cross PWSS

SI/E

SI/H

SO/E

SO/H

NB - also shown are the SPZs for Esmore Bridge PWSS. SPZ legend is for Lislea Cross only.

12 CONCLUSIONS

A conservative ZOC for borehole PWSBH01 has been delineated based on approximately 200% of the current abstraction rate of 79m^3/day, assuming that all of the abstraction comes from diffuse recharge to the bedrock aquifer. Part of the ZOC, within 132 m of the borehole, has been designated as SI with the remainder designated as SO. The source protection zones delineated in this ZOC are SI/E, SI/H, SO/X, SO/E and SO/H.

A conservative ZOC for borehole PWSBH03 has been delineated based on a maximum likely sustainable yield from the borehole of 68 m^3/day. It is not known if an abstraction of this magnitude from the borehole would be sustainable in the long term. Part of the ZOC, within 24 m of the borehole, has been designated as SI with the remainder designated as SO. The source protection zones delineated in this ZOC are SI/E, SI/H, SO/E, and SO/H.

Based on the limited available data, the untreated groundwater appears to be currently unpolluted.

The surface water intake has not been specifically considered as part of the Lislea Cross report. However, since the stream is thought to contribute water to the Esmore Bridge water supply borehole, the stream has been buffered and incorporated within the Esmore Bridge ZOC. As such, it is incorporated with the Omeath PWSS combined ZOC.

Particular care should be taken when assessing the location of any activities or developments that might cause contamination of the Lislea Cross Source, particularly within the inner source protection zone (SI). Reference should be made to the guidelines contained within the DELG/EPA/GSI “Groundwater Protection Scheme” publication regarding the siting of certain activities, such as septic tanks and landspreading of organic wastes, within source protection areas.

The conclusions and recommendations of the report are based on current understanding of groundwater conditions and bedrock geology as inferred from the available data. The report should not be used as the sole basis for site-specific decisions.

13 RECOMMENDATIONS

- Monitoring of untreated groundwater quality should continue at boreholes PWSBH01 and PWSBH03;
- If a larger abstraction is required from the supply, the existing pump should be overhauled or replaced as necessary. Given the elevated manganese and iron reported by the caretaker, regular maintenance of the pump should be undertaken in order to maintain its efficiency.
- A suitably specified submersible pump should be installed in borehole PWSBH03 and the borehole should be subjected to a long term pumping test, of at least 72 hours, to determine the sustainable yield of the borehole. This should be supervised by a hydrogeologist.

14 REFERENCES

BS 5930:1999. Code of practice for site investigations. British Standards Institute - BSI

Collins, J.F. and Cummins, T., 1996. Agroclimatic Atlas of Ireland. Joint Working Group on Agricultural Meteorology, AGMET.

DELG/EPA/GSI, 1999. Groundwater Protection Schemes. Dept. of the Environment & Local Government; Environmental Protection Agency; Geological Survey of Ireland.

EPA website. www.epa.ie

Fitzgerald, D. and F. Forrestal, 1996. Monthly and annual averages of rainfall for Ireland 1961 to 1990. Meteorological Service Climatological Note No. 10. Glasnevin Hill, Dublin 9.

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

Geraghty, M., 1996. Bedrock Geology 1:100,000 Scale Map Series, Sheet 8/9, Monaghan and Carlingford. Geological Survey of Ireland

Geraghty, M., 1997. Geology of Monaghan – Carlingford. A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 8/9, Monaghan Carlingford. Geological Survey of Ireland.

GSI website. www.gsi.ie

GSI, 2004. Louth Groundwater Body – Water Framework Directive Initial Characterisation Summary – 1st Draft. Geological Survey of Ireland.

IWWG 2005. Guidance on the Assessment of the Impact of Groundwater Abstractions. Guidance Document No.GW5. Intergovernmental Working Group on Groundwater.

SI No. 278 of 2007. European Communities (Drinking Water) (No.2) Regulations 2007. Stationary Office, Dublin.

Teagasc, 2004a. Subsoils map of County Louth. Map produced as part of EPA Soils and subsoils Mapping Project. Teagasc, Kinsealy, Dublin.

