1 MAGHERABEG/VEAGH PUBLIC WATER SUPPLY SCHEME

1.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the Magherabeg/Veagh Water Supply Scheme; namely the two boreholes.
- To outline the principal hydrogeological characteristics of the surrounding area.
- To assist Donegal County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the abstraction points. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The protection of public water supplies is also mentioned in Circular letter SP 5-03, which was issued from the DEHLG to all County/City Managers in July 2003. The circular states that source protection zones around public water supplies should be included in all county development plans. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection scheme for the county. The maps produced for the scheme are based largely on mapping techniques that use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole county 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.

1.2 Summary of Supply Details

GSI Number	2041SEW073	2039NEW052
Grid ref. (GPS)	22766 41001	22745 40994
Townland	Galdonagh	Galdonagh Glebe
Source type	Borehole No.1	Borehole No.2
Drilled	January 1997	April 1997
Owner	Donegal Co Co	Donegal Co Co
Elevation (m O.D.)	c. 111 m	c. 78 m
Depth of Borehole	60 m	50 m
Depth of casing	49 m	7.5 m
Diameter	200 mm	200 mm
Depth to rock	0.5 m	7.5 m
Static water level	12.5 m	Artesian
Pumping water level	c. 49 m b.g.l.	c. 25 m b.g.l.
Consumption (CoCo records)	c. 325 m^3/d	c. 186 m^3/d
Pumping test summary: **(i) abstraction rate**	450 m^3/d	382 m^3/d
(ii) specific capacity	c. 40 m^2/d	31 m^2/d
(iii) transmissivity	c. 11 m^2/d	c. 12 m^2/d

1.3 Methodology

1.3.1 Desk Study

Details about the boreholes such as depth, date commissioned and abstraction figures were obtained from County Council personnel and a report written by K.T. Cullen & Co. Ltd (KTC) in 1997. Additional geological and hydrogeological information was provided by GSI and Teagasc mapping programmes (Long and McConnell, 1997; Meehan, 2004 respectively).

1.3.2 Site Visits and Fieldwork

This part of the work included the following:

- meetings with Donegal County Council Staff in October 2002 and March 2003;
- drilling of depth to bedrock/permeability holes in the general area;
- site walkovers in March and July 2003 to further investigate the subsoil geology, hydrogeology and vulnerability to contamination;
- water sampling in November 2002 and March 2003.

1.3.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

1.4 Location and Site Description

The Magherbeg/Veagh Scheme is located in the adjacent townlands of Galdonagh and Galdonagh Glebe, approximately 4 km southeast of Manor Cunningham and 10 km east-southeast of Letterkenny Town. (Figure 1.1). The scheme comprises two boreholes; BH1 is some 250 m east of the Galdonagh crossroads, located on the west-facing side of a ridge and BH2 is situated at the crossroads. BH1 is c.33 m higher in elevation than BH2, which is at 78 m O.D. Additionally there is a unused trial well (TW3) situation approximately 2 m north of BH2 (Figure 1.2).

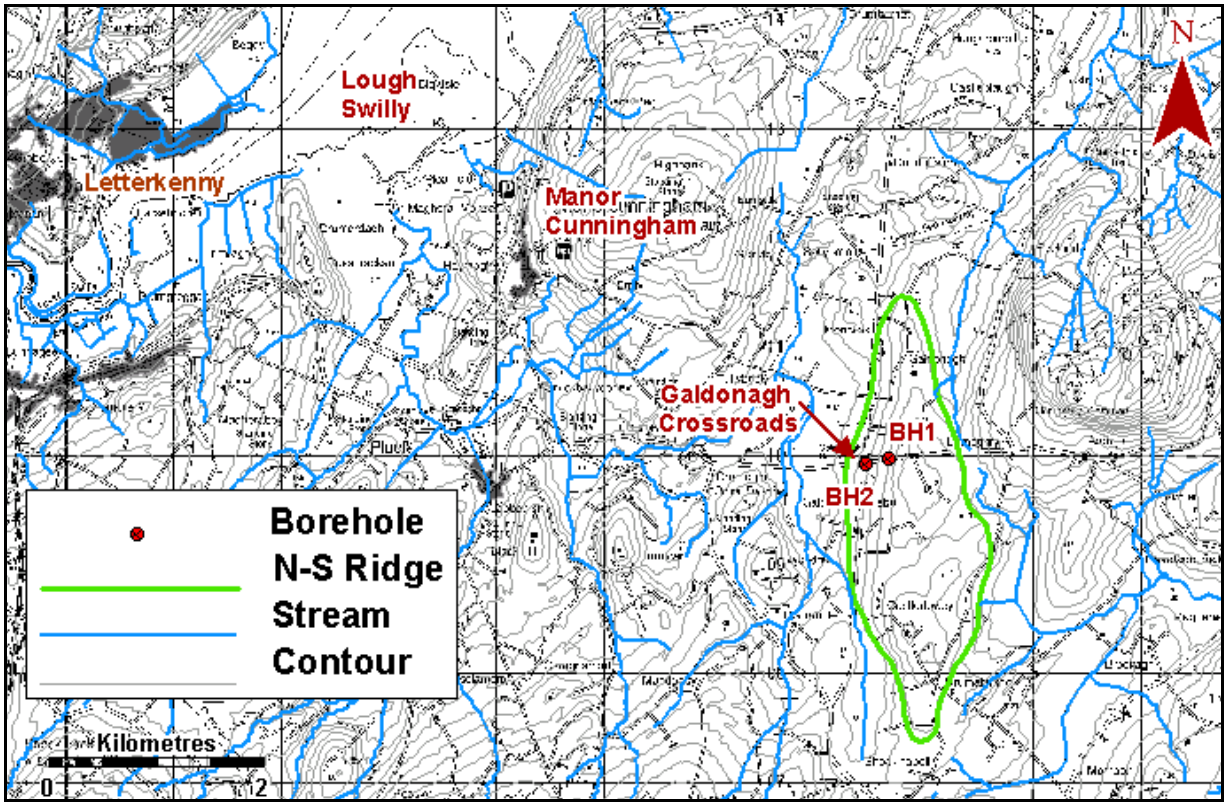

Figure 1.1. Location and Features of the Magherabeg/Veagh Water Supply Scheme.

BH1 is enclosed in a small fenced-off area (maximum of 20 m^2) adjacent to the road. The pump controls and raw water taps for both boreholes are also located in the enclosed area, next to BH1. BH2 is located on the corner of the crossroads although it is not fenced off (Figure 1.2). The borehole location is identified by an adjacent sign. Both boreholes have man-hole covers (unlocked) that are slightly raised above ground level.

