Cavan County Council

Establishment of Groundwater Source Protection Zones

Ballyconnell Water Supply Scheme

Lough Cuillaghan Boreholes

January 2013 Rev C

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Document control information

Revision	Date	Author	Checked	Approved
A	16/03/2011	Peter Conroy	JD/RM	
B	05/04/2011	Peter Conroy	CH	
C	22/01/2013	Peter Conroy		

Project description

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

Cavan County Council contracted GSI to delineate source protection zones for groundwater public water supply sources in Co. Cavan. In the current phase of investigations the sources for which delineations have been requested are Kingscourt and Ballyconnell.

This report documents the delineation of the Ballyconnell source protection zones for the Lough Cuillaghan source boreholes. A summary of the delineation of source protection zones for the Mucklagh Borehole, which is due to be abandoned in 2012, is also provided.

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

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1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Ballyconnell Public Water Supply Scheme according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

The Lough Cuillaghan source boreholes (PWSBH01 and PWSBH02) are located in the townland of Killywilly, Ballyconnell, Co. Cavan, approximately 2.5 km west of Ballyconnell town. The sources have not yet been commissioned.

Ballyconnell is currently supplied by the Lough Cuillaghan spring source (400 m^3/day) and by the Mucklagh Borehole Source (PWSBH03; 352 m^3/day). Cavan County Council plan to phase out the abstraction from Lough Cuillaghan spring, and borehole PWSBH03 by 2013 and replace them with the newly constructed boreholes PWSBH01 and PWSBH02. The boreholes will operate on a duty-standby basis. Each borehole is considered to have a sustainable yield of 1,500 m^3/day[1] (JBB, 2008). This yield greatly exceeds the projected demands of 814 m^3/day (WYG, 2007). The spring, and boreholes PWSBH01 and PWSBH02, are located within the same compound. Abstraction from the boreholes diminishes the spring discharge. The SPZs have been delineated to protect both the borehole abstraction and the diminished spring discharge. The delineation of SPZs for borehole PWSBH03 has also been carried out and is summarised in Appendix 1.

The objectives of the study were:

- To outline the principal hydrogeological characteristics of the Lough Cuillaghan area where the supply boreholes are located.
- To delineate source protection zones for boreholes PWSBH01, PWSBH02 and Lough Cuillaghan Spring, and the soon to be decommissioned borehole PWSBH03.
- To assist Cavan County Council in protecting the water supply from contamination.

The protection zones are intended to provide a guide in the planning and regulation of development and human activities to ensure groundwater quality is protected. More details on protection zones are presented in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

2 Methodology

The methodology applied to delineate the SPZ consisted of data collection, desk studies, site visits and field mapping, and subsequent data analysis and interpretation.

A desk study of existing data sources relevant to the source was carried out prior to a site visit. Site visits, site walk-over and field mapping of the study area were conducted on 08/07/2010, 09/09/2010, 29/09/2010, 16/11/2010 and 17/11/2010. An interview with the source caretaker was carried out on 08/07/2010.

While specific fieldwork was carried out in the development of this report, the maps produced are based largely on the readily available information and mapping techniques using inferences and judgements from experience at other sites. As such, the maps may not be definitively accurate

[1] This takes account of large leakage rates back to groundwater experienced during the pumping tests (JBB, 2008)

across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

3 Location, site description and well head protection

Boreholes PWSBH01 and PWSBH02 are located within the existing Cavan County Council compound for the Lough Cuillaghan spring source. Both boreholes are production wells. A trial well (TW01) is also located within the compound, between the production wells.

The compound is approximately 50 m long (north-south) and 25 m wide. It is located adjacent to the northwest extremity of Lough Cuillaghan. There are two pump houses and a sump in the northern half of the site. The spring source is located in a concrete chamber at the southern end of the site. Borehole PWSBH01 is located approximately half-way between the spring source and the buildings (i.e. 20 m north of the spring). Borehole PWSBH02 lies between the buildings and the lake, approximately 5 m from the shore and 35 m north-northeast of the spring. Both boreholes were completed as 250 mm diameter wells, lined with uPVC well casing and screen.

Both boreholes have a large diameter casing sticking up above ground level, set in a concrete plinth at ground level, and capped with a steel lid (See photos 1 and 2). The steel lid is provided with a dipper hole for water level measurements and a 150 mm access cylinder sticking up above the lid. The concrete plinth of borehole PWSBH02 is broken. There is no record of a grout seal being installed during the construction of the boreholes.

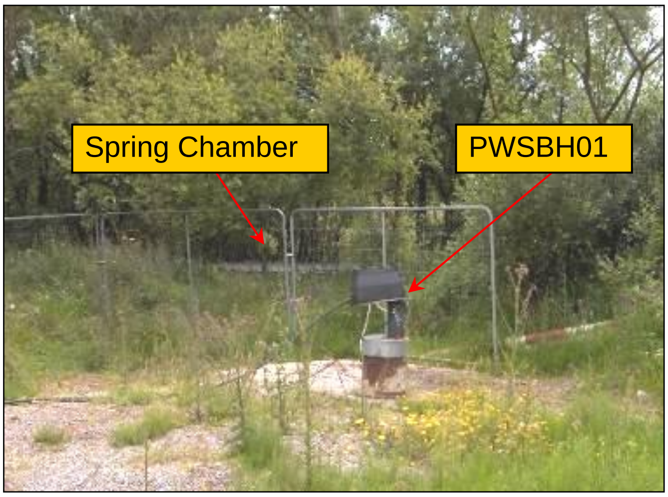

Photo 1: Borehole PWSBH01 with spring chamber beyond

Photo 2: Borehole PWSBH02

Boreholes PWSBH01 and PWSBH02 were drilled in the period May to July of 2008 by Dunnes Water Services Ltd. with JB Barry Ltd. as hydrogeological consultants. The borehole locations are shown on Figure 1.

4 Summary of well details

The well details are derived from the JB Barry hydrogeological investigation reports and accompanying borehole logs prepared in 2008. The borehole logs for boreholes PWSBH01 and PWSBH02 (and trial well TW01) are provided in Appendix 2.

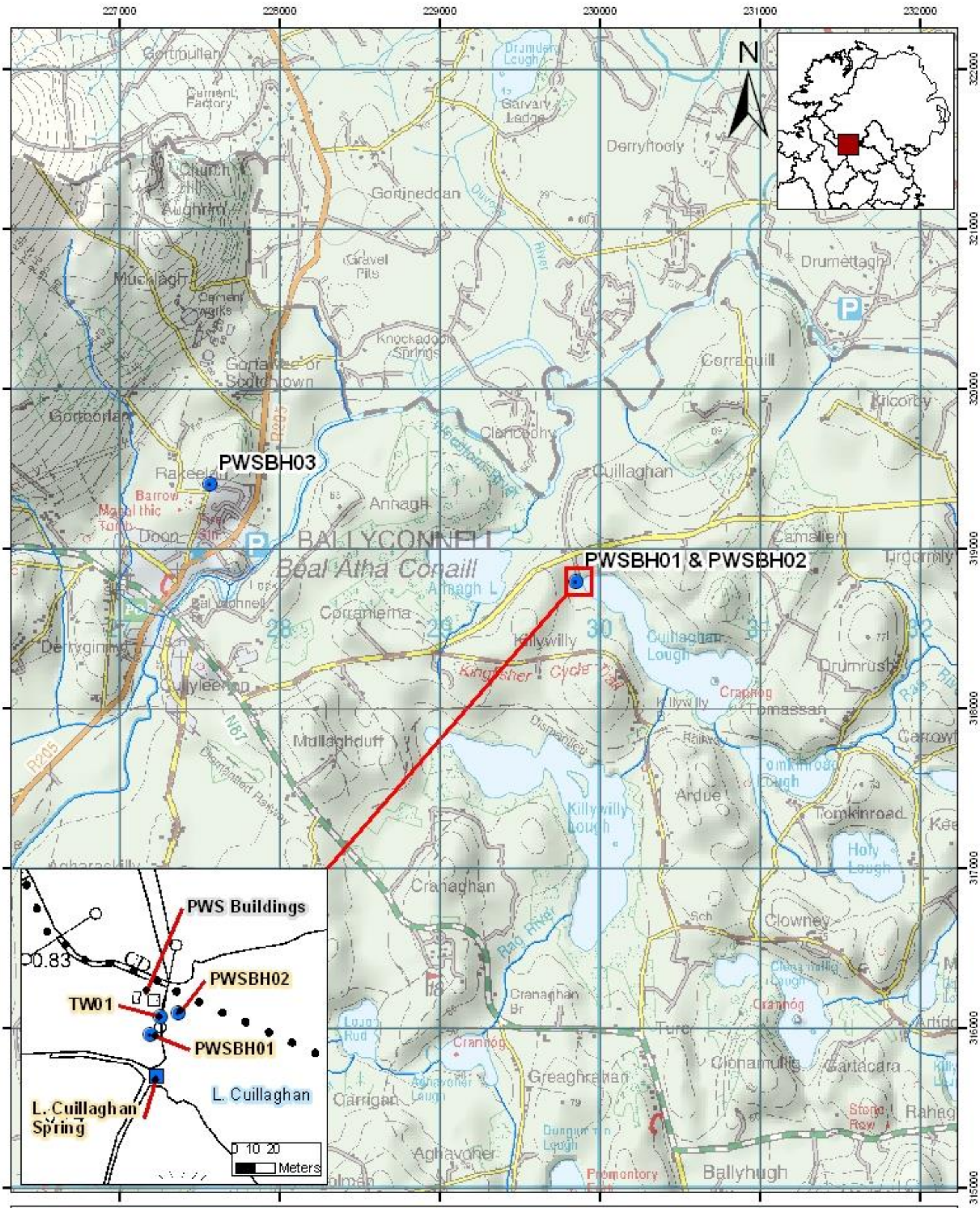

Figure 1 Ballyconnell PWS Site Location Map

- PWS Borehole Abstraction
- PWS Spring Abstraction
- Rivers

0 0.25 0.5 0.75 1 km

Both boreholes encountered significant groundwater inflow from a karst conduit at between 24 m and 26 mbgl in fractured cherty and dolomitised limestone. The groundwater returned during borehole development contained a significant sediment load from the conduit. Drilling conditions were difficult, with shattered rock encountered from rockhead to total depth. This necessitated the installation of steel casing and/or PVC liner to the total depth to keep the holes open (Table 4-1).

Trial well TW01 was drilled at the site in January 2006 to a depth of 70 mbgl. Groundwater inflows were encountered in the fractured, cherty and dolomitised limestone conduit at 24 m to 26 mbgl; and at 40 m to 41 mbgl in a fractured sandstone bed with interbedded limestone.

Table 4-1: Well Details

	PWSBH01	PWSBH02
Grid ref. (GPS)	X: 229859 Y:318789	X: 229873 Y:318800
Townland	Killywilly	Killywilly
Source type	Borehole	Borehole
Drilled	May – June 2008	June – July 2008
Owner	Cavan County Council	
Elevation (Ground Level)	47.322 m OD	47.203 m OD
Dipper Hole Elevation	47.907 m OD	47.873 m OD
Depth (m)	34	44
Depth of casing (m)	508 mm: 7.3 406 mm: 10 305 mm: 26.5 250 mm: 0 to 20 (steel casing); 19 to 34 m (Boode well screen)	762 mm: 3 609 mm: 10 406 mm: 39 250 mm: 0 to 15 (uPVC casing); 15 to 40 m (Boode well screen)
Grout Seal	none recorded	none recorded
Diameter	250 mm	250 mm
Depth to rock	10 m	10 m
Static water level	0.3 (m below top of dipper hole) (0.28 m above ground level)	0.28 (mb top of dipper hole) (0.39 m above ground level)
Drawdown	4.21 m at 1,800 m^3/day Footnote 2	2.71 m at 1,800 m^3/day
Consumption (Co. Co. records)	Not commissioned. Proposed combined maximum abstraction rate of 1,500 m^3/day	
Pumping test summary: (i) abstraction rate m^3/d	Combined 7-day yield test 15/07/2008 to 22/07/08. Both boreholes pumping at approx. 1800 m^3/day each (combined rate approx. 3,500 m^3/day), but 973 m^3/day leaking back to ground via sump in PWS pumping system. No raw data available for analysis.	
(ii) specific capacity	427 m^3/day/m Footnote 3	664 m^3/day/m Footnote 3
(iii) transmissivity	approx. 832 m^2/day based on analysis of pumping test data for TW01[4]	

[2] PWSBH01 & PWSBH02 were pumped simultaneously at about 1800 m^3/day each for 7 days giving rise to the quoted drawdowns in the two wells. During the test up to approx. 960 m^3/day of water leaked back to groundwater (JBB, 2008). The raw test data were not available, therefore it was not was possible to correct the drawdown values for the leakage.

[3] Observed pumping rate (1,800 m^3/day) divided by observed drawdown (4.21m at PWSBH01; 2.71m at PWSBH02). Does not take leakage into account. Not possible to account for leakage as raw data unavailable. Specific capacity would be less if leakage could be taken into account.

[4] See Appendix 3. Analysis does not take account of drawdown associated with artesian overflow or leakage/recharge from the nearby PWS sump. These factors result in an apparent drawdown which is less than the actual drawdown and therefore result in an overestimation of the transmissivity, which cannot be quantified based on the available data.

5 Topography, surface hydrology, landuse

The wells are at an elevation of approximately 47.3 mAOD, adjacent to the shore of Lough Cuillaghan. The pumping compound is set in a drumlin landscape with crests at 70 mAOD to 80 mAOD and with lakes in the intervening troughs. Lake surface levels are in the region of 46.6 (Lough Cuillaghan) to 48.55 mAOD (Lough Clonamullig)[5]. Occasionally the higher surrounding hills are not drumlins, and are bedrock cored. To the northwest of Ballyconnell, Slieve Rushen rises steeply to 404 mAOD. To the east of Ballyconnell and the pumping compound the regional gradient is very shallow and is directed east-northeast towards the River Erne.

At the local scale, drainage density is high with frequent minor streams and drains taking runoff from drumlins into the various lakes. The main surface water feature is the Woodford river which flows northeast through Ballyconnell before turning east-northeast to meander north of the site. The river comes within 600 m of the site at its closest point and had a surface level of 45.33 mAOD in the townland of Cloncoohy/Cuillaghan on 19/11/2010. The lakes in the vicinity of the site are drained by the Rag River which meanders roughly northeast to east-northeast through the area and flows into the Woodford River approximately 5.4 km east-northeast of the PWS compound (see Figure 1).

The landuse in the catchment is predominantly agricultural grazing. There are numerous domestic residences and residential farms along the roadsides in the vicinity of the PWS compound. The Slieve Russell hotel and golf course is located 2.5 km to the south-southeast.

6 Hydrometeorology

Establishing groundwater source protection zones requires an understanding of general hydrometeorological patterns across the area of interest. This information was obtained from Met Eireann.

Annual rainfall: 942 mm. The closest meteorological station to borehole PWSBH01 is Belturbet (Vocational School)[6], located 6.8 km east of the source boreholes. The annual average rainfall from 1961 to 1990 is 942 mm (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: 416 mm. The closest synoptic weather station to the study area is Clones, located 22 km to the east northeast. Average potential evapotranspiration (P.E.) at Clones between 1961 and 1990 was 438 mm (Fitzgerald and Forrestal, 1996). The contoured mean annual potential evapotranspiration for Ireland shows that PE at Ballyconnell is less than 450 mm/yr therefore, Clones is likely to adequately represent the study area P.E. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 416 mm.

Annual Effective Rainfall: 526 mm. This is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 526 mm/year.

[5] Both lake surfaces measured on 19/11/2010 using Cavan County Council GPS surveying equipment

[6] Note: This rainfall station closed in 1993 and was replaced by Belturbet (Naughan), 3.8 km to the north.

7 Geology

7.1 Introduction

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

The desk study data used comprised the following:

- Reports on groundwater resource investigations for the Ballyconnell Regional Water Supply Scheme between 2007 and 2008 (WYG, JB Barry, Jennings O'Donnovan)
- Boreholes logs of trial and production wells: Dunnes Water Services Ltd / WYG / JB Barry
- Geology of Monaghan - Carlingford. Bedrock Geology 1:100,000 Scale Map, Sheet 8. Geological Survey of Ireland (Geraghty, M. 1997)
- BCL borehole data and Hydrogeological Reports: 2003 and 2010 on behalf of Quinn Group
- EPA Subsoils Map (Teagasc,2006)

7.2 Bedrock geology

Sheet 8, the Geology of Monaghan - Carlingford published by the GSI shows that the area is underlain by the bedrock types described in Table 7-1. The bedrock types are shown in stratigraphic order in Table 7-1. The distribution of the bedrock units is shown in Figure 2.

Table 7-1: Bedrock Descriptions

Bedrock Formation	Generalised Rock Unit Classification	Geological Description	Max thickness (m)[7]
Drumgesh Shale (DH)	Dinantian shales and limestones (DSL)	Dark shale with fine grained limestone	
Meenymore Formation (ME)	Dinantian mixed sandstones, shales and limestones (DMSSL)	Shale, laminated carbonate, evaporite	500
Dartry Limestone (DA)	Dinantian pure bedded limestones (DPBL)	Dark, fine grained, cherty limestone	220
Benbulben Shale (BB)	Dinantian shales and limestones (DSL)	Calcareous shale with minor calcarenite	90 [8]
Mullaghmore Sandstone (MU)	Dinantian Sandstones (DS)	Sandstone, siltstone and shale (no outcrop in study area; present at depth)	
Bundoran Shale (BN)	Dinantian shales and limestones (DSL)	Dark shale with minor fine grained limestone	500

The source boreholes are located in the Dartry limestone, which underlies the bulk of the study area. Dolomitisation and fine silicification are common (Geraghty, 1997). The borehole logs for TW01, PWSBH01 and PWSBH02 record the presence of brown, dolomitised, fractured limestone with dark cherty limestone between 10 m and 40 mbgl, which includes the zone of groundwater inflow.

[7] Maximum thickness values taken from BCL (2005).

[8] Thickness from Geraghty (1997)

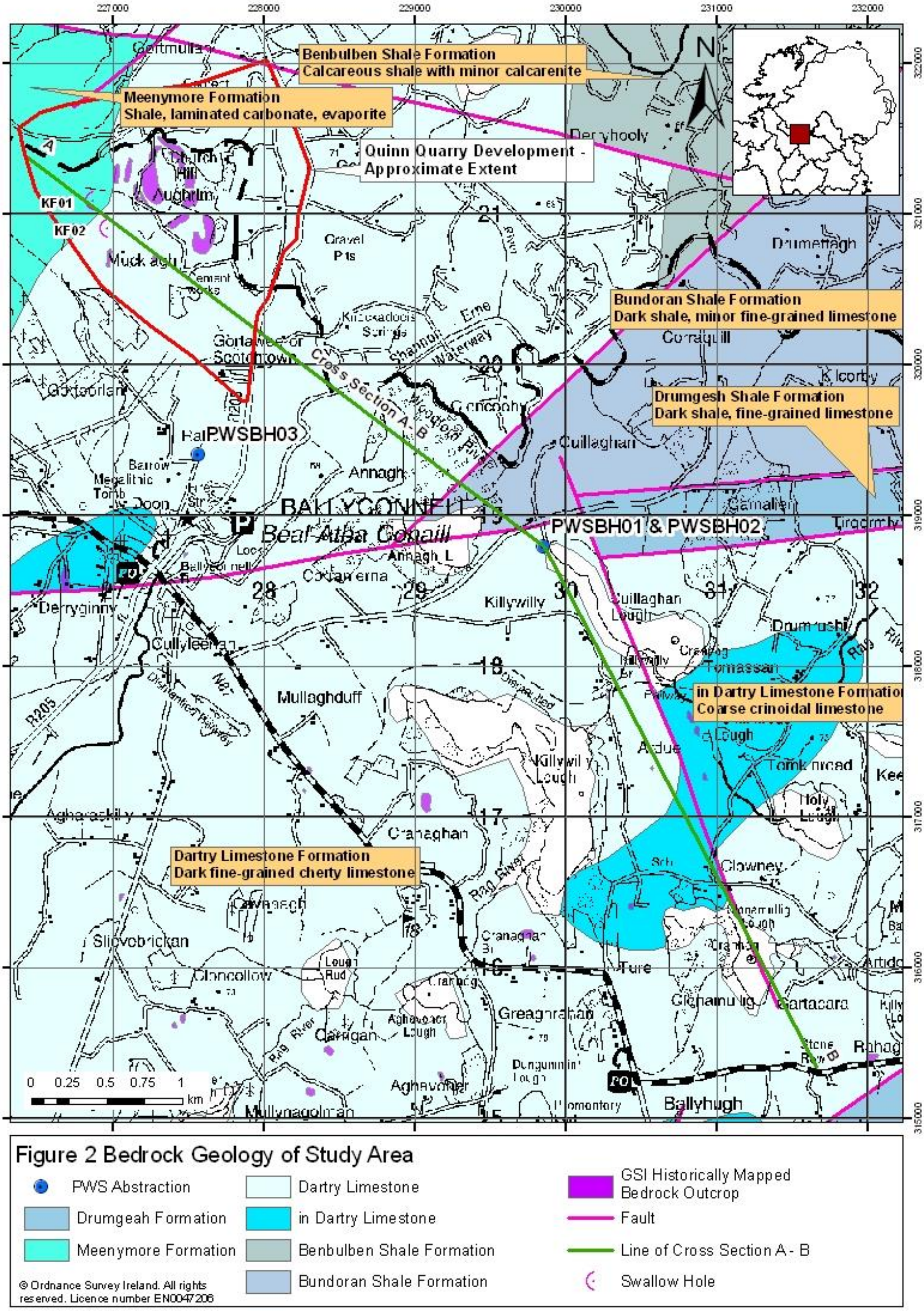

Figure 2 Bedrock Geology of Study Area

A mapped fault with downthrow on the southern side runs east – west, 150 m north of the source boreholes, and juxtaposes the Dartry Limestone and Bundoran Shale bedrock. A cross fault running northeast abuts the main fault 1 km west of the source and generates the same juxtaposition, this time with downthrow on the northwest side. Another fault runs north-northwest to south-southeast 300 m east of the source with downthrow on the western side. Two further east-west faults immediately to the east preserve a minor block of the youngest bedrock of the area, the Drumgesh Shale, between limestones to the south and older shales to the north. The bedrock strata are considered to dip northwest at approximately 5 degrees (Geraghty, 1997).