Teagasc, 2004b. Soils map of County Louth. Map produced as part of EPA Soils and subsoils Mapping Project. Teagasc, Kinsealy, Dublin.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edition New York: John Wiley & Sons.

APPENDIX 1

FLOW DATA

- Table A1.1a – Point Data from Hydro geological Mapping
    - Table A1.1b – GSI Well Database Data
    - Table A1.1c – GSI Depth to Bedrock Data
- Table A1.2 – Louth County Council Water Quality Data For Lislea Cross Boreholes
- Table A1.3 – Field Water Quality Data For Lislea Cross Boreholes
    - Borehole PWSBH01 Borehole Log
    - Borehole PWSBH03 Borehole Log
- Pumping Test Analysis Summary
    - Table A1.4 – Pumping Test Data

Table A1.1a - Point Data from Desk Study Hydrogeological Mapping - Omeath - Lislea Cross Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						18/06/1998	Mar-07	29/04/2010	29/06/2010							
PWSBH01	Groundwater	Borehole	312383	317093	Referred to as ' Borehole No.3 Omeath' on Des Meehan BH log. Also known as 'Lislea Cross PWS Borehole'. 'tc' = steel rim of well chamber cover = 0.63 m above top of orange PVC pipe attached to the top of the 6" steel casing. PVC pipe stuck on to keep chamber flooding out of the borehole. Pump depth approx 52m . Drilled by Des Meehan in August 1997 by rotary percussion. 6" Steel casing to 5.19mbgl (stick up approx 10 cm above chamber floor). 115mm ID PVC slotted liner 0 to 110m. Water strikes at 7.6 (13m3/d); 49m (32m3/d); 61m (78m3/d); & 94m (345m3/d). No grout seal. GWL in Mar 07 & Apr 10 = PWL; GWL on 30/6/10 = Rest GWL. GL estimated from EPA 20m grid DTM of Louth.		3.605	6.4	5.99	110	0.15	94.63	88.79	3		
PWSBH02	Groundwater	Borehole	314468	315829	Also known as 'Esmore Bridge PWS Borehole'. Drilled /completed 14/05/1984.10" SC 0 to 3.66m; 6" SC 0 to 7.31m, incorporating a 2.89m long 6" dia steel screen between 3.66 and 6.4m. Water strike in gravels between 3.66 and 6.4m. Well drilled with 10" SC to TD, 6" casing installed inside 10", gravel pack installed between 10" and 6" SC, then 10" SC retracted to 3.66m. 'tc' = top of 6" SC. BH was pumping @ 116m3/d when GWLs measured. Pump depth approx 5.5mbtc.			1.4	1.435	7.31	-0.4	7.01	5.175	6.4		
PWSBH03	Groundwater	Borehole	312741	317177	Referred to as ' Borehole No.1 Omeath' on Des Meehan BH log. Also known as 'Lislea Cross Reserve Borehole'. 'tc' = top of 6" steel casing = 0.3m below steel rim of well cover. Drilled by Des Meehan in August 1997 by rotary percussion. 6" steel casing to 9.14mbgl; No PVC liner. Water Strike @ 29m (19m3/d) & below 75m yield = 32m3/d. No grout seal. GWLs are rest levels. Borehole hydro-fractured on 25/08/1997 with packer set placed in turn at 7.m, 55m & 37m, improved yield from 32m3/d to 106m3/d. GL estimated from EPA 20m grid DTM of Louth.	1.2		0.77	0.81	95	0.23	60.5	59.92	4.87		
BH01	Groundwater	Borehole	312816	317101	Referred to as 'Borehole No.2 Omeath' in Des Meehan borehole records. Abandonned borehole approximately 200m south of PWSBH03. Borehole casing sticks up apporx 0.6m agl and is welded shut with a steel cap. GL estimated from EPA 20m grid DTM of Louth.											
BH02	Groundwater	Borehole	313437	316889	Private borehole. Drilled 05/07/2007. 8" & 6" steel casing & 5" PVC liner visible at GL. Grout seal between 8" & 6" casings, no info on grouting of annulus. 6" casing stick up = 1.44magl, which may indicate artesian GWL during winter (GWL below GL at time of visit). BH not currently in use. Water strikes @ 45m (3m3/d) & 70m (162m3/d). 'tc' = top of 6inch steel casing = 1.44magl (top of 5" PVC liner at same level). GL estimated from EPA 20m grid DTM of Louth.				9.93	79	1.44	61.43	52.94	3.05		
BH03	Groundwater	Borehole	313415	316975	Private borehole adjacent to local road and water treatment building. No borehole construction info available. Proabably drilled since 2005. 'tc' = top of 6" steel casing. BH covered with a square manhole. GL estimated from EPA 20m grid DTM of Louth.				0		0.11	60.01	60.12			
BH04	Groundwater	Borehole	312208	317209	Private Borehole. Recorded by GSI in Mar 2007. Drilled approx 2002 by Dunnes. Assume 'tc' = top of 6" steel casing & = GL		10.35			79	0	112.34	102			
SW01	Surface Water	Abstraction	312308	316964	Lislea Surface Water Abstraction Point											
SW02	Surface Water	Monitoring Point	314474	315829	Surface water quality monitoring point in the Ryland River adjacent to PWSBH02											
GW01	Groundwater	Spring	312103	317052	Spring recorded by the GSI											
GW02	Groundwater	Spring	312450	316908	Spring recorded by the GSI											
GW03	Groundwater	Spring	312970	316975	Area of "numerous springs" recorded on GSI 6-inch geology field map											

