Ballyshannon Source

Extracted from:
County Donegal Groundwater Protection Scheme,
Volume II: Source Protection Zones December 2005

County Donegal
Groundwater Protection Scheme

Volume II: Source Protection Zones
December 2005


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Volume I comprise an overall introduction, classifications of aquifers and vulnerability, and overall conclusions.

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1 BALLYSHANNON PUBLIC WATER SUPPLY SCHEME

1.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the Ballyshannon Water Supply Scheme; namely the spring (hereafter referred to as the Parkhill Spring) and the augmentation borehole (BH1)[1].
- 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 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	1735NEW093	1735NEW094	1735NEW092
Grid reference (GPS)	189276 363786	189305 363633	189331 363847
Townland	Parkhill		
Source type	Borehole (BH 1)	Borehole (BH 5)	Spring
Drilled/Developed	2002	2004	2002
Owner	Donegal Co. Council		
Elevation (ground level)	c.55.3 m	c.54.5 m	c.56 m
Depth	90 m	90 m	-
Depth of casing/sump	5.5 m	c.6 m	c.4 m
Diameter/ Width BH/sump	20 cm	20 cm	c.1 m
Depth to rock	4 m	c.6 m	-
Static water level	2.9 m bgl (09-02-05)	1.3 m bgl (09-02-05)	-
Depth of pump	Estimated as c.70 m bgl	Estimated at c.70 m bgl	-
Pumping water level	Not in use yet		-
Consumption (Co.Co. records)	-	-	-
Pumping test summary:			
(i) abstraction rate m^3/d	504 m^3/d	504 m^3/d	-
(ii) specific capacity	962 $m^3/d/m$	312 $m^3/d/m$	-
(iii) transmissivity	508 m^2/d	508 m^2/d	-

[1] The second augmentation borehole (BH5) was installed sometime after the initial proposals for the scheme were made. Due to the location of this borehole and the variable nature of the aquifer, it is considered that significant additional work would be required to delineate source protection zones for this borehole. Such work is beyond the remit, timeframe and resources estimated for the initial proposal and this report.

1.3 Methodology

1.3.1 Desk Study

Details about the boreholes such as depth, date of commissioning and estimated abstraction figures were obtained from Donegal County Council personnel. Data were also obtained from the following Minerex Environmental Limited (MEL) reports:

- Geophysical Survey. August 2002. Report Reference 1492-044.
- Well Design, Drilling Supervision, Preliminary Yield Determinations, Vulnerability Assessment and Reporting. April 2003. Report Reference 1492-067.
- BH1, BH2, BH3, BH4 and Spring 2 Pumping Test Supervision, Monitoring, Interpretation and Reporting. July 2003. Report Reference 1492-103.

Additional geological and hydrogeological information has been provided by the GSI and Teagasc mapping programmes (Long and McConnell, 1999; Meehan, 2004 respectively).

1.3.2 Site visits and Fieldwork

These included the following:

- Meetings with County Council personnel and walkover surveys in October 2002, July 2003, November 2004, January 2005 and February 2005.
- Water quality sampling in November 2002 and March 2003.
- Depth to bedrock drilling programme and site walkover in July 2003 to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.
- A 12-hour pumping test in February 2005 (BH1 09.02.05; BH5 15.02.05) to determine any influence from the nearby Abbey River. Temperature and conductivity were measured.
- Site walkover in September 2005 to resolve discrepancies in the mapped bedrock geology.

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

Although the Ballyshannon Water Supply Scheme had not been fully commissioned at the time of writing, the County Council were proposing to use the Parkhill Spring as the main source of water, which would be augmented by one, or possibly two, boreholes (BH1; BH5[2]) during times of low spring flow.

The well field is located in the townland of Parkhill, approximately 3 km northeast of Ballyshannon Town (Figure 1.1). The spring and BH1 are situated north of the Abbey River (c.30 m and c.10 m respectively), with BH1 adjacent to the farmhouse access road and the spring within a small copse (Figure 1.2). BH5 is located c.15 m southeast of a river meander.

The Parkhill Spring comprises a number of discharges that form a pond beneath the copse. The pond overflows via a small channel to the Abbey River. Recent site works included the installation of a concrete sump (c.4 m deep by c.1 m diameter), which appears to be capturing the main spring flow. The boreholes are comprehensively sealed and the casing is capped just above ground level. The boreholes are not fenced off from the surrounding area.

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[2] BH1 was initially developed by MEL in October 2002 as part of the site investigation works. The location of BH1 was informed by geophysical investigations. BH5 was developed by the County Council in 2004. The location of BH5 was not informed by previous site investigation work.

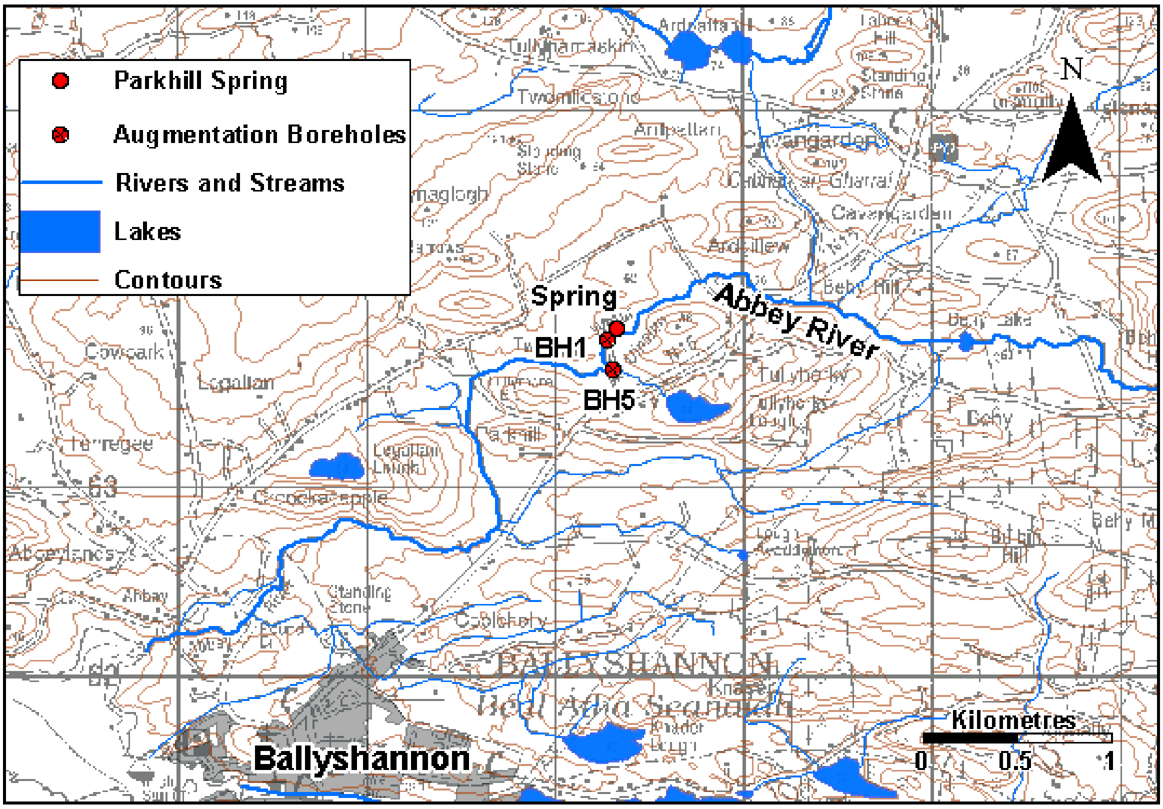

Figure 1.1. Location of Ballyshannon Water Supply Scheme.

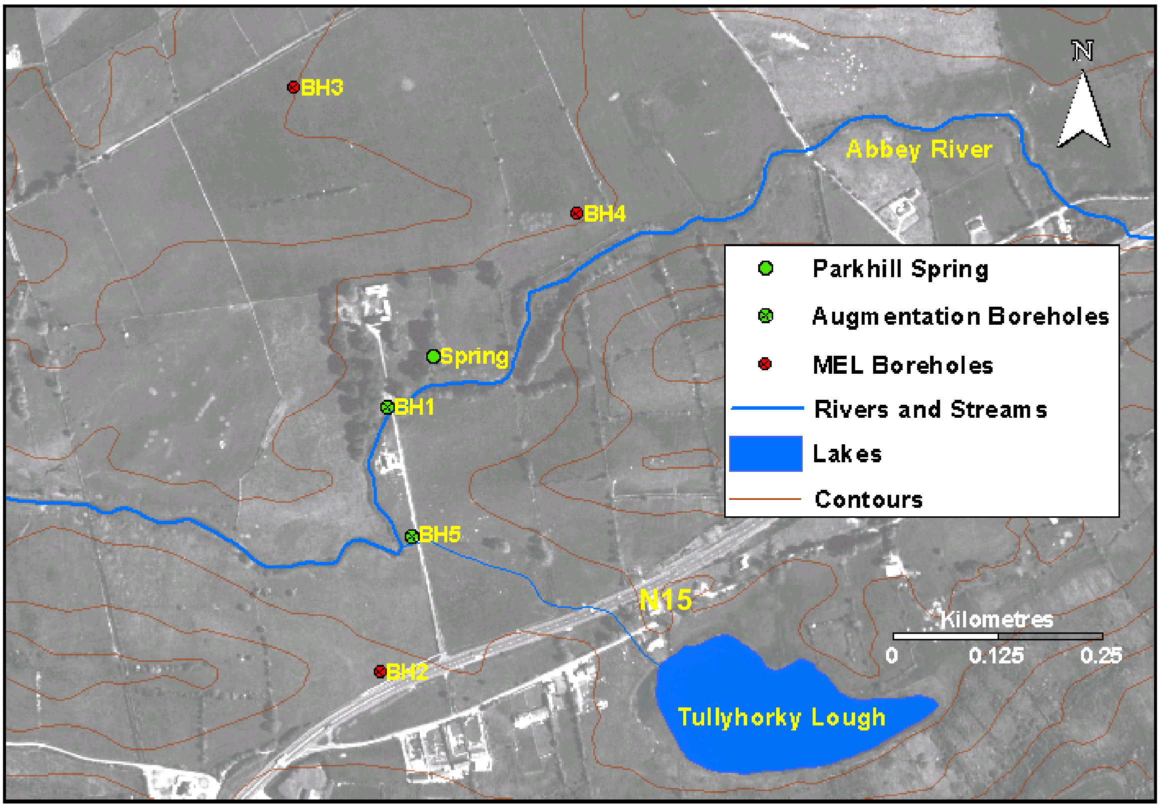

Figure 1.2. Ballyshannon Water Supply Scheme Well Field and Features.

Existing and Proposed Scheme

The Ballyshannon/Rossnowlagh areas are currently supplied from Lough Unshin. This supply was established as an interim scheme in the 1980s although had issues with water quality, namely high iron and thus discolouration. The remedial action included the installation of sand filters and a Dissolved Air Floatation Plant (DAF), which included the addition of the flocculent aluminium sulphate ('Alum'). However, due to the costs of maintaining a reasonable water quality and the continuing presence of post-treatment aluminium, an alternative supply was required.

Further to a) hydrogeological investigations by Minerex Environmental Limited (MEL) in 2002, b) information from the land owner that indicated the Parkhill Spring never ceased flowing, and c) subsequent monitoring of the spring discharge, the County Council decided to develop the spring as the main supply with one/two augmentation boreholes within close proximity.

The proposed scheme will supply c.60 m^3/hr (1440 m^3/d), with an anticipated future increase to 80-100 m^3/hr (1920-2400 m^3/d). The County Council plan to abstract the majority of the supply from the spring by sealing off the spring overflow and installing two sumps at that location. At times of low spring flow, the supply will be augmented by the boreholes, which will each be fitted with pumps capable of pumping 30 m^3/hr (720 m^3/d). Water from all three sources will be pumped to an on-site storage tank prior to being pumped to the existing reservoir (c.500 m south of the spring), where it will be treated (slow sand filtration and chlorination) before entering the distribution system.

1.4.1 Topography, Surface Hydrology and Land Use

The well field is located in a generally lower lying area (c.50 m AOD) where drumlins are a common feature, rising to c.50 m above the spring and boreholes. There is also a bedrock-cored ridge approximately 1 km northwest/north of the well field (c.120 m AOD).

In southwest Donegal, the surface water generally drains to the west/southwest, into Donegal Bay. Between Ballyshannon and Ballintra, lakes and discontinuous streams segments are common features. The Abbey River, which is one of the main surface water channels in the area, flows through the site, to discharge into the River Erne. Apart from a small tributary joining the Abbey River close to BH5 (sourced at Tullyhorky Lough), there are relatively few surface water streams, especially given the low lying nature of the general area.

Grazing is the main land use in this area and cattle and horses were noted on the land surrounding, and immediately up-slope, of the well field. Where the subsoil is thicker and the land is unmanaged, rushes are evident (e.g. drumlin to east). The main Ballyshannon-Donegal road (N15) is 300-350 m south of the well field and minor roads enclose the area of interest. A number of houses and farms exist along these roads, the closest of which is within 100 m of the well field.

1.5 Geology

1.5.1 Introduction

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

Geological information was taken principally from a desk-based study of data, which comprised:

- Bedrock Geology 1:100,000 Map Series, Sheet 3, South Donegal, Geological Survey of Ireland (Long and McConnell, 1999).
- Information from 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).
- MEL reports (August 2002; April 2003; July 2003).
- Karst mapping information (GSI, January 2005).