There are no karst features recorded for the study area in the GSI karst database. Three swallow holes were mapped historically to the west of the Quinn Mucklagh limestone quarry pit. One of these has been destroyed by quarrying, however the other two were located during this study (KF01 and KF02, Figure 2) and were found to have minor inflows (<0.5 l/s) from surface drainage. Further extensive karstification, including a cave feature, was observed in the walls of the Quinn limestone quarry (500 m northeast), although most were above the bedrock water table. Three caves are shown within the present day quarry footprint on the historical maps of the Mucklagh area. The mapped cave openings have been destroyed by the quarrying activity. Some discharge was observed from the quarry walls within 5 m of the quarry sump level. The groundwater inflow to the source boreholes is associated with heavily fractured, dolomitised rock at depth which is likely to be karstified, while the Lough Cuillaghan spring source is also considered to be a karst feature. Dolomitisation enhances the permeability of limestone by creating additional void space, which also increases the likelihood of karstification (GSI, 2004).

7.3 Soil and subsoil geology

The subsoil and soil distributions are illustrated in Figures 3 and 4, respectively.

Till subsoils cover the majority of the study area. Till derived from Namurian sandstones and shales (TNSSs) is mapped across the majority of the area east and west of source forming drumlins and covering the eastern flank of Slieve Rushen. To the southwest of Ballyconnell, the till type changes to that derived from chert and Carboniferous sandstones (TCSsCh).

Alluvial deposits are mapped along the Woodford River, and in places along the Rag River. Fen peat or cut peat deposits are mapped along the margins of numerous lakes, including Annagh and Killywilly loughs to the west and south of the source boreholes, and also across large areas to the south of Ballyconnell town. Lacustrine deposits are also mapped around several lakes, including around the shores of Lough Cuillaghan, which has no peat deposits flanking it, and in occasional inter-drumlin lows. Small areas of glaciofluvial sand and gravel deposits are mapped to the north of Ballyconnell and just west of Lough Cuillaghan, while made ground is mapped underlying Ballyconnell town and the Slieve Russell hotel, 3 km southeast of the town. Small areas of bedrock outcrop are mapped at the summits of the bedrock cored hills, such as at Ardue 1.5 km south-southeast of the source boreholes.

It is envisaged that, due to high clay content from their predominantly shale parent material, the TCSsCh and TNSSs tills in the study area are of low permeability. Borehole logs for boreholes TW01, PWSBH01 and PWSBH02 show 8 m of brown, gravelly CLAY. This overlies 2 m of angular, GRAVEL on top of bedrock. The GRAVEL is likely to be comprised of weathered bedrock. This suggests low permeability subsoil at this location. The lacustrine and peat deposits are also assumed to have a low permeability. The low permeability interpretations agree with the predominantly poorly drained soils mapped across the area (see below). GSI permeability mapping suggests that the alluvial deposits have moderate permeability. The small areas of glaciofluvial sand and gravel deposits are considered to have high permeability. The subsoil permeability observations correlate with the mapped soil types and are supported by field observations of poorly drained lands across the study area.

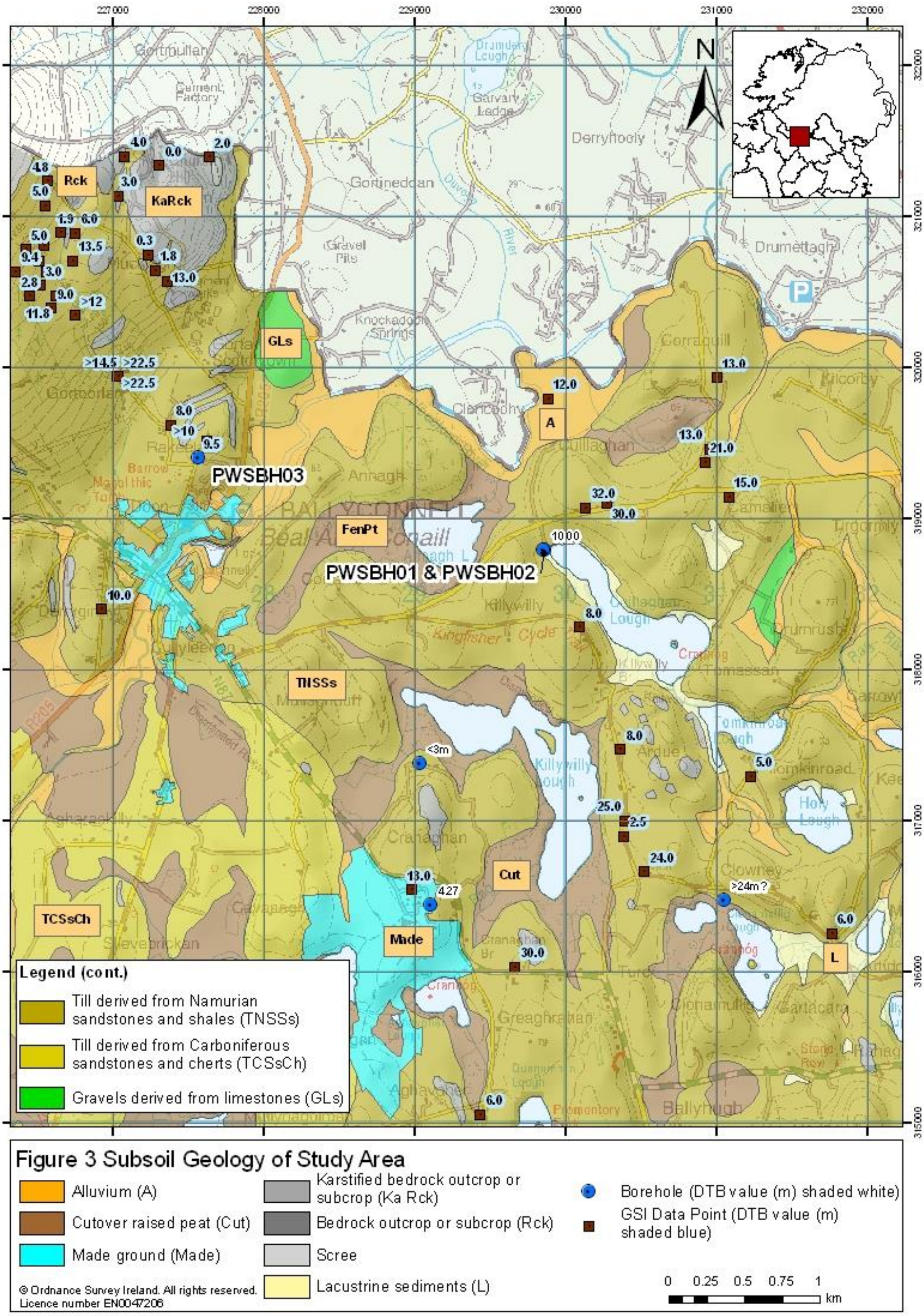

Figure 3 Subsoil Geology of Study Area

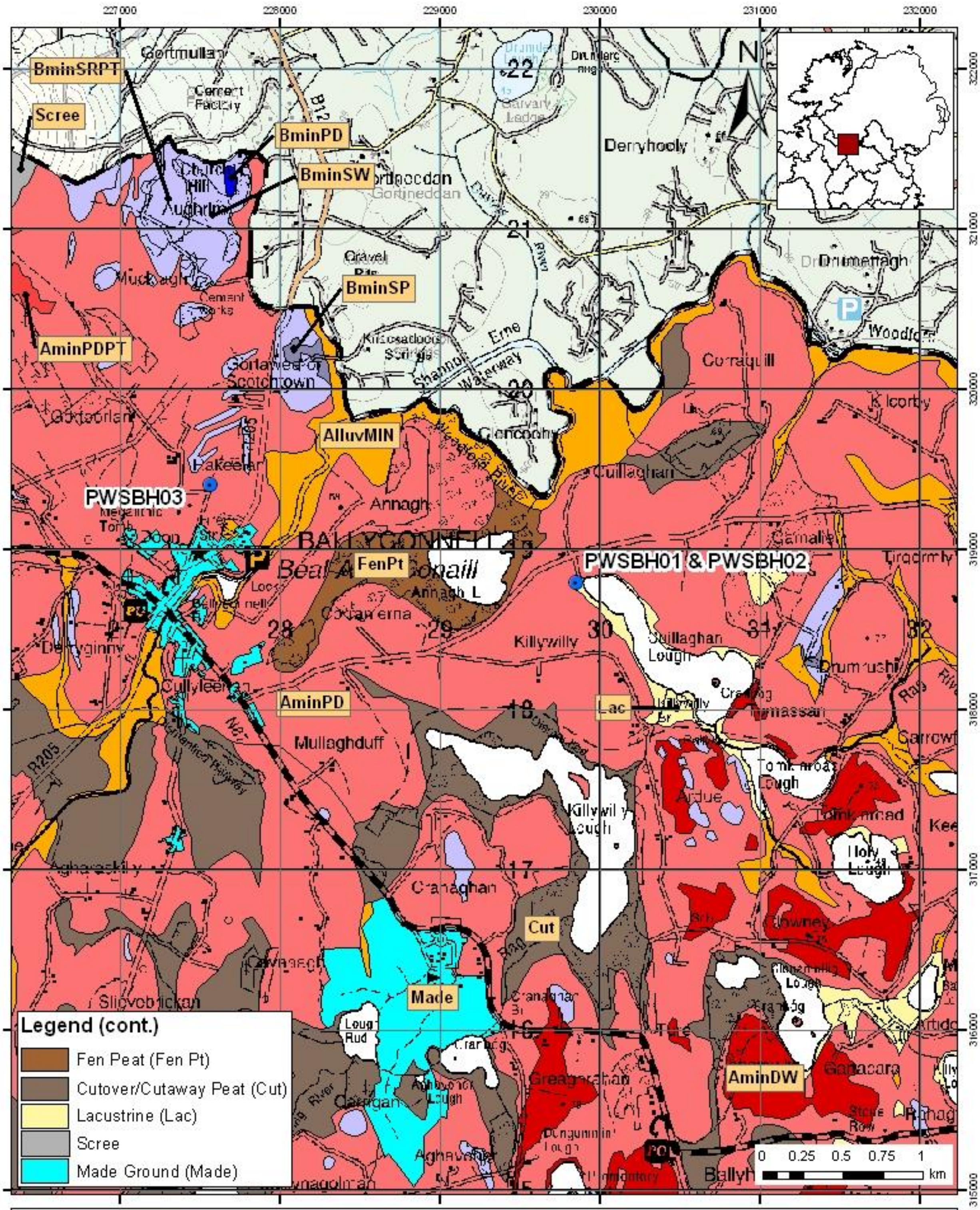

Figure 4 Soil Map of Study Area

Acid Deep Well Drained Mineral (AminDW)	Basic Deep Poorly Drained Mineral (BminPD)
Acid Deep Poorly Drained Mineral (AminPD)	Basic Shallow Well Drained Mineral (BminSW)
Acid Poorly Drained Peaty Mineral (AminPDPT)	Basic Shallow Poorly Drained Mineral (BminSP)
	Basic Shallow/Rocky/Peaty Mineral (BminSRPT)
	Mineral Alluvium (Alluvmin)

The EPA and GSI Web Mapping classify the soils at the source and surrounding Lough Cuillaghan as lacustrine. At distances typically greater than 10 m to 30 m from the source/lake (but up to 250 m at the southwest corner of the lake) the soils are predominantly mapped as deep, poorly drained, acidic mineral soils (AminPD). Peat and alluvial soils overlie the mapped peat and alluvial subsoils. Deep, well drained acid mineral soils (AminDW) occur on the tops of high hills to the southeast of the source, particularly atop bedrock-cored hills. Shallow, variable acidic to basic, well drained mineral soils are mapped on areas of bedrock outcrop and glaciofluvial deposits, although these are mapped as having a peaty sod in places.

7.4 Depth to bedrock

The available depth to bedrock (DTB) data for the area are shown on Figure 3. These show that in the drumlin areas across the study area and on the lower slopes of Slieve Rushen, DTB is generally greater than 10 m. The areas of cut peat, lacustrine deposits and alluvium surrounding the lakes in the vicinity of the source boreholes are considered to have DTB between 3 m and 5 m. The DTB at Lough Cuillaghan spring is considered to be within this range as thicker low permeability deposits would be likely to have prevented the spring discharge. The 10 m DTB logged at boreholes PWSBH01 and PWSBH02 (9 m at TW01) is considered to be a localised increase in DTB. On the higher ground in the vicinity of the Slieve Russell Hotel, southwest of the source boreholes, the DTB is generally between 5 m and 10 m although occasional bedrock outcrop also occurs in bedrock cored hills. On the upper slopes of Slieve Rushen bedrock outcrop and subcrop dominates.

8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater ‘target’. This means that in this area the vulnerability relates to the permeability and thickness of the subsoil. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al*., 2003).

The vulnerability map is shown in Figure 5. In terms of subsoil coverage within the catchment of the wells, the area can be divided into the following zones:

- Across most of the study area the low permeability subsoils and DTB in excess of 10 m combine to give low vulnerability.
- The low permeability cut peat and lacustrine subsoils (DTB 3 m to 5 m) around the lake shores are mapped as high vulnerability. This includes the site of Lough Cuillaghan Spring, with the presence of the spring itself suggesting relatively thinner subsoil deposits. The high permeability glaciofluvial sand and gravel deposits are also high vulnerability.
- The areas of alluvial subsoils (which may have underlying tills) are mapped as moderate vulnerability. The areas of higher ground to the southwest of the source with low permeability subsoil and DTB of 5 m to 10 m are also mapped as moderate vulnerability. At the source boreholes (20 to 30 m north of the spring) the CLAY thickness is 8 m giving localised moderate vulnerability.
- On the upper slopes of Slieve Rushen and in bedrock cored hills where outcrop occurs the vulnerability is classified as extreme. Additional areas of extreme vulnerability were mapped northwest of PWSBH03 by Robert Meehan in September 2010 based on landscape morphology and good drainage characteristics (see Figure 5).

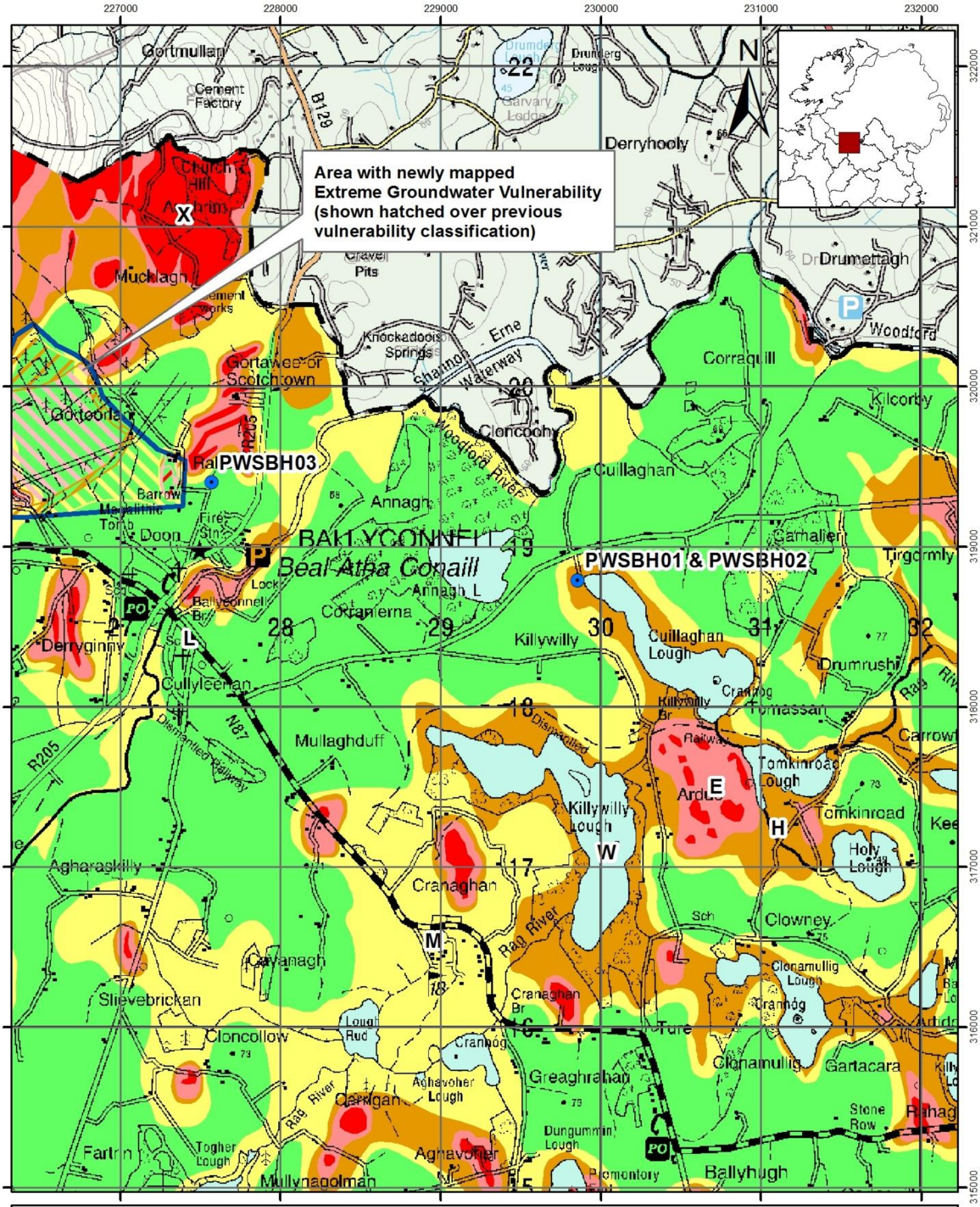

Figure 5 Groundwater Vulnerability of Study Area

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

0 0.25 0.5 0.75 1 km

9 Hydrogeology

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

- GSI Databases and WFD Groundwater Body Initial Characterisation Summaries
- County Council Staff
- GSI and EPA websites (September 2010)
- Reports on groundwater resources investigations and Preliminary Report for the Ballyconnell Regional Water Supply Scheme between 2007 and 2008 (WYG, JB Barry, Jennings O'Donnovan)
- BCL borehole data and Hydrogeological Reports: 2003 and 2010 on behalf of Quinn Group

9.1 Groundwater body and status

The boreholes are located in the Newtown-Ballyconnell groundwater body (GWB) (IEGBNI_NW_G_031) close to the boundary with the Derrylin GWB (IE_NB_G_016), which have been classified as being of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

9.2 Groundwater levels, flow directions and gradients

Desk study data and historical water level data pertaining to the source boreholes and surrounding private boreholes are shown in Table A2.1 in Appendix 2. A groundwater level survey of the Ballyconnell area was carried out on 16 and 17 November 2010. Water levels, water level datum point elevation and adjacent ground level elevation were measured across the study area. The data are shown in Table A2.2 in Appendix 2, with the data point locations shown in Figure A2.1 in this Appendix. The groundwater level in mAOD for each groundwater depth has been calculated and the resulting groundwater elevation at each monitoring point is shown in Figure 6. Interpreted contours of groundwater elevation derived from the point data are also shown.

