Ballymachugh Source

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County Cavan Groundwater Protection Scheme, Volume II: Water Quality Report and Source Protection Zones

County Cavan
Groundwater Protection Scheme

Volume II: Water Quality Report and Source Protection Zones

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10 Ballymachugh Source

10.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Ballymachugh Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Ballymachugh area.
- To assist Cavan 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 wells. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities within the framework of the county groundwater protection scheme. 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).

10.2 Methodology

10.2.1 Desk Study

Data on private groundwater wells in the area were taken from GSI archives. Existing water quality data were taken from the EPA raw water sampling programme. Geological and topographic maps were used, as described in Sections 10.3 and 10.4.

Borehole logs were obtained from the drilling contractors (Dunnes Water Services Ltd.). Abstraction and water level data were obtained from EPS Pumping & Treatment Systems who are contracted to operate and maintain the scheme. Further details and pumping test data were obtained from the K.T. Cullen Ltd (now White Young Green (Ireland)) report on the trial well drilling and testing (2000).

10.2.2 Site Visits and Field Work

Site visits and fieldwork to collect data for the Ballymachugh source protection consisted of:

- Meetings with County Council personnel and walkover surveys in January and May 2006.
- Depth to bedrock drilling programme in June 2006.
- Vulnerability mapping around the source in June and November 2006.
- Water level readings in April and June 2007.

10.2.3 Assessment

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

10.3 Location and Site Description

The Ballymachugh Group Water Scheme (GWS), which is also referred to as the Lavagh-Ballyheelin Supply, is located in the townland of Bracklagh, in south County Cavan, near the borders of Counties Longford and Westmeath. The source is located 2.4 km west of Lough Sheelin (Figure 10-1).

The supply consists of four boreholes located within a fenced site compound: two trial wells and two production wells. The layout of the site and boreholes is shown as Figure 10-2.

Figure 10-1: Ballymachugh Source Location, Topography and Hydrology

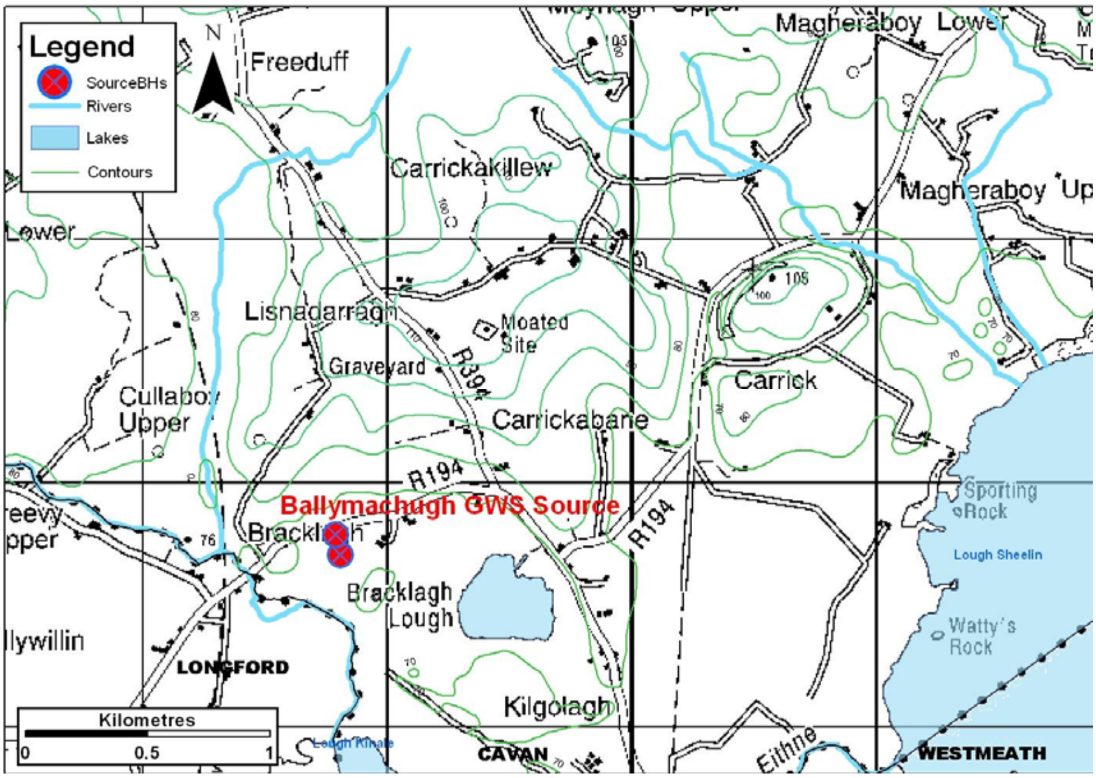
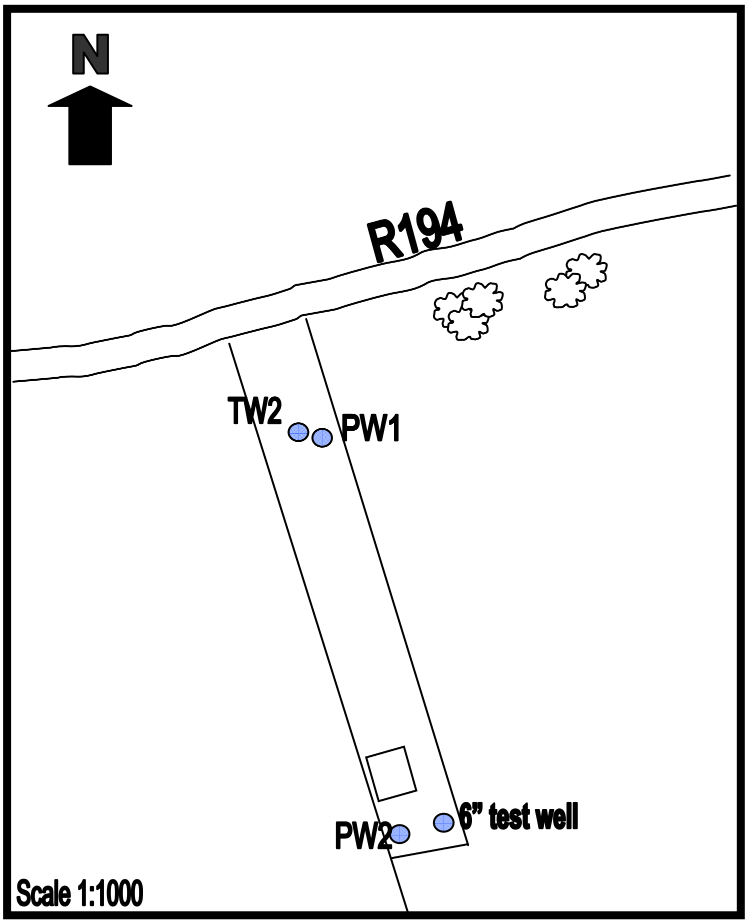


Figure 10-2: Ballymachugh Source Site Layout



Each borehole is located within its own concrete chamber outside the pump house. The pump house holds the electric housing and dosing equipment. The trial well was drilled in November/December 1999, and the production wells and '6" well' were subsequently drilled in December 2000/January 2001. A horizon of particularly broken rock at 30 m below ground level meant that screens could not be installed below this level, hence both of the production wells are open hole below 30 m.

Production boreholes PW1 and PW2 were tested at 2,182 m^3/day and 1,637 m^3/day respectively. An exploration borehole (LS54) that was drilled in 1979 near PW2 was recorded as being artesian (K.T. Cullen, 2000).

Table 10.1: Summary of Source Details

GSI no.	2327NWW211			
Grid ref. (1:25,000)	238734 282767			
Townland	Bracklagh (Clanmahon By)			
Source type	Two production boreholes (PW1 & PW2) & two standby (TW2 and 6" trial well)			
Borehole ID*	PW1	PW2	TW2	6" well
drill depth	131.0 m	132.6 m	128.0 m	45.7 m
drill diameter	telescopic to 200 mm	400 mm	200 mm	150 mm
casing diameter & depth	300mm to 29.3m depth	300mm to 29.3m depth	200mm to 12.2m depth	150mm to 9.4m depth
screen diameter & depth	250mm to 30m depth	250mm to 30m depth	No screen	No screen
Development date	2001			
Owner	Ballymachugh Group Water Scheme			
Elevation (ground level)	67.4 mAOD to 69.4 mAOD			
Depth to rock	7.5 m-12.2 m in vicinity of boreholes			
Static water level: mAOD (11/6/07)	~63.2	not known	~63.2	~63.1
Pumping water level: mAOD **(11/6/07)	~62.0	not known	~61.9	~60.9
Abstraction rate**	Typically 500 m^3/day (PW1 & PW2 tested at 2,182 m^3/day & 1,637 m^3/day respectively)			
Drawdown	10.03 m at TW2, during 1999 pump test			
Pumping test summary (TW2):				
(i) abstraction rate	1971m^3/day			
(ii) specific capacity	193 m^3/d/m			
(iii) transmissivity	200-400 m^2/day			

**Nomenclature used by the drilling contractors has been adopted for this report as their borehole logs are the only complete set.TW2 in this report was originally called TW1.*
*** The usual pumping rate as above has been increased to 860 m^3/day as of 6/6/07 to cope with leakages in the pipework system. This will be reduced down to 500 m^3/day when the leakages have been fixed.*

Abstraction typically alternates between production well 1 (PW1) and production well 2 (PW2) to normally provide between 400-500 m^3/day (pers comm. O&M contractors, based on a demand survey). However, the most recent water abstraction figure is 860 m^3/day to cope with increased demand due to pipe leakages (6/6/07). The additional abstraction has been provided by pumping TW2.

10.3.1 Topography and Surface Hydrology

The site is situated on the edge of a flat to gently undulating area (between 60 mAOD and 110 mAOD), to the west of Lough Sheelin. In the immediate vicinity of the boreholes, the elevations are 60-70 mAOD. The area has occasional drumlins. Elevations generally increase to the north, where the gradient is on the order of 1 in 21. The flatter area around the boreholes has a gradient typically less than 1 in 100 (refer to Figure 10-1).

In general, surface waters flow in a southeasterly direction to Lough Sheelin (2.4 km to the east of the source boreholes) and Lough Kinale (0.8 km to the south, Figure 10-1). The Mill River flows southeast to Lough Kinale, passing 300 m to the southwest of the boreholes. Nearby Bracklagh Lough lies in a topographic depression which is approximately 10 m lower than the GWS compound. Streams and drains flow into it, and artificial drains carry outflow to the Mill River. Lough Sheelin and Lough Kinale are linked by the Inny River.

The natural drainage density immediately around, and to the northwest of the site is low. Drainage density is higher around the low-lying land surrounding Bracklagh Lough, and between Loughs Sheelin and Kinale.

10.4 Geology

10.4.1 Introduction

This section briefly describes the geological setting and relevant characteristics of the geological materials that underlie the source area. It provides a framework for the conceptualisation of groundwater flow and, hence, the delineation of the source protection zones.

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

- Bedrock Geology 1:100,000 Map Series, Sheet 12, Longford-Roscommon (Morris *et al.*, 2003) Geological Survey of Ireland.
- Information from geological mapping in the nineteenth century (on record at the GSI).
- K.T. Cullen Report "Drilling and Testing of Trial Wells at Bracklagh, Co. Cavan, January 2000"
- EMD Public Files, Riofinex Graphical Logs.
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2004).

10.4.2 Bedrock Geology

The Ballymachugh Scheme boreholes are located in a fault-bounded area of Lower Carboniferous-age bedrock. Bedrock dips gently (3^{o}–5^{o}) to the southeast. The distribution of bedrock units is shown on Figure 10-3. The base of the Ballysteen Limestone rock unit (shales at the base of this impure limestone) underlies the source area, beneath which the Moathill and Meath rock units occur. These rocks in turn overlie the older Ordovician and Silurian rocks (the Slieve Glah and Lough Avaghon rock units) at depth (K.T. Cullen borehole logs, 2000).

In the Ballymachugh area, the Meath rock unit is reported to consist of 41 m of "fine-grained lime mudstone with thin horizons of … calcareous quartzitic sandstone" (Morris *et al.*, 2003). The latter horizons would be expected to be particularly water-bearing. The detailed log from exploration hole LS54 also identifies the mineral pyrite throughout this rock unit. The lithologies of each of these bedrock units is described in more detail in Chapter 2 of Volume I.

Interpretation of the drilling contractor's log indicates that all three Carboniferous rock units are water-bearing, but that significantly greater inflows occurred near the base of TW2, coinciding with the description of the Meath rock unit. Table 10.2 outlines the series of rock units encountered in TW2 at the site.

(See Appendix III for borehole logs in the vicinity of this source. Note that the borehole referenced as TW2 in this text is called 'TW1' on the borehole log in the Appendix. The discrepancy in nomenclature has arisen prior to this report; this report has adopted that used by the drilling contractors, as their borehole logs are the only complete set .)

Figure 10-3: Bedrock Geology in the Vicinity of Ballymachugh Source

See Figure 10-7 for cross-section following line of section shown (A-B-C).