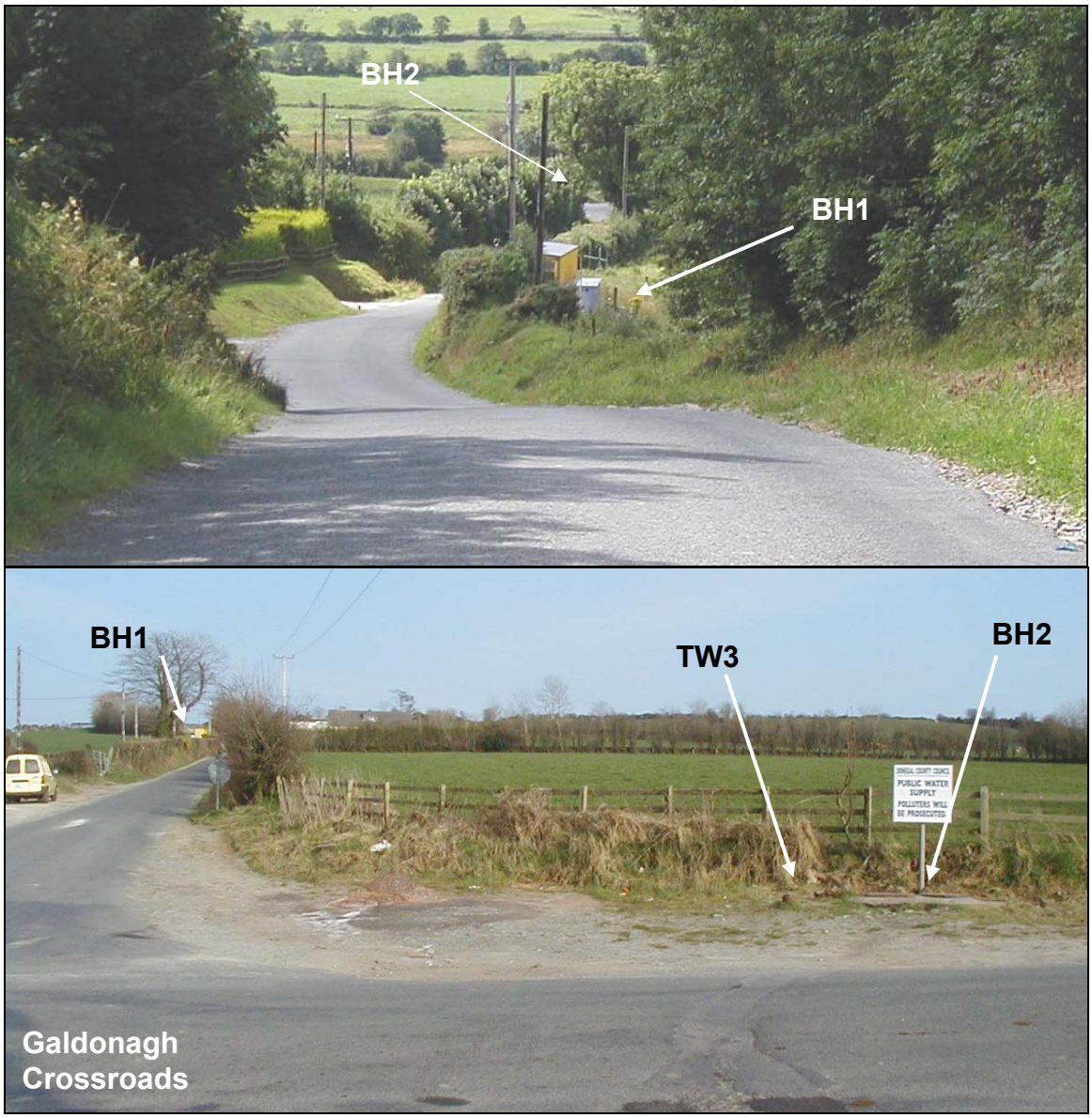

Figure 1.2. East to West View (Top). West to East View (Bottom).

Groundwater is pumped simultaneously from these boreholes to a reservoir before it enters the distribution system. There are somewhere in the region of 250-500 connections on this particular system.

The abstraction rate is recorded as 325 m^3/d and 185 m^3/d in BH1 and BH2 respectively. Previously, pumping did not occur overnight. However, during the summer of 2003 the length of pumping increased, sometimes up to 24 hours a day.

1.4.1 Topography, Surface Hydrology and Land Use

Both of the boreholes are located on the western side of a north-south trending ridge (Figure 1.1). The highest point of the ridge rises to 132 m O.D. and forms part of the lower area of the Dooish Mountain.

The ridge forms a local surface water divide. An (un-named) stream, approximately 675 m west of the BH2, flows northwards past the ridge to eventually discharge into Lough Swilly. There are a number of stream sources on the eastern side of the ridge, which flow eastwards into the River Foyle, c.8 km east of the Galdonagh crossroads. There are very few drainage channels on the ridge itself although they do feature on the less steep, lower-lying, valley-bottom area to the west of the ridge.

Grazing and some tillage are the main land uses in this general area. The Galdonagh crossroads are relatively busy and are used by heavy goods vehicles as well as cars. There are an additional number of smaller roads run which cross the ridge. Individual houses and farms are located along all of the roads, the closest being within 30 m of BH1.

1.5 Geology

1.5.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the site. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Geological information was taken from a desk-based survey of available data, which comprised the following:

- The Geology of South Donegal. Bedrock Geology 1:100,000 Map Series, Geological Survey of Ireland (Long and McConnell, 1999).
- Geological mapping in the nineteenth century (on record at the GSI).
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2004).
- Report on the Drilling and Testing of a Water Well at Galdonagh (KTC, 1997).

1.5.2 Bedrock Geology

The Magherabeg/Veagh Water Supply Scheme boreholes are located in the Marble Unit of the Aghyaran and Killygordon Limestone (DGmb). This rock outcrops in a northwest to southeast trending band, which is approximately 1 km wide and underlies the western and higher part of the ridge. As the name suggest, this unit is essentially a marble-rich rock, with other minor constituents.

The Undifferentiated Aghyaran and Killygordon Limestone (DG) is located to the west of the Marble Unit and the Lough Foyle Succession (LFS) is to the east. Both of these units contains an amalgamation of different rock types and are therefore considered to be more impure than the Marble Unit. Consequently they are also considered to have a lower permeability.

The entire sequence of rocks is dipping to the northeast, which means that the older rocks are to the west and the younger to the east. The dip at this particular location is not known but is likely to be around 20-30° in the general region. All of these rock units are described in more detail in Section 2 (Volume 1) and their distribution in the area of interest is shown on Figure 1.3.

Drilling logs for the two production boreholes (KTC, 1997) both record soil over ‘weathered shale and schists (and grits)’, which is over ‘solid dark blue rock (shale or limestone)’. The solid dark blue rock was encountered at 48 m depth in BH1 and 20 m below ground in BH2. The drilling contractor also logs a number of water strikes and specific fracture zones, mainly within the upper weathered material. From subsequent communication with the drilling contractor, it is noted that a private production borehole at the crest of the ridge encountered the solid dark blue rock from only a few

metres below ground. The differences in the encountered strata and fracture zones suggests lateral and vertical variability in the rock type rather than representing specific layers of different material.