Site visits were also undertaken in January and February 2005 to carry out karst mapping, a dye tracer test and to resolve discrepancies between the mapped bedrock geology and the location of karst features.

1.5.2 Bedrock Geology

As shown in Figure 1.3, the well field is underlain by a northeast-southwest trending block of Ballyshannon Limestone (Dinantian Pure Bedded Limestone Rock Group), which is generally described as a medium to light grey, massively bedded coarse-grained, 'pure' limestone. Units of other lithologies (cherty beds, sandy beds, impure limestone) are interspersed with the principal limestone lithology, and can be subdivided where there is enough evidence.

The bedrock block is dipping to the southwest, with the younger Bundoran Shale (dark shale with minor fine-grained limestone) and Mullaghmore Sandstone (sandstone, siltstone and shale) located to the southwest towards the coast, and marginally older subdivisions of the Ballyshannon Limestone to the northeast. This sequence of rocks sits unconformably on significantly older metamorphosed rocks (Precambrian Quartzites, Gniesses and Schists Rock Group (SWQ)), which are described as light coloured, fine-grained metamorphosed sandstone rocks.

Due to faulting and rock displacement in the area, Bundoran Shale and Mullaghmore Sandstone are also mapped c.1.0-1.5 km north of the well field and Precambrian rocks are mapped approximately the same distance to the south.

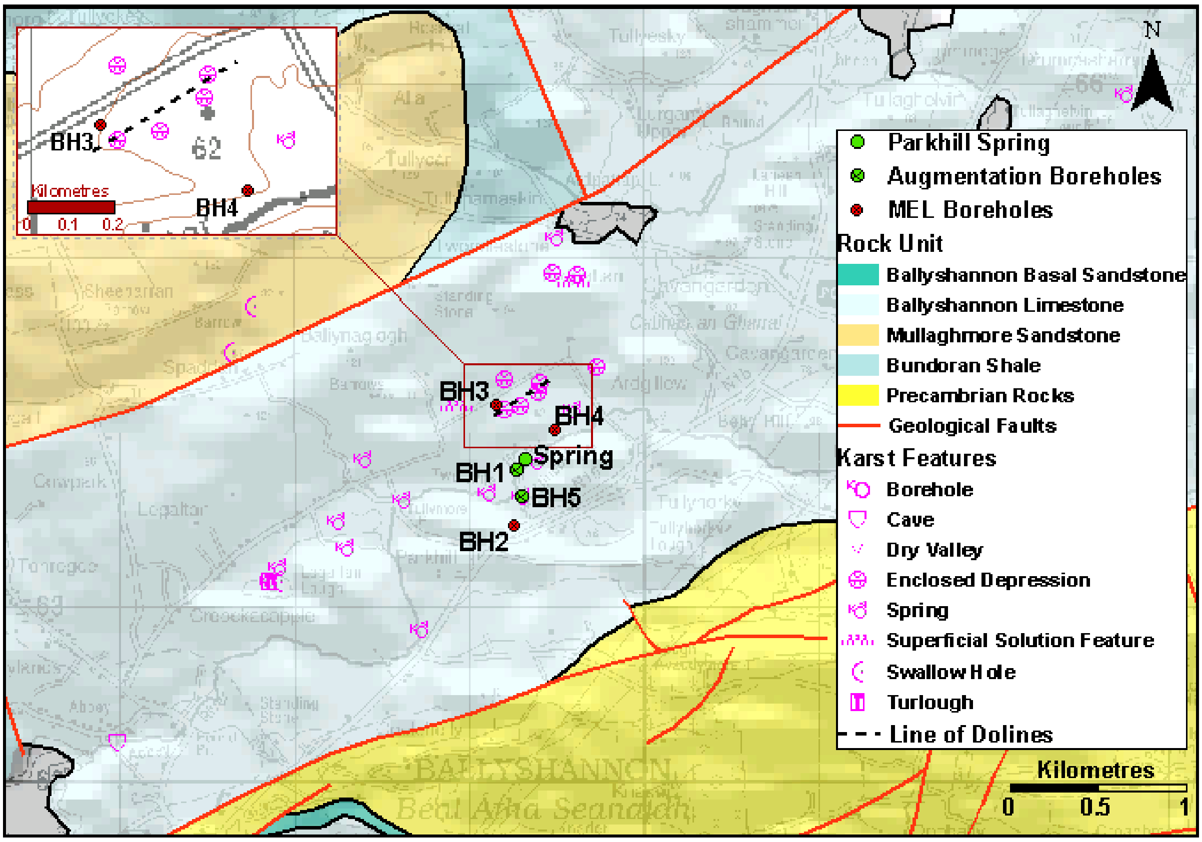

Figure 1.3. Mapped Bedrock Geology of the Ballyshannon Area.

Drilling logs for four MEL boreholes (April, 2003), record alternating layers of light grey and light brown limestone (3-25 m in thickness, averaging 9 m), which in turn overlie a dark grey limestone (identified in BH1 at 84 m b.g.l, BH2 at 45 m b.g.l. and BH3 at 41 m b.g.l). In all of the boreholes, the rock is generally more weathered in the upper 45-50 m, with the light brown strata corresponding to significantly more weathered material than the light grey material.

Static water levels are recorded between 2-5 m b.g.l., with water strikes noted at 15-24 m b.g.l. in three of the boreholes.

1.5.3 Karst Features

Further to a small number of recorded karst features and personal communication with the land owner, a brief karst mapping programme was undertaken in the Parkhill area in January 2005. As shown on Figure 1.3, the mapping identified 27 features that comprised 12 springs (including the Parkhill Spring), 8 enclosed depression (dolines), 3 swallow holes, 2 areas of superficial solution ('karren'), 1 cave and 1 turlough. Interestingly, 4 of the dolines are in an approximate northeast- southwest trending line c.325 m north of the Parkhill Spring (Figure 1.3 inset). The line of dolines are within a topographic hollow, and BH3 is located at the western end of the line.

Site development works around the spring (February 2005) revealed a large conduit within the rock (Figure 1.4). Conduits of this shape and dimension can result from solution of the rock i.e. the process of karstification.

Photographs courtesy of Hugh Kerr, Donegal County Council.

Figure 1.4. Conduit within the Ballyshannon Limestone, Parkhill Spring Area.

1.5.4 Re-Evaluation of Bedrock Geology in the Ballyshannon Area

From the Ballyshannon source protection work, two sets of unusual features were identified in the Mullaghmore Sandstone rock unit, c.1.75 km northwest of the well field. These comprised a) a discontinuous stream segment, and b) two swallow holes. Both features are associated with the karstification, which would not be expected in the Mullaghmore Sandstone. The subsequent tracer test (February 2005) also established a groundwater connection between the sets of features (Section 1.6.4). On further investigation, the nineteenth century geological mapping indicated some ambiguity in this particular area.

Due to these discrepancies, site visits by GSI Bedrock Section personnel resulted in further interpretation of the geology in this area. From the on-site evidence (outcrops, topography), mapped karst features, historic maps and known geological history in the region, it would appear that the fault between the Ballyshannon Limestone and Mullaghmore Sandstone is more complex than the original interpretation. The re-evaluated fault between the Ballyshannon Limestone and Mullaghmore Sandstone is now located c. 350 m north of the previously mapped fault (Figure 1.5). It is noted however, that additional drilling will be required to determine the actual delineation of these rocks.

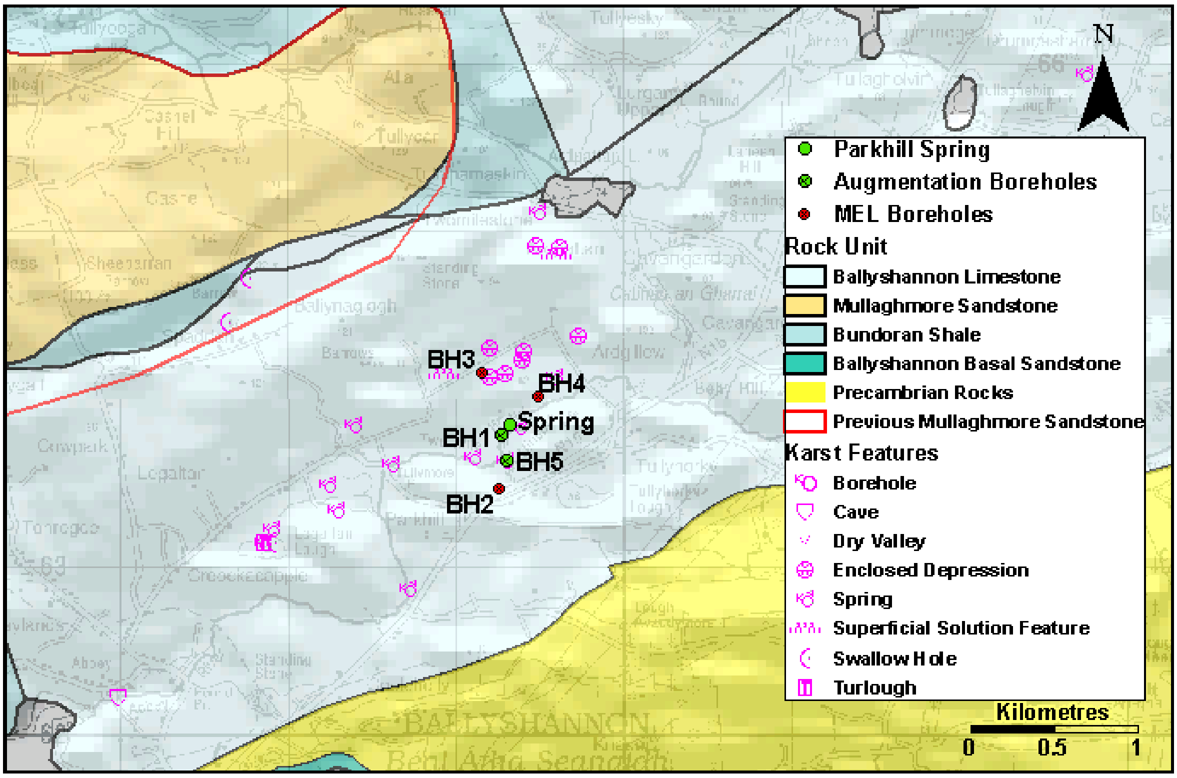

Figure 1.5. Re-Evaluated Bedrock Geology of the Ballyshannon Area (2005).

1.5.5 Subsoil Geology

Subsoil around the well field is dominated by 'till', or boulder clay (Figure 1.6). Till is an unsorted mixture of coarse and fine materials laid down by ice. Regionally, thicker till deposits (>3 m) are characterised by clay-sized material. Samples from five of the seven closest GSI boreholes (all within 4 km radius of the well field) have been described as CLAY (BS 5930). The remaining two boreholes are described as either SAND or GRAVEL (BS 5930) and interestingly, the four MEL boreholes (April, 2003) all also record the subsoil matrix as either SAND or GRAVEL.

In this part of Donegal, there is likely to be some degree of subsoil matrix variability due to several depositional phases of differing materials and more recently, fluvial deposition (Dr. R. Meehan, *pers. comm.,* 2005). The resulting subsoil variability is likely to be in the lower-lying, inter-drumlin areas and along river valleys, which is sometimes indicated by the mapped alluvium. All four MEL boreholes are in such locations (Figure 1.6).

The other main subsoil category in the general area is peat. Peat is mapped in the low lying areas, such as hollows around lakes and along the course of the river.

The subsoil in this area is not classed as an aquifer and thus its main significance is in relation to the protection it provides to the underlying bedrock aquifers from infiltrating contaminants.

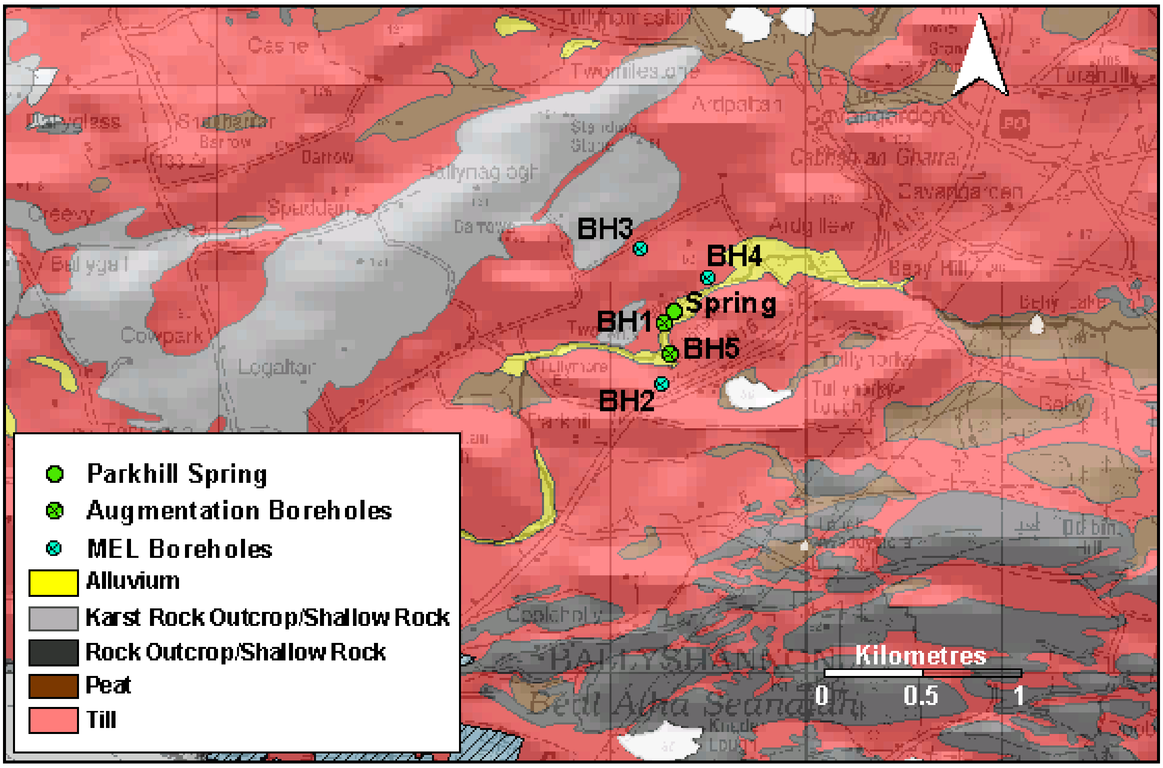

Figure 1.6. Mapped Subsoil Geology of the Ballyshannon Area.