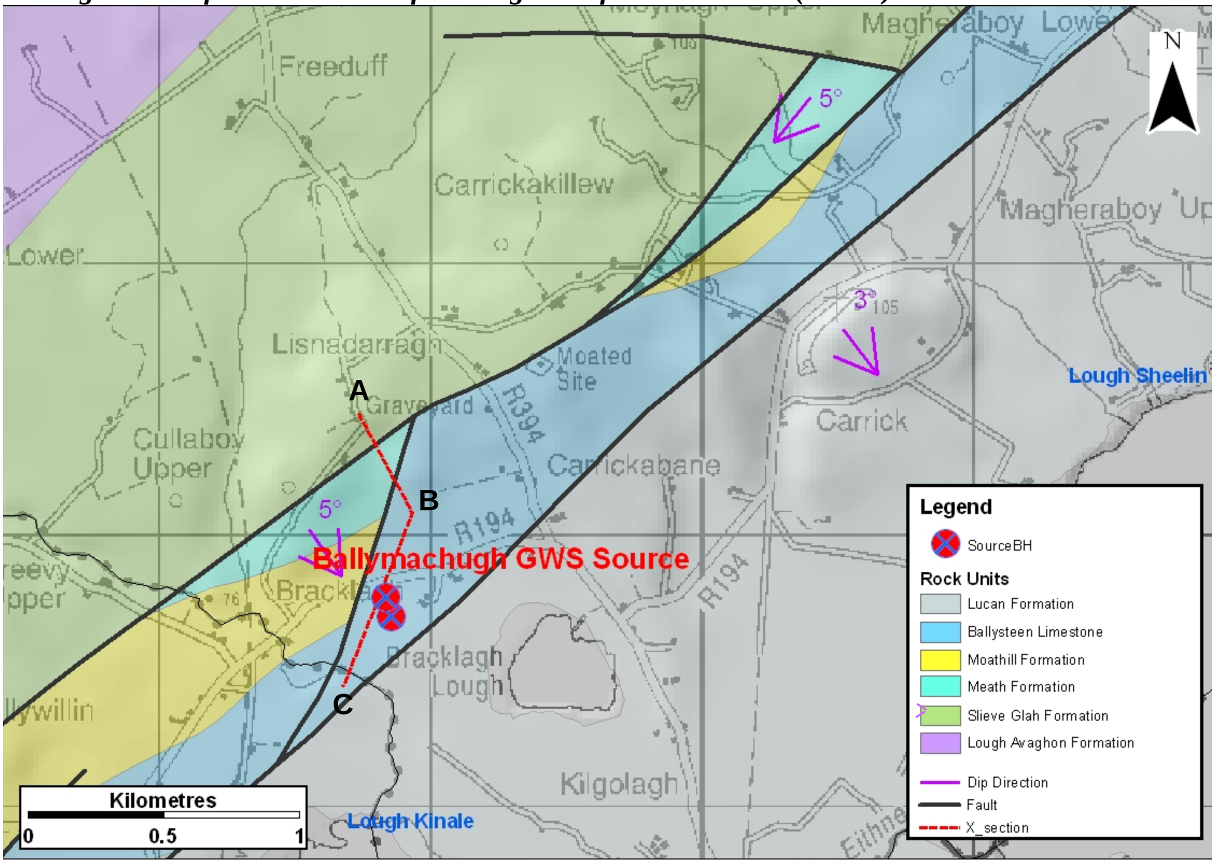


Table 10.2: Rock units and descriptions recorded in the TW2 borehole log

Interpreted Stratigraphy at Ballymachugh	Thickness encountered (m)	TW2 Log Description
Overburden	12.2	
Ballysteen Limestone (Base)	33.5	Dark grey shale
Moathill Formation (Rockfield Sandstone member)	21.3	Pale grey sandstone
Meath Formation	41.1	Medium grey over dark grey fine-grained siltstone with dolomite and quartzite at base.
Ordovician & Silurian	19.8	Red and green mudstone & greywacke

Structurally, the Ballymachugh boreholes lie between two NE-SW faults. The faulting juxtaposes a thin NE-SW zone of Ballysteen Limestone against older Silurian bedrock on the northwest side, and against the younger Lucan rock unit on the southeast side (Figure 10-3). To the west of the site, a NNE-SSW trending fault has laterally displaced the Meath and Moathill rock units. According to Dunphy (2004), NE–SW trending faults are generally less productive in terms of groundwater. The cross cutting NNE-SSW fault is likely to have occurred under a compressional setting as found elsewhere in Ireland (Dunphy, 2004 and Ashton *et al*., 2003). Therefore the fault adjacent to the Ballymachugh site is most likely to be a closed fault, that allows little groundwater to flow across it.

Drilling records indicate that small offshoot fractures related to the larger surrounding faults were encountered during the drilling of the two production wells. These include:

- Weathered bedrock from base of subsoil to 30 m b.g.l. in PW1.
- Broken rock and clay encountered from 18 to 67 m b.g.l. in PW1, with significant additional inflows at 50, 80 and 90 m b.g.l., where estimated initial inflows increased from c. 700 m^3/d to 1,000 m^3/d, 1,800 m^3/d and then 2,300 m^3/d.
- Very weathered bedrock from 13.5 to 32 m b.g.l. in PW2, particularly from 18 m.
- In PW2, broken rock and notable water entry from 26 m b.g.l. (initial flow estimate of c. 550 m^3/d at total borehole depth 42 m), with significant further inflows between 81 and 93 m b.g.l., with a driller's total yield estimate of c. 1,600 m^3/d.

10.4.3 Subsoil

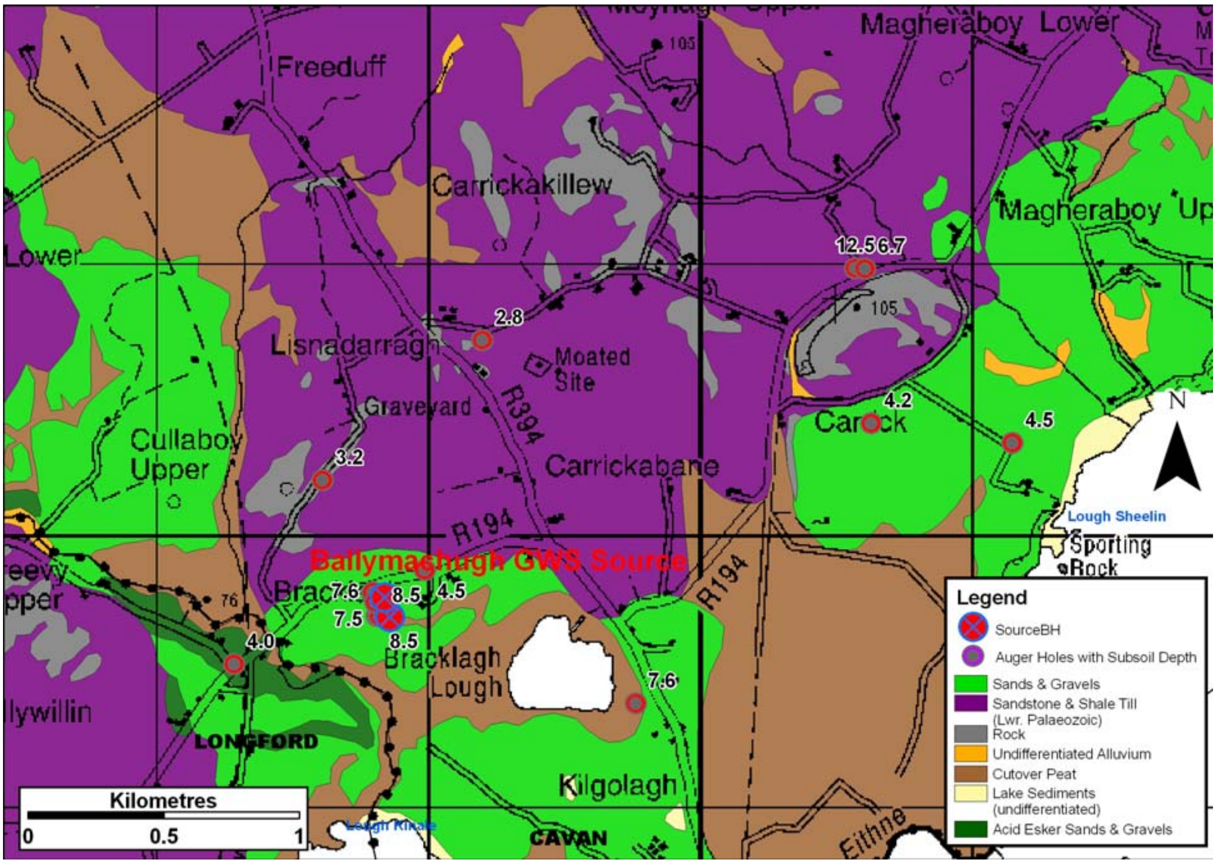
The Ballymachugh site is located in a small area (c. 0.3 km^2) recorded as sand and gravel derived from sandstone and shale (Figure 10-4). Similar areas occur in patches on the west and northwest side of Lough Sheelin (Meehan, 2004). The mapped sand and gravel extends at least 150 m from the two production boreholes. The four wells drilled on the supply source site found 'gravels with clay' in the overburden (drilling contractor's description). Samples from a GSI auger hole on the site, and one 200 m from the site, indicate that the subsoil is gravel-dominated (55-57% of the total sample being sub-rounded gravels). However, they are not extensive enough to be considered as an aquifer in their own right.

Sandstone and shale till (Lower Palaeozoic) is mapped on the slightly elevated area directly north of the site. The tills in this part of Cavan comprise a mixture of low (CLAY or SILT/CLAY BS5930 descriptions) and moderate (SILT/CLAY BS5930 description) permeability areas. Two auger holes in the tills on the elevated area to the north of the site describe the subsoils as "very gravelly SAND" and "gravelly, sandy SILT/CLAY" according to BS5930.

Bracklagh Lough, approximately 350 m southeast of the site, is more low-lying than the gravels discussed above, such that an area of peat has developed around the lake. Similar patches of peat are found in depressions between drumlins to the northwest of the Ballymachugh area.

Subsoil geology is described in more detail in Chapter 3 of Volume I.

Figure 10-4: Subsoil Geology in the Vicinity of Ballymachugh Source



10.5 Groundwater Vulnerability

10.5.1 Introduction

The concept of vulnerability is discussed in detail in Chapter 5 of Volume I. Groundwater vulnerability is dictated by the nature and thickness of the material overlying the aquifer. The subsoils described above provide protection for the underlying bedrock aquifers in the area of the Ballymachugh source.

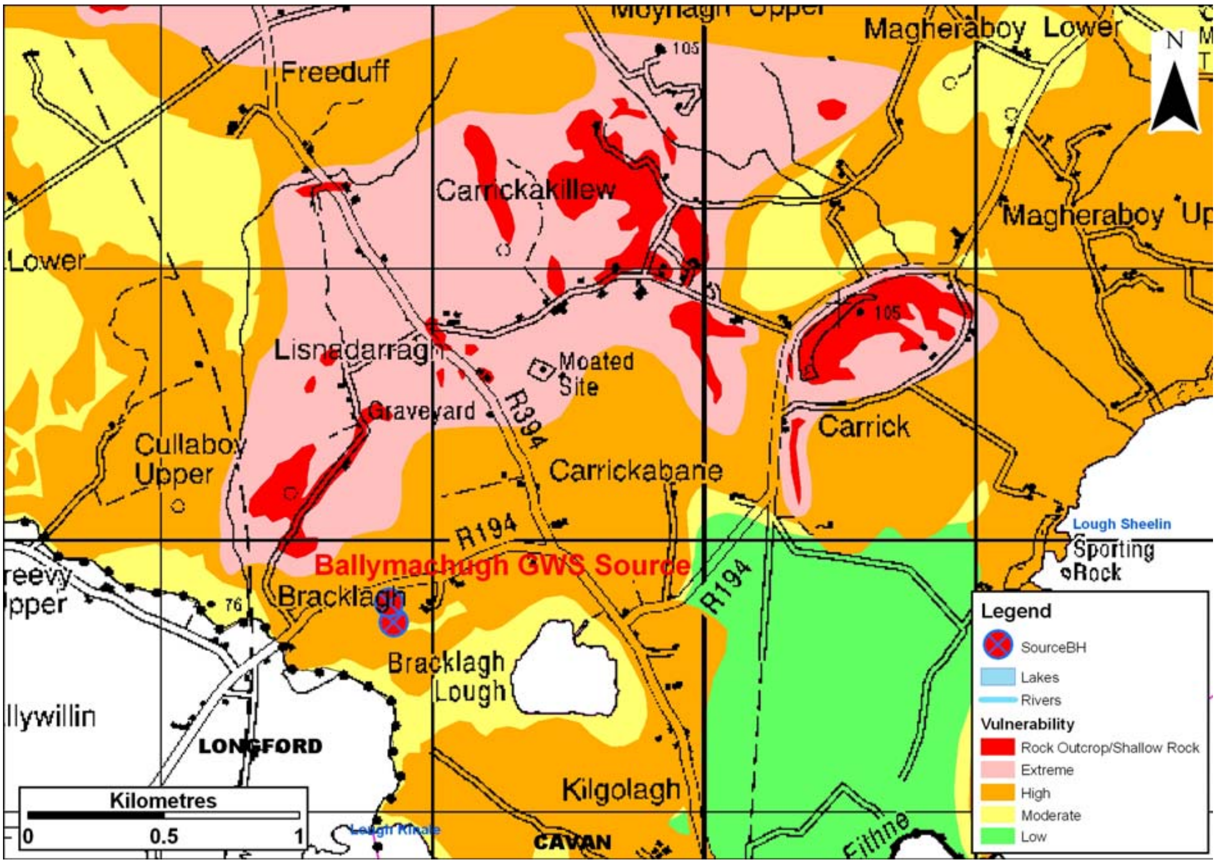
Subsoil thickness over the supply source site varies from 7.6 m in the north to 8.5 m in the south, according to the driller's logs for the production boreholes, and GSI augering. (The trial well logs indicate thicknesses of 12.2 m; this may include some weathered bedrock.) Generally, the gravels in the area around Lough Sheelin have varying proportions of silt. Overall, the gravels are considered to be 'high' permeability. The area of sands and gravels around the Ballymachugh production boreholes is therefore categorised as high vulnerability.