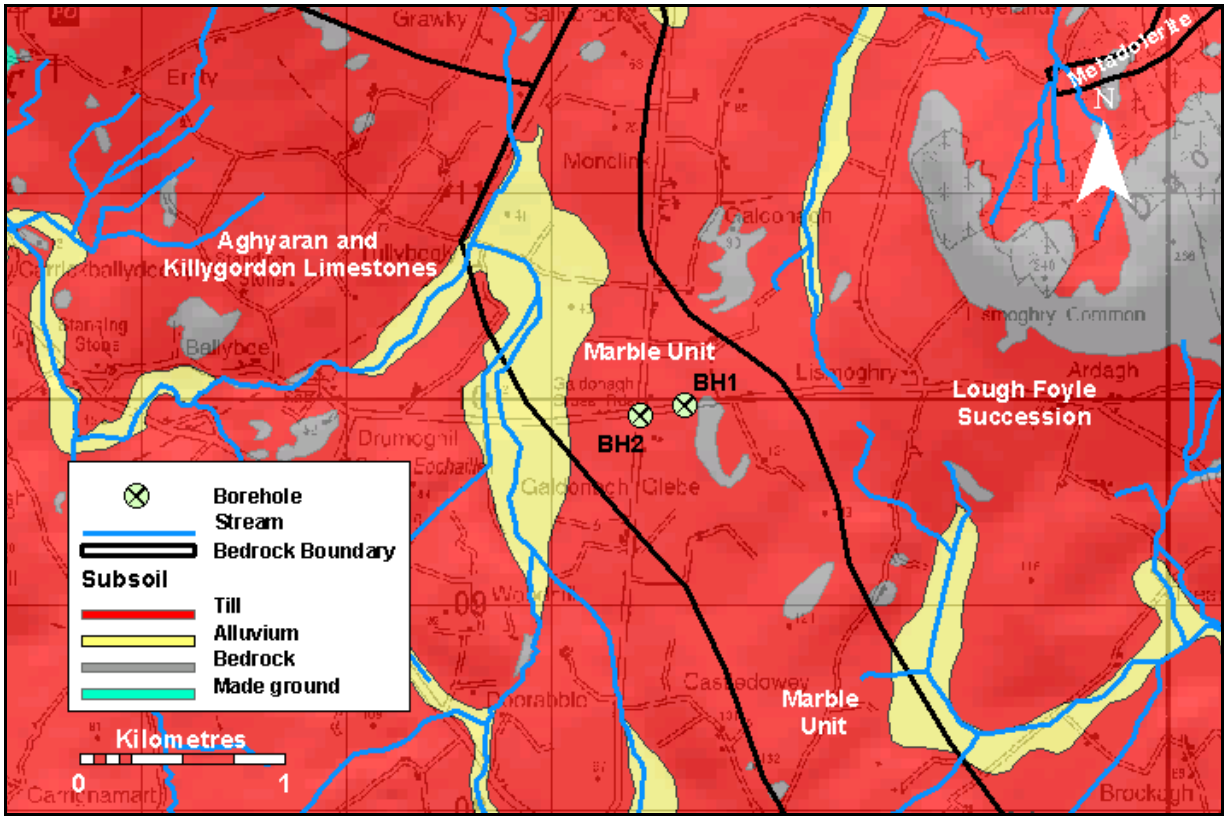

Figure 1.3. Geology in the Magherabeg/Veagh Area.

1.5.3 Subsoil Geology

The main subsoil category throughout this general area is 'till' (or boulder clay). Till is an unsorted mixture of coarse and fine materials laid down by ice. Throughout the majority of the area to the east and southeast of Letterkenny, thicker areas of till (>3 m) are frequently characterised by silt, or sometimes sand, sized material. There are six samples within a 2 km radius of the crossroads. Five of these have been described as SILT (BS 5930) and the remaining sample is described as SAND. There are three available Particle Size Distributions (PSD) [1] with a 5 km radius of the crossroads, which support these descriptions (Table 1.1).

[1] A particle size distribution test provides data that can indicate the likely permeability of subsoil. For the required permeability of 1 x 10^{-8} m/s, the clay content should be greater than 13% (where the particle size distribution is adjusted by excluding materials larger than 20 mm). In circumstances where the clay content is >13% clay but there is evidence of a higher permeability, e.g. the area is free draining or the BS5930 description of the subsoil is SILT, it may be advisable to assume that the 1 x 10^{-8} m/s requirement is not met.

Table 1.1. Sample Descriptions and PSD in the Galdonagh Area.

Number	Approximate Distance and Direction from Crossroads	BS 5930 Description	PSD (%) (Gravel:Sand:Fines:Clay)
6-19	1.6 km southwest	Silty SAND	–
6-20	2.0 km east	Slightly sandy SILT	–
6-21	1.25 km north	Very stony SILT	–
6-22	3.25 km southeast	Slightly sandy SILT	25:30:45:12
6-23	5 km north	Slightly sandy SILT	24:30:46:12
6-24	1.5 km north	Slightly sandy SILT	–
6-25	4.6 km south	Sandy SILT	28:30:41:07
DG-vul-21	0.25 km north	Slightly sandy SILT	–
DG-vul-42	1.5 km south	Sandy SILT	–

These data provide a regional picture of SILT dominated till but in some instances, there are likely to be local variations in the subsoil. For example the subsoil within valley areas closer to rivers is frequently thicker and more clay-rich than that found on the higher valley slopes. This would appear to be the situation in the Galdonagh area as the subsoil in BH2 is logged as c.8 m of slightly silty clay (KTC, 1997).

The till in this area does not constitute an aquifer. Its main significance is in relation to its protective capacity of the underlying rock aquifers from infiltrating contaminants.

1.5.4 Depth to Bedrock

All available drilling information was previously compiled and a drilling programme undertaken by the GSI to ascertain the general changes in subsoil thickness and permeability throughout County Donegal. There are four boreholes in close proximity to the Galdonagh crossroads and rock outcrops have been mapped in this region. It is inferred from these data that the higher ridge area is rock-cored with only a thin layer, if any, of subsoil. This shallow rock area continues towards the Dooish Mountain. Moving down the western side of the ridge, the subsoil becomes increasingly thicker towards the base of the valley. Thick subsoil in the valleys appears to reflect the general pattern of glacial deposits in this part of Donegal.

1.5.5 Groundwater Vulnerability

The concept of vulnerability is discussed in Section 5 (Volume I). The till in this general region is generally described as SILT (BS 5930), which is categorised as having a 'moderate' permeability. Where the till is thicker (>3 m), the vulnerability categorises range from 'high' to 'moderate'.