The available groundwater elevation, abstraction and source data suggest that:

- Groundwater flow radiates out from Slieve Rushen, flowing southeast off the mountain to the vicinity of Ballyconnell. Nested piezometers adjacent to the Woodford River and Gortawee Spring (GW01) show that there is an upwards hydraulic gradient on the western side of the river, which suggests that the groundwater flow off the mountain discharges to the river.
- There is another groundwater high immediately north of the source boreholes in the Cuillaghan and Corraquill townlands, with groundwater flow radiating out from the 50 m OD contour, northwards towards the Woodford River and southwards towards Lough Cuillaghan and the Rag River.
- Across the remainder of the study area, between the source boreholes and Ballyconnell and to the south, the spot measurements of groundwater level are considered to be too incoherent to permit contouring. This is likely to be due to the karstified nature of the limestone bedrock. The bedrock in this area is confined by the overlying thick, low permeability subsoil creating a pressurised system. Recharge to the system occurs via "windows" of extreme vulnerability. Groundwater subsequently flows to discharge points, such as Lough Cuillaghan spring and the Woodford River, following potentially chaotic flow paths through the karstified bedrock. Possible generalised flow lines are shown on Figure 6. Discharge may also occur to lakes in the area *via* submerged springs.

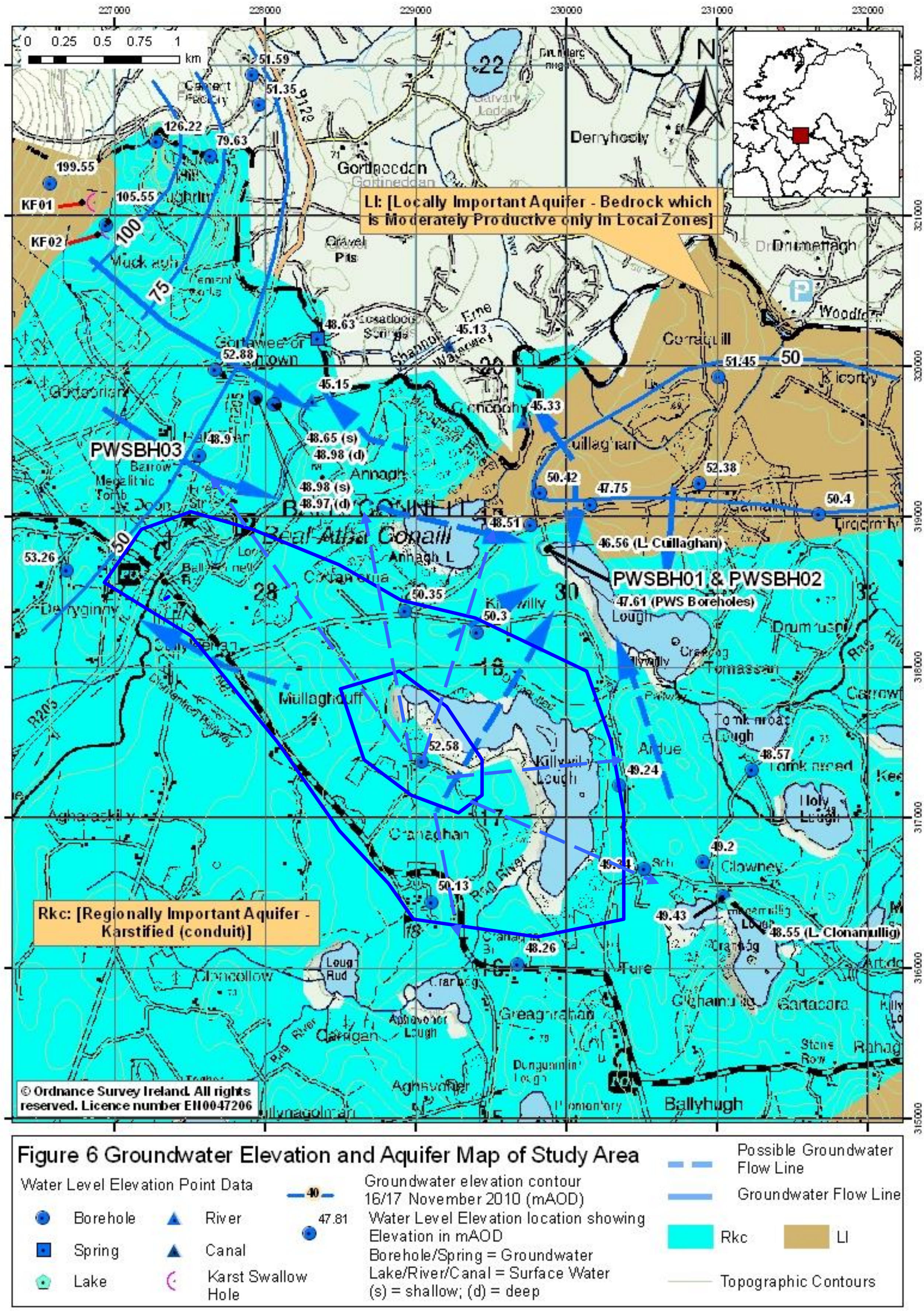

Figure 6 Groundwater Elevation and Aquifer Map of Study Area

- The mapped north-northwest trending fault to the east of the source boreholes suggests a potential alignment for bedrock fractures and karstification, which may provide a preferential pathway for recharge in the Ardue extreme vulnerability area to reach Lough Cuillaghan Spring.
- Drawdown in the source boreholes during pumping tests in July 2008 resulted in a drawdown of 4.2 m in PWSBH01 and 2.7 m in PWSBH02. These pumping water levels are below the water level in the adjacent Lough Cuillaghan and create a hydraulic gradient from the lake towards the boreholes. The water level and yield from Lough Cuillaghan Spring drop to a minimum during summer months (WYG, 2007). Lake inflows may be most likely at this time of year when the difference between demand and the natural yield of the system is maximised, resulting in greatest drawdown in the boreholes.
- The hydraulic gradient driving groundwater flow southeast off Slieve Rushen is estimated to be approximately 0.05. In the vicinity of the Lough Cuillaghan source boreholes, based on linear interpolation between individual data points and the source, gradients range from 0.001 (between the Slieve Russell Hotel area and the source) to 0.004 (between data points in Killywilly townland and the source).

9.3 Hydrochemistry and water quality

Untreated water quality data were collected at either borehole PWSBH01 or PWSBH02 on nine occasions in 2009 by JB Barry Consulting Engineers, on behalf of Cavan County Council. Further untreated water quality data for the source site were collected by WYG Consulting Engineers from borehole TW01 and from Lough Cuillaghan Spring during the pumping test on borehole TW01 on 24/01/2007. The samples were analysed by Alcontrol Laboratories in accordance with the appropriate Drinking Water Quality Regulations (SI 439 of 2000 for samples prior to June 2007; SI 278 of 2007 for samples after June 2007). Further samples were collected as part of this study from borehole TW01, and from Lough Cuillaghan at a point adjacent to the source site in November 2010 and were analysed for major ions and physico-chemical parameters.

Data from boreholes TW01, PWSBH01, PWSBH02 and Lough Cuillaghan Spring are all considered to represent groundwater inflow from the same zone of karstification at 24 m to 26 mbgl. The data from the borehole sources are summarised graphically in Figures 7 to 9 and the data interpretation is summarised below. The available data are tabulated in Table A2.3 in Appendix 2.

- The water is moderately hard (169 to 199 mg/l as $CaCO_3$) and has a calcium bicarbonate hydrochemical signature with a moderately significant magnesium component. The average conductivity is 369 µS/cm and average pH is slightly alkaline at 7.6. The groundwater (based on TW01) is saturated for calcite but under-saturated for dolomite. The available hydrochemistry data do not show any clear indication of mixing between lake water and groundwater in the discharge from boreholes PWSBH01 and PWSBH02.
- No total or faecal coliforms were detected at the boreholes; however Clostridium Perfringens was detected at TW01 at 2 cfu/100ml on 24/01/2007. Faecal and total coliforms were detected at the spring on 24/01/2007 at 2 cfu/100ml and 30 cfu/100ml respectively. Ammonium was detected at 0.21 mg/l as N at PWBH02 on a single occasion on 27/10/2009, but was below the detection limit in all other samples. These occurrences may suggest that the borehole and spring can be impacted by spikes of pollution in the karst system. No cryptosporidium detections occurred during monitoring for cryptosporidium at boreholes PWSBH01 and PWSBH02 over nine months in 2009.
- Nitrate was detected in 7 out of the 11 samples between 2007 and 2010. The values were all well below the EPA threshold for nitrate and indicate a low background concentration in the aquifer. Measured chloride concentrations ranged from <10 mg/l to 13 mg/l which is in the range of typical natural background concentrations.

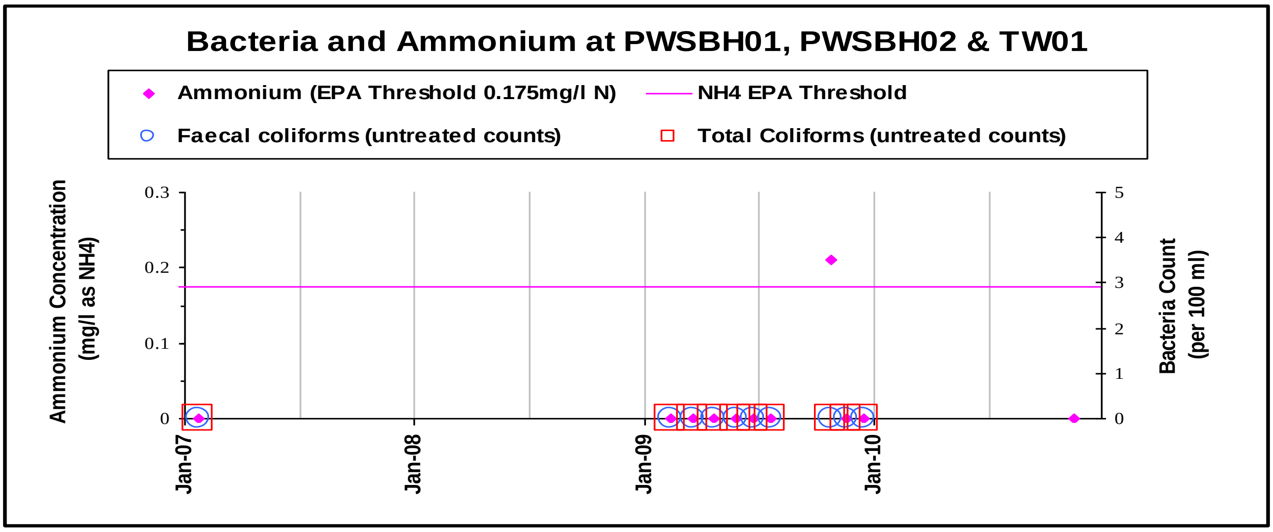

Figure 7 Key Indicators of Agri and Domestic Contamination (BW02): Bacteria and Ammonium

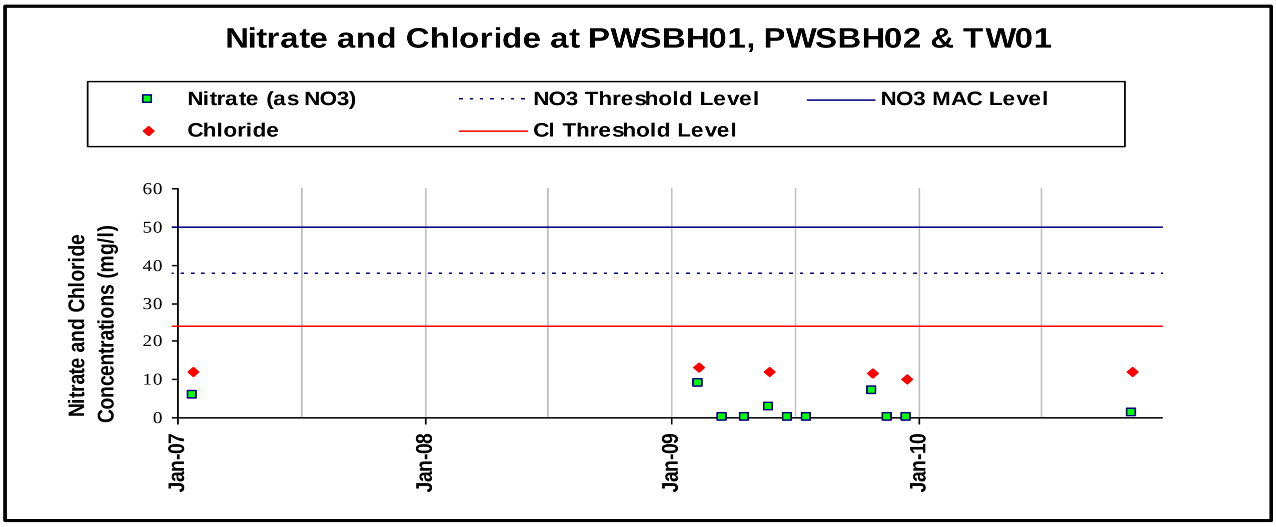

Figure 8 Key Indicators of Agri and Domestic Contamination (BW02): Nitrate and Chloride

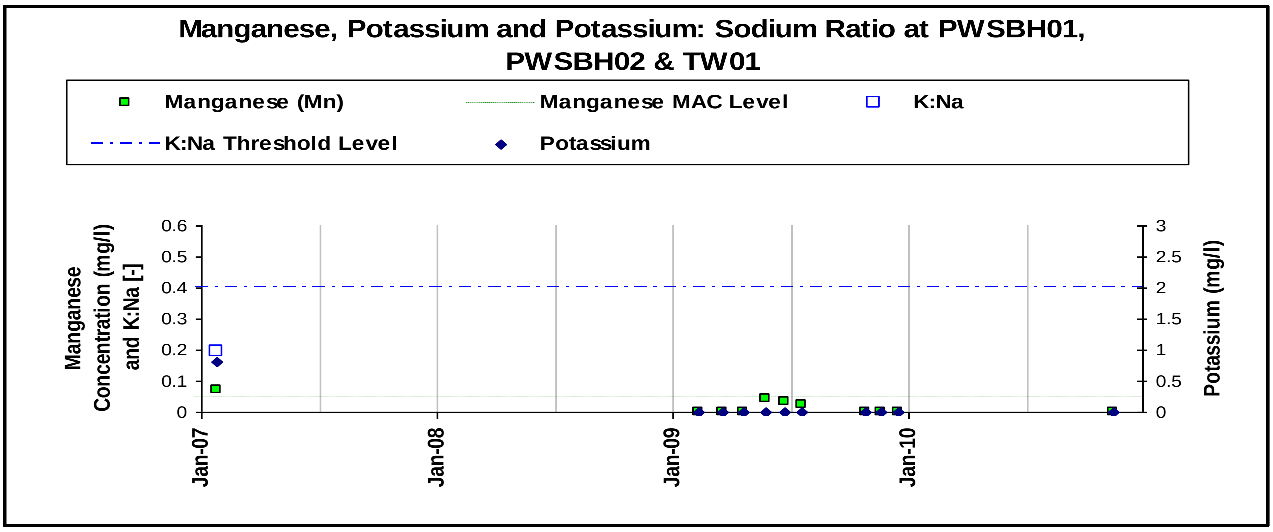

Figure 9 Key Indicators of Agri and Domestic Contamination (BW02): Mn, Fe, K and K:Na ratio

- The sulphate, potassium, sodium, magnesium and calcium levels and the K:Na ratio are within normal ranges (only one data point for K and K:Na; from TW01 on 24/01/2007).
- Concentrations of total iron and total manganese in excess of the drinking water standard were recorded in borehole TW01 in January 2007. Elevated total iron was also detected in the spring on the same date. These were total concentrations associated with sediment in an unfiltered sample. Concentrations of dissolved iron and manganese from the same sample as well as iron and manganese concentrations from subsequent analyses at PWSBH01 and PWSBH02 were below the MAC levels.
- Other trace metals were either within the normal range for good quality drinking water or were not detected. Similarly, organic compounds and herbicides have not been detected.

The data suggest that the groundwater from both of the source boreholes is unpolluted but may be susceptible to spikes of pollution passing through the karst system. This is corroborated by the detection of faecal and total coliforms in a sample from Lough Cuillaghan Spring taken on 24/01/2007. Naturally elevated concentrations of iron and manganese are also associated with sediment in the unfiltered groundwater. Apart from the detection of coliform bacteria, the spring water quality is very similar to the borehole water quality.

9.4 Aquifer characteristics

Boreholes PWSBH01, PWSBH02 and TW01 abstract water from the Dartry Limestone bedrock. The Dartry Limestone is classified by the GSI as a *Regionally Important Aquifer – Karstified (Conduit) (Rk$_c$)*. The various shale bedrock strata which outcrop across the study area are classified as *Locally Important Aquifers – bedrock which is moderately productive only in local zones* (*Ll*) (see Figure 6). During pumping tests at the source site (TW01 72 hour test in January 2007; PWSBH01 and PWSBH02 combined 7 day test in July 2008), in which the wells were pumped in excess of current demand, the pumping water level in the boreholes remained above the base of the subsoil (10 mbgl), and the top of the well screen (19 mbgl). Rest water level data at boreholes PWSBH01 and PWSBH02 show that the piezometric level is generally above ground level, while borehole TW01 overflows strongly (approximately 300 m^3/day at start of January 2007 pumping test). These data indicate that the limestone bedrock intersected by the boreholes is confined by the low permeability overburden.

The presence of Lough Cuillaghan spring suggests the existence of some permeable discharge pathways through the shallower, high vulnerability subsoil at the spring. The leakage from the Council PWS sump also suggests some preferential pathways through the gravelly CLAY subsoil at the source boreholes. During the 2008 pumping test on the source boreholes, the combined abstraction rate was 3,500 m^3/day. Approximately 973 m^3/day was lost by leakage from the Council sump and is considered to have (at least partially) recycled back through the overburden to the borehole intakes (JBB, 2008). The sump leakage was identified and quantified through water balance calculations using flow meter data from the pumping test discharge set-up. The sump floor was subsequently cleaned of sediment and found to be shattered.

Groundwater flow in the Dartry limestone is dominated by conduit flow. This is seen by the large inflow at 24 m to 26 mbgl in each of boreholes PWSBH01, PWSBH02 and TW01. A further inflow occurred at 40 m to 41 mbgl in borehole TW01 in a fractured sandstone bed within the limestone. Dolomitisation of parts of the limestone aquifer (as recorded in the source borehole logs) may also cause enhanced permeability by creating additional interconnected void space. Long groundwater flow paths (kilometres in length) can be expected in Rk$_c$ aquifers, although they may be shorter (100 – 300 m) in discharge areas (GSI, 2004).

The thick till cover and lakes obscure many of the typical karst surface features which give insight into these aspects of a karst system (e.g. swallow holes and springs). The shallow and variable hydraulic gradients observed in the groundwater level data means that no dominant regional groundwater flow direction could be identified. As such based on the current scale of study, which relies on available data and largely non-intrusive field mapping, it was not possible to identify the hydraulic boundaries of the karst system, and therefore the scale of the groundwater flow paths.

The minimum, summer yield from the Lough Cuillaghan Spring is considered to be 396 m^3/day (WYG, 2007).

Pumping tests were carried out on TW01 in January 2007 and on boreholes PWSBH01 and PWSBH02 in July 2008. Analysis of the data from the test on borehole TW01 suggests that the aquifer transmissivity is in the region of 832 m^2/day; however this may be an overestimation due to re-cycling of leakage from the sump (Appendix 3). Pumping tests by BCL (2005) in the Dartry Limestone in the vicinity of the Quinn limestone quarry to the north of Ballyconnell suggests that the competent bedrock away from karst conduits has a low transmissivity in the range of 0.1 m^2/day to 26 m^2/day (no conduits were encountered in boreholes drilled for the testing programme). A layer of highly weathered limestone, described as "disaggregated" by BCL (2005) overlay the competent rock, below the subsoil, and had a transmissivity of approximately 180 m^2/day.

Bulk aquifer permeability in the vicinity of the source boreholes has been calculated using data for borehole TW01 by dividing the transmissivity from the January 2007 pumping test by the thickness of the karst conduit zone at 24 m to 26 mbgl. The resulting bulk aquifer permeability (K) estimation is shown in Table 9-1.

The velocity of water moving through the aquifers to the boreholes is estimated using Darcy's Law:

Velocity (V) = (K x Groundwater Gradient (i)) / porosity (n)

The hydraulic gradient in the Rk_c aquifer in the vicinity of the source boreholes is estimated at between 0.001 and 0.004 (Section 9.2). The average natural gradient is therefore estimated at 0.0025. No data on bedrock porosity are available however; the fracture porosity of the karst conduit intersected by the source boreholes is estimated at 0.3 based on experience of similar aquifers at other locations.