Table A1.1b - GSI Well Database Points in Study ARea - Omeath - Lislea Cross Public Water Supply

GSINAME	ORIGNAME	TYPE	DEPTH_M	DPTH_RCK_M	DTRCONFID	DRILLDATE	EASTING	NORTHING	LOC_ACC	TOWNLAND	TOWN	COUNTY	SIXINSHTNO
2931SEW017	682	Borehole	73.2	3.1	Bedrock Met	23/07/1997	312760	316550	to 50m	ARDAGHY		Louth	5
2931SEW105	NERDO L5/1B	Borehole	42	4	Bedrock Met	00:00:00	312930	316240	to 20m	ARDAGHY		Louth	5
2931SEW106	NERDO L5/1C	Borehole	33	7	Bedrock Met	00:00:00	312760	316300	to 20m	ARDAGHY		Louth	5
2931SEW019	1336	Borehole	94.5	6.1	Bedrock Met	04/06/1998	313030	316190	to 100m	ARDAGHY	oMEATH	Louth	5
2931SEW131		Borehole	91.4	13.7	Bedrock Met	20/08/2002	312400	317160	to 100m	LISLEA		Louth	5
2931SEW063	2021	Borehole	79.3	3.1	Bedrock Met	14/02/2000	313750	317010	to 1km	DRUMMULLAGH	Omeath	Louth	5
2931SEW013	628	Borehole	36.6	6.1	Bedrock Met	03/02/1997	313440	317760	to 200m	DRUMMULLAGH		Louth	2
2931SEW014	626	Borehole	54.9	12	Bedrock Met	28/01/1997	313410	317820	to 200m	DRUMMULLAGH		Louth	2
2931SEW015	627	Borehole	36.6	12	Bedrock Met	29/01/1997	313380	317890	to 200m	DRUMMULLAGH		Louth	2
2931SEW016	629	Borehole	30.5	6.1	Bedrock Met	04/02/1997	312920	317860	to 200m	DRUMMULLAGH		Louth	2
2931SEW033		Borehole	36.6	4.6	Bedrock Met	21/09/1998	313460	317880	to 200m	DRUMMULLAGH		Louth	2