Where the subsoil is less than 3 m thick, the vulnerability is classified as 'extreme'. In such instances, the bulk permeability becomes less relevant because infiltration is more likely to occur through 'bypass flow' mechanisms, such as cracks in the subsoil. The mapped vulnerability[2] for the area of interest is shown in Figure 1.4, below.

[2] The permeability estimations and depth to bedrock interpretations are based on regional-scale evaluations. The mapping is intended only as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large-scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards.

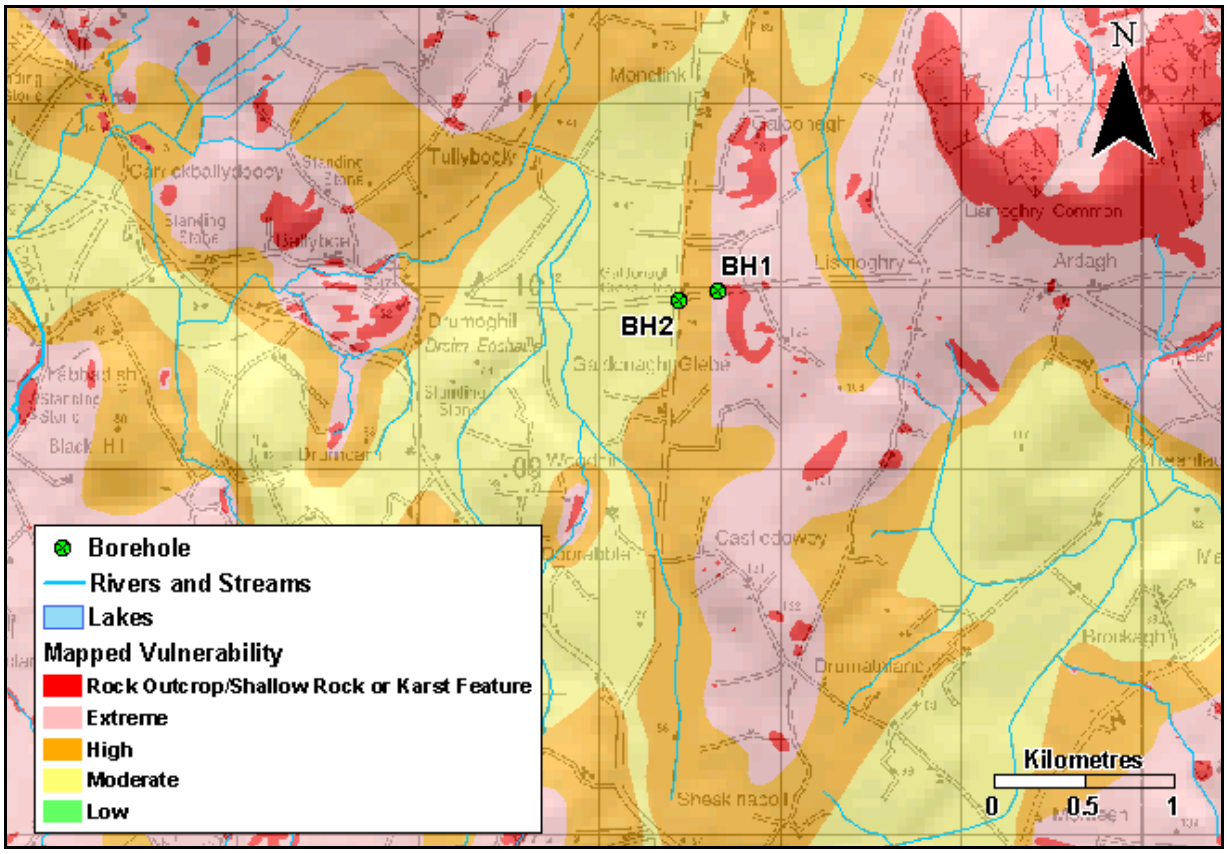

Figure 1.4. Mapped Vulnerability in the Magherabeg/Veagh Area.

1.6 Hydrogeology

1.6.1 Introduction

This section presents our current understanding of groundwater flow in the area of the boreholes. The hydrogeological and hydrochemical information for this study was obtained from the following sources:

- Report on the Drilling and Testing of a Water Well at Galdonagh (KTC, 1997).
- Depth to bedrock and subsoil permeability drilling programme carried out by GSI in July 2003.
- Site walkover and short pumping test carried out by GSI in March 2003.
- GSI/County Council water quality sampling in November 2002 and March 2003.
- Water Quality analyses from the EPA (2002 – 2003).
- Donegal County Council drinking water returns for 2002 and 2001.
- GSI files and archival Donegal County Council data.
- Met Eireann rainfall and evapotranspiration data.

1.6.2 Rainfall, Evaporation and Recharge

The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (i.e. annual rainfall) less water losses (i.e. annual evapotranspiration and runoff), prior to entry into the groundwater system. The estimation of a realistic recharge rate is important in source protection delineation as it is used to estimate the size of the zone of contribution (i.e. the outer source protection area). The calculations are summarised below.

- *Annual rainfall:* **1144 mm**.

The nearest rainfall gauging stations (Fitzgerald and Forrestal, 1996) to the scheme are situated 7 km west of the crossroads (Letterkenny, Dromore) and 8 km to the northeast (Newtown Cunningham G.S.). The Letterkenny, Dromore gauging station appears to be at a more comparable elevation and position in the landscape and is therefore assumed to represent the average annual rainfall experienced at this source. This value is also indicated by the interpreted contour maps of precipitation presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996).

- *Annual evapotranspiration losses:* **450 mm**.

  Potential evapotranspiration (P.E.) is estimated to be 475 mm/yr (Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is estimated as 95% of P.E., to allow for seasonal soil moisture deficits. More local measurements of evapotranspiration are not available.

- *Annual effective rainfall:* **~ 695 mm**.

  This figure is based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.

- *Annual recharge:* ~ **485 mm**.

  In this area, the subsoil is thought to be thin and moderately permeable over the majority of the ridge. This suggests that a high proportion of the effective rainfall can reach the bedrock aquifer, which is supported by the lack of surface drainage over this area. The upper bedrock is described as highly weathered, suggesting a high level of infiltration into the rock that can recharge the groundwater reserves. As the subsoil on the lower part of the ridge around BH2 is thicker and possibly more clay-rich, recharge to groundwater is expected to be lower. Overall, recharge estimates are thought to be in the order of 70% (GWWG, November 2004).