Table 9-1: Indicative Aquifer Hydraulic Parameters

Parameters	Source of Data	***Rk_c*** **aquifer (BW03)**
Transmissivity (m^2/d)	Calculated (based on pumping test data)	832
Permeability (m/d)	estimated from T value assuming saturated thickness is the aperture of the intersected karst conduit	416
Effective Porosity	Assumed (based on regional experience)	0.3
Groundwater gradient	Assumed based on groundwater level data	0.0025
Velocity (m/d)	calculated based on above	3.5

The average velocity of groundwater moving through the Rk_c is estimated at approximately 3.5 m/d. The aquifer parameters are summarized in Table 9-1.

10 Zone of Contribution

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

10.1 Conceptual model

The source boreholes PWSBH01 and PWSBH02 abstract from the Rk_c aquifer *via* a karst conduit at 24 m to 26 mbgl. The Rk_c aquifer is a pressurised system confined by the overlying thick, low permeability subsoil. Recharge to the confined system occurs predominantly *via* windows of extreme groundwater vulnerability. These occur at bedrock outcrop at the crests of the occasional bedrock cored hills which are scattered across the drumlin landscape. Groundwater subsequently flows from the localised recharge zones to discharge points within the karst network, *i.e*. borehole intakes, spring discharges, submerged lake springs and baseflow to the Woodford River. Flow directions within the karst network are unpredictable and chaotic as they are dependent on the locations of the more permeable fractured, karstified and dolomitised conduits.

In the absence of any clearly identified hydraulic boundaries for the karst system, it is assumed that the system is likely to be restricted to the local topographic catchment of the source boreholes/spring and nearby lakes, while groundwater flow from Slieve Rushen discharges to the Woodford River to the west of the sources. The karst aquifer is confined and the surface water system is largely perched above it, with discrete points of interaction occurring at spring discharges. Therefore there is a lot of uncertainty associated with using the topographic catchment to constrain the karst system; however the concept of recharge to the system via extreme vulnerability windows, which occur at the top of bedrock cored hills, gives some justification for this approach.

The likelihood of shallow bedrock at Lough Cuillaghan Spring and of leakage pathways between the Council sump and the source boreholes, suggest that there are permeable pathways through the subsoil at the source site, which is adjacent to Lough Cuillaghan. As such, because the pumping water levels in the boreholes are lower than the level of the lake, there is a possibility that leakage of lake water into the boreholes, through the subsoil, could be induced. The available hydrochemistry data do not show any clear indication of mixing between lake water and groundwater in the discharge from boreholes PWSBH01 and PWSBH02; however this should be further investigated after the boreholes have been brought into full commission.

Groundwater level data for the wedge-shaped *Ll* aquifer located immediately north and northeast of the source boreholes suggest that there is a localised groundwater high in that aquifer, with groundwater radiating outwards towards the Woodford River to the north and Lough Cuillaghan and the Rk_c aquifer to the south. Given the aquifer classification and limited recharge footprint, the magnitude of the groundwater flow volume is likely to be small.

The hydrochemistry of the source boreholes appears to be dominated by interaction with the limestone bedrock of the karst system. To date the groundwater has been generally unpolluted but may be susceptible to spikes of pollution entering the karst conduit system. Naturally elevated levels of manganese appear to be associated with sediment within the karst system.

The conceptual model for the area is illustrated in the cross section in Figure 10.

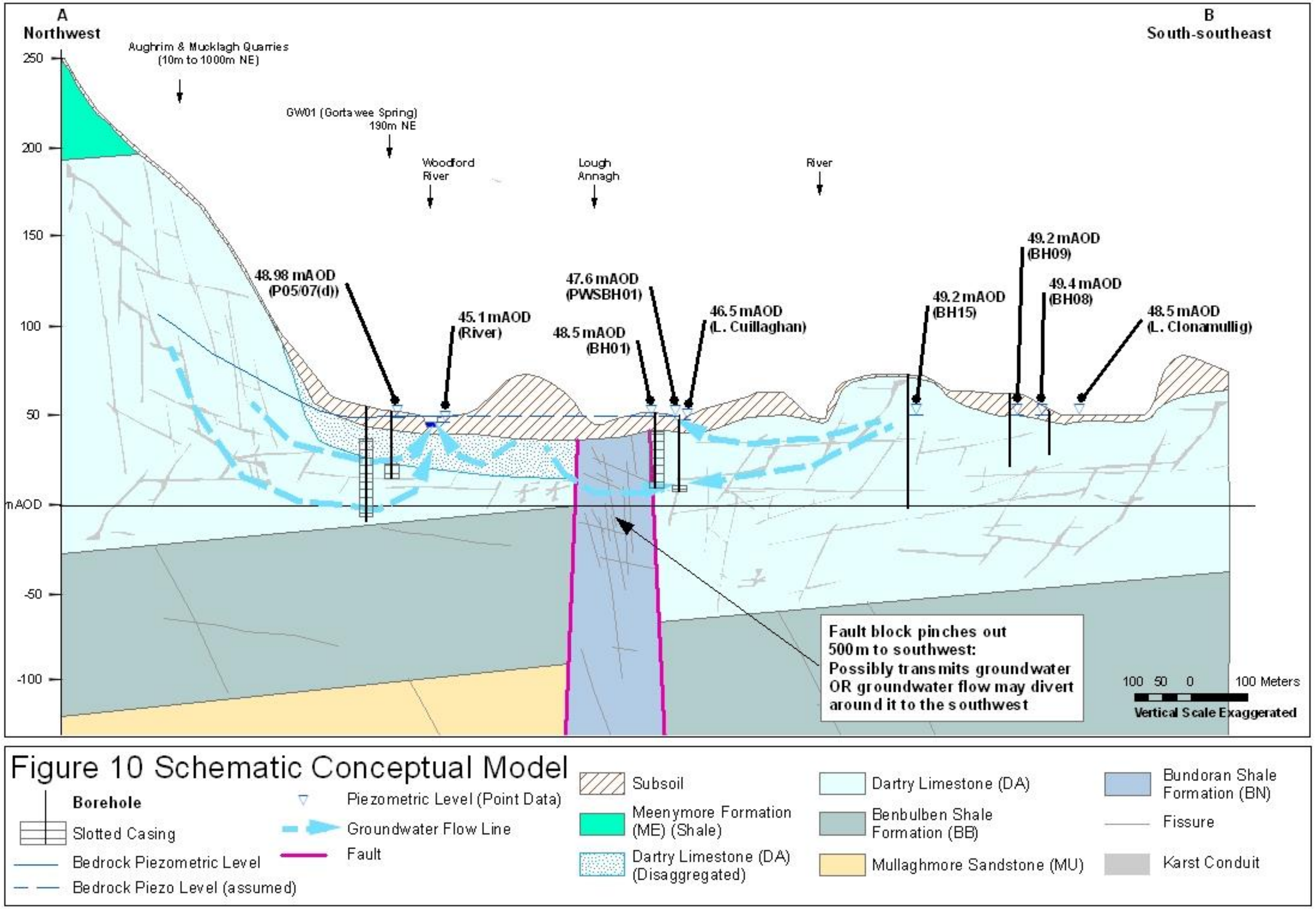

Figure 10 Schematic Conceptual Model

10.2 Boundaries of the ZOC

The ZOC has been delineated across both the Rk_c and *Ll* aquifers. It is considered that the source boreholes, the artesian trial well TW01, and Lough Cuillaghan Spring all derive their discharge from the same karst conduit. As such, individual ZOCs cannot be differentiated for the individual sources and the various sources are covered by a single ZOC. The boundaries of the areas contributing to the source boreholes, trial well and spring are considered to be as follows (Figure 11):

The **northern boundary** is delineated through the *Ll* aquifer along the topographic divide between the west-east reach of the Woodford River and Lough Cuillaghan. Groundwater flow to the north of the boundary is considered to go to the river while to the south it flows towards the lake, discharging from the *Ll* aquifer into the Rk_c aquifer and flowing to the lake/source boreholes. The boundary is extended west into the Rk_c aquifer as far as the topographic divide northwest of Lough Annagh in order to conservatively include the catchment of Lough Annagh within the ZOC.

The **western boundary** is delineated along the topographic divide between Lough Annagh/Lough Killywilly and the northeast trending reach of the Woodford River through Ballyconnell town. Recharge to the west of the boundary is considered to flow to the river while to the east it is directed towards the source boreholes/lake system.

The **southern boundary** follows the topographic divide to the south of Lough Killywilly and Holy Lough. This boundary encloses recharge areas of extreme groundwater vulnerability with measured, high groundwater elevation which are considered likely to drive groundwater flow towards Lough Cuillaghan Spring and the source boreholes.

The **eastern boundary** follows the topographic divide east of Holy, Tomkinroad and Cuillaghan Loughs. Recharge to the west of the boundary is considered likely to discharge to the lake system. Submerged springs in the lake beds may be linked to the same karst system as the boreholes. Drawdown at the boreholes will create a hydraulic gradient between the lakes and the boreholes which may induce leakage from the lakes to the source boreholes.

Because clear hydraulic boundaries could not be identified for the karst system, there is a large degree of uncertainty in all of the delineated ZOC boundaries. Nonetheless, the measured groundwater elevations across the delineated ZOC are higher than the groundwater elevation at the source boreholes. This suggests that where the karst pathways exist, groundwater flow to the boreholes could potentially occur. The ZOC also incorporates the nearest lakes surrounding the source boreholes in case of any borehole-groundwater-lake interactions.

10.3 Recharge and water balance

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (*i.e*. annual rainfall) less water loss prior to entry into the groundwater system (*i.e*. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is important in source protection delineation, as it will dictate the size of the ZOC to the source (and therefore the Outer Source Protection Area). The recharge is estimated as follows.

Potential recharge is equivalent to 526 mm/yr i.e. (Annual Effective Rainfall, see Section 6).

Actual recharge has been estimated to be 79 mm/yr, which is 15% of potential recharge; this value is based on averaging of the recharge for the different settings outlined in Table 10-1.

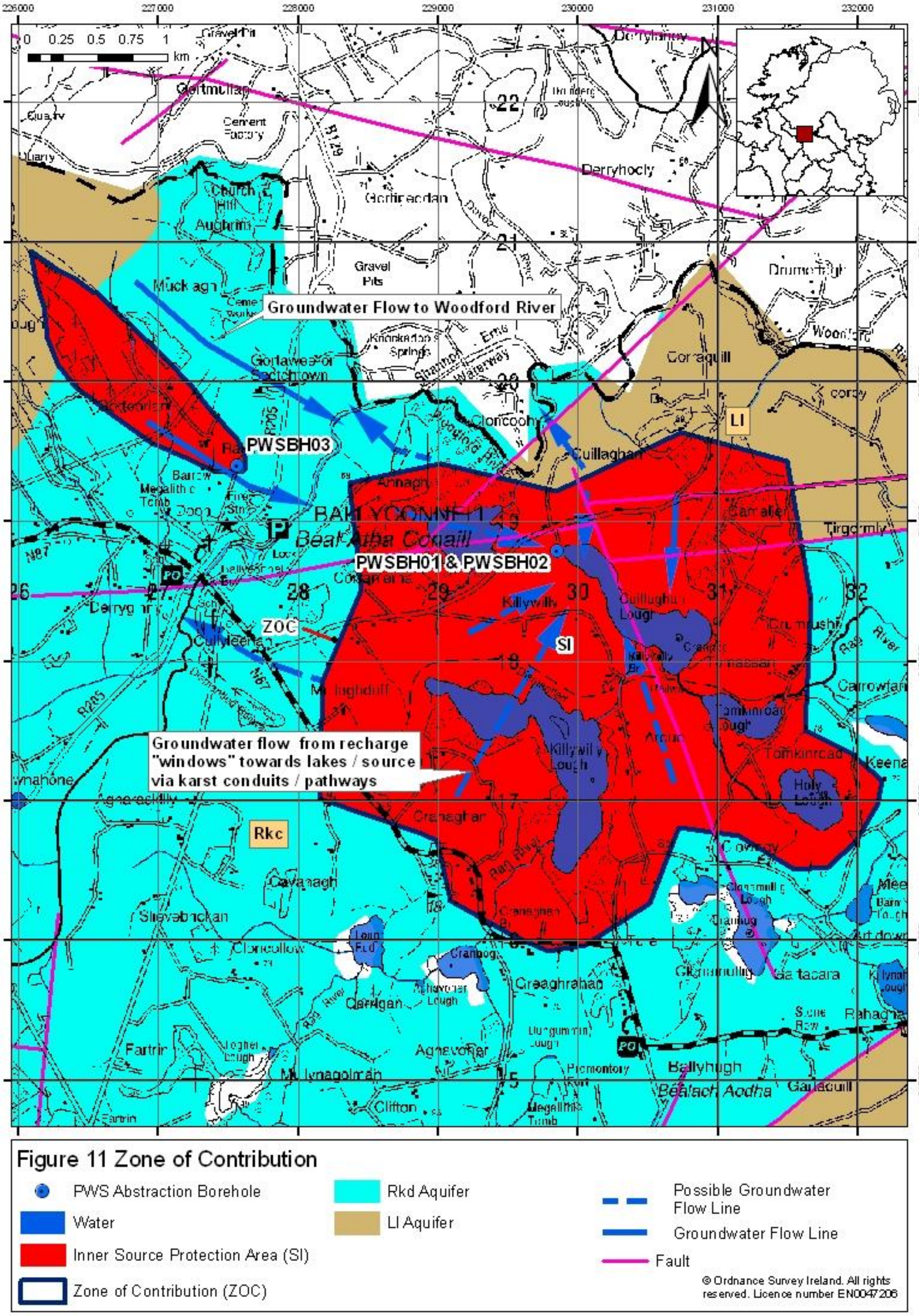

Figure 11 Zone of Contribution

Runoff losses: 447 mm (85% of potential recharge). Rejected potential recharge is assumed to runoff to surface water via surface and interflow.

These calculations are summarised in Table 10-2.

Table 10-1 Recharge co-efficients for the study area

Vulnerability	Location in Study Area	Additional Factors	% Area	Recharge Coefficient Guidance		Chosen Recharge Coefficient	Calculated Recharge Component
				Inner Range	Outer Range		(mm/yr)
Low	Peat subsoils	Confined bedrock aquifer	5.5	3 - 5%	0 - 10%	0.03	4.3
	Low permeability subsoils, i.e. tills, lacustrine deposits	Confined bedrock aquifer. Limited more permeable zones	42.8	5 - 15 %	2 - 20%	0.1	33.7
Moderate	Low permeability subsoils, i.e. tills, lacustrine deposits	Confined bedrock aquifer	19.9	10 - 20%	5 - 30%	0.1	15.7
	Moderate permeability subsoils (alluvial deposits) with poorly drained soils	In groundwater discharge, riparian zones. Probably overlying low k subsoils	1.2	20 - 40%	10 - 50%	0.2	0.9
	Thin cut peat subsoils	Confined bedrock aquifer	3.2	3 - 5%	0 - 10%	0.03	2.5
High	High permeability subsoil (GLs) with poorly drained soil due to groundwater discharge	Groundwater discharge zone	0.1	0%	0%	0	0.1
	High permeability subsoil (GLs) with well-drained soil	Low slope	0.9	80 - 90%	60 - 100%	0.9	0.7
	Low permeability subsoils, i.e. tills, lacustrine deposits	Higher ground, possibly reduced confining pressure	10.2	23 - 30%	10 - 40%	0.3	8.0
	Moderate permeability subsoils (alluvial deposits) with poorly drained soils	In groundwater discharge, riparian zones	0.9	25 - 40%	15 - 50%	0.25	0.7
	Thin cut peat subsoils		7.8	5 - 15%	0 - 20%	0.05	6.1
Extreme (E)	Till subsoils with poorly drained soil	Main recharge area	4.9	25 - 40%	15 - 50%	0.4	3.9
	Till subsoils with well-drained soil	Main recharge area	1.1	50 - 70%	45 - 80%	0.8	0.9
Extreme (X)	Bedrock outcrop	Main recharge area	1.5	80 – 90%	60 – 100%	0.9	1.2

The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. At a recharge of 79 mm/yr, a PWS demand of 814 m^3/day requires a recharge area of 3.8 km^2. The area of the delineated ZOC is 8.9 km^2 (equivalent to 1927 m^3/d). This is 2.4 times the target area and is shown in Figure 14. In addition to the borehole abstraction there will also be continued discharge from Lough Cuillaghan spring.

The maximum summer discharge from the spring is 396 m^3/day. As such the ZOC is large enough to accommodate the PWS borehole abstraction and the spring discharge, particularly since drawdown from the borehole abstraction is likely to reduce the natural spring discharge. Finally, there is a residual component of the ZOC which is available to sustain the unquantified component of the recharge which is likely to discharge to lakes within the ZOC via submerged springs.

Boreholes PWSBH01 and PWSBH02 are estimated to each have a sustainable yield of 1,500 m^3/day, giving a total of 3,000 m^3/day. This exceeds the delineated ZOC footprint by 55% and could be interpreted as suggesting that at a total abstraction 3,000 m^3/day the boreholes may be obtaining a component of their discharge from Lough Cuillaghan.

Table 10-2 Bedrock Recharge Calculation Summary

Parameter	Coefficient	Rate
Average rainfall (R)		942 mm/yr
Estimated P.E.		438 mm/yr
Estimated A.E. (95% of P.E.)		416 mm/yr
Effective rainfall		526 mm/yr
Potential recharge		526 mm/yr
Averaged runoff losses	(85%)	447mm/yr
Bulk recharge coefficient	0.15	
Recharge		79 mm/yr

11 Source Protection Zones

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

The Inner Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (TOT) to the supply (DELG/EPA/GSI 1999). Based on the indicative aquifer parameters presented in section 8.5, the groundwater velocity is 3.5 m/d in the Rk_c aquifer, such that the 100-day TOT distance is 350 m. Parts of the ZOC delineated in the *Rk* aquifer lie outside the relevant 100-day TOT limit, however flow velocity in individual karst conduits can greatly exceed the calculated average for the bulk aquifer, thereby compromising the calculated SI extent. As such, the entire ZOC is conservatively classified as SI. The Inner Protection Area is illustrated in Figure 11.

The groundwater Source Protection Zones are shown in Figure 12 and are listed in Table 11-1. They include SI/X, SI/E, SI/H, SI/M and SI/L. Almost 50% of the ZOC is designated as SI/L.

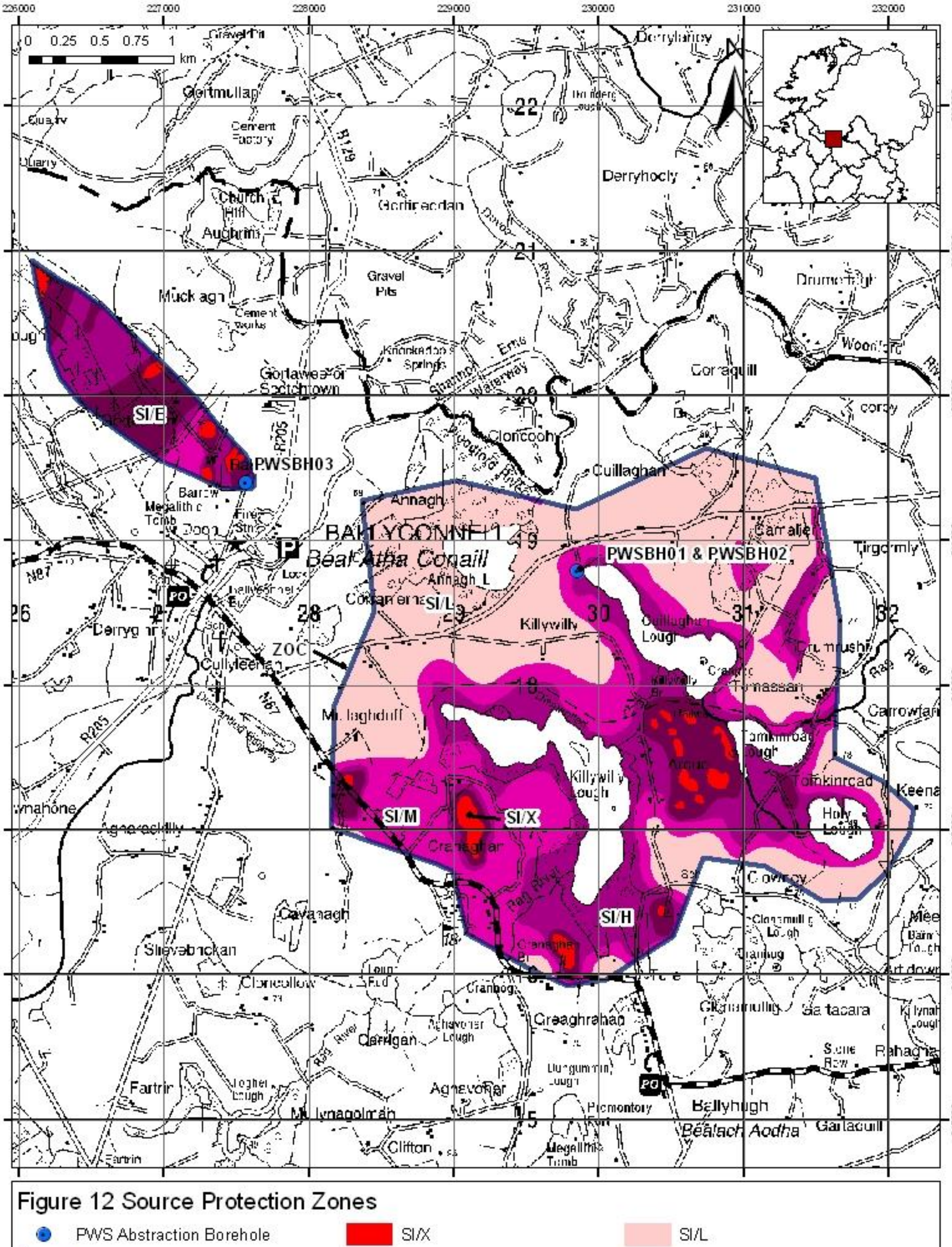

Figure 12 Source Protection Zones

PWS Abstraction Borehole
Zone of Contribution (ZOC)
SI/X
SI/E
SI/H
SI/M
SI/L

Table 11-1 Source Protection Zones

Source Protection Zone		% of total area (km^2)	
SI/X	Inner Source Protection area / ≤1 m subsoil	1.5%	(0.13 km^2)
SI/E	Inner Source Protection area / <3 m subsoil	6.1%	(0.54 km^2)
SI/H	Inner Source Protection area / High vulnerability	19.8%	(1.77 km^2)
SI/M	Inner Source Protection area / Moderate vulnerability	24.3%	(2.17 km^2)
SI/L	Inner Source Protection area / Low vulnerability	48.3%	(4.31 km^2)

12 Potential pollution sources

Neither the source boreholes PWSBH01 and PWSBH02, nor the trial well TW01, have a grout seal in the borehole annulus. As such, there is potential for contamination of the boreholes by surface contaminants. This is particularly true of PWSBH02, which has a severely broken concrete plinth and is the most susceptible to flooding by the adjacent lake. The two production wells are capped, however the trial well is uncapped and vulnerable to direct contamination from surface spills or animal activity (e.g. despite the artesian nature of the borehole, high density hydrocarbons (DNAPL) could sink into the borehole if spilled on site).