Drilling on the elevated areas revealed tills that are typically between 1 m and 4 m in thickness. Two auger holes in the tills on the elevated area to the north of the site describe the subsoils as "very gravelly SAND" and "gravelly, sandy SILT/CLAY" according to BS5930. Both are categorised as having a 'moderate' permeability and therefore a high vulnerability where thicknesses are between 3 m and 10 m.

In the elevated area north of the source, the bedrock has been mapped as close to the surface (Meehan, 2004). In such locations, the degree of protection by subsoils of the bedrock aquifer is limited by the thin subsoil cover. Vulnerability is therefore classified as extreme.

The low permeability cutover peat to the south and southeast of the site is recorded to be 7.6 m thick in a mineral exploration borehole (LS54, see Appendix III), which results in a moderate vulnerability classification. The vulnerability for the area of interest is shown in Figure 10-5.

Figure 10-5: Groundwater Vulnerability in the Vicinity of Ballymachugh Source



10.6 Hydrogeology

10.6.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the source, which is based on the available data. Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- GSI files and archival Cavan County Council data.
- Site walkovers in January and May 2006, and water level measurements in June 2007.
- Drilling programme carried out by the GSI to ascertain depth to bedrock and subsoil permeability.
- K.T. Cullen Report on Drilling & Testing of Trial Wells at Bracklagh for the GWS, 2000.
- Drilling Logs (Dunnes Drilling Services Ltd).
- Environmental Protection Agency water quality data (1996-2005).
- Cavan County Council treated drinking water samples for 2002 to 2006.

10.6.2 Aquifer Setting

The Ballymachugh source is located in the Ballysteen Limestone bedrock aquifer, overlying the Moathill and Meath rock units which have also been encountered at depth in the source wells. All three rock units are classed as **Locally Important Aquifers which are Moderately productive only**

in Local Zones (Ll). The area is located within the Inny groundwater body, which also includes Silurian Metasediments and Volcanics (a poorly productive aquifer, productive only in local zones, **Pl**).

10.6.3 Rainfall, Evaporation and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. Recharge is generally estimated on an annual basis, and is assumed to consist of an input (i.e. annual rainfall) less water losses (i.e. annual evapotranspiration and runoff). The estimation of recharge is critical in source protection delineation as, in combination with abstractions and overflows at the source, it largely dictates the size of the zone of contribution. The calculation of recharge is as follows:

- *Average annual rainfall:* **1004 mm**
  Rainfall figures have been taken from the average annual rainfall (1971-2004; Met Éireann, 2004) at Granard Springstown Station, approximately 2 km south of the site in County Westmeath.

- *Average annual evapotranspiration losses:* **436 mm**.
  Potential evapotranspiration (P.E.) data are taken from Ballinamore synoptic station (1971-2000, Met Éireann, 2006). Examination of the 1971-2000 contours for actual evaporation across Ireland shows that Ballinamore is the most representative station for Ballymachugh.

- *Average annual effective rainfall:* **581 mm**
  This figure is derived by subtracting estimated monthly evapotranspiration losses from average monthly rainfall (which accounts for months when evaporation losses exceed rainfall – May, June and July). It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.

- *Estimated actual recharge:* **300 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, 2004). Groundwater recharge based on the subsoil characteristics alone would be c. 400 mm/yr. However, a recharge cap is applied to certain aquifers to account for the limited storage capacity in poor and locally important aquifers with limited productivity.

  The maximum recharge for Ll aquifers is in the range of 150-200 mm/yr and for Pl or Pu aquifers is taken as 100 mm/yr (WFD, GW5, 2005). However, the fractured nature of the bedrock in this particular location, together with the gravel subsoils overlying the source, is expected to increase the storage capacity (refer to Section 10.4). Thus, an adjusted recharge cap of 300 mm has been applied. The higher recharge rate is supported by the relatively low surface water drainage density over the area of interest.

These calculations are summarised as follows:

Average annual rainfall (R)	*1004 mm*
Potential Evaporation	*436 mm*
Potential Recharge (summed monthly R – monthly P.E.)	*581 mm*
Overall Recharge Coefficient	*n/a, recharge cap applied*
Estimated Actual Recharge	***300 mm***

10.6.4 Groundwater Levels

A static water level of 0.6 m b.g.l. was recorded at TW2 in December 1999. More recent static water levels could not be obtained due to the requirement for continuous pumping at the source. However, following a 30 minute cessation of pumping at TW2 on 11th June 2007, the water level was measured at 63.2 mAOD, which corresponds to approximately 6 m b.g.l. The water level measured in the adjacent PW1 borehole was the same, and was approximately 20 cm lower in the 6" trial well. It is expected that a large proportion of groundwater level recovery would occur within the first 30 minutes of pumping cessation (66% recovery occurred during the first 30 minutes following the 1999 pumping test), yet the water level in 2007 is notably lower than in 1999, despite allowances for seasonal fluctuation of the piezometric level.

The water level in three of the boreholes on the site indicates that the water table is in the overlying subsoils and was close to the ground surface in 1999. The exploration borehole LS54, which is in the vicinity of PW2, was recorded as artesian when drilled in 1979. However, there is no evidence of a low permeability layer between the gravels and the bedrock (K.T. Cullen 2000). Given the depths of recorded fractures, it is possible that some or all of these are relatively isolated water-bearing fractures, and that they are acting as 'confined', which would explain their chemistry (see Section 10.6.6 below) and their artesian nature. Further investigations would be required in order to determine the extent and reason for any confinement.

The gravels are considered to be water bearing (although the proportion of fine-grained material they contain, and their size, means they are not classified as an aquifer), and to be in hydraulic continuity with the bedrock aquifer, i.e. unconfined in the vicinity of the site. Based on the limited information on static water levels, the piezometric head of the bedrock aquifer is c. 6 m above the top of the bedrock. The drawdown during the 1999 pumping test was 10.3 m, which brought the water level to below the bedrock-subsoil interface in the immediate vicinity of the pumping well.

10.6.5 Groundwater Flow Directions and Gradients

The boreholes are located near to a general area of 'groundwater discharge' into the nearby Loughs: Bracklagh Lough in the first instance, and then Lough Kinale and Lough Sheelin, which are all to the southeast and east of the site. The streams and lakes surrounding the site, and local variations in topography, form natural boundaries to groundwater flow to the supply source.

The water-bearing fractures recorded in the borehole logs are likely to be associated with the two NE-SW trending faults located to the north and south of the boreholes, especially given their close proximity to each other (c.400-700m apart, see Figure 10-3).

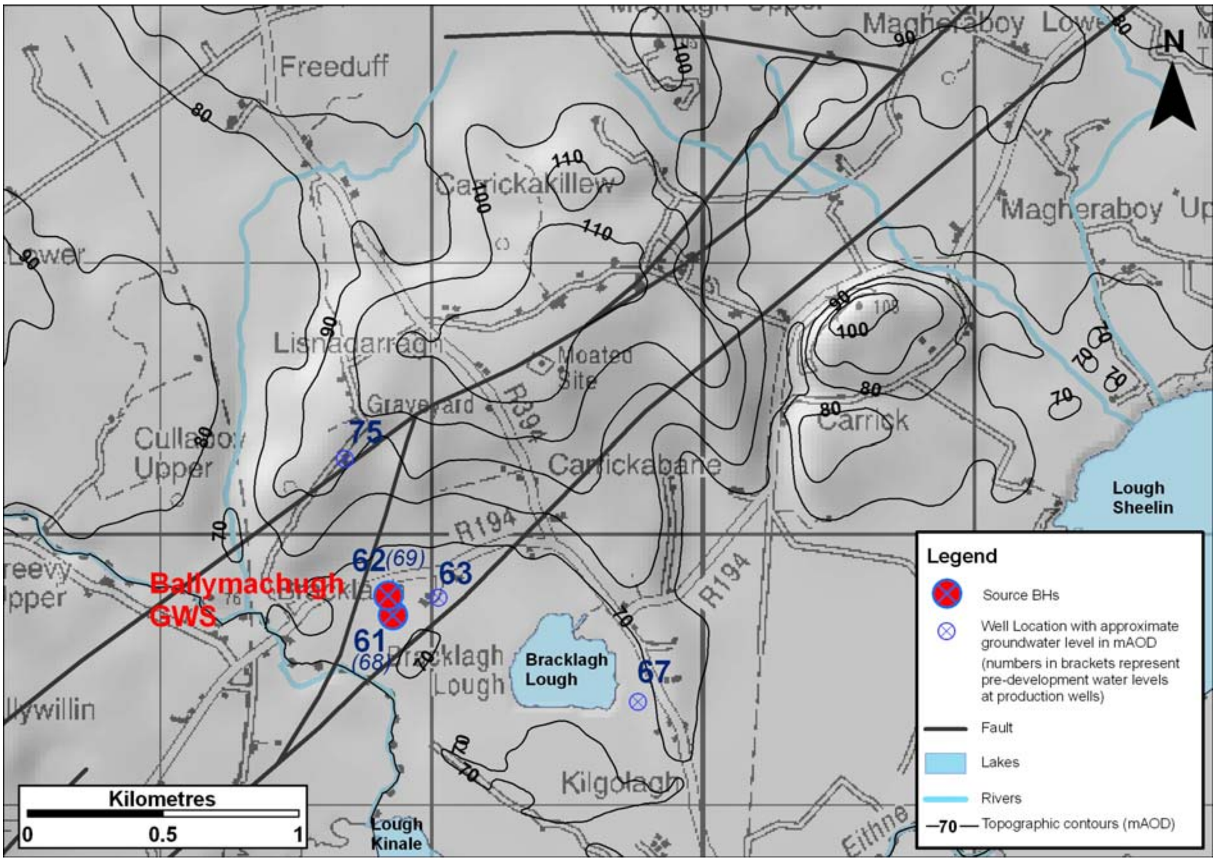
As such, it is likely that groundwater is being generally 'funnelled' in a southwesterly direction to the boreholes along this more productive, relatively narrow fractured zone from the elevated north-eastern area. This zone corresponds to the area of Ballysteen Limestone mapped around and northeast of the boreholes (Figure 10-3). The 'funnelling' will be most pronounced in the north of this zone, since the area to the north of the northern-most fault is underlain by poorly permeable Silurian age rocks, which will transmit only small volumes of groundwater.

Due to limited data, groundwater gradients in the bedrock are difficult to calculate. However, a water level was available in a well located c. 500 m upgradient of the boreholes (the 'Reynolds well'). The gradient between the Reynolds well and the boreholes is in the order of 1 in 40, or 0.02.

Groundwater flow directions in the small gravel deposits overlying the site will reflect the local topography. Due to their high permeability, groundwater gradients in these deposits will be low.

The time-drawdown graph for the TW2 pumping test indicates that a 'barrier boundary', or impediment to groundwater flow, is reached after 80 minutes of pumping. Using the aquifer parameters derived from the pumping test (discussed in Section 10.6.7, below), a distance to the barrier of 50 m is indicated. The available geological information indicates that the barrier is the NNE-SSW trending fault, which is mapped as occurring c. 55 m west of the boreholes. The likely "no-flow" characteristic of this fault is also supported by the likely compressional nature of this fault (Section 10.4).

Figure 10-6: Natural (non-pumping) Groundwater Levels in the Vicinity of Ballymachugh Source



10.6.6 Hydrochemistry and Water Quality

A raw water sample was taken from TW2 at the end of the 70 hour pumping test in 1999, and a further sample was taken from the production wells after the group water scheme was established (16th May 2003). The results, which are given in Appendix IV and summarised in Table 10.3, are discussed below.

Table 10.3: Ballymachugh GWS Chemistry

Parameters		**TW1 result**	**Production BHs**	**EC Drinking Water Regs (2000)***
Sample date:	**Unit**	**9/12/99**	**16/5/03**	
pH	pH units	7.8	7.6	n/a
Colour	Hazen	<5	5 (apparent)	20
Conductivity	µS/cm	645 @20^{o}C	722 @25^{o}C	2500
Total Hardness	$CaCO_3$ mg/l	361	366	n/a
Total Alkalinity	$CaCO_3$ mg/l	218	217	n/a
Bicarbonate	HCO_3 mg/l	266	217	n/a
Calcium	mg/l	110	not measured	n/a
Magnesium	mg/l	21	11.07	50
Sodium	mg/l	16	8.96	200
Potassium	mg/l	2.8	2.307	n/a
Iron (dissolved)	mg/l	0.17	<0.002	n/a (total MAC is 0.2)
Manganese	mg/l	*0.05*	0.0119	0.05
Copper	mg/l	<0.01	<0.0028	2
Aluminium	mg/l	<0.05	<0.0066	0.2
Nitrate	mg/l	5.2	1.02	50
Nitrite	mg/l	0.02	0.015	0.5
Chloride	mg/l	15	15	250
Sulphate	mg/l	161	164	250
Total Ammonium	N mg/l	<0.05	0.06	0.3
Non-purgeable org C	C mg/l	0.60	10 (TOC)	No abnormal change
Plate Count (22^{o}C)	T.C.C./ml	122	320	n/a
Plate Count (37^{o}C)	T.C.C./ml	Nil	<1	n/a
Coliforms	count/100ml	Nil	3	0
E. Coli	count/100ml	Nil	3	0
Faecal Strep	count/100ml	Nil	not measured	n/a
Clostridia	count/ml	not measured	0	0
Solids (Total Dissolved)	mg/l	not measured	442	n/a

*S.I. No. 439 of 2000, European Communities (Drinking Water) Regulations, 2000
Italicised text indicates exceedances of the EC Drinking Water Regs (2000).