The calculations (mm/yr) are summarised as follows:

Average annual rainfall (R)	1144 mm
Estimated P.E.	475 mm
Estimated A.E. (95% of P.E.)	650 mm
Effective Rainfall (R – A.E.)	695 mm
Estimated Recharge (70% of effective rainfall)	**485 mm**

1.6.3 Groundwater Levels, Flow Direction and Gradients

The static, post pumping test (1997) and present day abstraction water levels were measured in the two boreholes. Water level information was also taken from the short pumping test undertaken by the GSI in March 2003. The main points of interest are outlined below:

- The static water level in BH2 is recorded as artesian, from which it is inferred that the groundwater at this location is confined. The confining layer probably comprises the 8 m of overlying subsoil, which is likely to be more clay-rich than seen in the surrounding area.
- There does not appear to be any interference between the two boreholes during pumping, as indicated by the continually rising water level is BH1 during and after the 12 hours of pumping at BH2 (GSI test).
- Assuming that there is no distinct change in the aquifer between BH2 and TW3, which are situated approximately 2 m away from each other, the difference in the pumping water level between the two (c.39 m and c.25 m b.g.l. respectively) suggests that there are well losses, or inefficiencies, with BH2. Thus the pumping water level in TW3 is more likely to be reflecting the properties of the aquifer itself.
- The pumping water level at the present day abstraction rates are approximately 42 m and 25 m below the surface in BH1 and TW3 respectively. These drawdown are considered to be

relatively large and result in a pumping water level in both boreholes at a similar elevation as the base of the ridge.

In the vicinity of the boreholes, the ***flow direction*** inferred from the topography, surface drainage patterns and available static water level data is down the western face of the ridge towards the unnamed stream. Based on the water levels recorded in the boreholes, the natural groundwater ***gradient*** is in the region of 0.07. The groundwater flow direction and gradient are likely to be influenced by the pumping in the vicinity of the boreholes.

1.6.4 Hydrochemistry and Water Quality

Hydrochemical data for the Magherabeg/Veagh Scheme have been obtained from the County Council (1999), the Department of the Environment (2000-2001), the Environmental Protection Agency (2002-2003) and the GSI in conjunction with the County Council (2002-2003). The data are summarised graphically for BH1 in Figure 1.5 below.

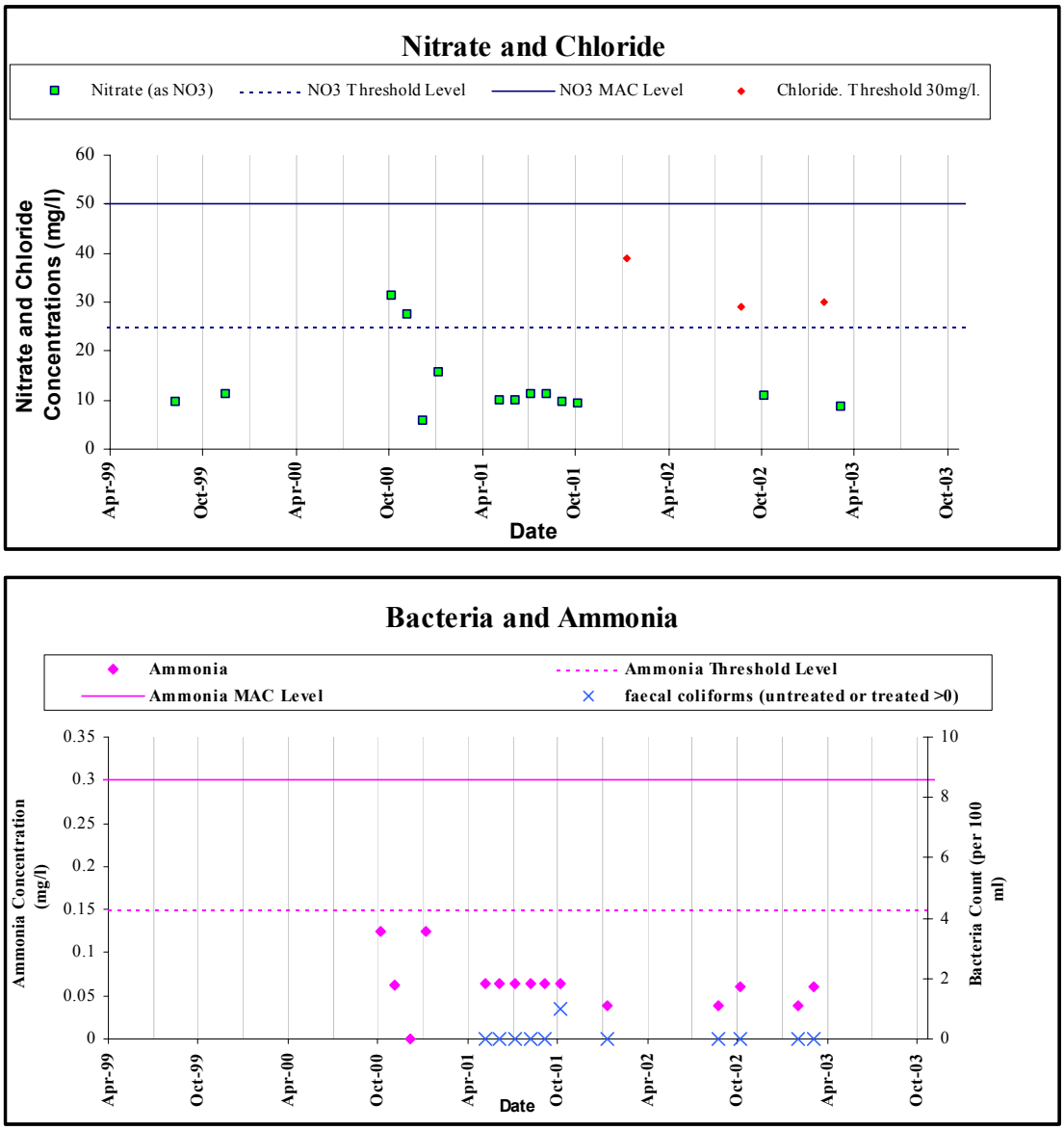

Figure 1.5. Key Indicators of Agricultural and Domestic Contamination (continued overleaf).