The landuse within the ZOC is primarily agricultural with numerous residential farms and pasture for grazing animals. Agricultural activities such as grazing and landspreading of agricultural waste present a potential risk of microbial pollution to the boreholes as well as the potential for elevated concentrations of ammonia, nitrate, phosphate, chloride, potassium, BOD, COD, TOC and pesticides. Testing to date suggests that the water quality at the source boreholes is good. Single detections of ammonia in borehole PWSBH02 and Clostridium Perfringens in borehole TW01, and detection of coliform bacteria in Lough Cuillaghan Spring suggest that the karst system can be subject to sporadic spikes of pollution. Given the Rk_c aquifer classification and the conceptual model of recharge *via* areas of extreme vulnerability within the ZOC/SI, the potential risk from cryptosporidium and viruses is high. Nonetheless, no cryptosporidium detections occurred during monitoring for cryptosporidium at boreholes PWSBH01 and PWSBH02 over nine months in 2009.

Domestic residences across the majority of the ZOC are likely to be serviced by onsite wastewater treatment systems discharging to groundwater. There are residences in some areas of extreme groundwater vulnerability. As such there is a possibility of treated wastewater discharging to groundwater in these areas. The potential contaminants from treated wastewater are similar to those from agricultural waste. A national primary road and several third class roads traverse the ZOC. The main potential contaminants from these sources are surface water runoff contaminated with hydrocarbons and metals.

13 Conclusions

The Lough Cuillaghan expansion of the Ballyconnell Water Supply Scheme is proposed to comprise two existing production wells at the site of the existing Lough Cuillaghan Spring pumping compound. The boreholes will abstract water from the underlying karstified limestone bedrock, which is classified as an Rk_c aquifer. The proposed design yield for the boreholes is 1,500 m^3/day. The projected scheme demand is 814 m^3/day. There will also be an on-going natural discharge, from the karst system feeding the boreholes, *via* Lough Cuillaghan Spring (summer maximum approximately 396 m^3/day) and the surrounding lakes. The delineated ZOC has a recharge footprint of 2,054 m^3/day, which allows for the borehole abstractions and the natural discharges.

Due to the high groundwater velocities that are common through the conduits in karst aquifers such as this, groundwater and contaminants can reach the source quickly. The entire delineated ZOC is therefore classified as SI. Parts of the SI are classified as Extreme vulnerability with rock at or very close to the surface in places, but the majority of the ZOC is protected by a thick covering of low permeability subsoil and is therefore low vulnerability. The low vulnerability is reflected in the generally good water quality at the boreholes.

The ZOC encompasses an area of 8.9 km^2 which incorporates a recharge footprint of 2,054 m^3/day, i.e. in excess of the proposed design yield. The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries.

14 Recommendations

Comprehensive well head protection should be put in place at the production wells and trial well. In particular the concrete plinth around borehole PWSBH02 should be replaced and trial well TW01 should be converted into a sealed observation borehole with a pressure gauge to monitor the confined, artesian water pressure.

Groundwater quality at the boreholes should be monitored closely in the first year after commissioning of the boreholes to confirm the unpolluted condition of the groundwater under pumping conditions through the entire annual cycle.

The ZOC contains SI/X and SI/E designations. Source specific landspreading exclusion zones should be developed for the source boreholes to take account of the landspreading risk associated with this designation.

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APPENDIX 1

- PWSBH03 (Mucklagh PWS) Source Protection Zones

BCL Document Reference: bcl\QG\bycnl.F

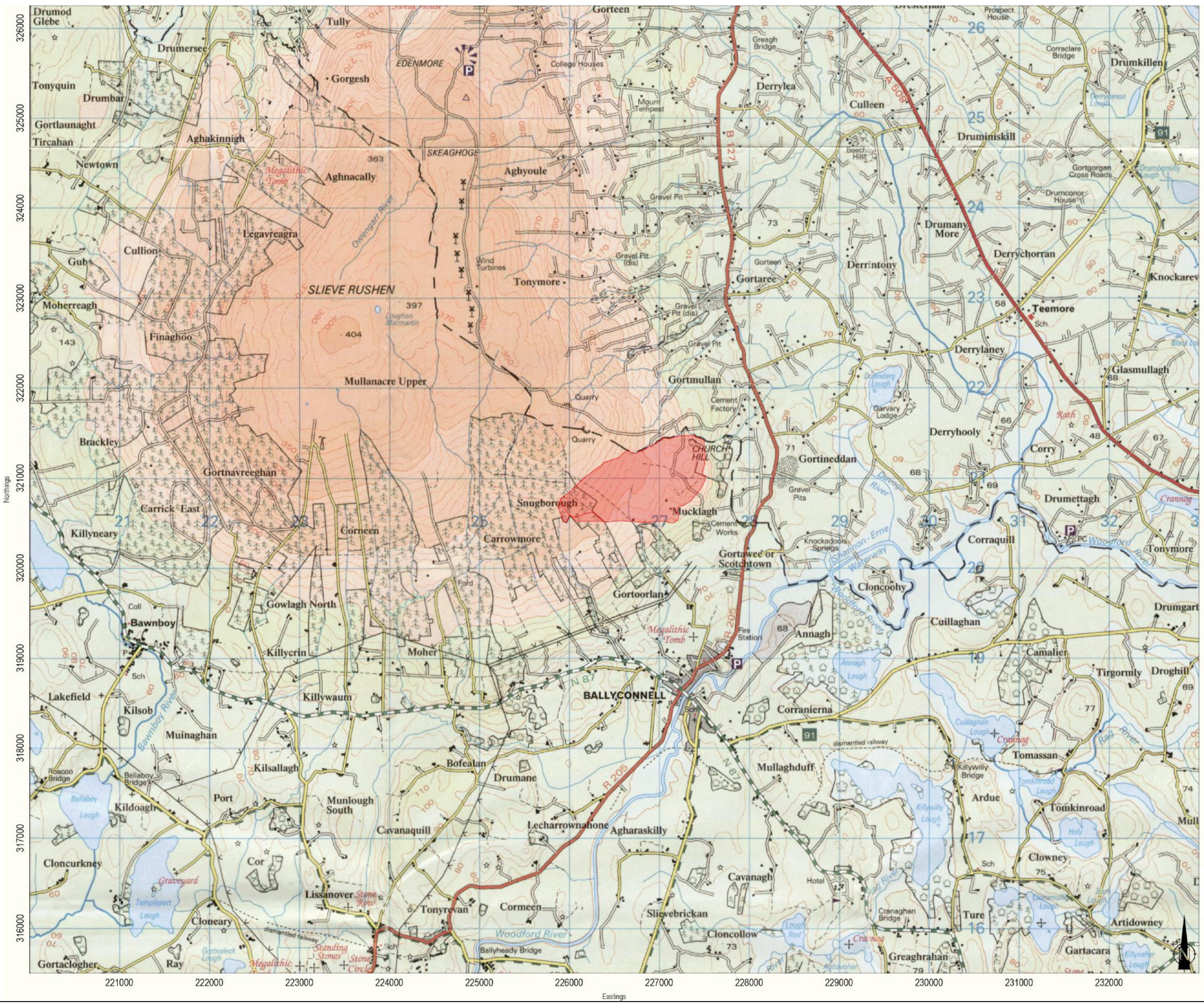
The Quinn Group

AUGHRIM & MUCKLAGH QUARRY COMPLEX
BALLYCONNELL, COUNTY CAVAN

Hydrogeological and Hydrological Assessment

16/10/2003

APPENDIX 1: Figures



Planning Application Area

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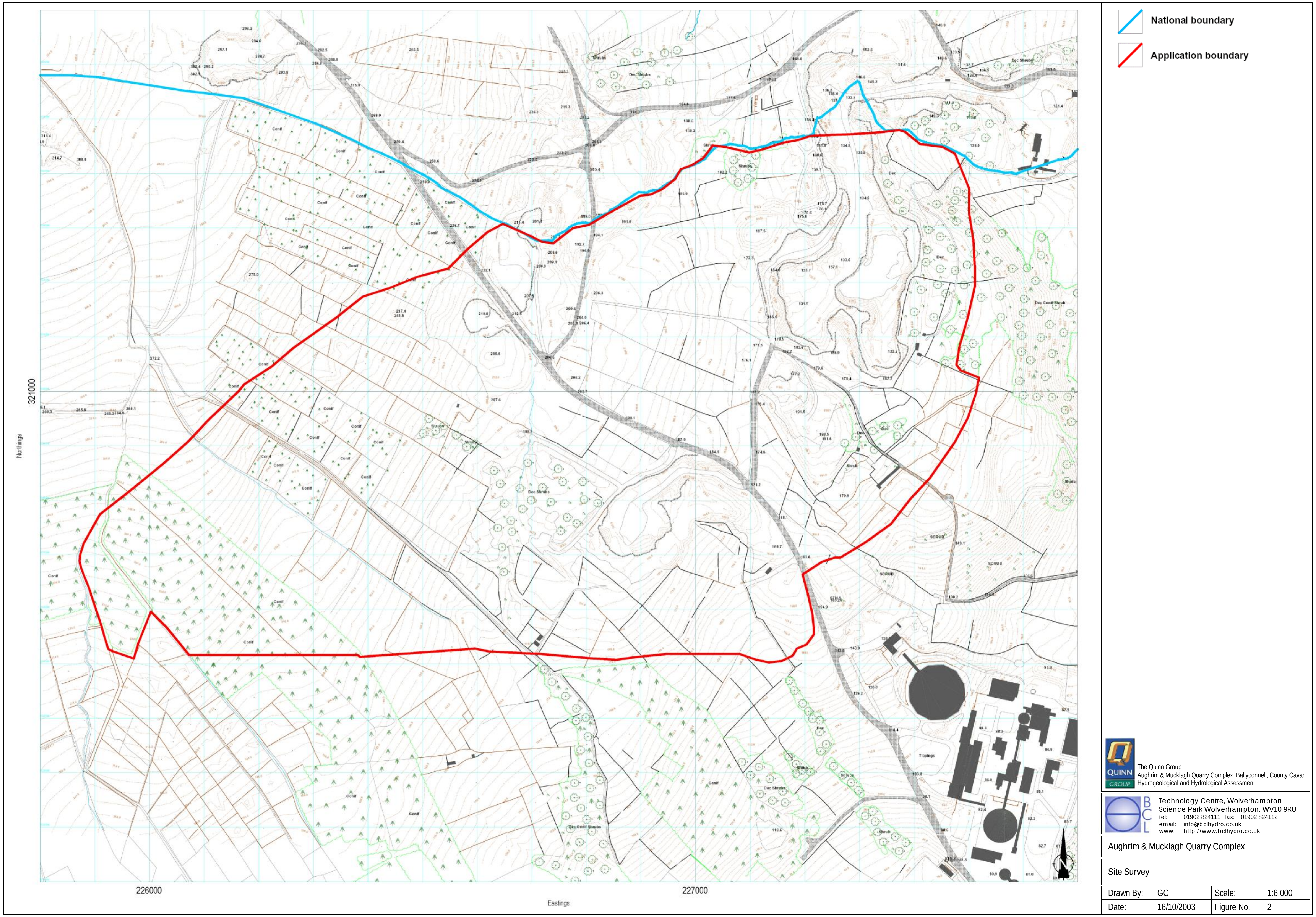
www: http://www.bclhydro.co.uk

Aughrim & Mucklagh Quarry Complex

Site Location

Drawn By:	GC	Scale:	1:40,000
Date:	16/10/ 2003	Figure No.	1



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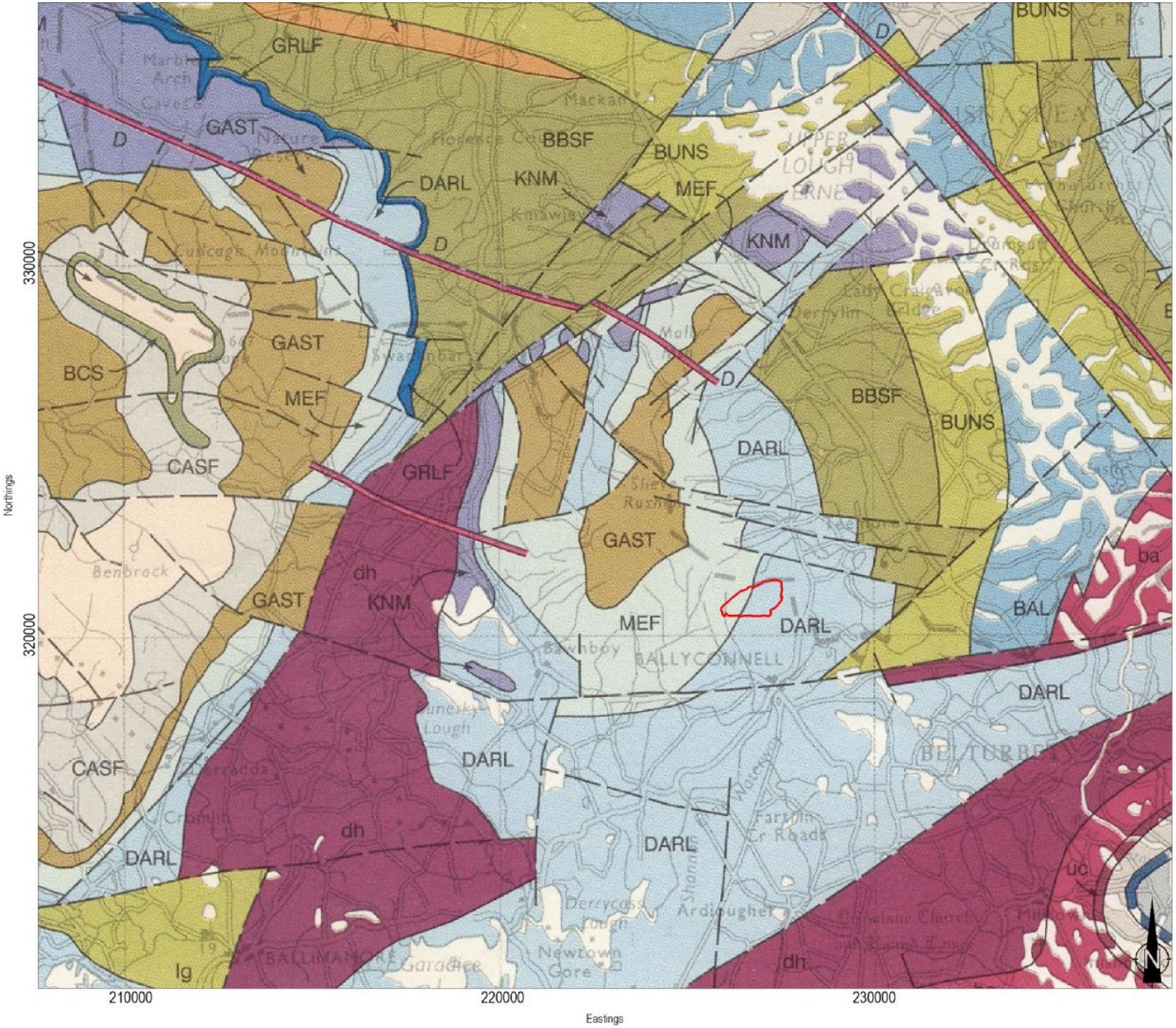
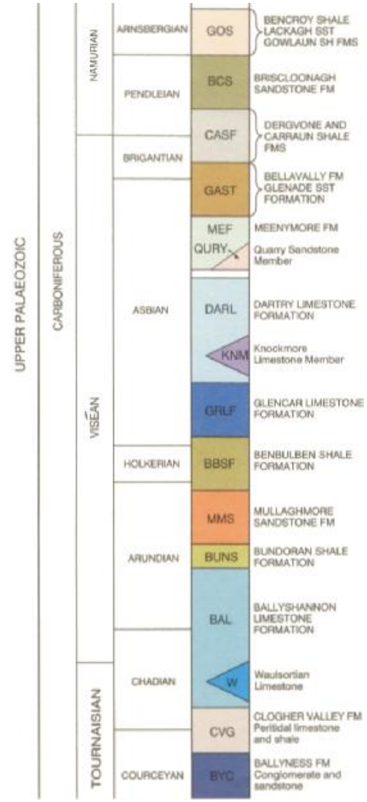
Site Survey

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/2003	Figure No.	2





Planning Application Boundary

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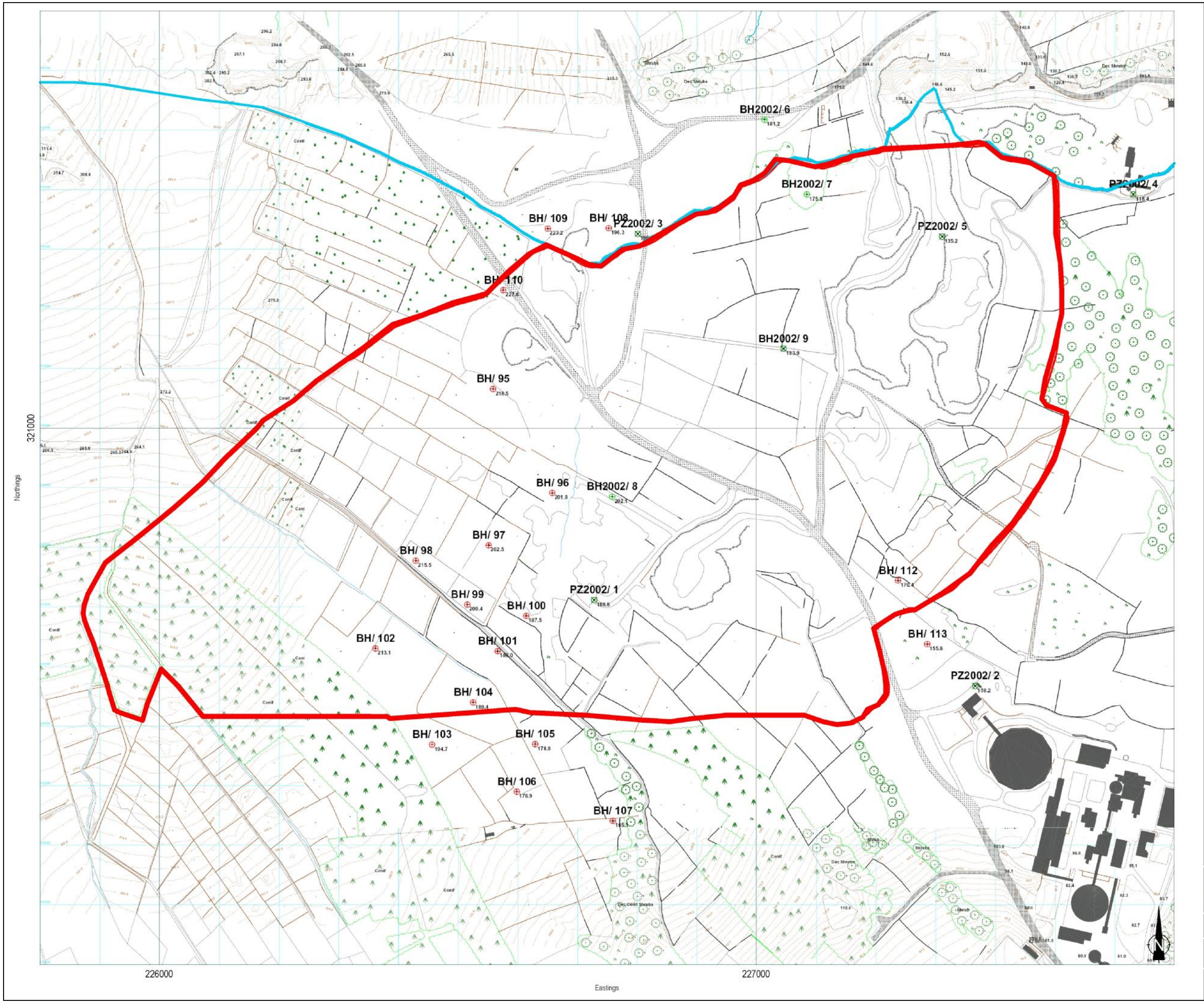
Regional Geology