The following key points have been identified, primarily from the two full water sample results available:

- Analysis of five samples indicates a 'very hard' (>350 mg/l $CaCO_3$) water, with a calcium-bicarbonate hydrochemical signature, which is typical of most Irish groundwaters in limestone areas.
- Both the nitrate and nitrite levels are low. However, high nitrate levels have been found in the limestone aquifers around Lough Sheelin, both recently and as far back as 1981 (An Foras Forbartha, VII). Low nitrate concentrations may indicate low loadings in the source zone of contribution, or may reflect denitrification in the deeper fracture network.
- Bacterial contamination was found in the more recent sample, although not at significant levels. The organic carbon content was correspondingly higher in the 2003 sample compared to the 1999 sample. The sustained presence of bacterial contamination over a period of regular monitoring would be a concern. However, regular raw water samples for the source are not available.

- The potassium:sodium ratio is below 0.4. A value above this is indicative of contamination from an organic source. However, a value below 0.4 does not guarantee that contamination from an organic source is not occurring.
- The sulphate concentration is above average, which may arise as a result of dissolution of pyrite that was identified in the logs of the Meath rock unit. It could also be sourced from gypsum, which occurs in the Meath rock unit elsewhere in the country, although it was not specifically identified in the site boreholes.
- The manganese concentration reached the drinking water limit on one occasion. Elevated manganese and iron concentrations are common in impure limestones, such as the rock units making up the bedrock aquifer around the source.

10.6.7 Aquifer Parameters

The main aquifer parameters of significance for source protection zone delineation are permeability and porosity. Together with groundwater gradients, these parameters are used to estimate the extent of the inner source protection area in Section 10.7.3.

Aquifer parameters for this source are derived from analysis of a pumping test undertaken by K.T. Cullen (2000). Trial Well TW2 (refer to site plan, Figure 10-2) was pumped at an average rate of 1,918 m^3/day for 70 hours. A maximum drawdown of 10.3 m was reached at the end of the test, although steady state was not achieved as a result of 'barrier boundary effects', which occurred after approximately 80 minutes of pumping (see time-drawdown plots in Appendix V).

In order to estimate the transmissivity, and therefore the permeability of the aquifer, three analytical methods were applied to the pumping test data in Aquifer Win32 (Table 10.4). The transmissivity value of 200 m^2/day from Theis *recovery* data analyses is thought to be more representative of the aquifer around the source. However, the higher value calculated from the *pumping* phase of the data is more likely to reflect the transmissivity due to induced flow in the open fractures, which would represent what is likely to be actually occurring. This value would also provide larger, and therefore more conservative, protection zones. As such, the highest estimated transmissivity is used: 400 m^2/day.

Table 10.4: Estimated Transmissivity Values for the Ballymachugh Source

Analytical Method	Transmissivity Value (m^2/day)
Cooper-Jacob drawdown in AquiferWin	400
Theis drawdown in Aquifer Win (1)	260
Theis drawdown in Aquifer Win (2)	330
Theis recovery in Aquifer Win	200

The bulk aquifer permeability is estimated by dividing the transmissivity by the effective thickness of the aquifer. The aquifer effective thickness is considered to comprise the interval of fractured aquifer that is indicated by the driller's logs as likely to be transmitting the majority of the groundwater to the boreholes. In the vicinity of the boreholes, the highest volumes of groundwater inflow occur at depths greater than 50 m b.g.l. Although the groundwater inflows generally occur in discrete intervals along the borehole, a value of c. 65 m is taken for the aquifer effective thickness, since the fractures intersecting the borehole are connected to a larger fracture network in the wider aquifer. Applying this value gives a median bulk permeability value of 4 m/day. This value is chosen since it is considered to be representative of the shallower groundwater flow system which will be more vulnerable to contamination than the deeper flow system (although comprising highly fractured and permeable rocks, the upper part of the bedrock aquifer is not as transmissive as the fracture system deeper in the aquifer). A balance is therefore struck between the need for adequate, but not overly-restrictive, groundwater protection.

A porosity of 0.02 is assumed as being applicable to this aquifer, which is at the higher end of the range used by the GSI for bedrock aquifers (0.01 to 0.025). This value reflects a combination of the higher porosities typically found in the Meath and Moathill bedrock units, and the high degree of fracturing recorded in the borehole logs.

The change in gradient of the time-drawdown curve at about 80 minutes into the pumping test indicates that a barrier to groundwater was reached during the test. An estimate of the distance to the barrier can be made using a rearrangement of the Cooper-Jacob equation. Using the values outlined above (i.e. transmissivity 400 m^2/d; Storativity (effective porosity in the unconfined aquifer) 0.02; time 80 minutes), a distance of 50 m to the barrier is estimated. This value agrees very closely with the distance from TW2 to the mapped fault (55 m), and is supported by Dunphy's (2004) results, which indicate that NE-SW faults tend to be closed due to compressional forces acting upon them.

10.6.8 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, flow and discharge patterns across the aquifer contributing groundwater to the source. It represents a summary of the main inferences drawn in previous sections, and provides a foundation upon which the quantitative analyses required for delineating source protection areas can be drawn.

The conceptual model is based on available data in relation to the source and in the vicinity of the source, and is as follows:

- The Ballymachugh Group Water Scheme abstracts water from the Meath (siltstones), Moathill (sandstones) and Ballysteen (lower impure limestone) bedrock units. All three bedrock units are classified as **Locally Important Aquifers which are Moderately Productive only in Local Zones (Ll)**.
- The source principally draws water from these Ll aquifers. A small volume of groundwater is likely to be contributed from the Silurian Metasediments and Volcanics, which underlie the elevated area north of the site. These rocks are classified as a **Poor Aquifer which is Generally Unproductive except for Local Zones (Pl)**.
- Around the boreholes, significant fracturing is noted in the top 20 m or so of bedrock, and at various specific depths, particularly below 50 m b.g.l. Groundwater inflows occur from all three Carboniferous-age rock units (i.e. the Ballysteen, Moathill and Meath rock units). The largest inflows occur towards the bottom of the boreholes, and are associated with the Meath rock unit.
- Groundwater flow through, and storage in, the aquifer is in the secondary porosity, developed as fracture openings throughout the Carboniferous bedrock units and as dissolution features (in the Meath rock unit).
- Groundwater gradients in the limestone are estimated at 0.02 (1 in 50), becoming steeper closer to the pumping well. Groundwater gradients in the Silurian bedrock aquifer are likely to be higher. Overall, the water table will be a subdued reflection of topography.
- Groundwater flow to the wells is considered to be primarily from the elevated area in the north-east, along the zone bounded by the two NE-SW trending faults (i.e. the groundwater flow direction is south-westerly). The body of rock between these faults is considered likely to be considerably fractured, due to the proximity of the major faults.
- Pumping test results indicate that the NNE–SSW trending fault immediately west of the boreholes is a barrier to groundwater flow. This is supported by the understanding from regional studies that this is a compressional fault.
- However, shallow groundwater flow is interpreted to be able to cross the fault zone in the weathered, broken zone at the top of the bedrock aquifer, with the groundwater flow direction

controlled by topography – i.e. in a north-northwest to south-southeast direction, towards the boreholes.

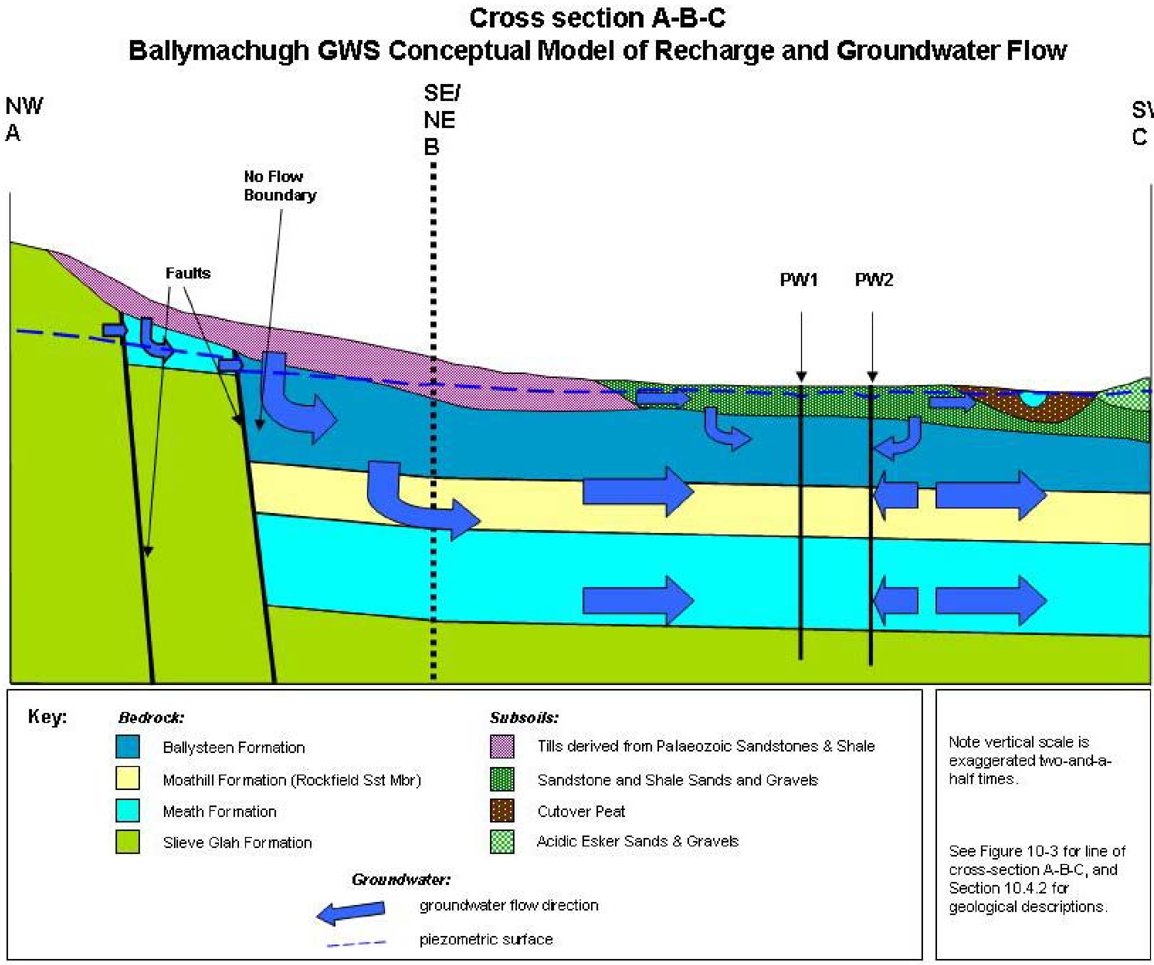
- Thus, the fault nearest to the boreholes is interpreted to be a barrier to groundwater flow at depths greater than about 30m, but to allow groundwater to flow across it in the upper, very weathered and fractured zone. This groundwater cannot flow directly into the borehole over the extent of this weathered zone, as the boreholes are cased-off to about 30 m b.g.l.
- The gravels overlying the area in the immediate vicinity of the boreholes are interpreted to be hydraulically connected to the underlying bedrock aquifer, and therefore provide additional groundwater storage. They also create a pathway for groundwater to flow towards the abstraction wells across the fault zone situated to the west of the supply boreholes.
- Localised flow in the overlying gravels is expected to be mainly influenced by topography and, therefore, is expected to be in a north-northwest to south-southeast direction, towards the boreholes.
- The GWS site is located near to a general area of 'groundwater discharge' into the Loughs: Bracklagh Lough in the first instance, and then Lough Kinale and Lough Sheelin, which are all to the southeast and east of the site.
- There is some evidence of artesian conditions in this area, although there are not enough data to determine the nature and extent of the confining unit.
- Recharge to the aquifer in the Ballymachugh source area is expected to be diffuse via rainfall percolating through subsoils. Percolating rainwater will then collect in interconnected bedrock faults and fractures in the aquifer. Groundwater recharge is estimated as 300 mm/yr.
- Groundwater vulnerability in the area around and upgradient of the source is mainly "extreme" or "high".
- Nitrate concentrations at the source are relatively low and may indicate low nitrate loadings. It may reflect denitrification associated with confinement in parts of the aquifer or the presence of pyrite that is known, as in other areas of the country, to create reducing conditions.
- Sulphate concentrations are relatively high. The origin of the sulphates is unknown; they may originate from the oxidation of pyrite in the impure limestone horizons within the aquifer, or from the dissolution of gypsum, which is known elsewhere in these rock types although not identified in the borehole logs.

Based on the information above, a schematic depiction of the groundwater flow to the source is shown in Figure 10-7. The conceptual model is based on the data that were available at the time of writing this report. The data limitations constraining the development of the conceptual model include:

- The groundwater gradient to the source, which has been estimated based on topography and limited water level values. No seasonal water level data are available.
- The aquifer chemistry, which is based on only three available samples – two taken when the source was established, and one in 2003.
- The lack of information regarding the possibly artesian nature of the exploration borehole LS54, which appears to be supported by the low nitrate levels in TW2.
- The degree to which groundwater flow occurs across the fault zone closest (55 m west) of the boreholes.

Figure 10-7: Schematic Conceptual Model of Groundwater Flow at Ballymachugh Source

See Figure 10-3 for location of cross-section.