GSINAME	SOURCEUSE	YLDCLASS	YIELD_M3D	CAS1DIA_MM	WTRSTRK1_M	WTRSTRK2_M	WTRSTRK3_M	WTRSTRK4_M	GENCOMMS	DRILLCOMMS	CASINGCOMS
2931SEW017		Poor	32.7	152	61				Driller Dunnes, Dromiskin		Yield estimated
2931SEW105		Poor	26							INFORMATION FROM THE NERDO REPORT 1981	
2931SEW106		Poor	26							INFORMATION FROM THE NERDO REPORT 1981	SILURIAN STRATA
2931SEW019		Poor	21.8	152	54.9	61	85.3	88.4	Driller Dunnes, Dromiskin		Yield estimated
2931SEW131	Agri & domestic use	Poor	15.3	203					Driller Dunnes, Dromiskin		Y estimated
2931SEW063	Domestic use only	Poor	6.5	203					Drilled by Dunnes, Dundalk		Yield estimated
2931SEW013		Moderate	43.6	152					Driller Dunnes, Dromiskin		Yield estimated
2931SEW014	Domestic use only	Poor	13.1	152	42.7				Driller Dunnes, Dromiskin		Yield estimated
2931SEW015	Domestic use only	Moderate	55	152	24.4				Driller Dunnes, Dromiskin		Yield estimated
2931SEW016		Moderate	76.6	152					Driller Dunnes, Dromiskin		Yield estimated
2931SEW033	Domestic use only	Poor	21.8	152	18.3	30.5			Drilled by Dunnes, Dundalk		Yield estimated

GSI Sources

Table A1.1b - Other known GSI Data Points in Study Area - Omeath - Lislea Cross Public Water Supply

Type	Name	DTB	EASTING	NORTHING	Subsoil_K	SubSL_Desc
Exposure	4d	1.5	313006	315210	Moderate	Firm, sandy SILT with frequent gravels.
Exposure	4e	5	314220	315566	High	gravelly SAND with frequent cobbles.
Exposure	5b	2	313613	317127	High	Soft, gravelly SAND with frequent cobbles.
OMBH	OMBH08	1	312829	317381		
OMBH	OMBH09	1.5	312716	316289		
OMBH	OMBH06	2.9	312196	317014		
OMBH	OMBH02	3.5	314123	316123	High	Very dense, coarse grained sandy GRAVEL.
OMBH	OMBH10	4	312568	317057	High	Very dense SAND.
OMBH	OMBH05	4.5	312397	317094	High	Very sandy, GRAVEL.
OMBH	OMBH07	4.5	312403	317096	High	Loose, sandy GRAVEL.
OMBH	OMBH03	6	314258	316023	High	Very dense becoming soft, very silty GRAVEL.
OMBH	OMBH01	8	314054	315732		
OMBH	OMBH11	7	313179	315849	High	Sandy, coarse GRAVEL.
OMBH	OMBH12	2	313832	315897		
OtherDTB		0.3	312260	315840		
OtherDTB		0.6	315830	314220		
OtherDTB		16.8	312670	314740		
OtherDTB		21.34	313663.4913	315455.3801		
OtherDTB		24.4	313340	315280		
OtherDTB		39.6	313252	315939		
OtherDTB		3.048	311939	316432		
OtherDTB		3.05	313104.8801	316225.8569		
OtherDTB		4.57	312341	317161		
OtherDTB		8.55	314295	314295		
OtherDTB		8.53	312494	318853		
OtherDTB		6.7	312012.5923	318361.7573		
OtherDTB		5.79	312826	318431		
OtherDTB		9.1	314310	316760		

Table A1.2 - Louth County Council Water Quality Data for Omeath PWS Source (Lislea Cross Boreholes - PWSBH01 PWSBH03)

			mg/l NO3	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l NO2	mg/l SO_4	mg/l $CaCO_3$	mg/l $CaCO_3$	uS/cm	ug/l Al
GSI Name	**Date**		**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**
	Jan-82	**Threshold**	**37.5**				**150**	**24**	**0.375**	**187.5**			**800**	**150**
	Jan-82	**DWS**	**50**				**200**	**250**	**0.5**	**250**			**2500**	**200**
GSI Name	**Date**		**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**
PWSBH01 (LIS2900950)	02-Apr-09		6.51					17			137		361	
PWSBH01 (LIS2901249)	07-May-09		6.86					18			133		355	
PWSBH01 (LIS2904197)	18-Nov-09		9.83					22			67		66	
PWSBH01 (LIS1001142)	26-Apr-10		11.78	28.30	5.47	1.13	15.82	24.00	<0.007	18.00	70.00	103.00	277	<10
PWSBH03 (Reserve BH)	29-Jun-10		0.66	51.00	6.40	0.76	14.00	13.30		11.20	148.00		318	
PWSBH01 Average		mg/l	8.7	28.3	5.5	1.1	15.8	20.3		18.0	101.8	103.0	264.8	