1.5.6 Depth to Bedrock

All available information was compiled and a drilling programme undertaken by the GSI to ascertain the general changes in subsoil thickness and permeability throughout County Donegal.

There are seven depth to bedrock boreholes in close proximity to the well field as well as mapped rock outcrops. It is inferred from these data that the ridge to the northwest of the well field is rock-cored with only a thin layer of subsoil. The presence of a spring suggests that the subsoil is also shallow, and the MEL boreholes record a depth to bedrock of between 3.0-5.5m, suggesting that the subsoil may become slightly thicker towards the bottom of the river valley. The drumlins (e.g. c.200 m east of the spring) are likely to comprise greater thicknesses (> 10 m) of CLAY till. Thick drumlin deposits and thinner subsoil in inter-drumlin zones appears to reflect the general pattern observed in this part of Donegal.

1.5.7 Groundwater Vulnerability

The concept of vulnerability is discussed in Section 5 (Volume I). In summary, the vulnerability category mainly relates to the protection afforded by the material overlying the aquifer, which in this instance is the subsoil.

Regionally, the till in is generally described as CLAY (BS 5930), which is categorised as having a ‘low’ permeability. Where till is thicker (>3 m), the vulnerability categorises range from ‘high’ to ‘low’[3], with the thickest subsoil providing the greatest protection to the underlying aquifer.

[3] The permeability estimations and depth to rock 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.

Where data are available for the lower-lying inter-drumlin areas, such as around the well field, the matrix variability can be taken in account. The material mapped by MEL (April, 2003) is described as either SAND or GRAVEL, which are both categorised as having a 'high' permeability and therefore, a 'high' vulnerability for their recorded thicknesses.

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 for the area of interest is shown in Figure 1.7 below.

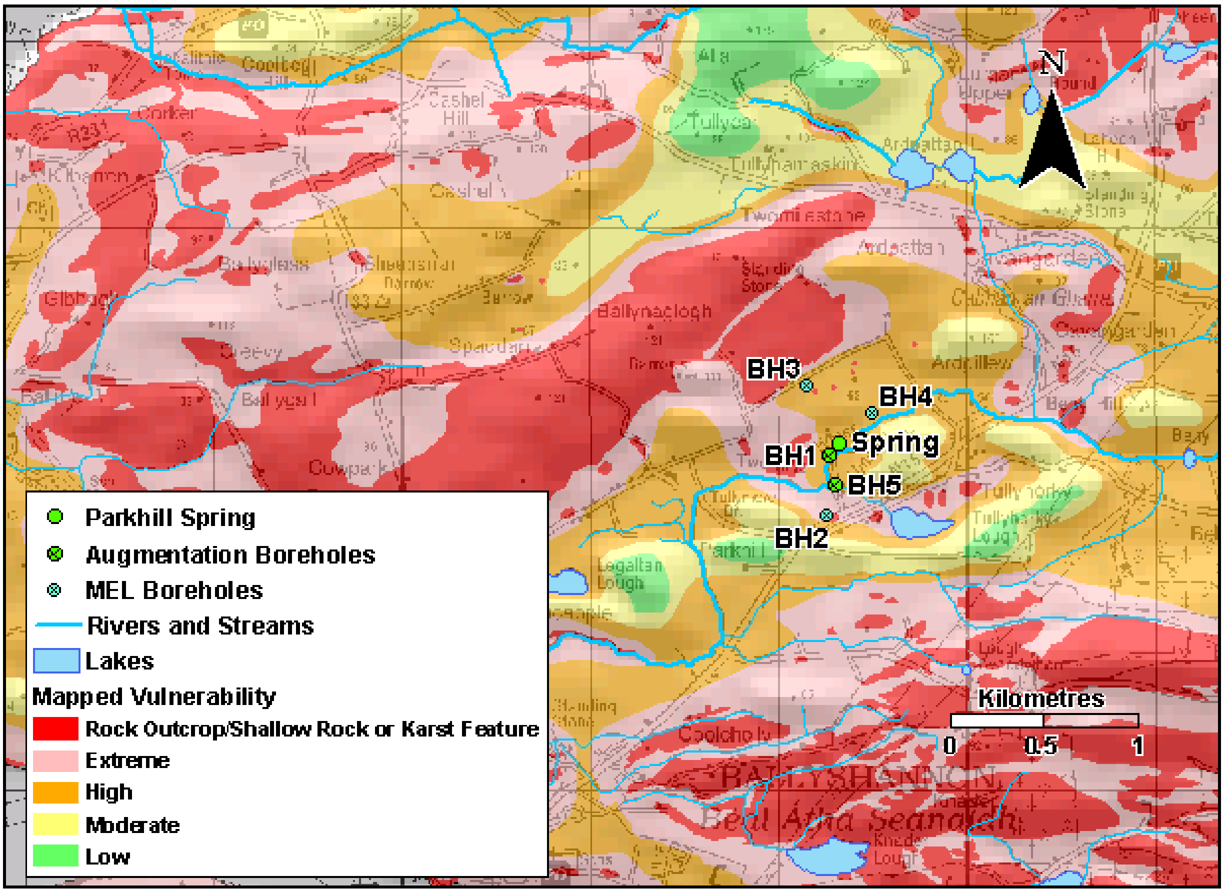

Figure 1.7. Mapped Vulnerability in the Ballyshannon Area.

1.6 Hydrogeology

1.6.1 Introduction

This section presents our current understanding of groundwater flow in the area around the Ballyshannon Water Supply Scheme well field. The hydrogeological and hydrochemical information for this study was obtained from the following sources:

- Hydrogeological mapping carried out by GSI in May 2002, October 2002, March 2003, January 2005 and February 2005.
- Monitoring of spring discharge: May 2003 - September 2004 (County Council).
- Pumping tests carried out by MEL (April, 2003).
- Two 12 pumping test undertaken by the GSI to determine any influence from the Abbey River (February 2005). Temperature and conductivity were measured.
- Dye tracer tests undertaken by the GSI to determine any connections between surrounding karst features and the Parkhill Spring (February 2005).

- GSI depth to bedrock and subsoil permeability drilling programme (July 2002).
- GSI/County Council water quality sampling in November 2002 and March 2003.
- MEL/County Council water quality analyses in October 2002 and April 2003.
- 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 is 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.

- *Average annual rainfall:* **1283 mm**

  The nearest rainfall gauging station (Ballyshannon; Cathleen's Falls) is situated approximately 2 km to the southwest of the source, at a similar elevation (Fitzgerald, D., Forrestal., F., 1996). Therefore the average annual rainfall (1971-2000; Met Eireann, 2004) is thought to be representative of that experienced at the source. The average based on the 1961-1990 data was 1082 mm/yr. This increased rainfall is in keeping with national trends.

- *Average annual evapotranspiration losses:* **458 mm**.

  Actual evapotranspiration (A.E.) is interpolated from a contour map that is derived from point values for 22 stations throughout the country (Met Eireann, 2004).

- *Average annual effective rainfall:* **825 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.

- *Estimated actual recharge:* **660 mm**

  The amount of water that will infiltrate to groundwater (recharge) is influenced by the subsoil permeability and thickness, as well as the aquifer characteristics. Recharge coefficients (rc) have been derived for various combinations of these factors (GWWG, November 2004). Over the entire area of interest, recharge estimates are thought to be in the order of 80% of effective rainfall. High proportions of recharge are also indicated by the lack of surface drainage in the area of interest.

These calculations are summarised as follows:

Average annual rainfall (R)	1283 mm
Estimated A.E.	458 mm
Potential Recharge (R – A.E.)	825 mm
Overall Recharge Coefficient	80%
Estimated Actual Recharge	**660 mm**

1.6.3 Discharge Estimates

On GSI recommendations, the spring discharge was monitored by the County Council. A 'V' notch weir, stilling well and automatic recorder were installed at the outflow of the spring pond area. The data available at the time of writing (May 2003-September 2004; Figure 1.8) show that the flow ranges from 90-3280 m^3/d. The annual average is 680 m^3/d (September 2003-September 2004).

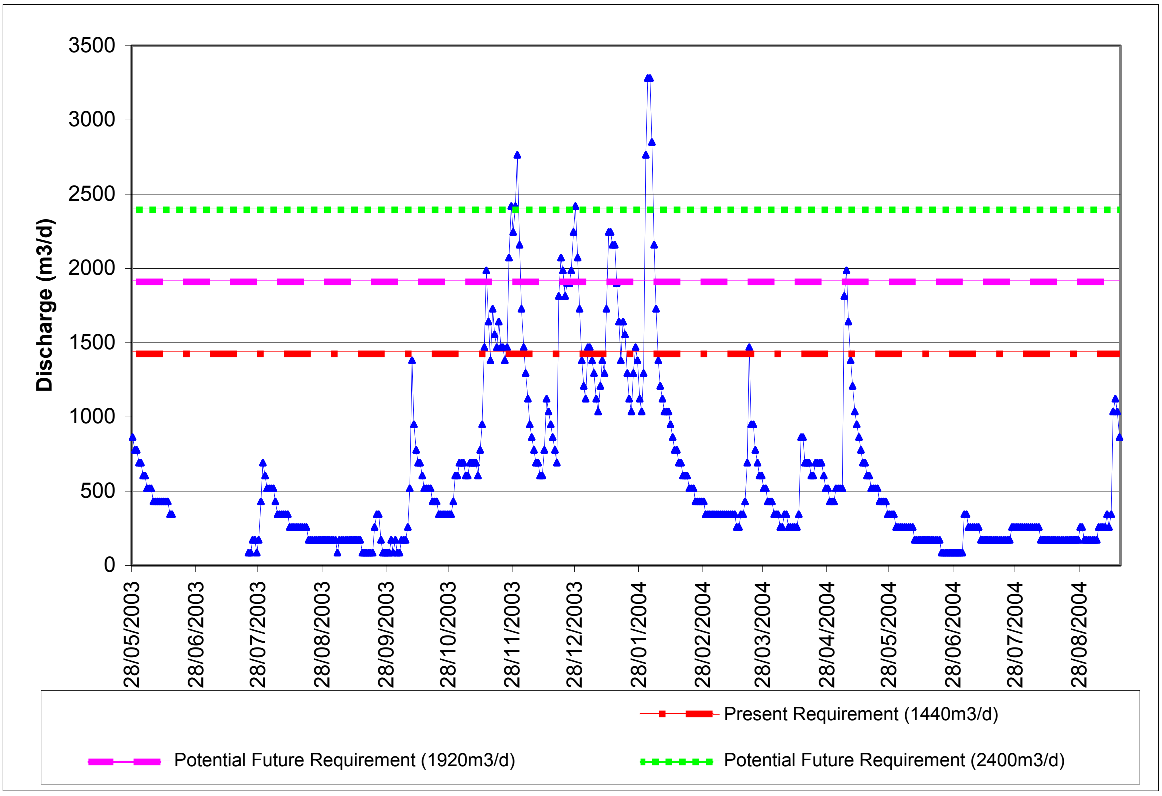

Figure 1.8. Parkhill Spring Overflow (May 2003-September 2004).

1.6.4 Groundwater Levels, Flow Directions and Gradients

To date, three pumping tests have been undertaken for the Ballyshannon Water Supply Scheme:

- MEL test: combined pumping of the Parkhill Spring and BHs1-4 to ascertain whether total demand could be met. On request from the GSI, the combined test was preceded by a 6 hour pumping test of BH1 alone (April 2003);
- GSI tests (Appendix A): separate tests on BH1 (09.02.05) and BH5 (15.02.05) to determine if there is a) any induced recharge from the Abbey River, and b) influence on the spring or remaining boreholes.

Static and pumping water levels were measured in the spring, the 4 MEL boreholes (BHs 1-4), BH5, and two additional trial wells: BH1 TW and BH5 TW. The main points of interest are outlined below:

- The relatively small drawdowns recorded in the MEL 6 hour test and both GSI tests suggest that enough water is able to flow through the rock to meet that abstraction (500 m^3/d), at that particular time of year. However, the larger drawdown in BH5 (1.6 m), as compared to BH1 (0.5 m), may indicate that BH1 is located within a larger/better connected conduit system.

GSI BH1 Pumping Test:

- The change in groundwater temperature and conductivity values of BH1 (9.9 to 9.5 ºC and 620 to 504 µS/cm respectively) suggests that there is induced recharge from the Abbey River, which is located c.10 m south of the borehole. From the change in conductivity[4], it is estimated that up to 40% of the abstraction is coming from the river.
- At the given abstraction rate, there does not appear to be any influence of pumping BH1 on the remaining boreholes/spring, as their water levels remained fairly constant throughout. The

[4] The change in groundwater temperature suggests that c.20% of the abstraction is coming from the river. However, possible temperature stratification in the river means that there is potentially more uncertainty with using the temperature, as opposed to using the conductivity.

exception is BH1 TW, which mirrored the pumping well drawdown. This would be expected due to the close proximity of the two wells (c.5 m distance).