Drawn By: GC	Scale: 1:150,000
Date: 16/10/2003	Figure No: 3



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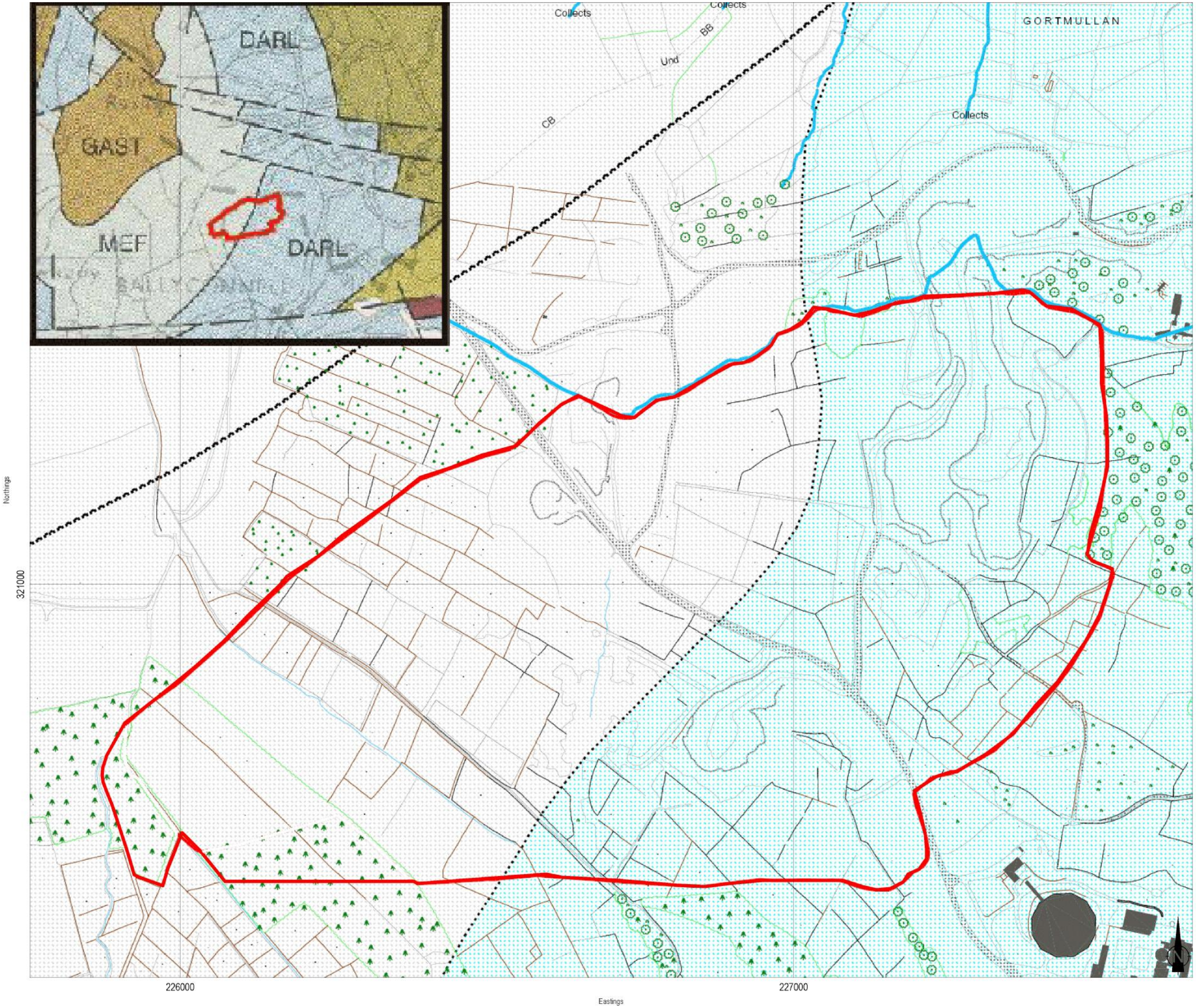
Mineral Evaluation & Piezometer Borehole Locations

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/2003	Figure No.	4



National boundary
Application boundary
Geological Boundary
Geological Fault
Meenymore Formation
Dartry Limestone Formation

1) Extract of GSNI geological map taken from 1997 1:250,000 scale mapping

2) Geological boundary on site plan taken from unpublished 1:50,000 GSNI mapping

Key to GSNI Inset Map

Carboniferous

GAST	Glenade Sandstone Fm
MEF / QURY	Meenymore Fm / Quarry Sandstone Member
DARL	Dartry Limestone Formation
KNM	Knockmore Limestone Member
GRLF	Glencar Limestone Formation
BBSF	Benbulben Shale Formation

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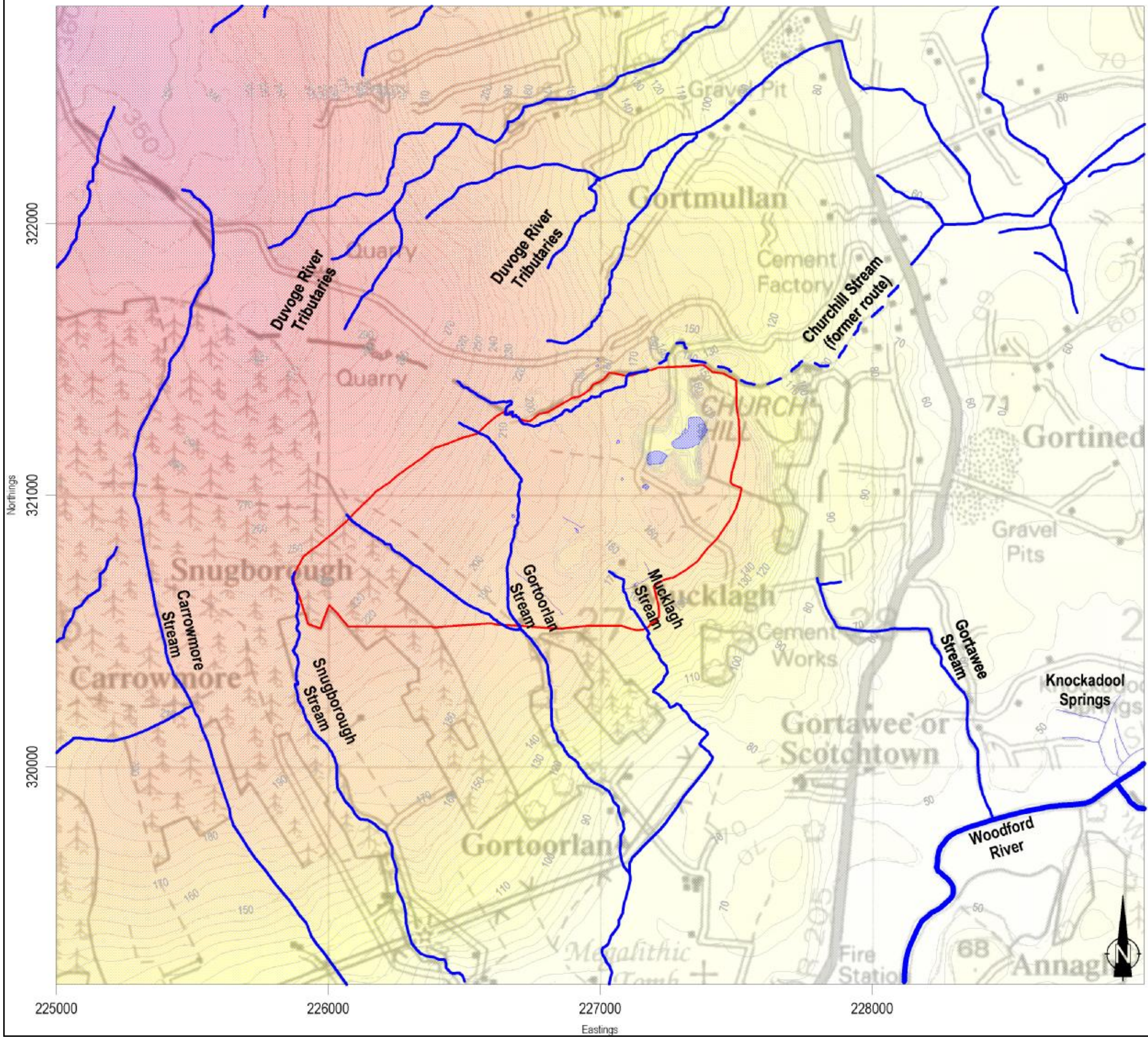
Local Geology

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/2003	Figure No.	5

Planning Application Boundary



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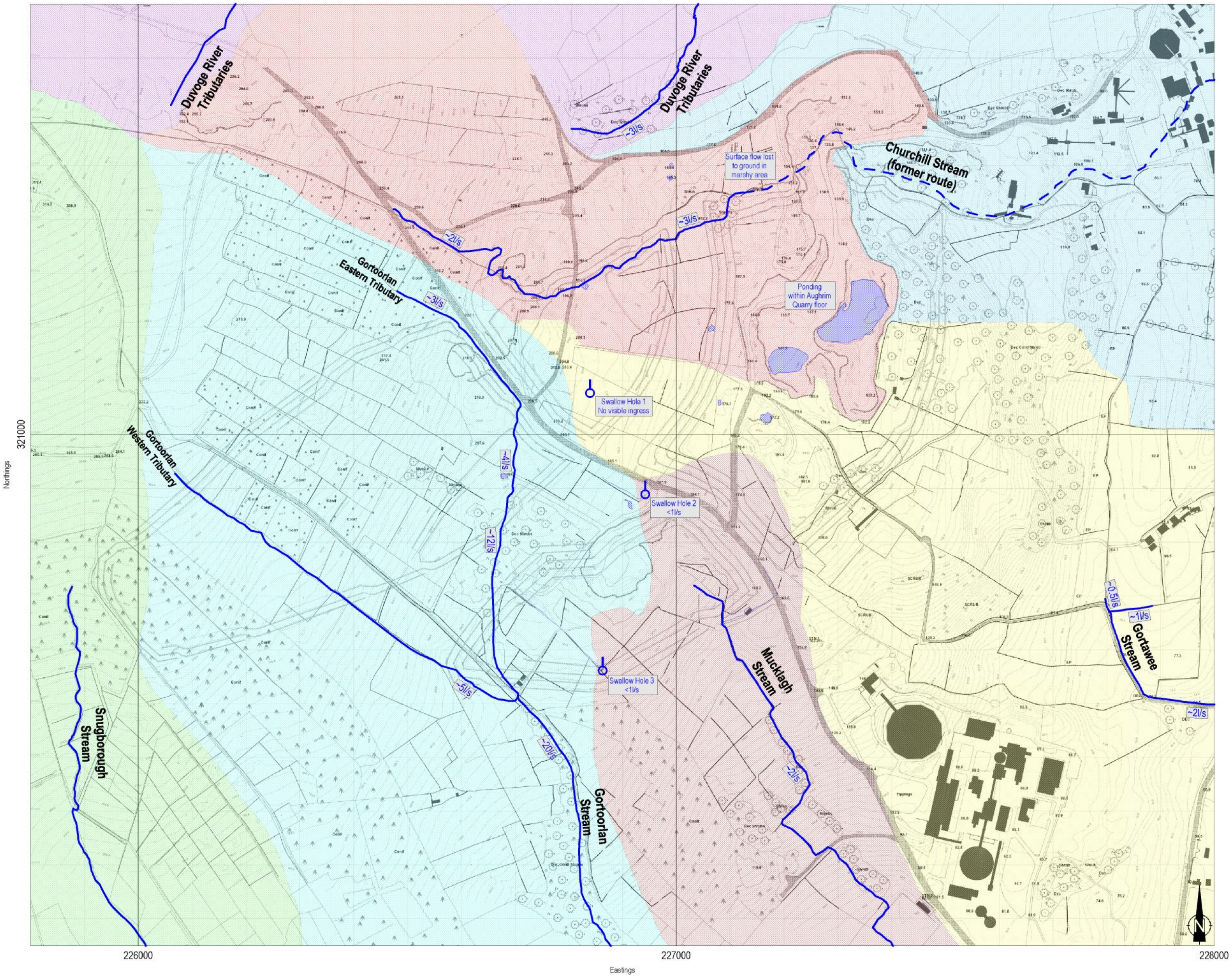
Water Features (1:20,000)

Drawn By: GC	Scale: 1:20,000
Date: 16/10/2003	Figure No: 6



Proposed Final Position of Quarry Faces

~2l/s Estimate Flow Rate (litres per second – October 2002)

Sub-catchment boundary

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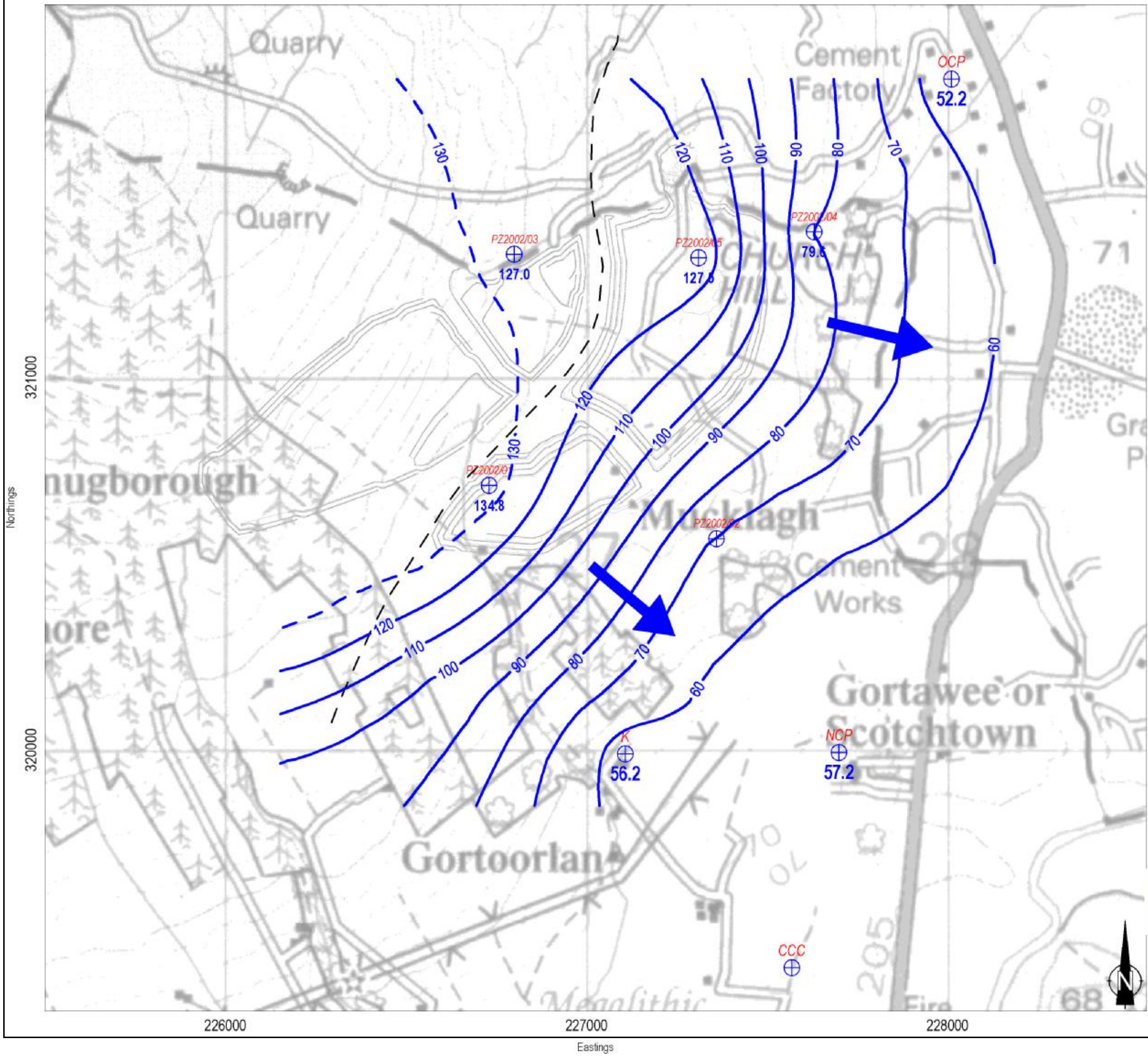
Water Features & Sub Catchment Boundaries

Drawn By:	GC	Scale:	1:7,000
Date:	16/10/2003	Figure No.	7



Groundwater Level (maOD)

Dartry Limestone / Meenymore Shale Boundary

Proposed Final Position of Quarry Faces

Inferred Direction of Groundwater Flow within the Dartry Limestone

Piezometer location, identification & average groundwater Level (winter 2002/2003)

OCP: Old Cement Plant Borehole
NCP: New Cement Plant Borehole
K: Kearns' Borehole
CCC: Cavan County Council Borehole

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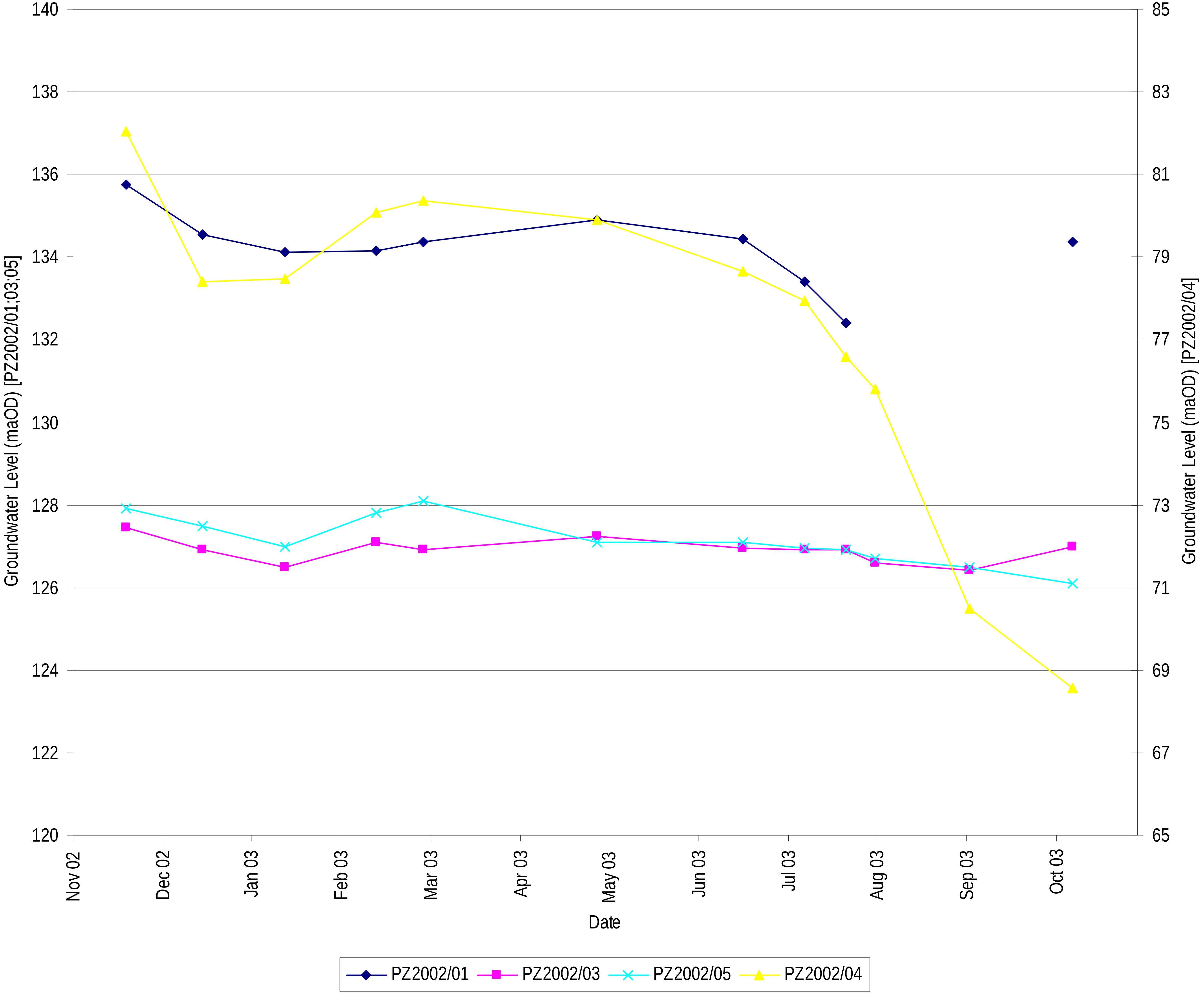
Groundwater Contours within the Dartry Limestone (Based upon data collected Nov.'02 to Feb.'03)