Red colour denotes result in excess of Drinking Water Standard (DWS)
Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

PWSBH01	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	
mmol/l	0.19	0.71	0.22	0.03	0.69	0.68		0.19	0.70	mmol of CaCO3 = mmol of CO3--
MW	62.00	40	25.31	39.1	22.99	35.45	47	96.066	100	
charge	1	2	2	1	1	1	1	2	2	
meq/l	0.19	1.42	0.43	0.03	0.69	0.68		0.37	1.40	meq of CO3-- = meq of HCO3-
									1.40	mmol HCO3-
meq cations	2.56								85.40	mg/l as HCO3-
meq anions	2.64									

PWSBH03	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	
mmol/l	0.01	1.28	0.25	0.02	0.61	0.38		0.12	1.48	mmol of CaCO3 = mmol of CO3--
MW	62.00	40	25.31	39.1	22.99	35.45	47	96.066	100	
charge	1	2	2	1	1	1	1	2	2	
meq/l	0.01	2.55	0.51	0.02	0.61	0.38		0.23	2.96	meq of CO3-- = meq of HCO3-
									2.96	mmol HCO3-
meq cations	3.68								180.56	mg/l as HCO3-
meq anions	3.58									

Source: available Louth County Council EPA data.

Table A1.2 - Louth County Council Water Quality Data for Omeath PWS Source (Lislea Cross Boreholes - PWSBH01 PWSBH03)

		ug/l Fe	ug/l Mn	mg/l NH4	No./100ml	No./100ml	ug/l Ba	mg/l B	mg/l Cd	ug/l Cr	mg/l Cu	mg/l F^-	mg/l Pb	ug/l Hg	ug/l Ni
GSI Name	**Date**	**Fe**	**Mn**	**NH4**	**TC**	**F. coli**	**Ba**	**B**	**Cd**	**Cr**	**Cu**	**F**	**Pb**	**Hg**	**Ni**
	Jan-82			**0.23**				**0.75**	**0.00375**	**37.5**	**1.5**		**0.01875**	**0.75**	**15**
	Jan-82	**200**	**50**	**0.3**	**0**	**0**		**1**	**0.005**	**50**	**2**	**1.5**	**0.025**	**1**	**20**
GSI Name	**Date**	**Fe**	**Mn**	**NH4**	**TC**	**F. coli**	**Ba**	**B**	**Cd**	**Cr**	**Cu**	**F**	**Pb**	**Hg**	**Ni**
PWSBH01 (LIS2900950)	02-Apr-09			< 0.039											
PWSBH01 (LIS2901249)	07-May-09			< 0.039											
PWSBH01 (LIS2904197)	18-Nov-09			< 0.039											
PWSBH01 (LIS1001142)	26-Apr-10	<10	<1	<0.039	0.00	0.00		0.0118	<0.0001	<1	<0.001	<0.150	<0.001	<0.1	<1
PWSBH03 (Reserve BH)	29-Jun-10			0.065											
	PWSBH01 Average				0.0	0.0									

Red colour denotes result in excess of Drinking Water Standard (DWS)

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.2 - Louth County Council Water Quality Data for Omeath PWS Source (Lislea Cross Boreholes - PWSBH01 PWSBH03)

		mg/l P	mg/l P	mg/l Se	mg/l Ag	mg/l Sr
GSI Name	Date	PO4	P	Se	Ag	Sr
	Jan-82	0.035				
	Jan-82			0.01		
GSI Name	Date	PO4	P	Se	Ag	Sr
PWSBH01 (LIS2900950)	02-Apr-09	<0.02				
PWSBH01 (LIS2901249)	07-May-09	<0.02				
PWSBH01 (LIS2904197)	18-Nov-09	<0.02				
PWSBH01 (LIS1001142)	26-Apr-10	<0.02	0.01	<0.001		
PWSBH03 (Reserve BH)	29-Jun-10					
PWSBH01 Average						