GSI BH5 Pumping Test:

- The BH5 solo pumping test was disrupted by the spring being pumped by the County Council between c.11am and 4pm. However there does not appear to be any resultant influence on BHs 1 and 4 at that abstraction rate, as their water levels remained fairly constant.
- A continual drawdown was recorded in BH2 throughout the BH5 test however, the total drawdown was minor (c.0.3 m). This change may indicate some influence from pumping BH5, especially as BH2 is upgradient of BH5.
- The minimal change in conductivity and temperature values of BH5 suggests that there is no induced recharge from the Abbey River (c.15 m distance), at that particular abstraction rate.

Spring Pumping:

- There does not appear to be any influence on BHs 1 and 4 from the pumping at the spring, as their water levels remained fairly constant.
- Although not initially influenced by the solo pumping of BH5, drawdown in BH3 was observed during the period of spring pumping (levels were maintained as the base of the sump). The water levels in BH3 then recovered 0.8 m of the overall 1.15 m drawdown once the spring pumping had ceased, even though pumping of BH5 continued for another 5 hours.

Groundwater Flow Directions

On the northern side of the Abbey River, the *principle* groundwater flow direction around the boreholes and spring is likely to be in a south to south-easterly direction, as indicated by:

a) *Topography and surface drainage:* higher ground to the northwest of the well field suggests a south-easterly flow direction. However, the influence of the westerly flowing Abbey River is likely result in a southerly flow direction around the well field.

b) *Groundwater levels:* become increasingly higher to the north/northwest of the well field.

c) *Monitored water levels:* drawdown response in BH3 to pumping at the spring suggests a natural link (e.g. specific highly weathered /conduit zone) in that south-easterly direction.

Topography and static water levels indicate that the general groundwater flow direction on the south side of the river is in a northerly direction.

Additionally, tracer testing was undertaken in February 2005 to determine if there were any specific groundwater connections to the Parkhill Spring. Dye was injected into two active swallow holes northwest of the spring. Eleven springs, including Parkhill Spring, two lakes and the Abbey River were frequently sampled for the first two days and then occasionally after this period. The results showed that under those specific flow conditions, the *primary* flow route was directly south, to the Laglaton Lough turlough and its associated springs (Figure 1.9). A *secondary* flow was identified to the northeast and a third, weaker connection was identified, in a south-easterly direction.

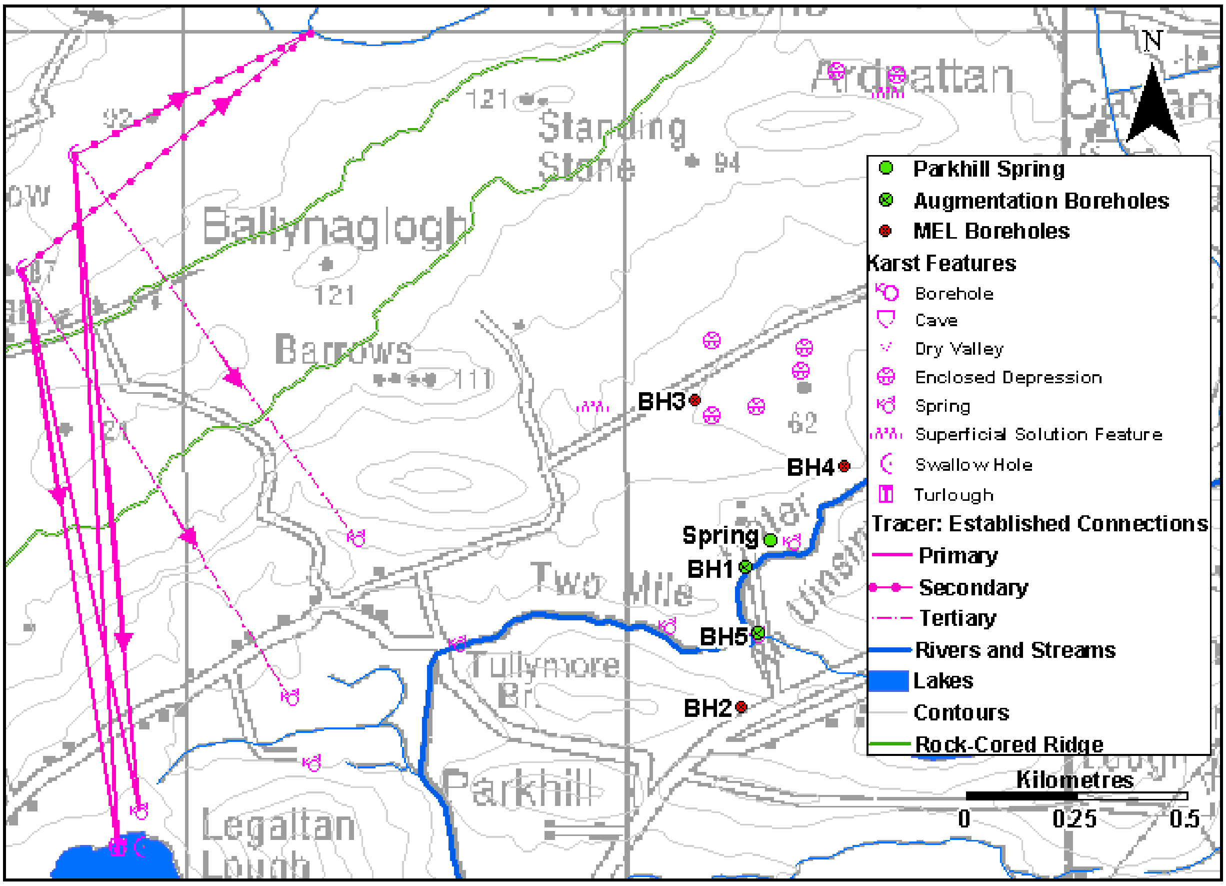

Figure 1.9. Established Groundwater Connections in the Ballyshannon Area.

Exact flow rates between specific points could not be established as the dyes were not identified during the first two days of sampling. However, the dyes did appear at all of the locations between 40-88 hours after injection. The minimum flow rates along the strongest connections (i.e. south to Lagaltan Lough) are estimated to range from c.15-38 m/hr.

No connection was established between the injection points and the Parkhill Spring. However, it is noted that under different flow conditions, other conduits/fractures may become active and consequently additional/alternative flow routes may be established.

Further to the actual tracer test connections, the pattern of karst features can also indicate the alignment of conduit systems, and therefore the direction of groundwater flow. Specifically, the line of 4 dolines c.325 m north of the Parkhill Spring are orientated along the main alignment of a slight topographic hollow (approximately northeast-southwest). This would suggest the presence of a conduit system in the same orientation. It is also noted that BH3 is located within the same hollow at the western end of this line. Therefore, BH3 may be connected to this conduit system.

Groundwater Gradients

Based on the static borehole water levels, the natural groundwater gradient north of the Abbey River is in the region of 0.02. Groundwater gradients to the south of the river are also likely to be in the order of 0.01-0.02. Both gradients are thought to be up to half of the topographic gradient in this area, which would be expected in a highly permeable aquifer.

Groundwater flow direction and gradient are likely to be influenced by the pumping in the immediately vicinity of the boreholes.

1.6.5 Hydrochemistry and Water Quality

Given that this is a new scheme, hydrochemical data were limited. Available data (summarised in Figure 1.10) comprised that from the County Council/MEL (2002-2004), and the GSI/County Council (2002-2003). The following key points have been identified:

- Analysis of hardness indicate a hard (250-350 mg/l $CaCO_3$) calcium bicarbonate hydro-chemical signature, which reflects a high calcium content associated with limestone aquifers.
- Available nitrate concentrations range from 0.4-8.5 mg/l NO_3 (3 samples from the spring and BH5). These values are within MAC and threshold levels (50 and 25 mg/l NO_3 respectively).
- Faecal coliforms were detected in five of the twelve available samples: 1 and 88 counts/100 ml in BH1, and 33 and 87 counts/100 ml in the spring and 9 counts/100 ml in BH2. A value of 1000 counts/100 ml was recorded in the Abbey River in October 2002. Levels over 10 counts/100 ml are considered to be gross contamination (Keegan *et al*., 2002).
- The chloride concentrations for the spring, all of the boreholes and the Abbey River were relatively high: 21-31 mg/l, averaging c.25 mg/l. High chlorides can indicate contamination by organic wastes e.g. on-site waste water treatment systems. However, they also occur naturally in coastal areas (influence of sea spray and salty rainfall), such as around Parkhill (c.5 km from the coast).
- Half of the 14 available manganese levels are elevated above the MAC (0.05 mg/l). Elevated levels were recorded in BHs 1, 2, 3 and 5, and in the Abbey River (0.07-0.15 mg/l). Although high concentrations of manganese can indicate pollution by silage effluent, soiled water or septic tank effluent, they are also associated with certain naturally occurring conditions, such as runoff from peat or groundwater from shale or impure limestone aquifers.

  In this instance, the manganese is thought to be naturally occurring for two main reasons. Firstly, levels were only elevated in the boreholes where 'dark grey limestone' was logged (BHs 1, 2 and 3[5]), which suggests that a proportion of the groundwater is derived from impure limestone. Secondly, levels were not elevated in the spring. Generally spring water is thought to a) flow through the top of the rock for which no 'dark grey limestone' is recorded, and b) be most susceptible to contamination i.e. manganese due to contamination would be expected in the spring discharge and not in the abstraction from deeper boreholes.

The minimal data indicate that microbial contamination is an issue for the spring and production boreholes. Given the surrounding land use, the source of contamination is likely to be point and/or diffuse organic wastes, such as on-site wastewater treatment systems or landspreading of organic wastes upslope of the spring/boreholes. The elevated levels of manganese and chloride can also suggest organic wastes as the hazard, although given the location and logged geology of the site, these parameters are likely to be naturally occurring.

A further water quality consideration for BH1 is the likely induced recharge from the Abbey River, which is estimated to be as much as 40% of the pumping test abstraction (Section 1.6.4). The one available sample highlights extremely high levels of faecal coliforms and elevated manganese. Although the manganese may be naturally occurring (associated with any groundwater input from the impure limestone), it is possible that the contamination as indicated by the faecal coliforms may have some influence on BH1.

The influenced of the river water will depend on the presence of any fine grained (silt, clay) material along the bed/banks of the river, as this can filter contaminants. At present, the data are too limited to determine the influence of the river water on the quality of the abstraction from BH1.

[5] No borehole log was available for BH5, although given its proximity to between BH1 and BH2, it is assumed to have a encountered similar strata.

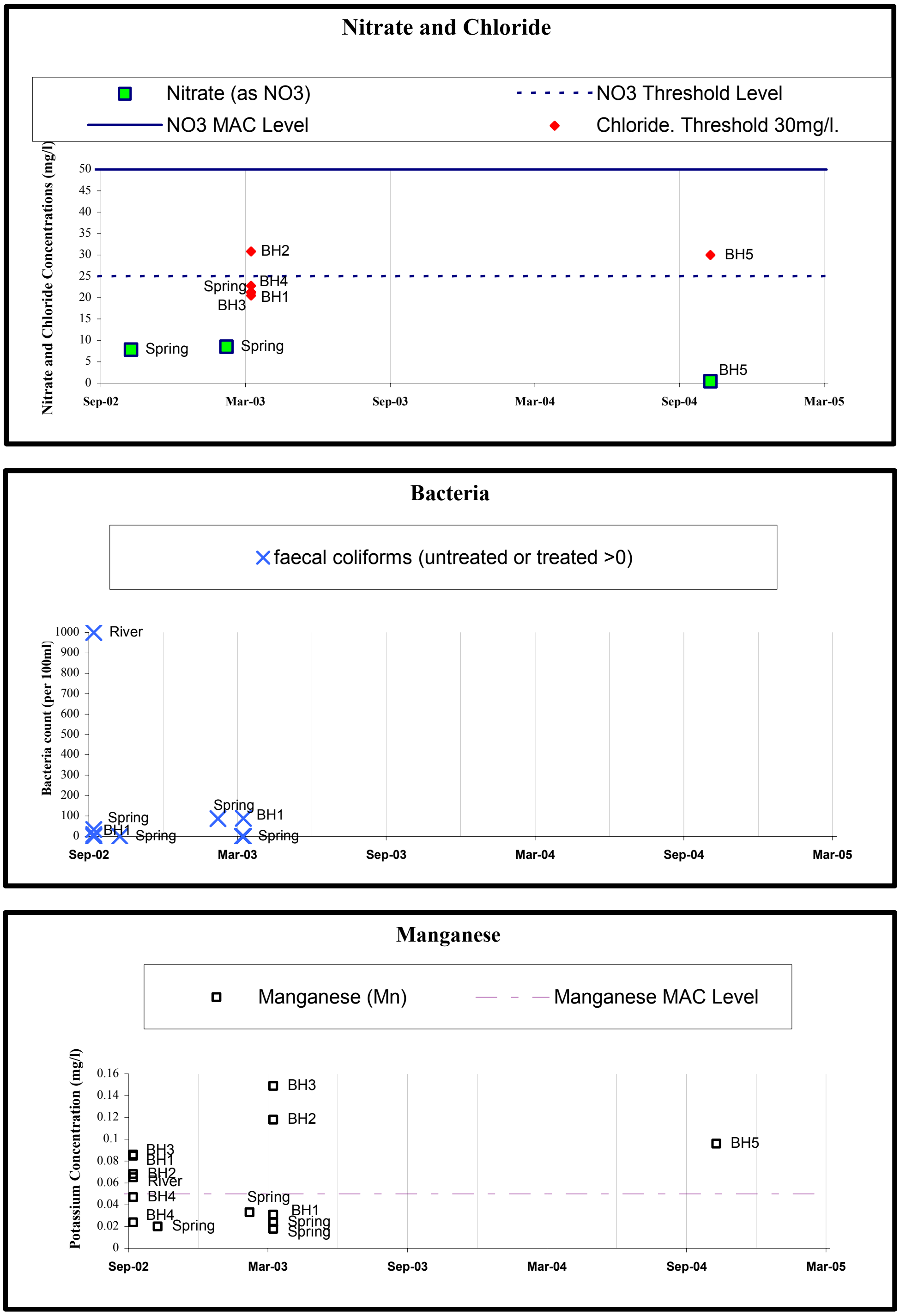

Figure 1.10. Indicators of Domestic and Agricultural Groundwater Contamination.