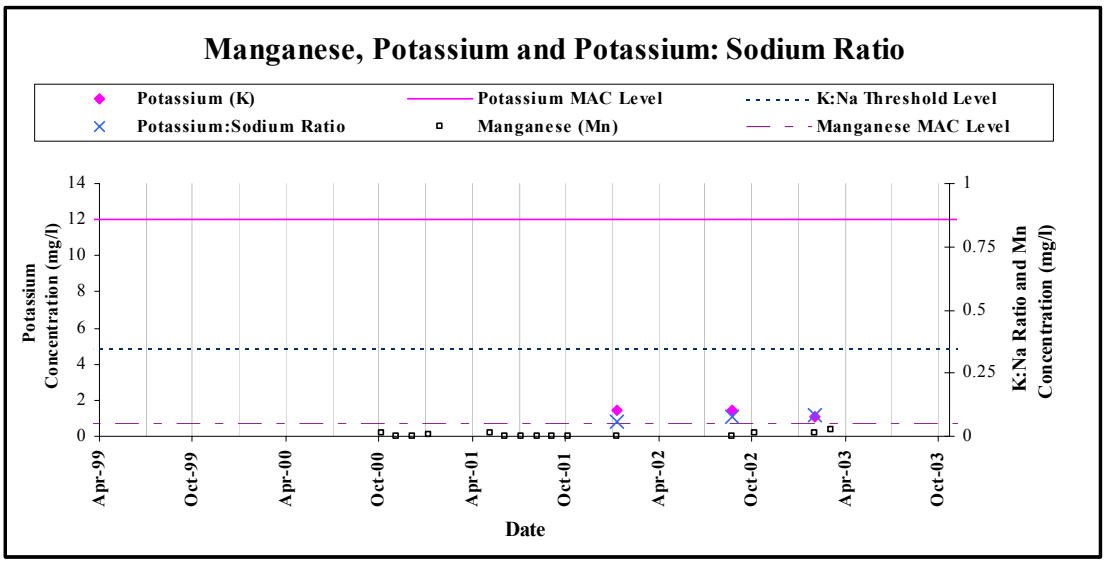

Figure 5.5. Key Indicators of Agricultural and Domestic Contamination (continued).

The following key points have been identified from these data.

- Analysis of hardness indicate a generally hard (250-350 mg/l $CaCO_3$) calcium bicarbonate hydrochemical signature. This is probably due to the high calcium content of the marble aquifer.
- The nitrate concentrations are in the order of 10 mg/l although there are two incidences of nitrates exceeding the threshold value of 25 mg/l; 31 mg/l in November 2000 and 28 mg/l in December 2000. A concentration of 16 mg/l was also recorded in February 2001, which is noticeable higher than the background level although does not exceed the threshold. Interestingly, two slightly raised ammonia concentrations (0.125 mg/l) were also recorded in November 2000 and February 2001. The record of nitrate concentrations extends back to September 1999 and shows that apart from the period of elevated levels, nitrates in the water supply are relatively constant. No seasonal trends can be depicted from these data.
- Of the other contaminant indicators examined, there is only one reported incident of faecal coliforms in the analyses (1 count/100ml), occurring in November 2001. There were three other occasions when total coliforms were detected – January and July 2001, and February 2002. The February 2002 sample also exhibited a slightly elevated concentration of chloride (39 mg/l) which is often used as an indicator of organic waste.

It is inferred from the available data that the incidents of elevated nitrates and presence of bacteria are isolated and do not indicate gross contamination or specifically highlight on-going problems. These incidents may reflect releases from point and/or diffuse hazards such as on-site wastewater treatment systems, landspreading of fertilisers, or the presence of grazing animal (especially where bedrock is shallow) upslope of the boreholes.

1.6.5 Aquifer Characteristics

The Magherabeg/Veagh Water Supply Scheme comprises two boreholes which abstracts water from the Marble Unit of the Aghyaran and Killygordon Limestone bedrock. This rock is classified as a **Locally Important Aquifer** that is moderately productive only in **local zones** (**Ll**). Refer to Section 4 (Volume 1) for further details.

Specific water-bearing fracture zones have been identified in both of the boreholes logs; 23-24 m and 46-48 m below ground in BH1 and 8-10 m below the surface in BH2. Furthermore, the upper weathered material in BH2 is noted as having (unspecified) water strikes. This information supports the conceptual model of groundwater circulation predominantly occurring in localised fracture flow.

The aquifer coefficients (summarised in Table 1.2) have been calculated from the pumping tests by KTC (1997), GSI (2003) and from the present day pumping for abstraction. The specific capacity (Sc)

ranges from 10 m^3/d/m to 45 m^3/d/m. A transmissivity (T) of 11 m^2/d was estimated from both sets of pumping test data (BH1 and BH2). The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer, which, based on the borehole information, is assumed to range between 35-50 m. The resulting permeability (K) is in the region of 0.26 m/d (ranging from 0.22-0.29 m/d). The velocity of water moving through this aquifer to the boreholes can be calculated from Darcy's Law:

$$\text{Velocity (V)} = \frac{\text{(K x groundwater gradient (i))}}{\text{porosity (n)}}$$

The groundwater gradient is estimated from the static water levels as 0.07 (refer to Section 1.6.3). There is no information to estimate the effective porosity (n) for this rock unit. However, based on regional knowledge of similar permeability rocks, this is assumed to be 0.01 (1%). Thus the velocity is in the order of 1.5-2.0 m/d. This is based on the permeability value for the *entire* saturated depth of borehole. It is recognised however, that the permeability – and therefore the velocity – is likely to be higher along the fracture/cavity zones, although no specific data exist for these zones.

Table 1.2. Estimated Parameters for Marble Unit Aquifer.

Parameter	***Source of data***	***Value***
Specific Capacities (m^3/d/m)	Local	10-45
Transmissivity (m^2/d)	Local	11
Permeability (m/d)	Local	0.26
Porosity	Assumed	1%
Velocity (m/d)	Local/Assumed	1.5-2.0

1.6.6 Conceptual Model

- The Magherabeg/Veagh Water Supply Scheme consists of two boreholes. BH1 is recorded as abstracting 325 m^3/d and BH2 abstracts 186 m^3/d. Both boreholes are pumping for approximately 17 hours a day and the water is pumped to a reservoir.
- The Marble Unit of the Aghyaran and Killygordon Limestone (DGmb) is classified as a **Local Important Aquifer** which is moderately productive only in **local zones** (**Ll**).
- A large proportion of groundwater is likely to flow through a main interconnected fracture system, outside of which groundwater may flow through smaller fractures and joints. This is supported by the recorded fracture zones (c.46 m in BH1 and 8 m in BH2) and the larger zones of smaller strikes (between 10-20 m below ground in BH2).
- The natural groundwater flow direction in the vicinity of the boreholes is thought to be westwards as suggested by the topography, drainage patterns and available water level data.
- Monitoring of BH1 during the pumping test of BH2 suggests that the boreholes do not interfere with each other.
- Given that the pumping water levels are around the base of the ridge, it is thought that the boreholes are capable of pulling water from as far up-gradient as the limit of the Marble Unit.
- Given the shallow subsoil over the ridge area, groundwater is generally thought to be unconfined. However, the artesian nature of the groundwater in BH2 suggests that groundwater flow is confined at this particular location.
- Diffuse recharge occurs over most of the land surface through the thinner subsoil. Recharge estimates are in the order of 485 mm/yr.

1.7 Delineation of Source Protection Areas

1.7.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, and are presented in Figure 1.6. Two source protection areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution;
- Outer Protection Area (SO), encompassing the zone of contribution (ZOC) to each of the boreholes and the infiltration gallery.

1.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the well field, i.e. the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the abstraction rate, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. The delineation of the ZOC uses:

i. hydrogeological mapping techniques and analytical modelling to determine the boundaries,
ii. a comparison of average discharge and recharge data to estimate the area required,
iii. a safety margin to allow for any variability in the groundwater flow direction, and
iv. a safety margin to account for the larger ZOC required during the drier summer months.