Drawn By: GC	Scale: 1:15,000
Date: 16/10/2003	Figure No: 8



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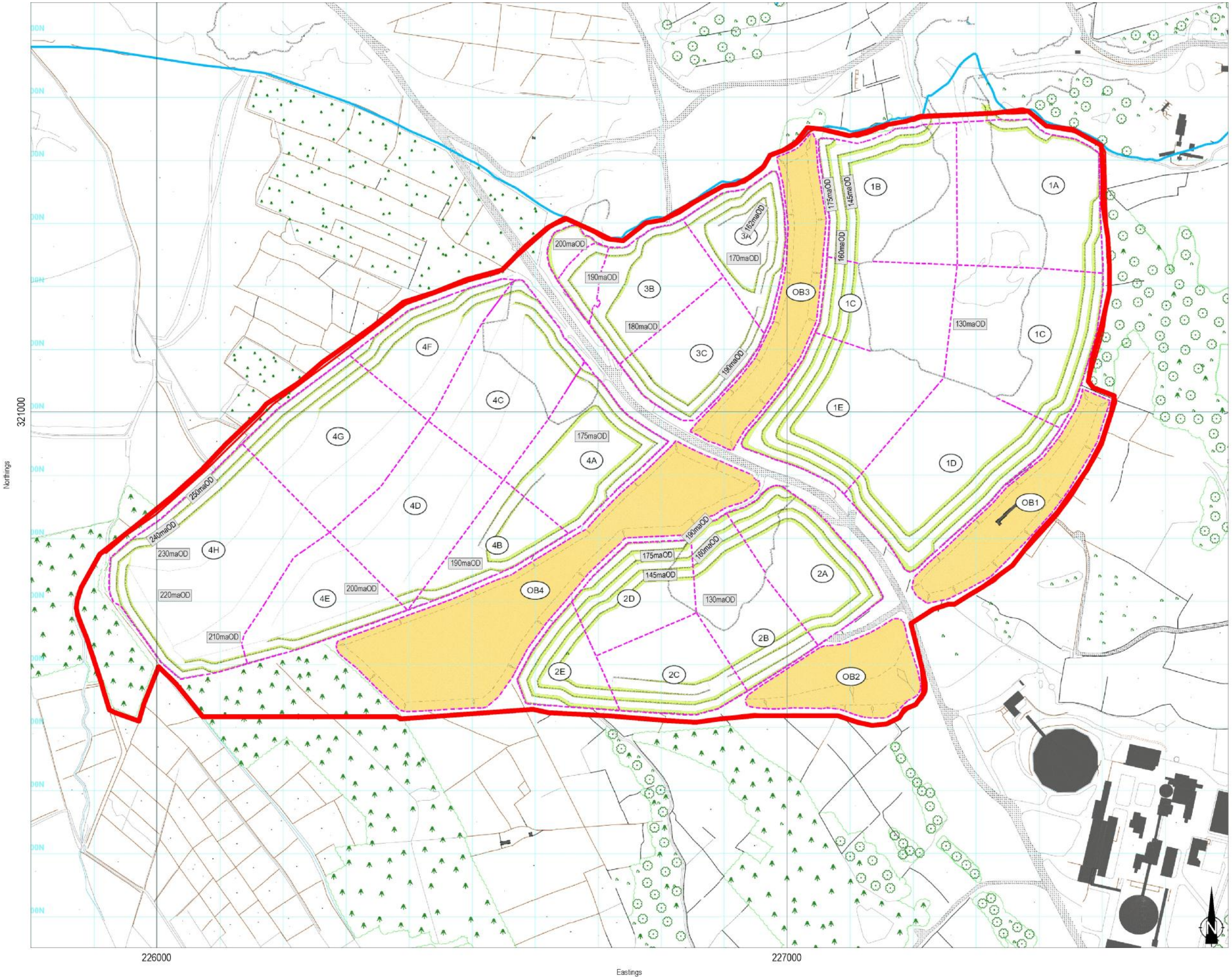
Groundwater Level Hydrograph

Drawn By:	GC	Scale:	N/A
Date:	16/10/ 2003	Figure No.	9



OB4 Overburden

200maOD Quarry Bench / Floor Elevation

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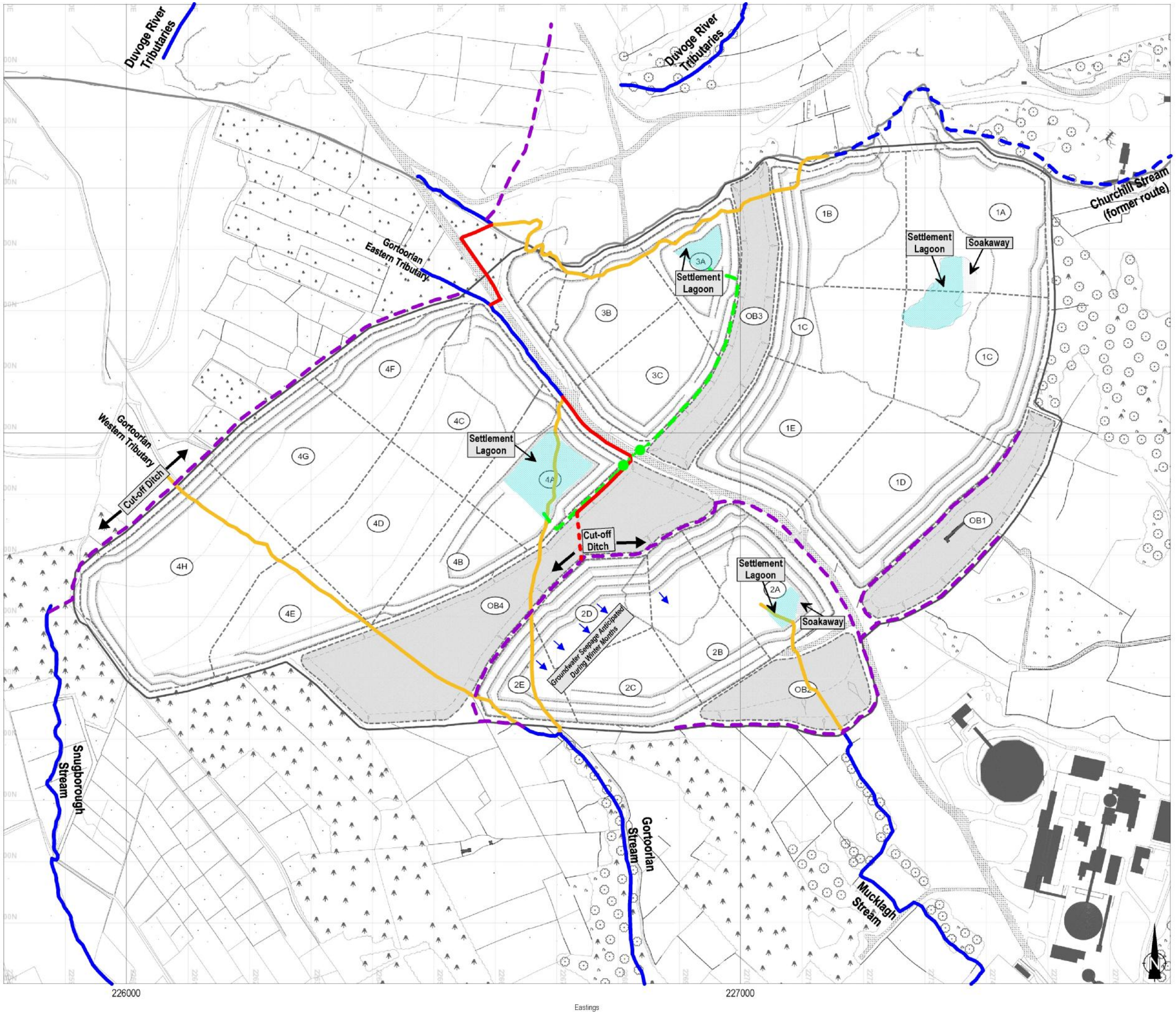
Areas of Proposed Future Mineral Extraction

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/ 2003	Figure No.	10



Existing Route of Watercourse (to be retained)

Existing Route of Watercourse (to be removed)

Former Route of Watercourse (previously removed)

Re-aligned Route of Watercourse (open-channel)

Re-aligned Route of Watercourse (in culvert)

Proposed Route of Cut-Off Ditch

Pumped Discharge Point

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Water Management Measures

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/2003	Figure No.	11

- Application boundary
- National boundary
- Overburden storage bunds
- Nutrient deficient species rich heath
- Podsolic limestone meadow
- Water body
- Main roads
- Main buildings
- Non-coniferous tree belt
- Coniferous tree belt
- Dry woodland
- Birch/willow/alder woodland
- Mixed broadleaved woodland
- Drainage direction

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Proposed Restoration

Drawn By:	GC	Scale:	1:6,000
Date:	16/10/2003	Figure No.	12

BCL Document Reference: bcl\QG\bycnl.F2

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AUGHRIM & MUCKLAGH QUARRY COMPLEX
BALLYCONNELL, COUNTY CAVAN

Hydrogeological and Hydrological Assessment

16/10/2003

APPENDIX 2
Settlement & Attenuation Assessment Calculations

PROPOSED MUCKLAGH SHALE QUARRY: EVALUATION OF SETTLEMENT AREA & ATTENUATION CAPACITY

i) TIME OF CONCENTRATION

Te = 7(Ln)^0.6 x S^-0.3 x I^-0.4

L =	670		
n =	0.02		
S =	0.08		
7(Ln)^0.6 x S^-0.3 =	70.865348		
1st estimate of Te =	10		
Iteration number	1	2	3
TE	10.00	11.13	11.32
I	102.30	98.00	97.00
Te	11.13	11.32	11.37
Te (calc)=	11.37		
Te (rounded) =	11		

iia) PEAK FLOW RATE

Q = 2.78 AKI

A (hectares) =	26
K =	0.75
I (mm/hr) =	97.00
Q (l/s) =	5258

iib) THEORETICAL SETTLEMENT AREA (Without provision of attenuation)

Based upon recommended overflow rate of 1 x 10-5 m/s

Area (m2) = 525,837

iib) AVAILABLE SETTLEMENT AREA

Area (m2) = 10,300

iii) MAXIMUM RECOMMENDED OUTFLOW RATE FROM AVAILABLE SETTLEMENT AREA

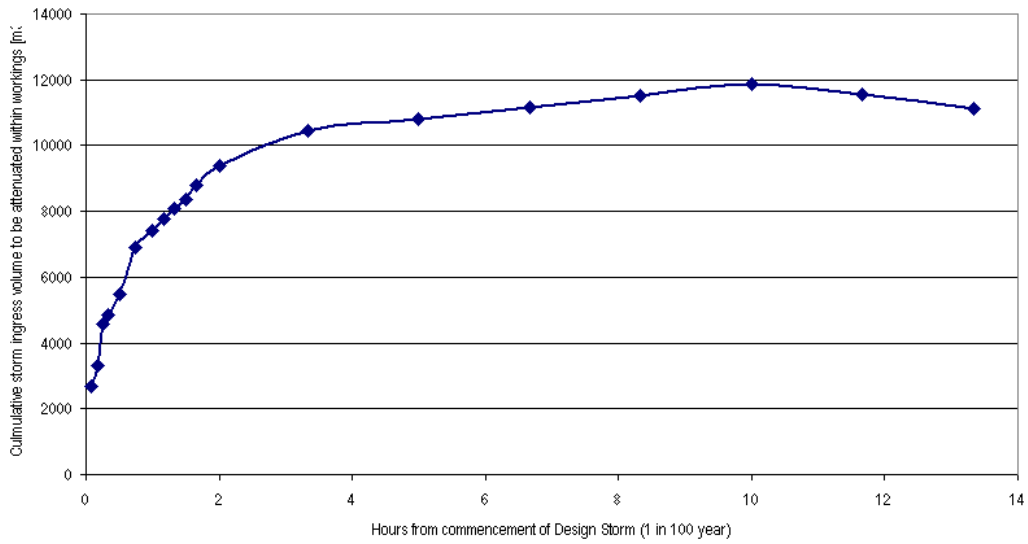
Q (l/s) = 103

iv) ATTENUATION VOLUME FOR RECOMMENDED OUTFLOW RATE (Flow Balancing Storage)

Assumed Discharge rate

Qp(l/s) = 50

Storm Duration	Storm Duration	Rainfall Intensity	Volume of Incident Rainfall since commencement of storm	Volume of Discharge since commencement of storm	Storage Required
(mins)	(hrs)	(mm/hr)	(m3)	(m3)	(m3)
5	0.08	166.5	2708	15	2693
10	0.17	102.3	3327	30	3297
15	0.25	95	4635	45	4590
20	0.33	75.2	4892	60	4832
30	0.50	57	5562	90	5472
45	0.75	48	7026	135	6891
60	1.00	39	7611	180	7431
70	1.17	35	7969	210	7759
80	1.33	32	8327	240	8087
90	1.50	29.5	8636	270	8366
100	1.67	28	9107	300	8807
120	2.00	25	9758	360	9398
200	3.33	17	11059	600	10459
300	5.00	12	11709	900	10809
400	6.67	9.5	12360	1200	11160
500	8.33	8	13010	1500	11510
600	10.00	7	13661	1800	11861
700	11.67	6	13661	2100	11561
800	13.33	5.2	13531	2400	11131



PROPOSED AUGHRIM SHALE QUARRY: EVALUATION OF SETTLEMENT AREA & ATTENUATION CAPACITY

i) TIME OF CONCENTRATION

Te = 7(Ln)^0.6 x S^-0.3 x I^-0.4

L =	300		
n =	0.02		
S =	0.2		
7(Ln)^0.6 x S^-0.3 =	33.241437		
1st estimate of Te =	10		
Iteration number	1	2	3
TE	10.00	5.22	4.30
I	102.30	166.50	175.75
Te	5.22	4.30	4.20
Te (calc)=	**4.20**		
Te (rounded) =	**4**		

iia) PEAK FLOW RATE

Q = 2.78 AKI

A (hectares) =	7.25
K =	0.75
I (mm/hr) =	175.75
Q (l/s) =	**2657**

iib) THEORETICAL SETTLEMENT AREA (Without provision of attenuation)

Based upon recommended overflow rate of 1 x 10-5 m/s

Area (m2) = 265,668

iib) AVAILABLE SETTLEMENT AREA

Area (m2) = 6,000

iii) MAXIMUM RECOMMENDED OUTFLOW RATE FROM AVAILABLE SETTLEMENT AREA

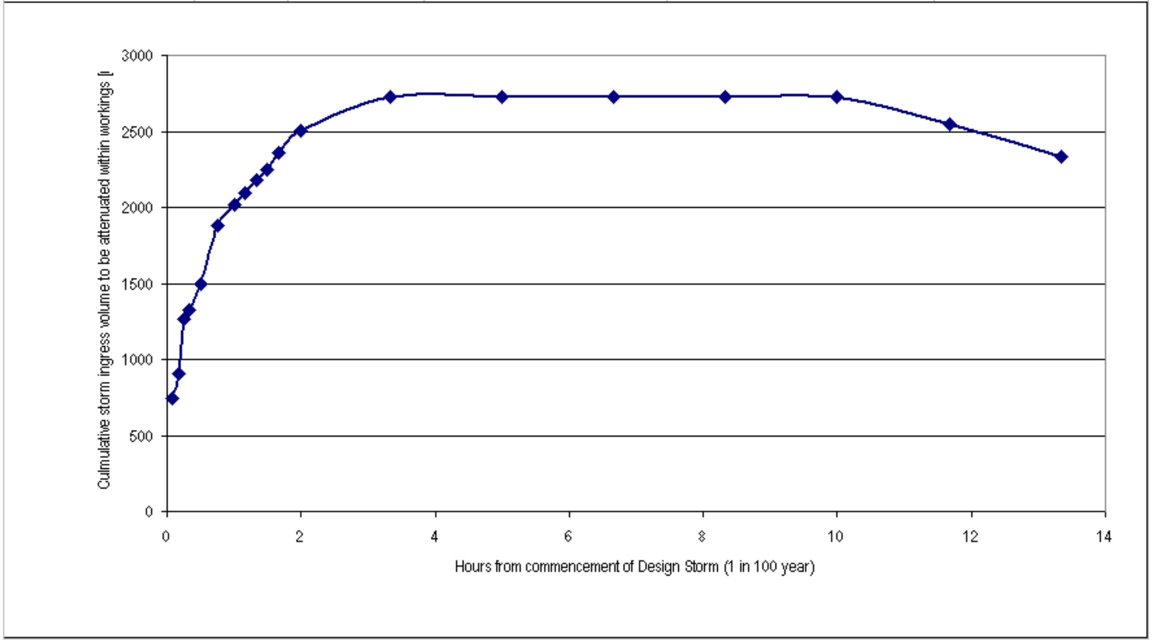
Q (l/s) = 60

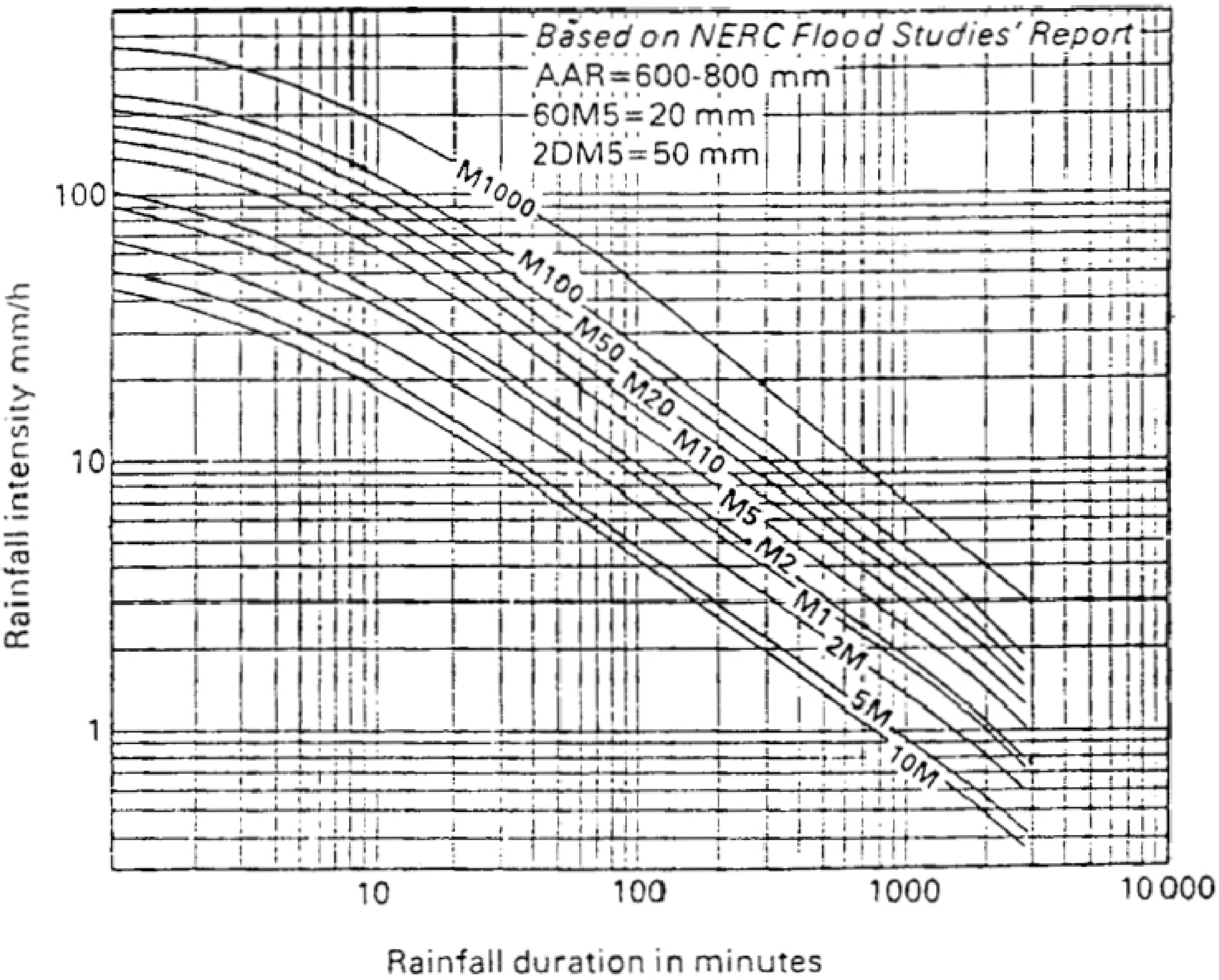
iv) ATTENUATION VOLUME FOR RECOMMENDED OUTFLOW RATE (Flow Balancing Storage)