1.6.6 Aquifer Characteristics

It is proposed that the Ballyshannon Water Supply Scheme will use the Parkhill Spring as the main source of water, with one or two augmentation boreholes. All three sources abstract water from the Ballyshannon Limestone, which is classified as a **Regionally Important Karstified Aquifer**, characterised by **diffuse flow (RK^d)**. Refer to Section 4 (Volume 1) for further details.

The Ballyshannon Limestone is generally described as a medium to light grey, massively bedded coarse-grained, 'pure' limestone. Additional drilling confirms this description and enables further subdivision of the upper portion of rock into alternating layers of light brown and light grey rock. The brown layers are likely to transmit more water that the grey, as they are recorded as significantly more weathered. It is also likely that the brown material corresponds to *dolomitised* limestone, especially as the nineteenth century geological mapping (GSI) notes dolomitised rock in this area. Dolomitisation a process where the original calcite ions in a limestone are replaced by magnesium ions, which often results in increasing the overall rock permeability.

Further to these subdivisions, the Ballyshannon Limestone in this particular area appears to have a reasonably high degree of karstification. Karstification is an important process in Irish hydrogeology. It involves the enlargement of rock fissures when groundwater dissolves the fissure walls as it flows through them. The process can result in significantly enhanced permeability and groundwater flow rates. It generally occurs in 'purer' limestones, such as the Ballyshannon Limestone. The main evidence for karstification includes:

- the presence of karst features (Figure 1.3),
- established connections (tracer tests) between active swallow holes and (karst) springs,
- an observed, potentially solutionally enlarged, conduit within the rock (Figure 1.4),
- relatively variable ('flashy') spring discharges (Figure 1.8) that indicates a rapid response to rainfall events and low aquifer storage,
- low surface drainage density, especially given the relatively low-lying position of the area.

The tracer tests indicates minimum groundwater velocities of between 15-38 m/hr. These flow rates depend on several factors including topography, rainfall and groundwater levels. However, such high velocities are characteristic of flow in well developed karst aquifers.

The Ballyshannon Limestone is likely to be characterised by:

- Groundwater flow in solutionally enlarged joints, faults and conduits i.e. concentration of flow into zones of high permeability;
- High groundwater velocities, several orders of magnitude greater that in sand/gravel aquifers;
- Minimal attenuation of contaminants, except by dilution;
- Low aquifer storage;
- High turbidity, suspended solids and colour after heavy rain, particularly in the autumn;
- Short response times when pollution incidents occur.

Aquifer coefficients, such as specific capacity, transmissivity and permeability, have been calculated from the pumping tests undertaken by the GSI in February 2005 (Appendix B). Although useful as a guide, the coefficients are based on the entire thickness of the aquifer, which in this instance is taken as the saturated depth of the boreholes (c.87 m). However, as the majority of groundwater flow is probably limited to the karstified/dolomitised fracture/cavity zones. Therefore the actual velocity calculated from the tracer test (15-38 m/hr) is more likely to give a realistic zone of contribution as it is thought that it relates specifically to these zones.

1.6.7 Conceptual Model

- The majority of the Ballyshannon Water Supply Scheme is planned to be abstracted from the Parkhill Spring (1440 m^3/d, potentially increasing to 1920-2400 m^3/d in the future). When the spring cannot meet the demand (e.g. times of low flow), the supply will be augmented by one/two boreholes, which will each be fitted with pumps capable of pumping up to 750 m^3/d.
- All three sources abstract water from the Ballyshannon Limestone. This rock unit has undergone karstification (presence of karst features, established links between swallow holes and springs, observed conduit in the rock, 'flashy' spring discharge), and is therefore classified as a **Regionally Important Karstified Aquifer** that is characterised by **diffuse flow (RK^d)**.
- It is likely that a large proportion of the groundwater is reaching the spring and boreholes through highly permeable zones comprising:
    1) interconnected, probably solutionally enlarged (karstified), fracture and joints i.e. conduits, and

2) highly weathered, light brown strata (possibly dolomitised).

- In the area of interest (north of the Abbey River), the *primary* groundwater flow direction is likely to be in a south to south-easterly direction. A *secondary* flow direction, as indicated by the tracer test and inferred by the line of dolines, may exist along an approximate east-west orientation.
- The tracer testing did not establish any specific groundwater flow pathways to the Parkhill Spring. However, the test highlighted the rapid groundwater velocity through this aquifer (minimum of c.15-38 m/hr in a southerly direction).
- There does not seem to be any interference between the Parkhill Spring, BH1 and/or BH5.
- When water is abstracted from BH1, there is likely to be induced recharge from the Abbey River, as indicated by the conductivity and temperature changes observed in the February 2005 pumping test.
- Pumping at the spring appears to influence water levels in BH3.
- Diffuse and point recharge occur in this general area. Diffuse recharge occurs over most of the land surface especially where the subsoil is thin and/or permeable, as indicated by the low density of surface drainage. Where the subsoil is thicker, a lower recharge potential is expected. Point recharge occurs through certain karst features such as swallow holes, caves and dolines. Overall, recharge estimates are in the order of 660 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 1.11.

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 total discharge of the spring, (b) the pumping rate of the augmentation borehole, (c) the groundwater flow direction, (d) the subsoil and bedrock permeability and (e) the recharge in the area. The delineation of the ZOC uses:

i. hydrogeological mapping techniques to determine 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.

Although reasonable hydrogeological data exists for this area, the underlying aquifer is karstified. Groundwater flow through karst areas is extremely complex and difficult to predict. Flow velocities are relatively fast and variable, both spatially and temporally. Catchment areas are often difficult to define and they may change seasonally. Consequently, some uncertainty generally exists when delineating boundaries in karst areas.

The derivation of the boundaries and any uncertainties associated with them are discussed below.

Parkhill Spring ZOC

The northern boundary of the spring's ZOC is principally constrained by topography. The north and north-western portion is delineated by a rock-cored, northeast-southwest trending ridge, which is the highest point in the local environs of the spring. Locally, the ridge acts as a surface water divide although groundwater connections across this divide were identified west of the area of interest. However, no actual connections to the Parkhill Spring were identified across this topographic divide. Furthermore, a proven secondary groundwater connections suggest that to the northeast of the ridge, groundwater is flowing in a north-easterly, rather than southerly, direction.

The western boundary is based on a) the topography high points formed by the local drumlins, and b) the pattern of groundwater connections identified in the tracer test. The primary connections are within the catchment area for the Lagaltan Lough turlough and its associated springs, which is down-gradient of the area of interest. The connections are therefore assumed to lie outside the catchment area for the Parkhill Spring.

The eastern boundary takes into account a) the influence of pumping the spring on BH3, and b) the possible connections between BH3 and the line of dolines (Section 1.5.2). Given the apparent rapid link between the spring and BH3, and that BH3 may be tapping into a conduit system to which the dolines are potentially connected, the hollow within which the dolines are located and the topographic catchment to the dolines are included in the spring's ZOC. BH4 is not included in the ZOC as it did not show any influence from the pumping at the spring.

The southern boundary is on the down-gradient side of the spring. It is assumed that the groundwater down-gradient of the spring will continue flowing to the Abbey River, rather than flow back to spring. This boundary comprises an arbitrary buffer of 30 m down-gradient of the springs i.e. up to, but not including, the Abbey River.

Borehole (BH1) ZOC

The northern, western and eastern boundaries of BH1's ZOC are constrained by topography. Although the aquifer coefficients (Appendix B) suggest a long, thin ZOC (extending several kilometres upgradient by c.60 m wide), the up-gradient extent of the ZOC is unlikely to extend beyond the rock-cored ridge due to likely north-easterly direction of groundwater flow, north of the ridge.

The western and eastern boundaries are based on the topographic catchment boundaries for the ZOC width estimated from the analytical modelling i.e. c.60 m (Appendix B). The direction of flow is taken as southeast i.e. perpendicular to the main slope in the area, rather than south (principle flow direction identified by the tracer test) as the BH1 pumping test did not appear to influence BH3 water levels. BH3, and the potentially connected line of dolines, are therefore not included in the ZOC for BH1. However, the ZOC does incorporate a safety margin of 20º to allow for the potential variability in groundwater flow direction.

The southern boundary is on the down gradient side of BH1 and is based on the results of the GSI pumping test that indicate there is induced recharge from the Abbey River. Given the presence of high permeability subsoil that is likely to be thin beneath the river (c.2.5 m beneath BH1, which records c.4 m depth to rock), and the highly permeable nature of the aquifer, there is likely to be good hydraulic connectivity between the river and the aquifer at this location, and therefore also between the river and BH1. On this basis, it is assumed that the induced recharge is coming solely from the river itself, rather than pulling in groundwater from the south side of the river. Therefore, the southern boundary includes the length of river that is adjacent to BH1.

Although the ZOC for BH1 takes account of the induced recharge from the Abbey River, it beyond the scope of this study to provide a ZOC for the river up-stream of BH1. However, the water quality of the river is highly likely to affect the water quality in BH1.

Resultant ZOC Area.

As Parkhill Spring and BH1 are likely to be used intermittently for the supply, the amalgamated ZOC for both spring and borehole will require protecting (Figure 1.11).

The recharge and discharge data (Section 1.6) are not comprehensive enough to undertake a water balance in order to accurately estimate the catchment area required. However, a comparison of the average demand (1440 m^3/d) and recharge (660 mm/year) indicate that the resultant ZOC (c. 1.0 km^2, 1850 m^3/d) is generally large enough to support this abstraction rate in the long term. These approximations also suggest that the ZOC is unlikely to be able to support the proposed future abstraction, especially in the drier summer months.

The question of meeting demand is further complicated by the large variability in the spring discharge, which is due to the low storage within the aquifer. The available spring discharge data (September 2003 to September 2004) shows that the spring would not meet the 1440 m^3/d demand on c.310 days (85% of the year). Even with augmentation from BH1, there is still likely to be a proportion of the year when demand would not be met. Although spring discharge data are limited at the time of writing, they do suggest that an alternative supply (e.g. potentially BH5) is likely to be needed to meet the present demand.

1.7.3 Inner Protection Area

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

Although the GSI tracer tests did not establish specific flow rates between injection and discharges points, the approximate minimum flow rates are estimated to range from c.15-38 m/hr. Given this minimum velocity and the karstified nature of the aquifer, it is possible that the groundwater could reach the spring or BH1 from any point in the delineated ZOC within 4 days. These data suggest that the ***entire*** ZOC should be incorporated into the Inner Protection Area.

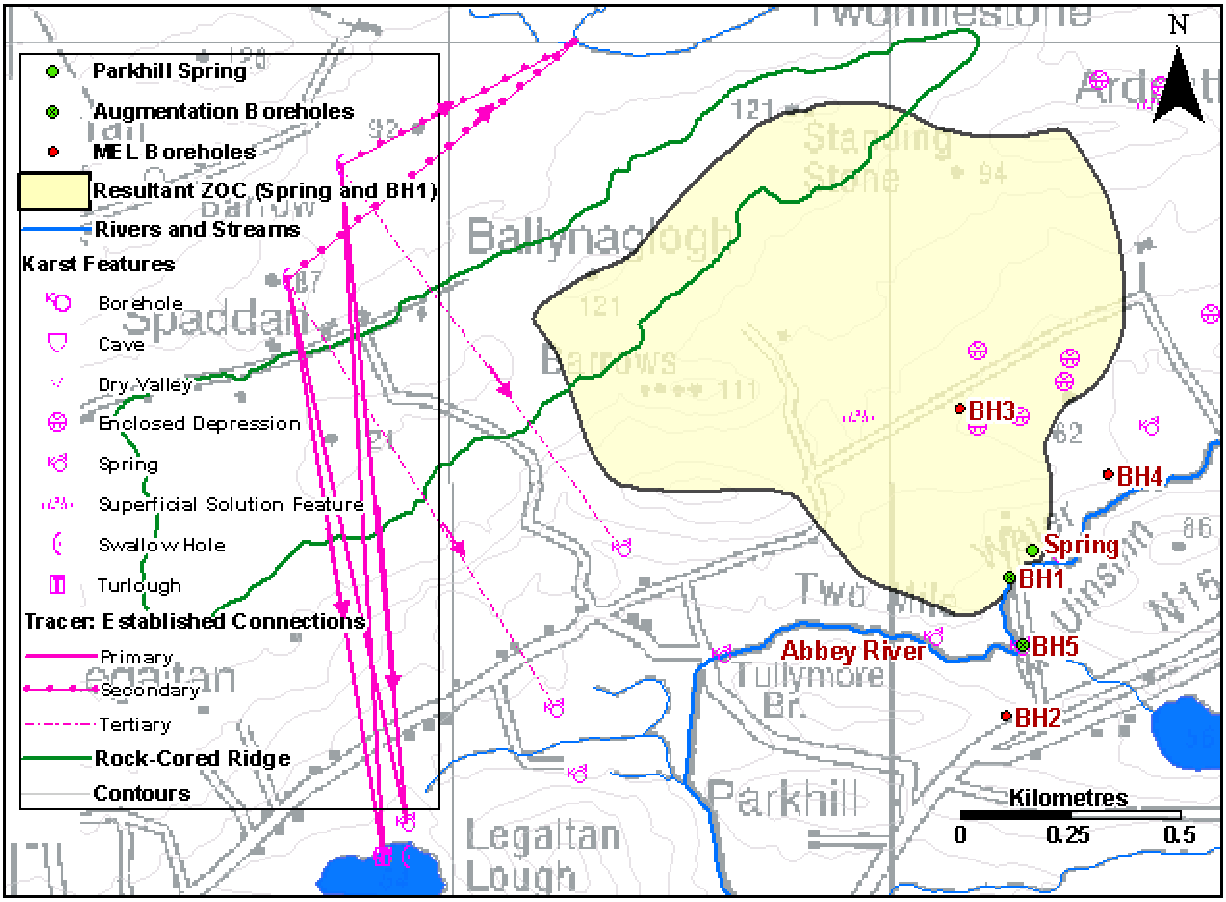

Figure 1.11. SO and SI Areas Around the Ballyshannon Public Supply Scheme Boreholes.