10.7 Delineation of Source Protection Areas

10.7.1 Introduction

This section delineates the area around the boreholes that is believed to contribute groundwater to the supply at the abstraction rate of 1000 m^3/day[6], and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 10.6.5 and 10.6.8.

Two source protection areas are delineated:

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

10.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), and is defined as the area required to support an abstraction from long-term

[6] The abstraction value used for the SI and SO calculations is taken as an average of the typical demand (500 m^3/day) and the present demand (860 m^3/day) and also includes a 50% margin or error to account for drier (summer) periods or slight increases in abstraction.

recharge. The ZOC is controlled primarily by (a) the groundwater flow direction and gradient, (b) the aquifer permeability and (c) the recharge in the area. The ZOC was delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation.

The general concept guiding the delineation of the ZOC is that groundwater is principally being 'funnelled' from the northeast along the fractured zone between the two NE-SW trending faults up-gradient of the boreholes. In delineating the ZOC, the following have been taken into account: (i) local topographic divides, (ii) probable groundwater flow from the Pl aquifers to the north of the site, (iii) shallow groundwater flow directions in gravel subsoils, (iv) fault zone behaviour as a function of depth – as barrier or conduit for flow. Thus the boundaries delineated and their potential issues are as follows:

- **North and north-western boundary:** This boundary is constrained by the local topographic watershed on the elevated area immediately to the north of the site, which is expected to coincide with a local groundwater divide. It is assumed that rainfall occurring on the area to the northwest of the NE-SW trending fault will either a) runoff downhill towards, and recharge, the more permeable Ll aquifer, or b) infiltrate into the more permeable upper fractured zone of the Pl aquifer and flow down-gradient into the Ll aquifer. Recharge to these aquifers, even if it is just into the top of the rock, is also suggested by the lack of surface drainage.
- **Western boundary:** The NNE-SSW trending fault just west of the boreholes is interpreted as a barrier to groundwater flow below the very fractured upper part of the aquifer. However, the western ZOC boundary extends beyond this to include (i) the local gravels that are deposited uphill of the boreholes and which lie across this fault, as these deposits are expected to provide storage and flow to the production boreholes and (ii) the natural catchment of the groundwater flow in the very fractured zone at the top of the aquifer. The actual boundary corresponds to the local topographic divide in this area, as groundwater in the gravels and fractured bedrock on the other side of this topographic divide is expected to flow towards the Mill River.
- **North-eastern boundary:** Based on the conceptual model of a zone of NE-SW trending, hydraulically connected, relatively deep fractures, it is possible that the groundwater divide does not coincide with the topographic divide. The extent to which the groundwater divide may be shifted north-eastwards by the pumping regime cannot be determined from the available data, so there is therefore less certainty associated with the delineation of this boundary.
- **Eastern and south-eastern boundary** is primarily constrained by the eastern NE-SW fault, which conceptually demarks the boundary of the fractured 'funnelling' zone. The boundary to groundwater flow is situated within the lower transmissivity Lucan rock unit as some groundwater will be pulled from this aquifer to the boreholes. However, less groundwater will come from this aquifer than the highly fractured Ballysteen, Moathill and Meath rock units. Groundwater east of this boundary would be expected to flow either south to Bracklagh Lough or southeast to Lough Sheelin and/or the Inny River.
- **Southern boundary:** The southern boundary is on the down-gradient side of the boreholes. Its maximum extent is constrained hydrogeologically by the Mill River and a slightly elevated area 150 m to the southeast of PW2.

These boundaries delineate the physical limits within which the ZOC is likely to occur. Calculations have been performed to help constrain the ZOC to the area which provides sufficient recharge for the source abstraction rate, and are as follows:

<u>Water Balance:</u> A basic water balance calculation has been applied to determine whether the delineation of the ZOC is realistic based on the available hydrogeological information. The water balance was calculated on a monthly basis to allow for zero recharge during months in which the

actual evaporation exceeded the average monthly rainfall. This occurs during the months of May, June and July:

Recharge area required to sustain discharge = abstraction rate ÷ average annual depth of recharge.
= (1000 m^3/day × 365 days) ÷ 0.30 m

Recharge area required to sustain discharge = 1.2 km^2

Uniform Flow Equation (Todd , 1980): this was applied to further constrain the downgradient ZOC extent:

$$\text{Approximate down-gradient extent} = \frac{\text{Abstraction rate}}{2 \times \Pi \times \text{transmissivity} \times \text{hydraulic gradient}}$$

$$= 1000/\ 2 \times 3.14 \times 400 \times 0.02$$
$$\approx 20 \text{ m.}$$

This value is increased to 60 m to take into account the fault-bounded nature of this part of the aquifer restricting groundwater flow to the boreholes, and to allow for uncertainties in aquifer parameter values.

The ZOC constrained by hydrogeological mapping, with consideration of the recharge area indicated to be required using a water balance, is shown on Figure 10-8 as the SO (ZOC). It has an area of 1.12 km^2. An increase in abstraction rate above the 1000 m^3/d allowed in the above calculations would require the ZOC to expand. The current understanding of the flow system indicates that the north-eastern ZOC boundary would move outwards – i.e. the groundwater divide would shift northeast. There would also be a small increase in the downstream extent of the ZOC.

10.7.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) to the source from a point below the water table and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone around the boreholes. The delineation of the inner protection area applies to the bedrock aquifer alone.

Subject to certain assumptions and conditions, Darcy's Law can be used to approximate groundwater flow velocities, as follows:

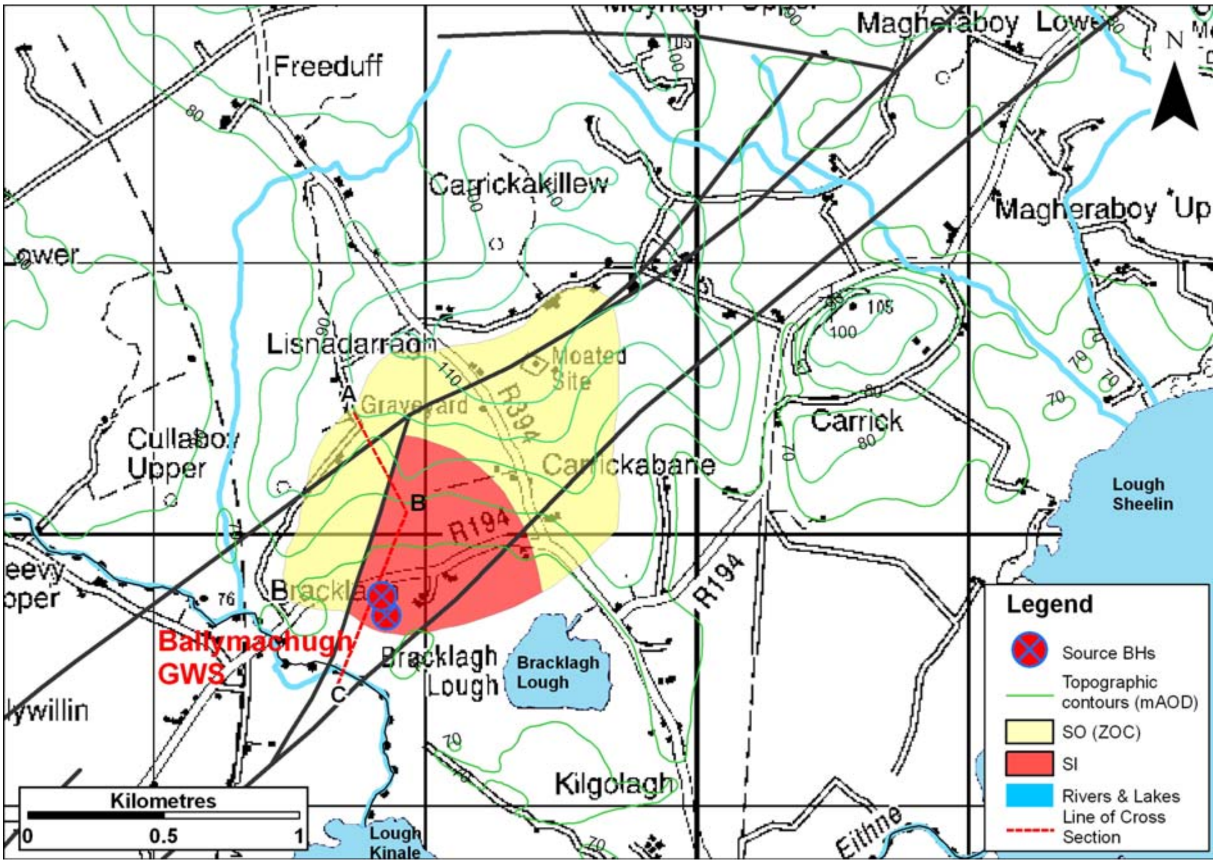
Velocity = groundwater gradient × permeability ÷ porosity

Using the estimates derived in Sections 10.6.5 and 10.6.7 for gradient, permeability, and porosity (0.02, 3.97 m/day, and 0.02 respectively), the equation gives a velocity of 4 m/day. This corresponds to a travel distance of 400 m over 100 days. Figure 10-8 also shows the extent of the inner source protection area.

Because the gravels overlying the aquifer together with the fractured upper portion of the bedrock aquifer are cased off, the inner protection area (SI) is delineated only on the east of the NNE-SSW fault, as this fault is interpreted to behave as a barrier to flow at depth.

Figure 10-8: The Physical Limits of the Catchment of the Ballymachugh Source and Inner Protection Area (SO & SI)

See Figure 10-7 for cross-section following line of section shown (A-B-C).



10.7.4 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of eight source protection zones (see the matrix in the table below). 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 Source Protection area where the groundwater is highly vulnerable to contamination.

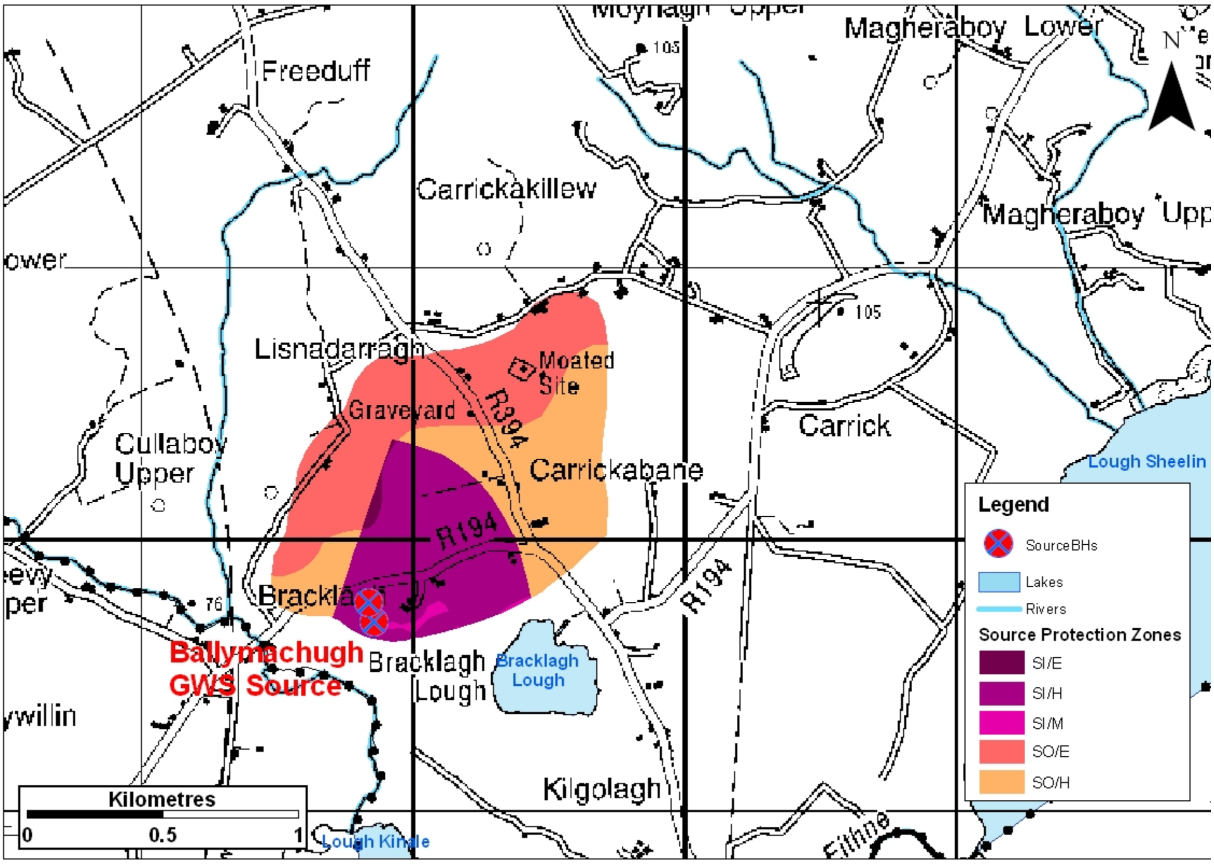
Five of the source protection zones are present in the Ballymachugh ZOC, where there is principally a mixture of moderate permeability till and high permeability gravels. These are shown in the matrix in Table 10.5 below.

Table 10.5: Matrix of Source Protection Zones

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

The appropriate responses imposing restrictions on development are presented in the document 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

Figure 10-9: The Groundwater Protection Zones of Ballymachugh Source



10.8 Land Use and Potential Pollution Sources

Land use in the area around the Ballymachugh source principally comprises livestock agriculture, such that landspreading is the greatest potential pollution source. A small number of domestic dwellings are also noted within the inner source protection area. These are likely to have on-site wastewater treatment systems (septic tanks).