The derivation of the boundaries is described below.

The **eastern boundary** is constrained by the extent of the Marble Unit. Without the pumping, the groundwater divide would be expected to mirror the surface water divide i.e. the ridge crest. However, the unnatural, large drawdown created by pumping BH1 can pull water from the beyond the ridge crest, especially as this borehole is reasonably close to the crest. Given that the main fracture system in this aquifer unit may transmit water fairly efficiently, the boundary is taken as the extent of the aquifer. An arbitrary buffer of 50 m is also added to the division.

The **western boundary** is on the down gradient side of the boreholes and it specifically derived by analytical modelling. From the aquifer parameters, the extent of the down-gradient influence is estimated using the uniform flow equation:

$$\text{Approximate down-gradient extent} = \frac{\text{(discharge rate)}}{\text{2 x pi x (transmissivity) x (hydraulic gradient)}}$$

The down-gradient extent for BH2 is 60 m, based on an abstraction[3] of 280 m^3/d, a transmissivity of 11 m^2/d and a hydraulic gradient of 0.07. As this estimate is further down-gradient than BH1 (which has an estimated influence of 100 m from its location), it is used to delineate the boundary for both boreholes.

The delineation of the **northern and southern boundaries** is not straightforward. For the *northern* boundary, there are no clear topographic or geological constraints to use as a basis. As with the eastern surface water divide, the *southern* surface water divide is relatively close to BH1 but given the large drawdown during pumping, it is anticipated that groundwater will be pulled from beyond this natural divide. Therefore, these ZOC boundaries are determined by the pumping regime of the individual boreholes and the estimated response of the aquifer. Using the above aquifer parameters (and an abstraction rate of 490 m^3/d for BH1), the up-gradient lateral extent of the area influenced by the boreholes' abstraction can be estimated using:

$$\text{Approximate up-gradient lateral extent} = \frac{\text{(discharge rate)}}{\text{2 x (transmissivity) x (hydraulic gradient)}}$$

[3] BH2 is presently abstracting 186 m^3/d. An additional 50% is added in order to account for lower groundwater levels in summer.

The pumping is estimated to pull water from 320 m either side of BH1 at its up-gradient extent and 180 m either side of BH2. The delineated boundaries link the estimated lateral up-gradient and down-gradients extents for each borehole and represent the groundwater that is drawn to the boreholes due to pumping.

As the ZOCs for the individual boreholes are adjacent to each other, they have been encompassed into a slightly larger, single ZOC, which ensures that the entire area supplying the boreholes is taken into consideration.

ZOC Area. The available recharge and discharge data are not comprehensive enough to undertake a water balance and thus accurately estimate the catchment area required. However, a comparison of average abstraction[4] (765 m^3/d) and recharge (485 mm/yr) indicate that the size of the delineated ZOC (c.0.6 km^2, or c.800 m^3/d) is realistic in terms of meeting the abstraction rates.

It is recognised that although groundwater from any part of the ZOC may reach the boreholes, a proportion of the recharge may be diverted e.g. effective rainfall within the ZOC on the eastern side of the ridge may contribute to the streams on this side of the ridge. Without further information a more accurate ZOC cannot be delineated.

1.7.3 Inner Protection Area

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

Based on the aquifer parameters in Section 1.6.5, velocity is calculated as between 1.5-2.0 m/d, which would give a maximum 100 day ToT distance of 200 m from each borehole.

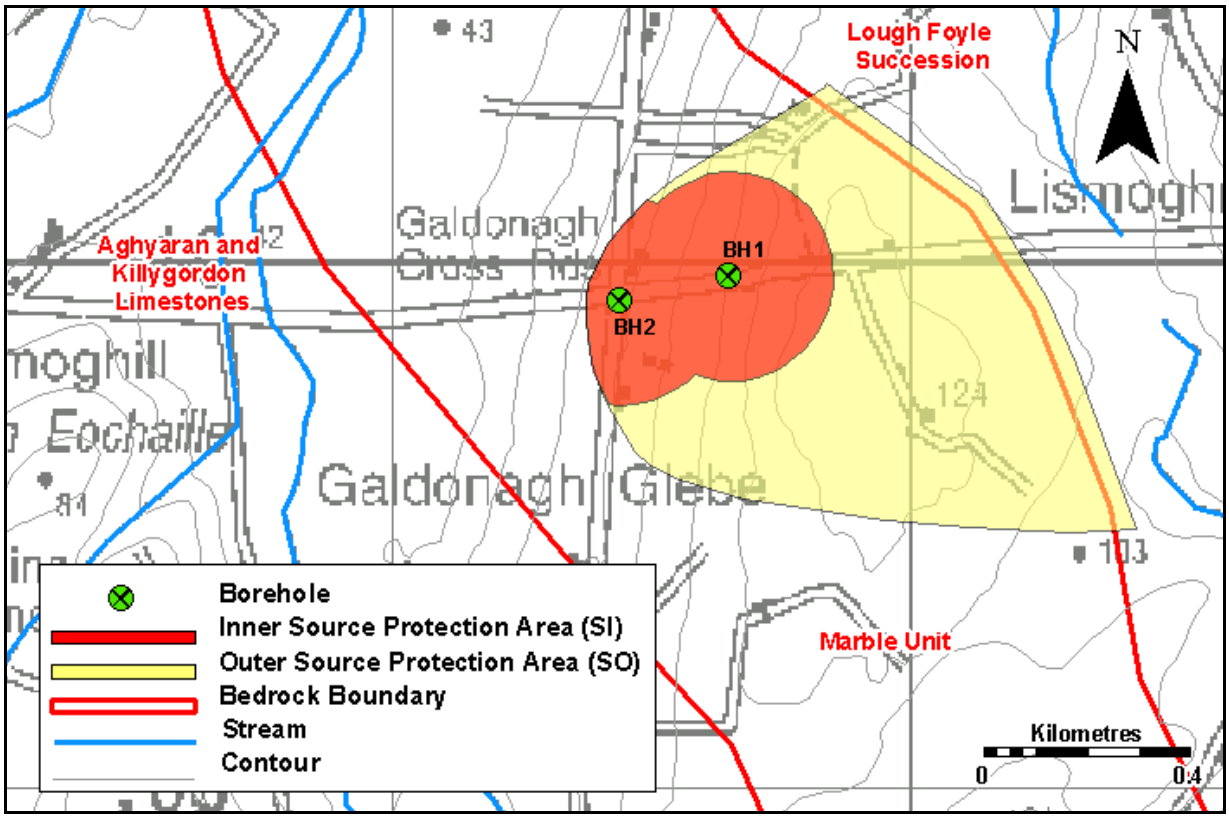

Figure 1.6. Delineated SO and SI for the Magherabeg/Veagh Water Supply Scheme.