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.

Two groundwater protection zones are present around the Ballyshannon Water Supply Scheme (Figure 1.12), as shown in Table 1.1 below. Due to a large proportion of outcrop and relatively thin subsoil over the ZOC, all of the groundwater in this ZOC is categorised as either extremely or highly vulnerable to contamination.

Table 1.1 Matrix of Source Protection Zones at Ballyshannon

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

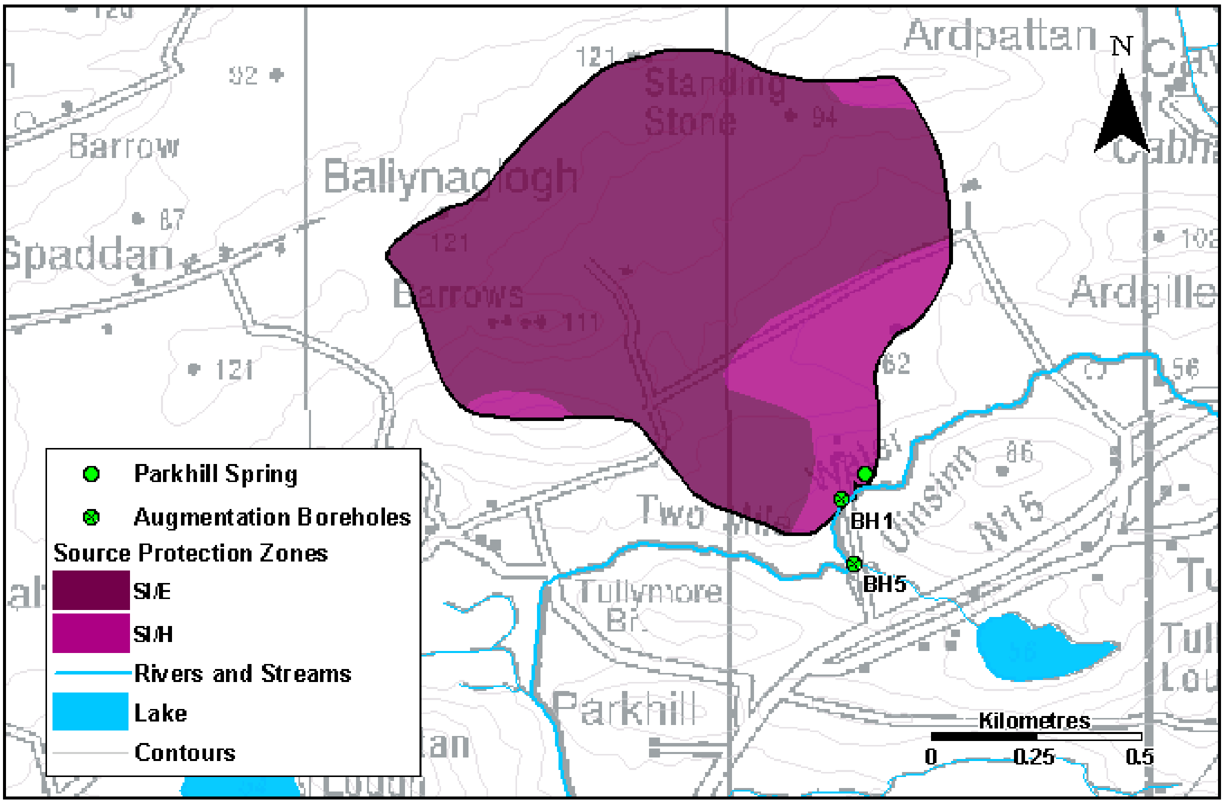

Figure 1.12. Source Protection Zones for the Ballyshannon Water Supply Scheme.

1.9 Potential Pollution Sources

Agriculture is the principal activity in the ZOC, with most of the land being used for pasture. Grazing cattle and horses were noted in close proximity to the well field on most visits. The farmhouse access road is adjacent to BH1 and c.50 m west of the spring. There are also two other minor roads crossing the ZOC. A small number of houses/farmyards (c.5) are located within the ZOC, the closest of these being the farmhouse, which is c.75 m northwest of the spring and c.100 m north of BH1.

Of the contaminant indicators examined, microbial contamination is a persistent issue for the spring and BH1, as are the elevated levels of manganese. Given the surrounding land use in combination with the extremely and highly vulnerable nature of the karstified aquifer, the source of contamination is likely to be point and/or diffuse organic wastes, such as on-site wastewater treatment systems, grazing or landspreading of organic wastes upslope of the spring/borehole. Although elevated levels of manganese and chloride can also suggest organic wastes as a hazard, they are thought to be naturally occurring in this particular well field. The application of pesticides and herbicides, and possible oil/diesel spillage along the roads/tracks, are also considered to be a potential cause for concern.

Further to the potential hazards within the delineated ZOC, the induced recharge from the Abbey River to BH1 suggests that the land use affecting the river water quality up-stream of the borehole is likely to indirectly influence the quality of the groundwater in the borehole itself. Furthermore, given proximity and elevation boreholes with respect to the river, flooding and river water inundation at the well heads is a potential source of contamination. This situation, however, is thought to be very unlikely to occur (E. McGrean, *pers. comm*., 2005).

1.10 Conclusions and Recommendations

- It is proposed that the majority of the Ballyshannon Water Supply Scheme will come from the Parkhill Spring, which will be augmented by one/two boreholes when the spring cannot meet the demand.
- All three sources abstract water from the Ballyshannon Limestone Formation, which is classified as a **Regionally Important Karst Aquifer**, characterised by **diffuse flow** (**Rk^d**)
- The scope of this report includes the provision of ZOCs and source protection zones for the Parkhill Spring and one of the augmentation boreholes: BH1. Augmentation borehole BH5 was subsequently installed but, due to its location and the complex hydrogeology in this area, would require considerable further investigation to delineate a realistic ZOC and therefore has not been included.
- Due the close proximity of the Parkhill Spring and BH1, much of their individual ZOCs overlap. For the resultant, amalgamated ZOC, the northern and western boundaries are principally based on topography but also take account of the results of the GSI dye tracer test (February 2005). The eastern boundary is based on the topographic catchments of a line of dolines, which, based on their topographic location, are possibly connected to the spring. The southern boundary takes account of the results of the GSI pumping test (February 2005), which indicate that there is induced recharge from the Abbey River to BH1.
- Due to the minimum rapid groundwater velocities through the karstified aquifer (c.15-38 m/hr), it is possible that groundwater within any part of the ZOC could potentially reach the spring or borehole within 100 days. Therefore the entire ZOC is classified as the Inner Source Protection Area (SI).
- The groundwater in the ZOC is categorised as either ‘extremely’ or ‘highly’ vulnerable to contamination due to the high proportion of outcrop and relatively thin subsoil over the area.
- Point (on-site wastewater treatment system and farmyard discharges) and diffuse (grazing livestock, landspreading of fertilisers, herbicides and pesticides) sources of contamination within the ZOC pose the main threats to the water quality in the spring and BH1.
- The water supply 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. given that only a year’s worth of spring discharge data have been reviewed, further assessments are undertaken to establish the long term sustainable yields of the spring and BH1.
    2. the potential hazards in the ZOC (e.g. on-site waste water treatment systems, grazing animals, land spreading) should be located and assessed especially with regard to their proximity to

mapped or unrecorded karst features that can provide preferential flow pathways directly into the aquifer.

3. particular care should be taken when assessing the location of any future activities or developments that might cause contamination at the well field.
4. a 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.
5. a full chemical and bacteriological analysis of the Abbey river, up-stream of BH1, is undertaken on a regular basis. Ideally, there should be an automatic water quality sampler that can flag any serious pollution incidents. This would act as a warning system to inform the County Council when BH1 should not be used, due to the induced recharge from the river (estimated as up to 40% of the abstraction).

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8 Appendices

Appendix A. Ballyshannon PWS: GSI Pumping Test Data.

SITE	Ballyshannon and Rossnowlagh Water Supply Scheme						**DATE**	9th February 2005
Borehole Name		BH1 (PW)		**Well Depth**	90 m		**Datum Point**	Lip of stand pipe
Borehole No.		1		**Well Diameter**	200 mm		**Height of Datum**	0.65 m above ground level
Well Owner		Donegal County Council		**Pump Depth**			**Ground Elevation**	55.30 m OD
Location		Parkhill, Ballyshannon		**Aquifer**	Rkd		**Datum Elevation**	55.95 m OD
Grid ref.		189278 363796					**Weather**	Overcast, occasional drizzle
6" Sheet No.		1735NE		**Discharge**	21 m3/hr		**Observer**	SML, ML.
Date	**Time**	**Elapsed Time**	**Water level below datum**	**Drawdown**	**Conductivity in BH1**	**Conductivity in river**	**Temperature in BH1**	**Temperature in river**
		Mins	**(m)**	**(m)**	**(uS/cm)**	**(uS/cm)**	**(oC)**	**(oC)**
02/09/2005	8.30.00	0.0	3.520	0.000	620	336	10.7	7.0
	9.50.00	0.0	3.520	0.000				
	9.50.30	0.5	3.750	0.230				
	9.51.00	1.0	3.780	0.260				
	9.51.30	1.5	3.780	0.260				
	9.52.00	2.0	3.780	0.260				
	9.52.30	2.5	3.780	0.260				
	9.53.00	3.0	3.780	0.260				
	9.53.30	3.5	3.780	0.260				
	9.54.00	4.0	3.790	0.270				
	9.54.30	4.5	3.790	0.270				
	9.55.00	5.0	3.790	0.270				
	9.55.30	5.5	3.800	0.280				
	9.56.00	6.0	3.800	0.280				
	9.56.30	6.5	3.800	0.280				
	9.57.00	7.0	3.800	0.280				
	9.57.30	7.5	3.800	0.280				
	9.58.00	8.0	3.810	0.290				
	9.58.30	8.5	3.810	0.290				

Date	Time	Elapsed Time	Water level below datum	Drawdown	Conductivity in BH1	Conductivity in river	Temperature in BH1	Temperature in river
		Mins	(m)	(m)	(uS/cm)	(uS/cm)	(oC)	(oC)
	9.59.00	9.0	3.810	0.290				
	9.59.30	9.5	3.810	0.290				
	10.00	10.0	3.810	0.290				
	10.01	11.0	3.820	0.300				
	10.02	12.0	3.820	0.300				
	10.03	13.0	3.820	0.300				
	10.04	14.0	3.825	0.305				
	10.05	15.0	3.825	0.305				
	10.06	16.0	3.830	0.310				
	10.07	17.0	3.830	0.310				
	10.08	18.0	3.835	0.315				
	10.09	19.0	3.835	0.315				
	10.10	20.0	3.835	0.315				
	10.11	21.0	3.840	0.320				
	10.12	22.0	3.840	0.320				
	10.13	23.0	3.840	0.320				
	10.14	24.0	3.840	0.320				
	10.15	25.0	3.850	0.330				
	10.16	26.0	3.850	0.330				
	10.17	27.0	3.850	0.330				
	10.18	28.0	3.850	0.330				
	10.19	29.0	3.850	0.330				
	10.20	30.0	3.850	0.330				
	10.22	32.0	3.855	0.335				
	10.24	34.0	3.860	0.340				
	10.26	36.0	3.860	0.340				
	10.28	38.0	3.865	0.345				
	10.30	40.0	3.865	0.345				
	10.32	42.0	3.870	0.350				
	10.34	44.0	3.870	0.350				
	10.36	46.0	3.875	0.355				