As well as domestic dwellings, an ESB sub-station is also located within the outer source protection area. The septic tanks probably associated with the dwellings potentially present a source of microbial contamination, whilst hydraulic oils used at the substation are another potential source of contamination.

The borehole compound is securely fenced off, and the boreholes are further protected by the concrete bunds, which surrounds each of the four wells on site.

It should be noted, however, that detailed assessments of hazards were not carried out as part of this study.

10.9 Conclusions and Recommendations

From analysis of all available data, and hydrogeological inferences made, the following conclusions can be drawn:

- The Ballymachugh Group Water Scheme is located in Lower Carboniferous limestones, sandstones shales and siltstones (all Ll aquifers) which have very well developed fracture permeability. The source principally draws water from these Ll aquifers. A small volume of groundwater is likely to be contributed from the Silurian Metasediments and Volcanics, which underlie the elevated area north of the site. These rocks are classified as Pl aquifers.

- Groundwater flow to the wells is considered to be primarily from the elevated area in the north-east, and to be generally 'funnelled' along the zone bounded by the two NE-SW trending faults (i.e. the groundwater flow direction is south-westerly). The body of rock between these faults is thought to be considerably fractured, due to the proximity of the major faults.
- Pumping test results indicate that the NNE–SSW trending fault immediately west of the boreholes is a barrier to groundwater flow. Analytical calculations indicate that the barrier is the mapped fault approximately 50 m from the water supply boreholes.
- The groundwater immediately around the supply is protected by high permeability sands and gravels.
- Over much of the zone of contribution to the well, i.e. the catchment area, groundwater vulnerability is principally categorised as either extreme (including rock close to the surface) or high, with a small zone of moderate vulnerability.
- Limited raw water analyses indicate that the groundwater for the Ballymachugh GWS is clean and free of significant contamination issues on the dates the samples were taken.
- The ZOC is delineated for an abstraction rate of 1,000 m^3/d. This rate is an average of the typical demand (500 m^3/day) and the present demand (860 m^3/day), and includes a 50% margin or error to account for drier (summer) periods or slight increases in abstraction.
- The protection zones delineated in this chapter are delineated to take account of groundwater flow in both bedrock and the overlying gravel subsoils. The zones 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:
  - regular monitoring of groundwater levels are undertaken over a period of continuous pumping at a steady rate (for a minimum period of a year) to determine the sustainability of current pumping rates, and estimate the long term sustainable rate of abstraction for the source.
  - a pumping test is undertaken using additional observation boreholes. This would enable confirmation of a) the 'no-flow' barrier effects of any nearby faults, b) a more precise determination of the north-eastern and south-eastern extents of the ZOC and c) more accurate aquifer parameters on which to base the SI boundary. These data would enable further refinement of the delineated source protection zones for this source.
  - chemical and bacteriological analyses of raw water as well as treated water should be carried out monthly. The chemical analyses should include all major ions – calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate – in addition to bacteriological parameters. Analysis of other parameters such as pesticides and hydrocarbons is also recommended.
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - particular care should be taken when assessing the location of any activities or developments that might cause contamination at the borehole.

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Appendix I

Discussion of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

Appendix I: Discussion Of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

A.1 Introduction

This appendix is adapted from Daly, 1996.

There has been a tendency in analysing groundwater samples to test for a limited number of constituents. A "full" or "complete" analysis, which includes all the major anions and cations, is generally recommended for routine monitoring and for assessing pollution incidents. This enables (i) a check on the reliability of the analysis (by doing an ionic balance), (ii) a proper assessment of the water chemistry and quality and (iii) a possible indication of the source of contamination. A listing of recommended and optional parameters are given in Table A1. It is also important that the water samples taken for analysis have not been chlorinated - this is a difficulty in some local authority areas where water take-off points prior to chlorination have not been installed.

The following parameters are good contamination indicators: E. coli, nitrate, ammonia, potassium, chloride, iron, manganese and trace organics.

TABLE A1

Recommended Parameters		
Appearance	Calcium (Ca)	Nitrate ($N0_3$)*
Sediment	Magnesium (Mg)	Ammonia ($NH_4$and NH_3)*
pH (lab)	Sodium (Na)	Iron (Fe)*
Electrical Conductivity (EC)*	Potassium (K)*	Manganese (Mn)*
Total Hardness	Chloride Cl)*	
General coliform	Sulphate ($S0_4$)*	
E. coli *	Alkalinity	
Optional Parameters (depending on local circumstances or reasons for sampling)		
Fluoride (F)	Fatty acids *	Zinc (Zn)
Orthophosphate	Trace organics *	Copper (Cu)
Nitrite ($N0_2$)*	TOC *	Lead (Pb)
B.O.D.*	Boron (B) *	Other metals
Dissolved Oxygen *	Cadmium (Cd)	
*** good indicators of contamination**		

A.2 Faecal Bacteria and Viruses

E. coli is the parameter tested as an indicator of the presence of faecal bacteria and perhaps viruses; constituents which pose a significant risk to human health. The most common health problem arising from the presence of faecal bacteria in groundwater is diarrhoea, but typhoid fever, infectious hepatitis and gastrointestinal infections can also occur. Although E. coli bacteria are an excellent indicator of pollution, they can come from different sources - septic tank effluent, farmyard waste, landfill sites, birds. The faecal coliform : faecal streptococci ratio has been suggested as a tentative indicator to distinguish between animal and human waste sources (Henry *et al.*, 1987). However, researchers in Virginia Tech (Reneau, 1996) cautioned against the use of this technique.

Viruses are a particular cause for concern as they survive longer in groundwater than indicator bacteria (Gerba and Bitton, 1984).

The published data on elimination of bacteria and viruses in groundwater has been compiled by Pekdeger and Matthess (1983), who show that in different investigations 99.9% elimination of *E. coli* occurred after 10-15 days. The mean of the evaluated investigations was 25 days. They show that 99.9% elimination of various viruses occurred after 16-120 days, with a mean of 35 days for Polio-, Hepatitis, and Enteroviruses. According to Armon and Kott (1994), pathogenic bacteria can survive for more than ten days under adverse conditions and up to 100 days under favourable conditions; enteroviruses can survive from about 25 days up to 170 days in soils.

Bacteria can move considerable distances in the subsurface, given the right conditions. In a sand and gravel aquifer, coliform bacteria were isolated 100 ft from the source 35 hours after the sewage was introduced (as reported in Hagedoorn et al., 1981). They can travel several kilometres in karstic aquifers. In Ireland, research at Sligo RTC involved examining in detail the impact of septic tank systems at three locations with different site conditions (Henry, 1990; summarised in Daly, Thorn and Henry, 1993). Piezometers were installed down-gradient; the distances of the furthest piezometers were 8 m,10 m and 9.5 m, respectively. Unsurprisingly, high faecal bacteria counts were obtained in the piezometers at the two sites with soakage pits, one with limestone bedrock at a shallow depth where the highest count (max. 14 000 cfu's per 1000 ml) and the second where sand/gravel over limestone was present (max 3 000 cfu's per 100 ml). At the third site, a percolation area was installed at 1.0 m b.g.l.; the subsoils between the percolation pipes and the fractured bedrock consisted of 1.5 m sandy loam over 3.5 m of poorly sorted gravel; the water table was 3.5 b.g.l. (So this site would satisfy the water table and depth to rock requirements of S.R.6:1991, and most likely the percolation test requirement.) Yet, the maximum faecal coliform bacteria count was 300 cfus per 100 ml. Faecal streptococci were present in all three piezometers. It is highly likely that wells located 30 m down gradient of the drainage fields would be polluted by faecal bacteria.

As viruses are smaller than bacteria, they are not readily filtered out as effluent moves through the ground. The main means of attenuation is by adsorption on clay particles. Viruses can travel considerable distances underground, depths as great as 67 m and horizontal migrations as far as 400 m have been reported (as reported in US EPA, 1987). The possible presence of viruses in groundwater as a result of pollution by septic tank systems is a matter of concern because of their mobility and the fact that indicator bacteria such faecal coliforms have been found not to correlate with the presence of viruses in groundwater samples (US EPA, 1987).

The natural environment, in particular the soils and subsoils, can be effective in removing bacteria and viruses by predation, filtration and absorption. There are two high risk situations: (i) where permeable sands and gravels with a shallow water table are present; and (ii) where fractured rock, particularly limestone, is present close to the ground surface. The presence of clayey gravels, tills, and peat will, in many instances, hinder the vertical migration of microbes, although preferential flow paths, such as cracks in clayey materials, can allow rapid movement and bypassing of the subsoil.

A.3 Nitrate

Nitrate is one of the most common contaminants identified in groundwater and increasing concentrations have been recorded in many developed countries. The consumption of nitrate rich water by young children may give rise to a condition known as methaemoglobinaemia (blue baby syndrome). The formation of carcinogenic nitrosamines is also a possible health hazard and epidemiological studies have indicated a positive correlation between nitrate consumption in drinking water and the incidence of gastric cancer. However, the correlation is not proven according to some experts (Wild and Cameron, 1980). The EC MAC for drinking water is 50mg/l.

The nitrate ion is not adsorbed on clay or organic matter. It is highly mobile and under wet conditions is easily leached out of the rooting zone and through soil and permeable subsoil. As the normal concentrations in uncontaminated groundwater is low (less than 5 mg/l), nitrate can be a good indicator of contamination by fertilisers and waste organic matter.

In the past there has been a tendency in Ireland to assume that the presence of high nitrates in well water indicated an impact by inorganic fertilisers. This assumption has frequently been wrong, as examination of other constituents in the water showed that organic wastes - usually farmyard waste, probably soiled water - were the source. The nitrate concentrations in wells with a low abstraction rate - domestic and farm wells - can readily be influenced by soiled water seeping underground in the vicinity of the farmyard or from the spraying of soiled water on adjoining land. Even septic tank effluent can raise the nitrate levels; if a septic tank system is in the zone of contribution of a well, a four-fold dilution of the nitrogen in the effluent is needed to bring the concentration of nitrate below the EU MAC (as the EU limit is 50 mg/l as NO_3 or 11.3 mg/l as N and assuming that the N concentration in septic tank effluent is 45 mg/l).

The recently produced draft county reports by the EPA on nitrate in groundwater show high levels of nitrate in a significant number of public and group scheme supplies, particularly in south and southern counties and in counties with intensive agriculture, such as Carlow and Louth. This suggest that diffuse sources – landspreading of fertilisers – is having an impact on groundwater.

In assessing regional groundwater quality and, in particular the nitrate levels in groundwater, it is important that:

(i) conclusions should not be drawn using data only from private wells, which are frequently located near potential point pollution sources and from which only a small quantity of groundwater is abstracted;
(ii) account should be taken of the complete chemistry of the sample and not just nitrate, as well as the presence of *E. coli*.;
(iii) account should be taken of not only the land-use in the area but also the location of point pollution sources;
(iv) account should be taken of the regional hydrogeology and the relationship of this to the well itself. For instance, shallow wells generally show higher nitrate concentrations than deeper wells, low permeability sediments can cause denitrification, knowledge on the groundwater flow direction is needed to assess the influence of land-use.

A.4 Ammonia

Ammonia has a low mobility in soil and subsoil and its presence at concentrations greater than 0.1 mg/l in groundwater indicates a nearby waste source and/or vulnerable conditions. The EU MAC is 0.3 mg/l.

A.5 Potassium

Potassium (K) is relatively immobile in soil and subsoil. Consequently the spreading of manure, slurry and inorganic fertilisers is unlikely to significantly increase the potassium concentrations in groundwater. In most areas in Ireland, the background potassium levels in groundwater are less than 3.0 mg/l. Higher concentrations are found occasionally where the rock contains potassium e.g. certain granites and sandstones. The background potassium:sodium ratio in most Irish groundwaters is less than 0.4 and often 0.3. The K:Na ratio of soiled water and other wastes derived from plant organic matter is considerably greater than 0.4, whereas the ratio in septic tank effluent is less than 0.2. Consequently a K:Na ratio greater than 0.4 can be used to indicate contamination by plant organic matter - usually in farmyards, occasionally landfill sites (from the breakdown of paper). However, a K:Na ratio lower than 0.4 does not indicate that farmyard wastes are **not** the source of contamination (or that a septic tank is the cause), as K is less mobile than Na. (Phosphorus is increasingly a significant pollutant and cause of eutrophication in surface water. It is not a problem in groundwater as it usually is not mobile in soil and subsoil).

A.6 Chloride

The principle source of chloride in uncontaminated groundwater is rainfall and so in any region, depending on the distance from the sea and evapotranspiration, chloride levels in groundwater will be fairly constant. Chloride, like nitrate, is a mobile cation. Also, it is a constituent of organic wastes. Consequently, levels appreciably above background levels (12-15 mg/l in Co. Offaly, for instance) have been taken to indicate contamination by organic wastes such as septic tank systems. While this is probably broadly correct, Sherwood (1991) has pointed out that chloride can also be derived from potassium fertilisers.

A.7 Iron and manganese

Although they are present under natural conditions in groundwater in some areas, they can also be good indicators of contamination by organic wastes. Effluent from the wastes cause deoxygenation in the ground which results in dissolution of iron (Fe) and manganese (Mn) from the soil, subsoil and bedrock into groundwater. With reoxygenation in the well or water supply system the Fe and Mn precipitate. High Mn concentrations can be a good indicator of pollution by silage effluent. However, it can also be caused by other high BOD wastes such as milk, landfill leachate and perhaps soiled water and septic tank effluent.