Red colour denotes result in excess of Drinking Water Standard (DWS)
Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.2 - Louth County Council Water Quality Data for Omeath PWS Source (Lislea Cross Boreholes - PWSBH01 PWSBH03)

		mg/l Zn	mg/l Sb	mg/l As	[-]	%	deg C	mg/l C	mg/l O2	mg/l O2	mg/l O2	mg/l O_2
GSI Name	**Date**	**Zn**	**Ant**	**As**	**K/Na Ratio (using meq)**	**DO (% Sat)**	**pH**	**Temp**	**TOC**	**COD**	**BOD**	**DO**
	Jan-82			0.0075	0.4							
	Jan-82		0.005	0.001			>6.5 & < 9.5					
GSI Name	**Date**	**Zn**	**Ant**	**As**	**K/Na Ratio**							
PWSBH01 (LIS2900950)	02-Apr-09						7.4	7.8	<1.5	<10	<1.5	62
PWSBH01 (LIS2901249)	07-May-09						7.4	11.2	1.8	<10	<1.5	30
PWSBH01 (LIS2904197)	18-Nov-09						6.7	10.8	<3.0	<10	<1.5	64
PWSBH01 (LIS1001142)	26-Apr-10	<0.001	<0.001	<0.001	0.04		6.70	15.50	1.50			65.00
PWSBH03 (Reserve BH)	29-Jun-10				0.03		7.01					
PWSBH01 Average							7.1	11.3				

Red colour denotes result in excess of Drinking Water Standard (DWS)

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.3 - Field Water Quality Data - Omeath - Esmore Bridge Public Water Supply

							degC	uS/cm	degC	mg/l O2	%	degC	mg/lCaCO3	
Name	X	Y		Time	RWL	pH	Tph	EC	Tec	DO	DO	Tdo	Alk	Ref
PWSBH01	312383	317093	30/06/2010	10:20	5.99	6.67	13.1	300	13.2	4.07	40	14	86	steel rim of chamber
PWSBH01	312383	317093	30/06/2010	15:15	5.99	6.78	13	294.2	12.9	5	45	13.8	84	steel rim of chamber
SW02	314474	315829	29/06/2010	11:30	-	8.38	15.1	108.5	15	10.25	103.6	15.4	28	
PWSBH02	314472	315831	29/06/2010	12:00	1.435	6.6	11.4	123.4	11.4	1.83	16.9	12	36.5	top of 6" Steel Casing
BH02	313437	316889	29/06/2010	15:05	9.93	8.25	10.5	207.9	10.7	1.33	12.5	11.9	77	top of 6" Steel Casing
PWSBH03	312741	317177	29/06/2010	16:45	0.81	7.02	10.5	332	10.6	0	0	11.5	133	top of 8" Steel Casing

APPENDIX 2

RECHARGE COEFFICENT TABLE

- Table A2.1 – Recharge Coefficient Table

Table A2.1 Recharge coefficients for the study area

GW Vul	Location in Study Area	Additional Factors	% Area	Recharge Coefficient Guidance		Chosen Recharge Coefficient	Calculated Recharge	Recharge after PI Recharge Cap
				Inner Range	Outer Range		(mm/yr)	(mm/yr)
High (H)	Till subsoils across the study area with well drained soils	Generally moderate slopes underlain by moderate permeability subsoils	27.6	50 - 70%	35 - 80%	0.6	390.6	100
	Till subsoils across the study area with poorly drained soils	Generally moderate slopes underlain by moderate permeability subsoils	25.4	25 - 40%	15 - 50%	0.25	162.75	100
	Blanket peat in trough of Knocknagoran valley	Toe slope	4.8	5 - 15%	0 - 20%	0.15	100	100
Extreme (E)	Scree on upper slopes of Black Mountain	Steep slope	0.8	80 – 90%	60 - 100%	0.7	455.7	100
	Till subsoils around outcrop on Black Mountain and bedrock outcrops along stream and in lower parts of Lislea and Ardaghy, with well drained soils	Moderate to steep slope	3.7	50 - 70%	45 - 80%	0.6	390.6	100
	Till subsoils around outcrop on Black Mountain and bedrock outcrops along stream and in lower parts of Lislea and Ardaghy, with poorly drained soils	Moderate to steep slope	11.0	25 – 40%	15 - 50%	0.25	162.75	100
Extreme (X)	Bedrock outcrop on Black Mountain, along stream and in lower parts of Lislea and Ardaghy	Moderate to steep slope	26.8	80 – 90%	60 – 100%	0.7	455.7	100