Date	Time	Elapsed Time	Water level below datum	Drawdown	Conductivity in BH1	Conductivity in river	Temperature in BH1	Temperature in river
		Mins	(m)	(m)	(uS/cm)	(uS/cm)	(oC)	(oC)
	10.38	48.0	3.875	0.355				
	10.40	50.0	3.875	0.355				
	10.45	55.0	3.875	0.355	922	293	9.9	7.4
	10.50	60.0	3.880	0.360				
	11.00	70.0	3.895	0.375				
	11.10	80.0	3.895	0.375				
	11.20	90.0	3.905	0.385				
	11.30	100.0	3.905	0.385				
	11.40	110.0	3.910	0.390				
	11.50	120.0	3.915	0.395				
	12.05	135.0	3.915	0.395				
	12.20	150.0	3.925	0.405				
	12.35	165.0	3.925	0.405	535	348	9.8	7.5
	12.50	180.0	3.935	0.415				
	13.05	195.0	3.940	0.420				
	13.20	210.0	3.940	0.420				
	13.35	225.0	3.940	0.420	522	348	9.8	7.7
	13.50	240.0	3.950	0.430				
	14.20	270.0	3.955	0.435				
	14.50	300.0	3.960	0.440	516	345	9.7	7.7
	15.20	330.0	3.965	0.445				
	15.50	360.0	3.975	0.455	513	348	9.6	7.7
	16.20	390.0	3.980	0.460				
	16.50	420.0	3.985	0.465	511	349	9.6	7.7
	17.20	450.0	3.990	0.470				
	17.50	480.0	3.995	0.475	508	350	9.6	7.7
	18.50	540.0	4.005	0.485	504	357	9.6	7.7
	19.50	600.0	4.015	0.495	504	363	9.6	7.7
	20.50	660.0	4.025	0.505	506	361	9.5	7.7
	21.50	720.0	4.040	0.520	504	358	9.5	7.7

SITE	Ballyshannon Water Supply Scheme						**DATE**	9th February 2005
Borehole Name		BH1 Trial Well (TW)		**Well Depth**	90 m		**Datum Point**	Inside lip of casing
Borehole No.		1		**Well Diameter**	200 mm		**Height of Datum**	0.20 m above ground level
Well Owner		Donegal County Council		**Pump Depth**			**Ground Elevation**	55.30 m OD
Location		Parkhill, Ballyshannon		**Aquifer**	Rkd		**Datum Elevation**	55.50 m OD
Grid ref.		189278 363796					**Weather**	Overcast, occasional drizzle
6" Sheet No.		1735NE		**Discharge**			**Observer**	SML, ML.
Date	**Time**	**Elapsed Time**	**Water level below datum**	**Drawdown**	**Conductivity in BH1 (PW)**	**Conductivity in river**	**Temperature in BH1 (PW)**	**Temperature in river**
		Mins	**(m)**	**(m)**	**(uS/cm)**	**(uS/cm)**	**(oC)**	**(oC)**
02/09/2005	8.30.00	0.0	3.060	0.000	620	336	10.7	7.0
	9.50.00	0.0	3.060	0.000				
	9.50.30	0.5	3.110	0.050				
	9.51.00	1.0	3.120	0.060				
	9.51.30	1.5	3.120	0.060				
	9.52.00	2.0	3.125	0.065				
	9.52.30	2.5	3.130	0.070				
	9.53.00	3.0	3.130	0.070				
	9.53.30	3.5	3.135	0.075				
	9.54.00	4.0	3.140	0.080				
	9.54.30	4.5	3.140	0.080				
	9.55.00	5.0	3.145	0.085				
	9.55.30	5.5	3.145	0.085				
	9.56.00	6.0	3.150	0.090				
	9.56.30	6.5	3.150	0.090				
	9.57.00	7.0	3.155	0.095				
	9.57.30	7.5	3.155	0.095				
	9.58.00	8.0	3.155	0.095				
	9.58.30	8.5	3.155	0.095				
	9.59.00	9.0	3.160	0.100				
	9.59.30	9.5	3.160	0.100				
	10.00	10.0	3.160	0.100				

Date	Time	Elapsed Time Mins	Water level below datum (m)	Drawdown (m)	Conductivity in BH1 (PW) (uS/cm)	Conductivity in river (uS/cm)	Temperature in BH1 (PW) (oC)	Temperature in river (oC)
	10.01	11.0	3.170	0.110				
	10.02	12.0	3.170	0.110				
	10.03	13.0	3.175	0.115				
	10.04	14.0	3.180	0.120				
	10.05	15.0	3.180	0.120				
	10.06	16.0	3.185	0.125				
	10.07	17.0	3.185	0.125				
	10.08	18.0	3.190	0.130				
	10.09	19.0	3.190	0.130				
	10.10	20.0	3.190	0.130				
	10.11	21.0	3.190	0.130				
	10.12	22.0	3.190	0.130				
	10.13	23.0	3.195	0.135				
	10.14	24.0	3.195	0.135				
	10.15	25.0	3.200	0.140				
	10.16	26.0	3.200	0.140				
	10.17	27.0	3.200	0.140				
	10.18	28.0	3.200	0.140				
	10.19	29.0	3.200	0.140				
	10.20	30.0	3.205	0.145				
	10.22	32.0	3.205	0.145				
	10.24	34.0	3.210	0.150				
	10.26	36.0	3.210	0.150				
	10.28	38.0	3.210	0.150				
	10.30	40.0	3.215	0.155				
	10.32	42.0	3.215	0.155				
	10.34	44.0	3.220	0.160				
	10.36	46.0	3.220	0.160				
	10.38	48.0	3.220	0.160				
	10.40	50.0	3.220	0.160				
	10.45	55.0	3.225	0.165	922	293	9.9	7.4

Date	Time	Elapsed Time Mins	Water level below datum (m)	Drawdown (m)	Conductivity in BH1 (PW) (uS/cm)	Conductivity in river (uS/cm)	Temperature in BH1 (PW) (oC)	Temperature in river (oC)
	10.50	60.0	3.230	0.170				
	11.00	70.0	3.240	0.180				
	11.10	80.0	3.240	0.180				
	11.20	90.0	3.250	0.190				
	11.30	100.0	3.250	0.190				
	11.40	110.0	3.255	0.195				
	11.50	120.0	3.260	0.200				
	12.05	135.0	3.265	0.205				
	12.20	150.0	3.265	0.205				
	12.35	165.0	3.270	0.210	535	348	9.8	7.5
	12.50	180.0	3.280	0.220				
	13.05	195.0	3.280	0.220				
	13.20	210.0	3.290	0.230				
	13.35	225.0	3.290	0.230	522	348	9.8	7.7
	13.50	240.0	3.290	0.230				
	14.20	270.0	3.295	0.235				
	14.50	300.0	3.300	0.240	516	345	9.7	7.7
	15.20	330.0	3.300	0.240				
	15.50	360.0	3.310	0.250	513	348	9.6	7.7
	16.20	390.0	3.310	0.250				
	16.50	420.0	3.320	0.260	511	349	9.6	7.7
	17.20	450.0	3.325	0.265				
	17.50	480.0	3.325	0.265	508	350	9.6	7.7
	18.50	540.0	3.335	0.275	504	357	9.6	7.7
	19.50	600.0	3.345	0.285	504	363	9.6	7.7
	20.50	660.0	3.355	0.295	506	361	9.5	7.7
	21.50	720.0	3.365	0.305	504	358	9.5	7.7

SITE	Ballyshannon and Rossnowlagh Water Supply Scheme						**DATE**	15th February 2005
Borehole Name		BH5 (PW)		**Well Depth**	90 m		**Datum Point**	Lip of stand pipe
Borehole No.		5		**Well Diameter**	200 mm		**Height of Datum**	1.2 m above ground level
Well Owner		Donegal County Council		**Pump Depth**			**Ground Elevation**	54.50 m OD
Location		Parkhill, Ballyshannon		**Aquifer**	Rkd		**Datum Elevation**	55.70 m OD
Grid ref.		189305 363633					**Weather**	Dry, sunny, cold.
6" Sheet No.		1735NE		**Discharge**	21 m3/hr		**Observer**	SML, CH.
Date	**Time**	**Elapsed Time**	**Water level below datum**	**Drawdown**	**Conductivity in BH5**	**Conductivity in river**	**Temperature in BH5**	**Temperature in river**
		Mins	**(m)**	**(m)**	**(uS/cm)**	**(uS/cm)**	**(oC)**	**(oC)**
15/2/2005	8.20.00	0.0	2.115	0.000		351		5.3
	8.26.00	0.0	2.115	0.000				
	8.26.30	0.5	2.950	0.835				
	8.27.00	1.0	3.070	0.955				
	8.27.30	1.5	3.140	1.025				
	8.28.00	2.0	3.180	1.065				
	8.28.30	2.5	3.210	1.095				
	8.29.00	3.0	3.230	1.115				
	8.29.00	3.5	3.260	1.145				
	8.30.00	4.0	3.280	1.165				
	8.30.30	4.5	3.290	1.175				
	8.31.00	5.0	3.310	1.195	632		10.0	
	8.31.30	5.5	3.320	1.205				
	8.32.00	6.0	3.330	1.215				
	8.32.30	6.5	3.340	1.225				
	8.33.00	7.0	3.350	1.235	628		10.9	
	8.33.30	7.5	3.350	1.235				
	8.34.00	8.0	3.360	1.245	626		11.0	
	8.34.30	8.5	3.370	1.255				
	8.35.00	9.0	3.370	1.255	633		11.0	
	8.35.30	9.5	3.380	1.265				

Date	Time	Elapsed	Water level	Drawdown	Conductivity	Conductivity	Temperature	Temperature
		Time	below datum		in BH5	in river	in BH5	in river
		Mins	(m)	(m)	(uS/cm)	(uS/cm)	(oC)	(oC)
	8.36.00	10.0	3.390	1.275	634		11.0	
	8.37	11.0	3.410	1.295	635		11.0	
	8.38	12.0	3.410	1.295	636		11.0	
	8.39	13.0	3.415	1.300	638		11.0	
	8.40	14.0	3.420	1.305	638		11.0	
	8.41	15.0	3.420	1.305	638		11.0	
	8.42	16.0	3.430	1.315	639		111.0	
	8.43	17.0	3.435	1.320	639		11.0	
	8.44	18.0	3.435	1.320	640		11.0	
	8.45	19.0	3.445	1.330				
	8.46	20.0	3.450	1.335				
	8.47	21.0	3.450	1.335				
	8.48	22.0	3.460	1.345				
	8.49	23.0	3.460	1.345				
	8.50	24.0	3.465	1.350				
	8.51	25.0	3.470	1.355				
	8.52	26.0	3.475	1.360				
	8.53	27.0	3.475	1.360				
	8.54	28.0	3.480	1.365				
	8.55	29.0	3.480	1.365				
	8.56	30.0	3.485	1.370				
	8.58	32.0	3.490	1.375				
	9.00	34.0	3.495	1.380				
	9.02	36.0	3.495	1.380				
	9.04	38.0	3.495	1.380	672		10.6	
	9.06	40.0	3.495	1.380	666		10.9	
	9.08	42.0	3.505	1.390				
	9.10	44.0	3.505	1.390				
	9.12	46.0	3.510	1.395				
	9.14	48.0	3.510	1.395				
	9.16	50.0	3.515	1.400				

Date	Time	Elapsed Time Mins	Water level below datum (m)	Drawdown (m)	Conductivity in BH5 (uS/cm)	Conductivity in river (uS/cm)	Temperature in BH5 (oC)	Temperature in river (oC)
	9.21	55.0	3.520	1.405				
	9.26	60.0	3.520	1.405				
	9.36	70.0	3.535	1.420	670	417	10.9	6.5
	9.46	80.0	3.540	1.425				
	9.56	90.0	3.550	1.435				
	10.06	100.0	3.565	1.450				
	10.16	110.0	3.575	1.460				
	10.26	120.0	3.575	1.460	671	355	10.9	5.7
	10.41	135.0	3.585	1.470				
	10.56	150.0	3.600	1.485				
	11.11	165.0	3.600	1.485				
	11.26	180.0	3.610	1.495				
	11.41	195.0	3.610	1.495	674		10.8	6.0
	11.56	210.0	3.615	1.500				
	12.11	225.0	3.620	1.505				
	12.26	240.0	3.625	1.510		350		6.2
	12.56	270.0	3.630	1.515			10.8	6.3
	13.26	300.0	3.640	1.525	672	354	10.8	6.4
	13.56	330.0	3.650	1.535				
	14.26	360.0	3.660	1.545				
	14.56	390.0	3.665	1.550	669	353	10.8	6.6
	15.26	420.0	3.670	1.555				
	15.56	450.0	3.680	1.565				
	16.26	480.0	3.680	1.565	671	352	10.7	6.7
	17.26	540.0	3.690	1.575	670	349	10.7	6.6
	18.26	600.0	3.690	1.575	670	352	10.7	6.7
	19.26	660.0	3.715	1.600	669	353	10.7	6.7
	20.26	720.0	3.715	1.600	668	355	10.7	6.7