Box A1 Warning/trigger Levels for Certain Contaminants

As human activities have had some impact on a high proportion of the groundwater in Ireland, there are few areas where the groundwater is in a pristine, completely natural condition. Consequently, most groundwater is contaminated to some degree although it is usually not polluted. In the view of the GSI, assessments of the degree of contamination of groundwater can be beneficial as an addition to examining whether the water is polluted or not. This type of assessment can indicate where appreciable impacts are occurring. It can act as a warning that either the situation could worsen and so needs regular monitoring and careful land-use planning, or that there may be periods when the source is polluted and poses a risk to human health and as a consequence needs regular monitoring. Consequently, thresholds for certain parameters can be used to help indicate situations where additional monitoring and/or source protection studies and/or hazard surveys may be appropriate to identify or prevent more significant water quality problems.

Parameter	**Threshold** mg/l	**EU MAC** mg/l
Nitrate	25	50
Potassium	4	12
Chloride	30 (except near sea)	250
Ammonia	0.15	0.3
K/Na ratio	0.3-0.4	
Faecal bacteria	0	0

Box A2 Summary : Assessing a Problem Area

Let us assume that you are examining an area with potential groundwater contamination problems and that you have taken samples in nearby wells. How can the analyses be assessed?

E. coli present ⇨ organic waste source nearby (except in karst areas), usually either a septic tank system or farmyard.
E. coli absent ⇨ either not polluted by organic waste or bacteria have not survived due to attenuation or time of travel to well greater than 100 days.
Nitrate > 25 mg/l ⇨ either inorganic fertiliser or organic waste source; check other parameters.
Ammonia > 0.15 mg/l ⇨ source is nearby organic waste; fertiliser is not an issue.
Potassium (K) > 5.0 mg/l ⇨ source is probably organic waste.
K/Na ratio > 0.4 (0.3, in many areas) ⇨ Farmyard waste rather than septic tank effluent is the source. If < 0.3, no conclusion is possible.
Chloride > 30 mg/l ⇨ organic waste source. However this does not apply in the vicinity of the coast (within 20 km at least).

In conclusion, faecal bacteria, nitrate, ammonia, high K/Na ratio and chloride indicate contamination by organic waste. However, only the high K/Na helps distinguish between septic tank effluent and farmyard wastes. So in many instances, while the analyses can show potential problems, other information is needed to complete the assessment.

A.8 References

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Appendix III

Borehole Logs for Ballymachugh GWS (Dunnes Water Services Ltd.)

WELL LOG

Well No.	Description	Client
TW3	Trial well	Ballymachugh Group Water Schem
	Location	**Driller**
	Group Scheme Pumphouse	Dunnes

Date Drilled
22/11/1999

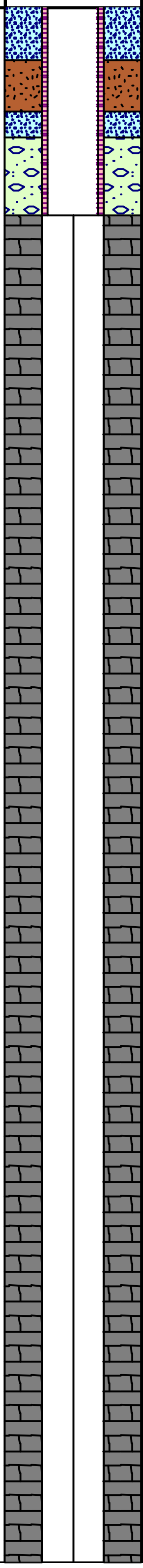
Water Level (mbtoc)
-1.20

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
	30.0

Depth [m]	Hole	Annulus	Casing	Screen		Lithology	Elev. [m]
					3.05	SAND	
5		Cement Grout	200		6.1	CLAY/SILT	-5
					7.62	SAND	
10		12.2	12.2		12.2	GRAVEL	-10
15							-15
20							-20
25							-25
30							-30
35							-35
40							-40
45	250					Limestone	-45
50							-50
55							-55
60							-60
65						NOTES: Approx 164m3/d water	-65
70							-70
75							-75
80							-80
85							-85
90	91.44						-90



WELL LOG

Well No.	Description	Client
TW2	Trial well	Ballymachugh Group Water Schem
	Location	**Driller**
	Carrick School	Dunnes

Date Drilled
1/12/1999

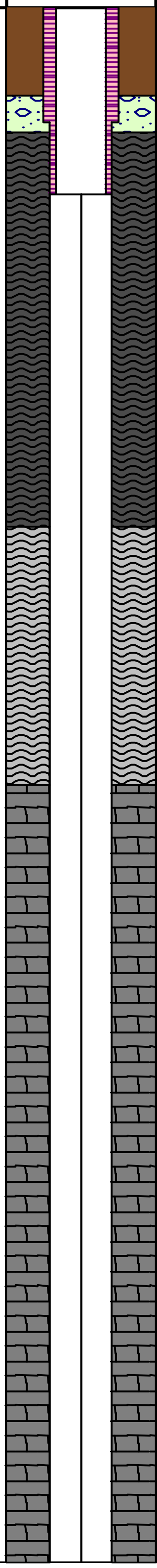
Water Level (mbtoc)

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
	30.0

Depth [m]	Hole	Annulus	Casing	Screen	Lithology	Elev. [m]
	300	Cement Grout	200		Overburden	
5	6.71				5.18 GRAVEL	-5
					7.32	
10		10.97	10.97			-10
15						-15
20					Dark grey SHALE	-20
25						-25
30					30.5	-30
35						-35
40					Grey SHALE	-40
45					45.72	-45
50	250					-50
55						-55
60					Limestone	-60
65						-65
70						-70
75					Notes: No Water	-75
80						-80
85						-85
90	91.44					-90



WELL LOG

Well No.	Description	Client
TW1	Trial well	Ballymachugh Group Scheme
	Location	**Driller**
	Bracklagh, Co Cavan	Dunnes

Date Drilled
26/11/1999

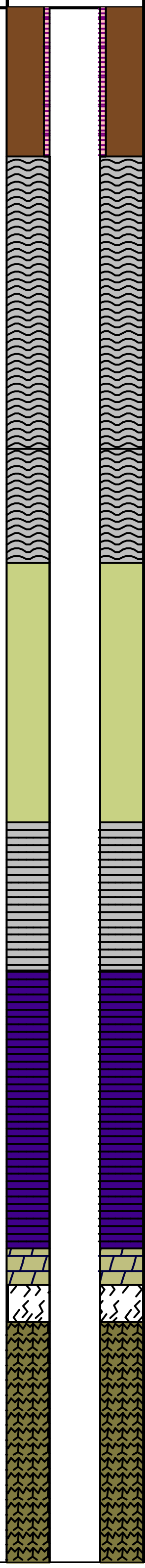
Water Level (mbtoc)
-0.55

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
	30.0

Depth [m]	Hole	Annulus	Casing	Screen
0 – 12.19	250	Cement Grout	200	
12.19	12.19	12.19	12.19	
12.19 – 128.02	200		200	
128.02	128.02		128.02	



Depth to base [m]	Lithology
12.19	Overburden
36.31	Dark grey SHALE
45.72	Grey SHALE
67.06	Pale grey SANDSTONE
79.25	Medium grey micritic SILTSTONE
102.11	Dark grey micritic SILTSTONE
105.16	DOLOMITE
108.2	QUARTZITE
	Red and green interbedded MUDSTONE and GREYWACKE

Depth [m]: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

Elev. [m]: -10, -20, -30, -40, -50, -60, -70, -80, -90, -100, -110, -120

WELL LOG

Well No.	Description	Client
LS54	MINERAL EXPLORATION	
	Location	**Driller**
	Bracklagh, Co.Cavan	

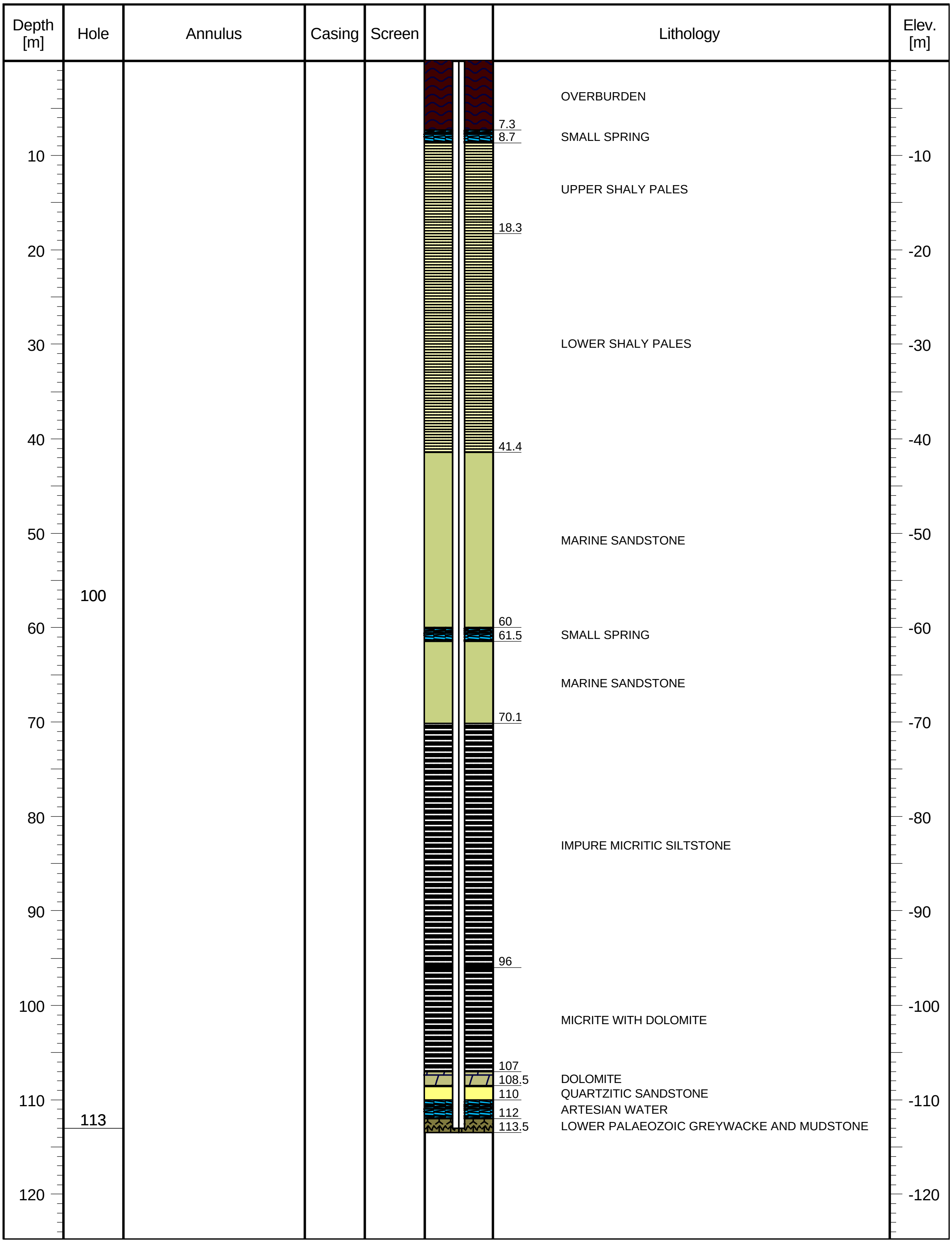
Date Drilled

Water Level (mbtoc)
0.00

All diameters in mm
All depths in metres

Scale

Vertical	Horizontal
600.0	50.0



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Appendix IV

RAW WATER QUALITY DATA FROM BALLYMACHUGH GWS

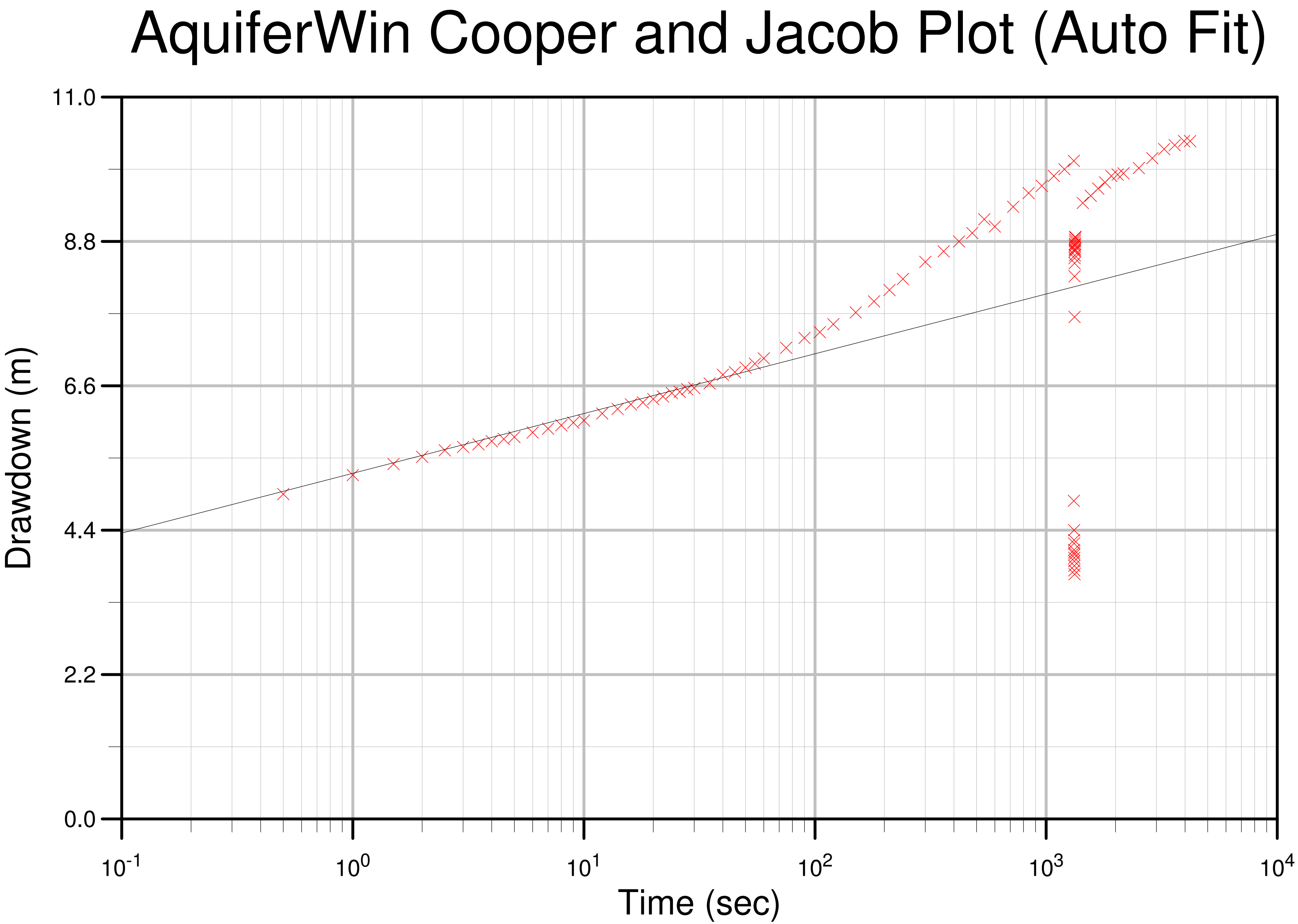
Lavagh / Ballyheelan GWSS
Raw Water Source - Borehole (Ground Water Source)