[4] The total abstraction rate for the two boreholes is approximately 510 m^3/d. An additional 50% is added to this in order to account for lower groundwater levels during the summer.

1.8 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories), giving a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination.

Six groundwater protection zones are present around the Magherabeg/Veagh Water Supply Scheme (Figure 1.7), as shown in **Table 1.3** below. Due to shallow rock over most of the ZOC, the majority of the source protection area is considered be either 'extremely' or 'highly' vulnerable to contamination.

Table 1.3 Matrix of Source Protection Zones for Magherbeg/Veagh Public Water Supply Scheme.

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

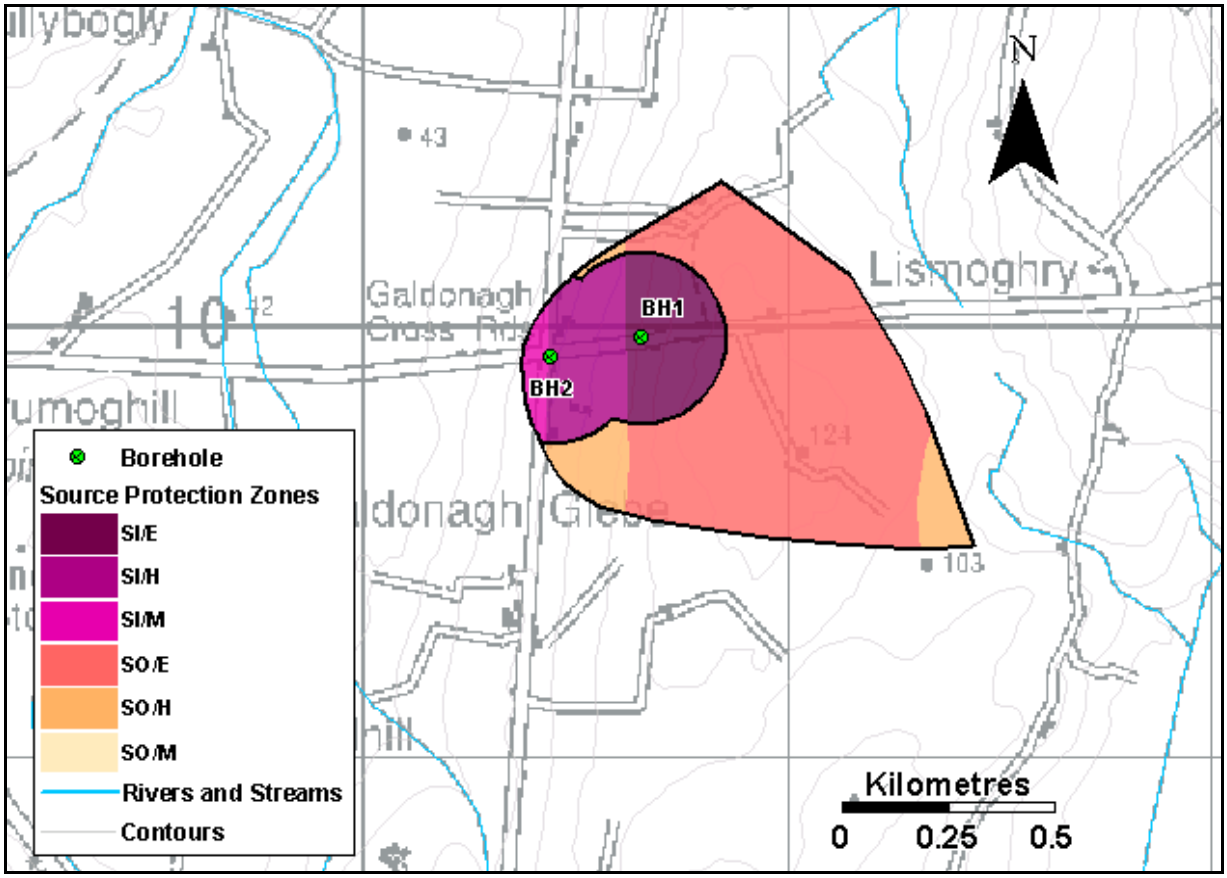

Figure 1.7. Source Protection Zones around the Magherabeg/Veagh Water Supply Scheme.

1.9 Potential Pollution Sources

Agriculture is the principal activity in the ZOC. The majority of the ridge area is used for pasture although tillage is a common land use in the area. There are two well-used roads which cross the ZOC. A number of single houses and farmyards are situated along these roads. All of these activities are also within the SI.

Potential hazards include wastewater from farmyards, on-site wastewater treatment systems, application of fertilisers (organic and inorganic) and pesticides, the presence of grazing animals, especially in the SI/E zone, and oil/diesel spillage along the roads.

Of the contaminant indicators examined, none were at significant levels in available samples. The data generally indicate good water quality. There were isolated incidents of elevated nitrate concentrations above the threshold and presence of bacteria. These may reflect releases from point or diffuse hazards, such those mentioned above.

1.10 Conclusions and Recommendations

- The Magherabeg/Veagh Water Supply Scheme comprises two boreholes, which abstract 325 m^3/d (BH1) and 186 m^3/d (BH2). This abstraction is pumped to a reservoir before entering into the distribution system.
- Both of the boreholes abstract water from the Marble Unit of the Aghyaran and Killygordon Limestone, which is classified as a **Locally Important Aquifer** that is moderately productive only in **local zones** (**Ll**).
- The northern, southern and western (down-gradient) ZOC boundaries have been based on the pumping regimes of the boreholes and the local aquifer properties. The eastern boundary is based on the extent of the aquifer boundary. None of these boundaries are coincident with the topographic divides. The SI is based on the 100 day ToT to the boreholes, as estimated from the aquifer parameters.
- The groundwater vulnerability is categorised as extreme over a large proportion of the ZOC due to the high proportion of outcrop and thin subsoils (< 3 m in thickness). On the lower slopes of the ridge within the ZOC, the moderately permeable tills become thicker. This area is categorised as having a high to moderate vulnerability.
- Wastewater from farmyards, discharges from on-site wastewater treatment systems, fertiliser and pesticide application, presence of grazing animals, diesel/oil spills and runoff from the roads all pose a potential threat to the water quality at the boreholes.
- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.
- It is recommended that:
    1. abstraction rates do not exceed the estimated long term recharge rates for the ZOC.
    2. BH2 is fenced off and adequate well head protection is provided.
    3. particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well field.
    4. the potential hazards in the ZOC should be located and assessed especially with regard to the up-gradient proximity of farmyards and houses.
    5. full chemical and bacteriological analysis of the **raw** water at each abstraction point is carried out on a regular basis. The chemical analyses should include all major ions – ammonium, bicarbonate, calcium, chloride, magnesium, nitrate, potassium, sodium and sulphate.