SITE Ballyshannon Water Supply Scheme							**DATE**	15th February 2005
Borehole Name		BH5 Trial Well (TW)		**Well Depth**	90 m		**Datum Point**	Inner lip of casing
		5		**Well Diameter**	200 mm		**Height of Datum**	0.20m above ground level
Well Owner		Donegal County Council		**Pump Depth**			**Ground Elevation**	54.50 m OD
Location		Parkhill, Ballyshannon		**Aquifer**	Rkd		**Datum Elevation**	54.70 m OD
Grid ref.		189305 363633					**Weather**	Dry, sunny, cold.
6" Sheet No.		1735NE		**Discharge**			**Observer**	SML, CH.
Date	**Time**	**Elapsed Time**	**Water level below datum**	**Drawdown**	**Conductivity in BH5 (PW)**	**Conductivity in river**	**Temperature in BH5 (PW)**	**Temperature in river**
		Mins	**(m)**	**(m)**	**(uS/cm)**	**(uS/cm)**	**(oC)**	**(oC)**
15/2/2005	8.20.00	0.0	1.040	0.000		351		5.3
	8.26.00	0.0	1.040	0.000				
	8.26.30	0.5	1.300	0.260				
	8.27.00	1.0	1.355	0.315				
	8.27.30	1.5	1.395	0.355				
	8.28.00	2.0	1.420	0.380				
	8.28.30	2.5	1.440	0.400				
	8.29.00	3.0	1.470	0.430				
	8.29.00	3.5	1.485	0.445				
	8.30.00	4.0	1.490	0.450				
	8.30.30	4.5	1.500	0.460				
	8.31.00	5.0	1.510	0.470	632		10.0	
	8.31.30	5.5	1.520	0.480				
	8.32.00	6.0	1.525	0.485				
	8.32.30	6.5	1.530	0.490				
	8.33.00	7.0	1.535	0.495	628		10.9	
	8.33.30	7.5	1.540	0.500				
	8.34.00	8.0	1.540	0.500	626		11.0	
	8.34.30	8.5	1.545	0.505				
	8.35.00	9.0	1.550	0.510	633		11.0	
	8.35.30	9.5	1.550	0.510				

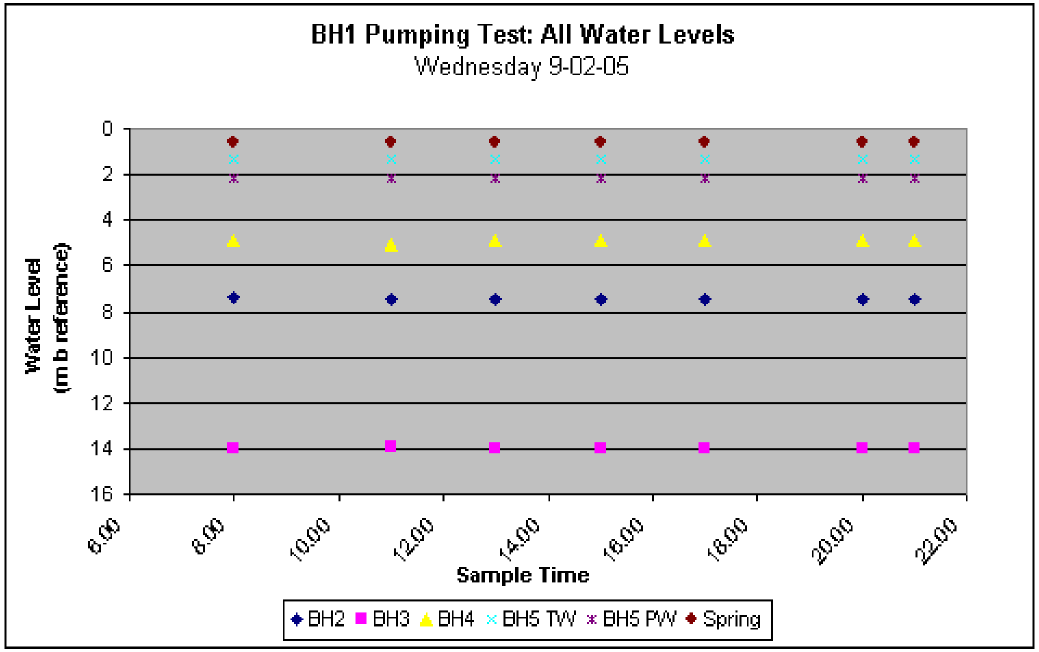
Date	Time	Elapsed Time Mins	Water level below datum (m)	Drawdown (m)	Conductivity in BH5 (PW) (uS/cm)	Conductivity in river (uS/cm)	Temperature in BH5 (PW) (oC)	Temperature in river (oC)
	8.36.00	10.0	1.555	0.515	634		11.0	
	8.37	11.0	1.565	0.525	635		11.0	
	8.38	12.0	1.565	0.525	636		11.0	
	8.39	13.0	1.570	0.530	638		11.0	
	8.40	14.0	1.575	0.535	638		11.0	
	8.41	15.0	1.575	0.535	638		11.0	
	8.42	16.0	1.585	0.545	639		111.0	
	8.43	17.0	1.585	0.545	639		11.0	
	8.44	18.0	1.590	0.550	640		11.0	
	8.45	19.0	1.595	0.555				
	8.46	20.0	1.595	0.555				
	8.47	21.0	1.595	0.555				
	8.48	22.0	1.600	0.560				
	8.49	23.0	1.600	0.560				
	8.50	24.0	1.600	0.560				
	8.51	25.0	1.605	0.565				
	8.52	26.0	1.605	0.565				
	8.53	27.0	1.605	0.565				
	8.54	28.0	1.610	0.570				
	8.55	29.0	1.610	0.570				
	8.56	30.0	1.610	0.570				
	8.58	32.0	1.615	0.575				
	9.00	34.0	1.620	0.580				
	9.02	36.0	1.620	0.580				
	9.04	38.0	1.620	0.580	672		10.6	
	9.06	40.0	1.625	0.585	666		10.9	
	9.08	42.0	1.625	0.585				
	9.10	44.0	1.630	0.590				
	9.12	46.0	1.630	0.590				
	9.14	48.0	1.630	0.590				
	9.16	50.0	1.635	0.595				

Date	Time	Elapsed Time Mins	Water level below datum (m)	Drawdown (m)	Conductivity in BH5 (PW) (uS/cm)	Conductivity in river (uS/cm)	Temperature in BH5 (PW) (oC)	Temperature in river (oC)
	9.21	55.0	1.640	0.600				
	9.26	60.0	1.640	0.600				
	9.36	70.0	1.650	0.610	670	417	10.9	6.5
	9.46	80.0	1.655	0.615				
	9.56	90.0	1.660	0.620				
	10.06	100.0	1.665	0.625				
	10.16	110.0	1.670	0.630				
	10.26	120.0	1.675	0.635	671	355	10.9	5.7
	10.41	135.0	1.680	0.640				
	10.56	150.0	1.690	0.650				
	11.11	165.0	1.690	0.650				
	11.26	180.0	1.700	0.660				
	11.41	195.0	1.700	0.660	674		10.8	6.0
	11.56	210.0	1.705	0.665				
	12.11	225.0	1.710	0.670				
	12.26	240.0	1.710	0.670		350		6.2
	12.56	270.0	1.720	0.680			10.8	6.3
	13.26	300.0	1.730	0.690	672	354	10.8	6.4
	13.56	330.0	1.735	0.695				
	14.26	360.0	1.740	0.700				
	14.56	390.0	1.750	0.710	669	353	10.8	6.6
	15.26	420.0	1.755	0.715				
	15.56	450.0	1.765	0.725				
	16.26	480.0	1.765	0.725	671	352	10.7	6.7
	17.26	540.0	1.775	0.735	670	349	10.7	6.6
	18.26	600.0	1.775	0.735	670	352	10.7	6.7
	19.26	660.0	1.795	0.755	669	353	10.7	6.7
	20.26	720.0	1.795	0.755	668	355	10.7	6.7

BH1 Pumping Test: Water Levels in Wells and Parkhill Spring.

	BH1 PW	BH1 TW	BH2	BH3	BH4	BH5 PW	BH5 TW	Spring
Static Water Level (m AOD)	52.43	52.44	54.1	58.12	56.34	53.24	53.4	54.65

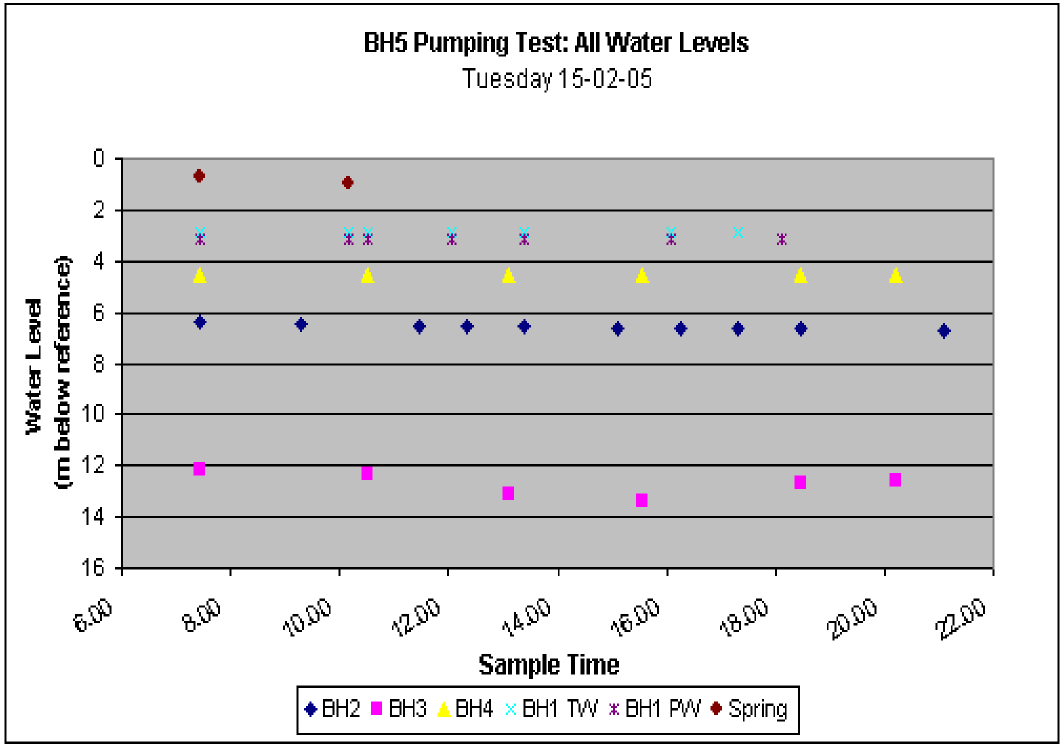
Sample Time (m below reference)	BH2	BH3	BH4	BH5 TW	BH5 PW	Spring
8.00	7.400	13.980	4.860	1.325	2.180	0.600
11.00	7.440	13.920	5.040	1.320	2.140	0.595
13.00	7.430	13.980	4.850	1.320	2.135	0.595
15.00	7.450	13.980	4.855	1.325	2.145	0.590
17.00	7.460	13.970	4.855	1.320	2.140	0.595
20.00	7.450	13.970	4.860	1.320	2.145	0.595
21.00	7.450	13.980	4.860	1.320	2.140	0.595



BH5 Pumping Test: Water Levels in Wells and Parkhill Spring.

	BH5 PW	BH5 TW	BH2	BH3	BH4	BH1 PW	BH1 TW	Spring
Static Water Level Level (m AOD)	53.58	53.69	55.11	59.91	56.64	52.61	52.6	54.54

(m below reference) Sample Time	BH2	BH3	BH4	BH1 PW	BH1 TW	Spring
7.45	6.39	12.19	4.53	3.14	2.88	0.71
9.30	6.47					
10.15				3.14	2.90	0.99
10.50		12.30	4.54	3.14	2.89	
11.45	6.55					
12.05				3.14	2.89	
12.35	6.57					
13.10		13.15	4.54			
13.40	6.59			3.16	2.90	
15.10	6.61					
15.55		13.34	4.55			
16.10				3.17	2.92	
16.25	6.64					
17.30	6.66				2.92	
18.10				3.17		
18.45	6.67	12.66	4.56			
20.20		12.56	4.56			
21.10	6.70					



Appendix B. Ballyshannon PWS: Aquifer Coefficients and Analytical Modelling.

Aquifer Coefficients

The general aquifer coefficients have been calculated from the pumping tests undertaken by the GSI (2005). The specific capacity (Sc) ranges from 312 $m^3/d/m$ (BH5) to 962 $m^3/d/m$ (BH1). 20-25 $m^3/d/m$. A transmissivity (T) of c.500 m^2/d was calculated from both sets of pumping test data. Permeability (K) is calculated by dividing the transmissivity by the saturated thickness of the aquifer, which in this case, is taken as the saturated depth of the boreholes (c.87 m). The resulting permeability (K) is in the region of 5.7 m/d. The velocity of water moving through this aquifer to the boreholes can be estimated from Darcy's Law:

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

The groundwater gradient is assumed to be in the region of 0.02. In the absence of further information, the effective porosity (n) is assumed to be 0.02 (2%), based on regional knowledge of similar permeability rocks. Thus the velocity is calculated to be in the order of 5.7 m/d. This is based on the permeability value for the *entire* depth of borehole. It is recognised however, that the permeability is likely to be significantly higher along the fracture/cavity zones, which may be more realistically reflected by the tracer test results.

Estimated Coefficients for the Ballyshannon Limestone Aquifer.

Parameter	*Source of data*	*Value*
Specific Capacities ($m^3/d/m$)	Local	312-962
Transmissivity (m^2/d)	Local	c.500
Permeability (m/d)	Local	5.6
Porosity	Assumed	0.02 (2%)
General velocity (m/d)	Local/Assumed	5.7

Analytical Modelling: Uniform Flow Equation

Using the above aquifer coefficients and an abstraction rate of 1125 m^3/d (750 m^3/d plus an additional 50% to account for summer water levels) for BH1, the up-gradient lateral extent of the area influenced by the boreholes' abstraction can be estimated using:

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

The pumping is estimated to pull water from c.30 m either side of BH1 at its up-gradient extent.

The down-gradient extent can estimated by using:

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

However, given the conceptual model for BH1, estimation of this distance is not required.