Test Parameter	Units	Result 16 May 2003	Recorded Minimum	Recorded Maximum	EC Regs 2000 Max Limit
Alkalinity (Bicarbonate)	mg/l HCO_3	217			n/a
Alkalinity (Total)	mg/l $CaCO_3$	217			n/a
Aluminium	ug/l	<6.6	<0.12	<6.6	200
Aluminium (Dissolved)	ug/l	<6.6			n/a
Ammonia	mg/l as N Ammonium	0.06	<0.01		0.3
Antimony	ug/l	<1.4			5
Arsenic	ug/l	<0.2			10
Boron	ug/l	47.9			1
Bromide	mg/l	<0.5			n/a
Cadmium	ug/l	<0.4			5
Carbon Dioxide	mg/l	110			n/a
Chloride	mg/l	15			250
Chlorophyll	mg/m_3	10.2			n/a
Chromium	ug/l	<2.0			50
Clostridia	no/ml Clostridium Perfringens	0	0		0
Coliforms (Total)	no/100ml Coliform bacteria	3	0		0
Colour (Apparent)	mg/l PtCo Units	5			n/a
Colour (True)	mg/l PtCo Units	8	<4	13	20
Conductivity	uscm -1 @ 25C	722	634	734	2500
Copper	ug/l	<2.8			2
Cryptospiridium	no/ml	0			n/a
Cyanide	ug/l	<3			50
Dissolved Organic Carbon	mg/l	10			n/a
Dissolved Oxygen	mg/l	9			n/a
E Coli	no/100ml Escherichia coli	3	0		0
Enterococci	no/100ml	0			0
Fluoride	mg/l	<0.07			1.5
Hardness (Bicarbonate)	mg/l $CaCO_3$	149			n/a
Hardness (Total)	mg/l $CaCO_3$	366		406	n/a
Iron (Dissolved)	ug/l	<2			n/a
Iron (Total)	ug/l	35	20	64	200
Lead	ug/l	<0.6			10
Magnesium	mg/l	11.07			n/a
Manganese	ug/l	11.9	0.7		50
Manganese (Dissolved)	ug/l	9.1			n/a
Mercury	ug/l	<0.4			1
Nickel	ug/l	<9.9			20
Nitrate	mg/l as N	1.02	0.37	5.05	50
Nitrite	mg/l as N	0.015		0.115	0.5
Pesticides (Organochlorine)	ug/l	<0.1			0.1
Pesticides (Organophosphorous)	ug/l Total	<0.1			0.5
pH	pH Units	7.6	7.48	7.6	n/a
Phosphate (Ortho)	mg/l as P	0.008			n/a
Phosphate (Total)	mg/l as P	0.086			n/a
Polyaromatic Hydrocarbons	ug/l	<1			0.1
Potassium	mg/l	2.307			n/a
Pseudomonas	no/100ml	0			n/a
Selenium	ug/l	<4.6			10
Semi Volatile Organic Compounds	microg/l	<1			n/a
Silica	mg/l as Si	13.8			n/a
Sodium	mg/l	8.96			200
Solids (Total Dissolved)	mg/l	442			n/a
Sulphate	mg/l as SO4	164			250
Total Organic Carbon	mg/l	10			No abnormal change
Turbidity	NTU	0.86	0.45	1.25	<1
TVC's @ 22^oc	no/ml	320	16		n/a
TVC's @ 37^oc	no/ml	<1	0	30	n/a
UV Abs @ 254nm	Abs	0.014			n/a
Volatile Organic Compounds	ug/l	<1			n/a
Zinc	mg/l	<0.007			n/a

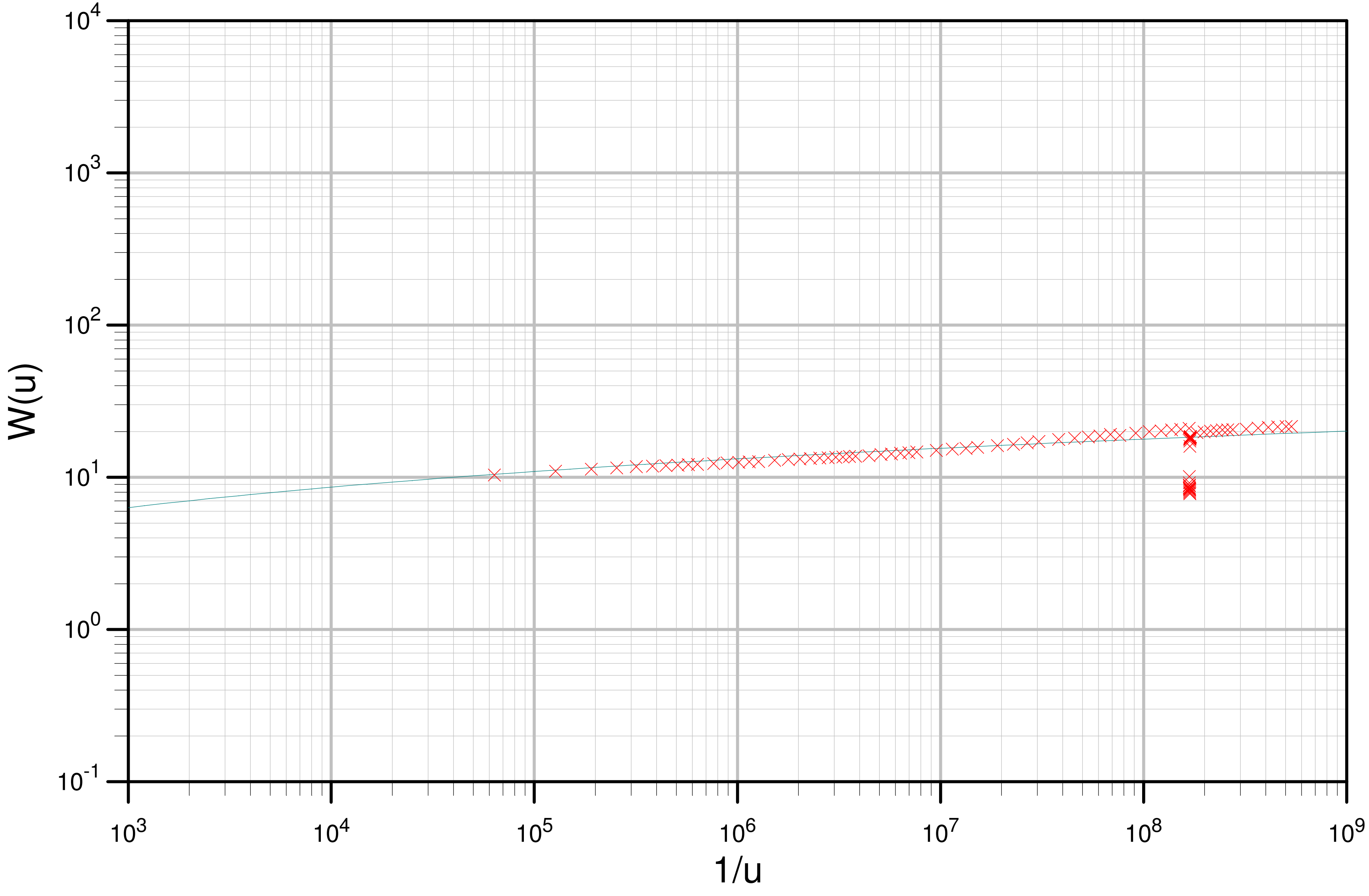
[1] Recorded Minimum and Maximum values have been obtained from historic analyses results and are shown only where the historic values are less than or greater than the results of the 2003 analyses.
[2] n/a = not applicable - does not form part of EC 2000 Regs

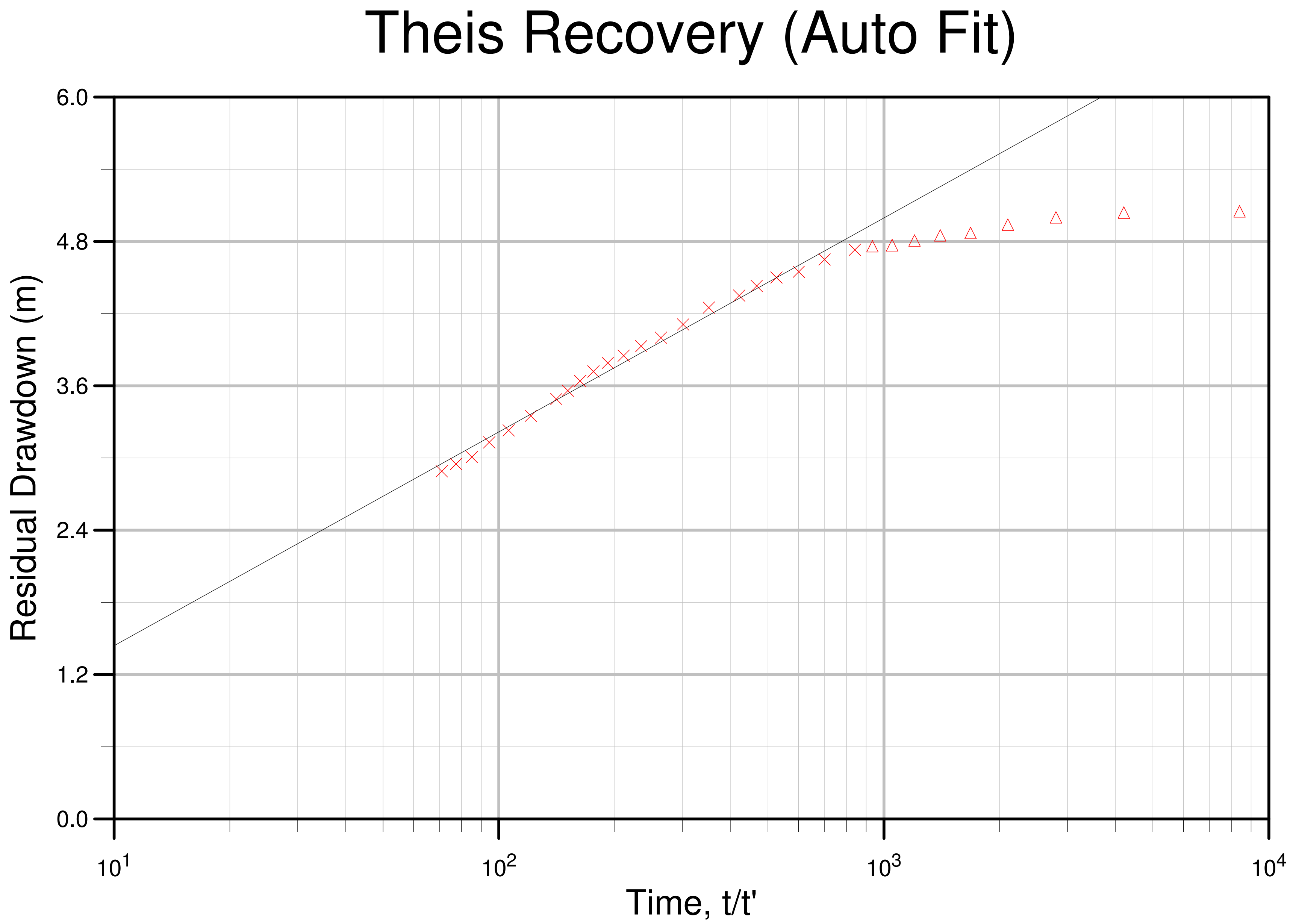
Appendix V

PUMPING TEST DATA FOR BALLYMACHUGH GWS


AquiferWin Cooper and Jacob Plot (Auto Fit)
11.0
8.8
6.6
4.4
2.2
0.0
Drawdown (m)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Time (sec)

Theis (Manual Fit_2)





Theis Recovery (Auto Fit)
6.0
4.8
3.6
2.4
1.2
0.0
Residual Drawdown (m)
10^1
10^2
10^3
10^4
Time, t/t'