Assumed Discharge rate

Qp(l/s) = 30

Storm Duration	Storm Duration	Rainfall Intensity	Volume of Incident Rainfall since commencement of storm	Volume of Discharge since commencement of storm	Storage Required
(mins)	(hrs)	(mm/hr)	(m3)	(m3)	(m3)
5	0.08	166.5	755	9	746
10	0.17	102.3	928	18	910
15	0.25	95	1292	27	1265
20	0.33	75.2	1364	36	1328
30	0.50	57	1551	54	1497
45	0.75	48	1959	81	1878
60	1.00	39	2122	108	2014
70	1.17	35	2222	126	2096
80	1.33	32	2322	144	2178
90	1.50	29.5	2408	162	2246
100	1.67	28	2540	180	2360
120	2.00	25	2721	216	2505
200	3.33	17	3084	360	2724
300	5.00	12	3265	540	2725
400	6.67	9.5	3447	720	2727
500	8.33	8	3628	900	2728
600	10.00	7	3809	1080	2729
700	11.67	6	3809	1260	2549
800	13.33	5.2	3773	1440	2333





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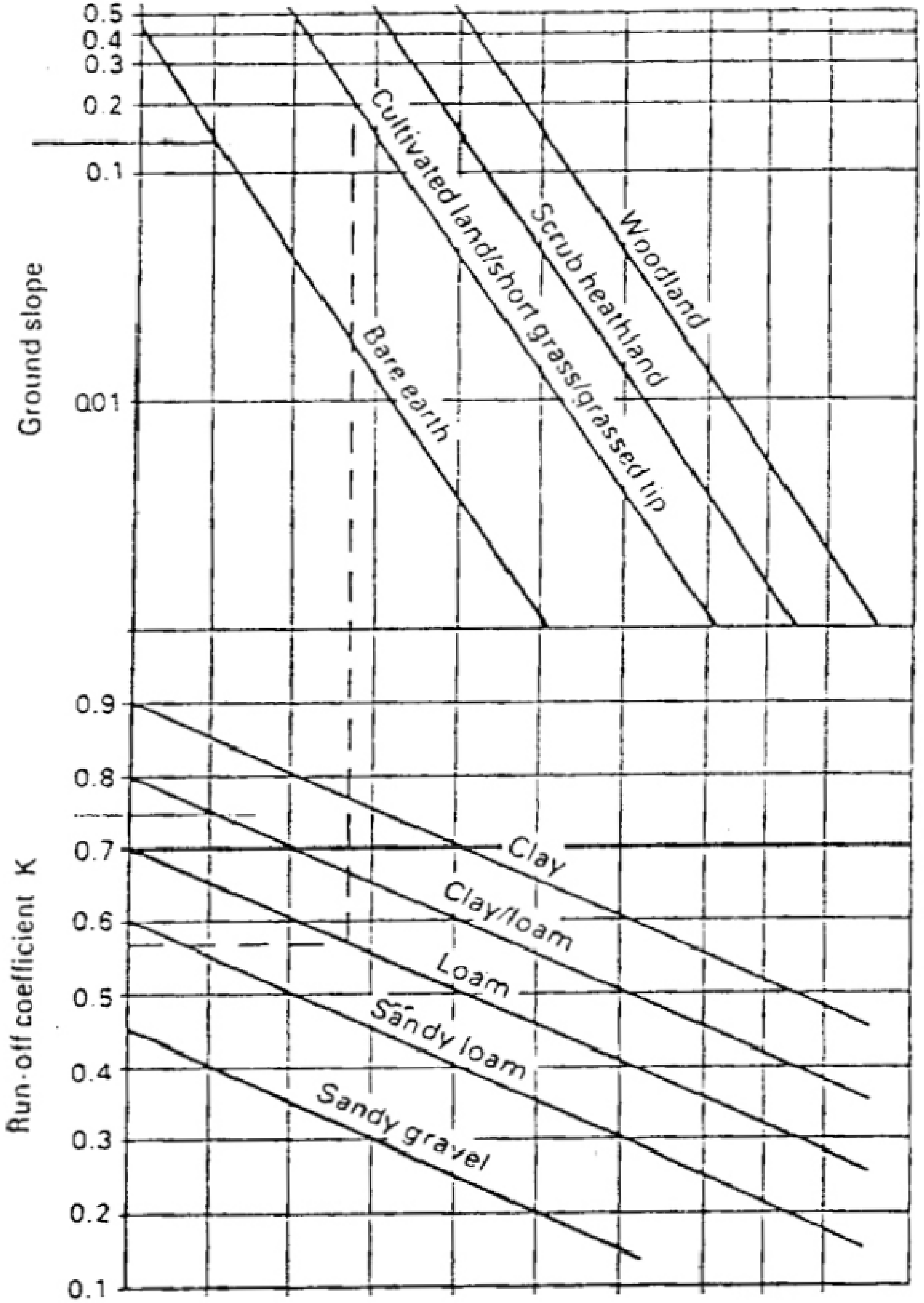
Depth Duration Frequency Curves employed in Settlement & Attenuation Assessment

Drawn By: GC	Scale: N/A
Date: 16/10/ 2003	Figure No: A2.1



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Nomogram to establish Runoff Coefficient used within Settlement & Attenuation Assessment

Drawn By: GC	Scale: N/A
Date: 16/10/ 2003	Figure No: A2.2

BCL Document Reference: bcl\QG\bycnl.F2

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Hydrogeological and Hydrological Assessment

16/10/2003

APPENDIX 3
Proposed Scheme of Groundwater Monitoring & Mitigation for the Protection of Existing Abstraction Boreholes

The Quinn Group
Mucklagh & Aughrim Quarry Complex

Proposed Scheme of Groundwater Monitoring & Mitigation for the Protection of Existing Abstraction Boreholes

1 Background

1.1 Hydrogeological investigations carried out in respect of the formalisation and extension of existing quarry workings have identified the potential for impact upon both the quality and quantity of groundwater abstracted from local abstraction boreholes. It is important to recognise that, in principle, as active quarrying is already occurring at the site, the potential future risk is not significantly than currently exists.

1.2 Measures have been proposed to minimise the occurrence of impact. However, given the difficulties inherent to impact prediction within limestone terrains (due to rapid transit times for groundwater flow and unpredictable flow paths), it is recognised that the most prudent approach involves precautionary monitoring coupled to contingency measures for the resolution of impacts should they occur.

1.3 This narrative is intended to provide a framework for the formulation of a prescriptive scheme of monitoring, providing recommended technical requirements that, it is envisaged, will be formalised and implemented by way of planning condition.

2 Potential Receptors

2.1 To date, the identified abstraction sources are abstraction boreholes at:

a. Kearns' property private water supply borehole
(approximate grid reference ^{2}271, ^{3}200)
located some 500m south of nearest section of proposed workings

b. Maguire's property private water supply borehole
(approximate grid reference ^{2}2706, ^{3}1988)
located some 575m south of nearest section of proposed workings

c. Cavan County Council (CCC) public water supply borehole
(approximate grid reference ^{2}2757, ^{3}1939)
Located approximately 1km south-west of nearest section of proposed workings

3 Baseline Monitoring

3.1 Overview

3.1.1 Characterisation of existing groundwater level and chemistry variations at the potential receptors is required to provide a baseline against which future monitoring data may be assessed for the determination of impact.

3.1.2 The existence of historical and on-going workings makes the definition of true baseline conditions impossible. This is because certain unmeasured effects may have already occurred. Therefore, it is necessary to make a pragmatic judgement regarding the period over which the collected data is taken to inform the characterisation of baseline conditions.

3.1.3 It is understood that significant westward workings (*i.e.* towards the identified borehole sources) will not occur until circa 2008. It is proposed that data collection in the period spanning from the date of implementation of this scheme until 2008 be taken to represent baseline conditions.

3.1.4 Data collected during the Baseline Monitoring Phase will be utilised to formulate Trigger Values against which subsequent monitoring data should be analysed. The purpose of the Trigger Values is to provide a mechanism for the identification of any quarrying related impacts upon the identified potential receptors.

3.1.5 It is anticipated that the Trigger Values shall be based upon prevailling statutory standards regulating potable water quality and an assessment of the yield capacity of the borehole sources.

3.1.6 Should any obvious derogation of quantity or quality occur during the Baseline Monitoring Phase, the Applicant shall undertake the agreed mitigation measures.

3.2 Technical Requirements

3.2.1 Groundwater levels within the Kearns' and Maguires properties shall be recorded on an at least monthly basis using a graduated dip tape.

3.2.2 Groundwater levels within the CCC borehole shall be monitored utilising an automated data-logger coupled with pressure transducer to allow an hourly frequency of measurement. The purpose of the intensive monitoring is to allow characterisation of the background variations in groundwater levels both seasonally and over shorter time periods. Data uploads should be performed once per month.

3.2.3 Groundwater samples should be retreived from the wells on a monthly basis and laboratory analysis carried out to include major & minor ions and anions (of sufficient scope to allow reasonable determinaton of the ionic/anionic balance), GCTPH and VOC's.

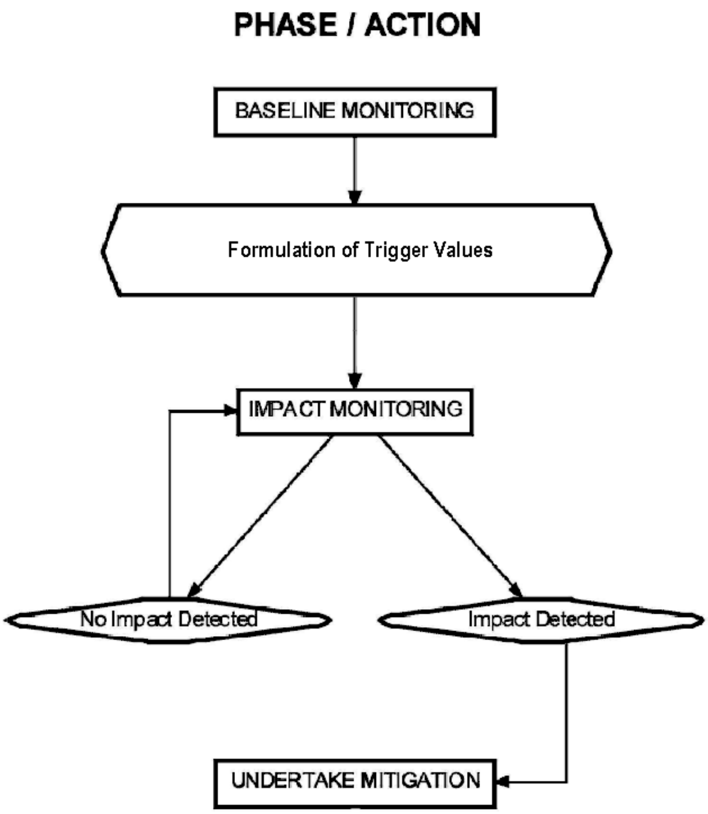
4 Impact Monitoring

4.1 Monitoring conducted post 2008 shall provide data for evaluation against the established Trigger Values.

4.2 The technical requirements for Impact Monitoring are as those described above at ***section 3.2***. As the CCC borehole provides for a public water supply, it would be prudent to increase the frequency of sampling for groundwater quality analysis. To facilitate this, on-line sampling systems should be considered for selected quality determinands.

5 Impact Mitigation

5.1 Should data collected during Impact Monitoring indicate material breach of the agreed Trigger Values, the Applicant shall undertake to provide alternative sources of supply to the satisfaction of **XXXXX.**



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Mucklagh & Aughrim Quarry Complex

Protection of Local Groundwater Abstraction Sources
Monitoring & Mitigation Flow Chart

Drawn By: GC	Scale: n/a
Date: 16/10/ 2003	Figure No: A2.1

APPENDIX 2

- Borehole Logs – PWSBH01, PWSBH02 & TW01
- Table A2.1 – Ballyconnell Point Data
- Table A2.2 – Ballyconnell Groundwater Level Survey
- Table A2.3 –Water Quality Data
- Figure A2.1 – Data Points in the Vicinity of Lough Cuillaghan PWS Site

PWSBH01 LOG aka PW1

Well No. PW1

Project No. Y6129 (JB Barry Ltd.)

Client. Cavan Co. Co

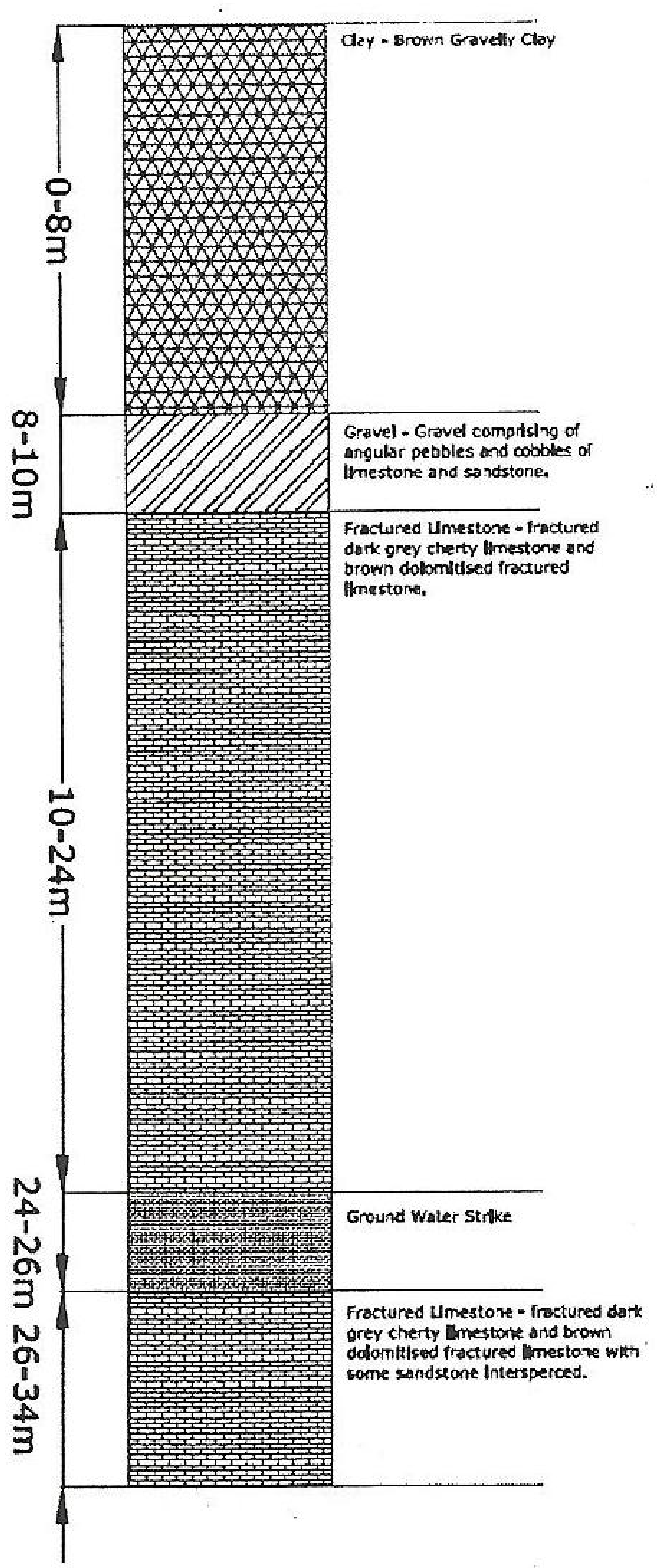
Drill Date. 19.05.08 - 12.06.08

Well Type. Production Well

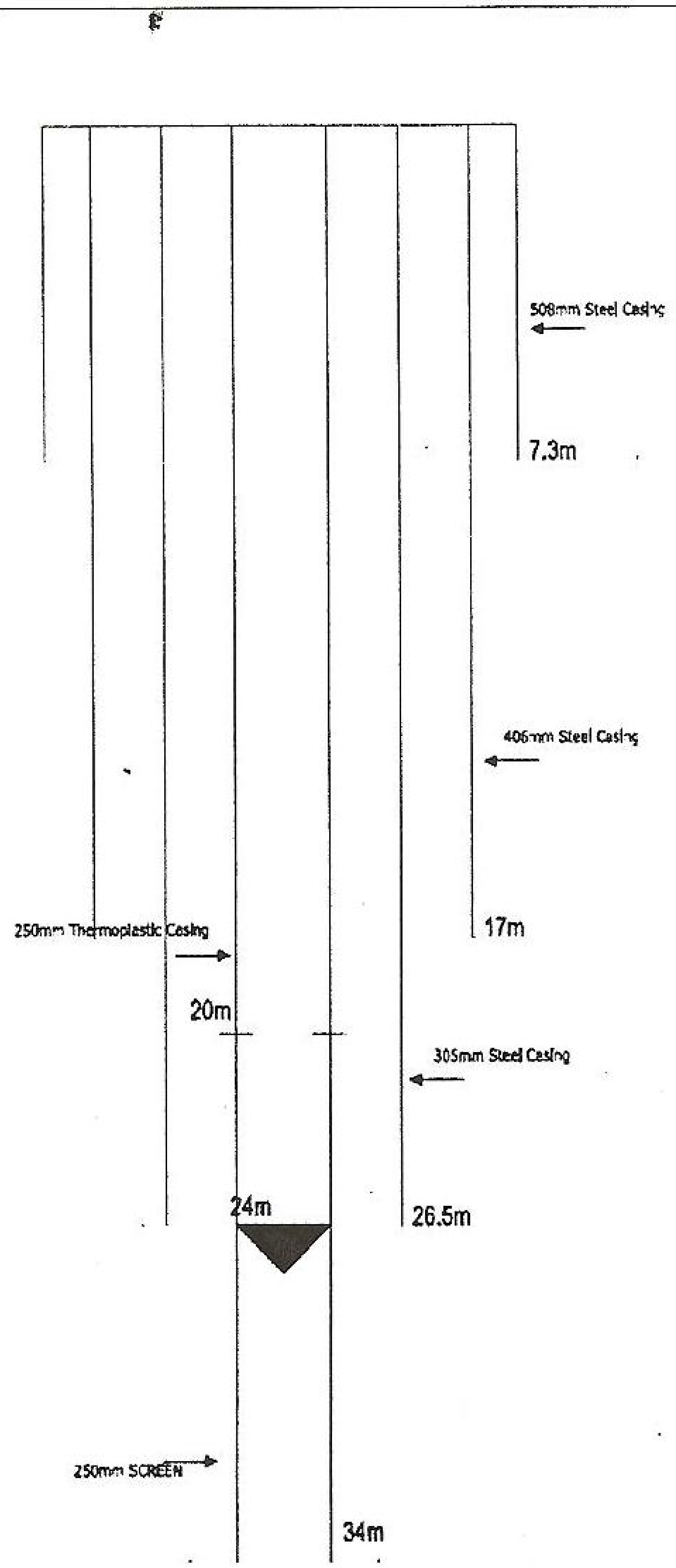
Location. Lough Cullaghan Ballyconnell

Geologist. KOD/SC

SUBSURFACE PROFILE



WELL CONSTRUCTION



Drill Method. Air Rotary

Hole Size. 250mm

Casing Length (m). 34m

Static Water Level (bgl).

Driller. Dunnes Drilling

PWSBH02 LOG - aka PW2

Well No. PW2

Project No. Y6129 (JB Barry Ltd)

Client. Cavan Co. Co

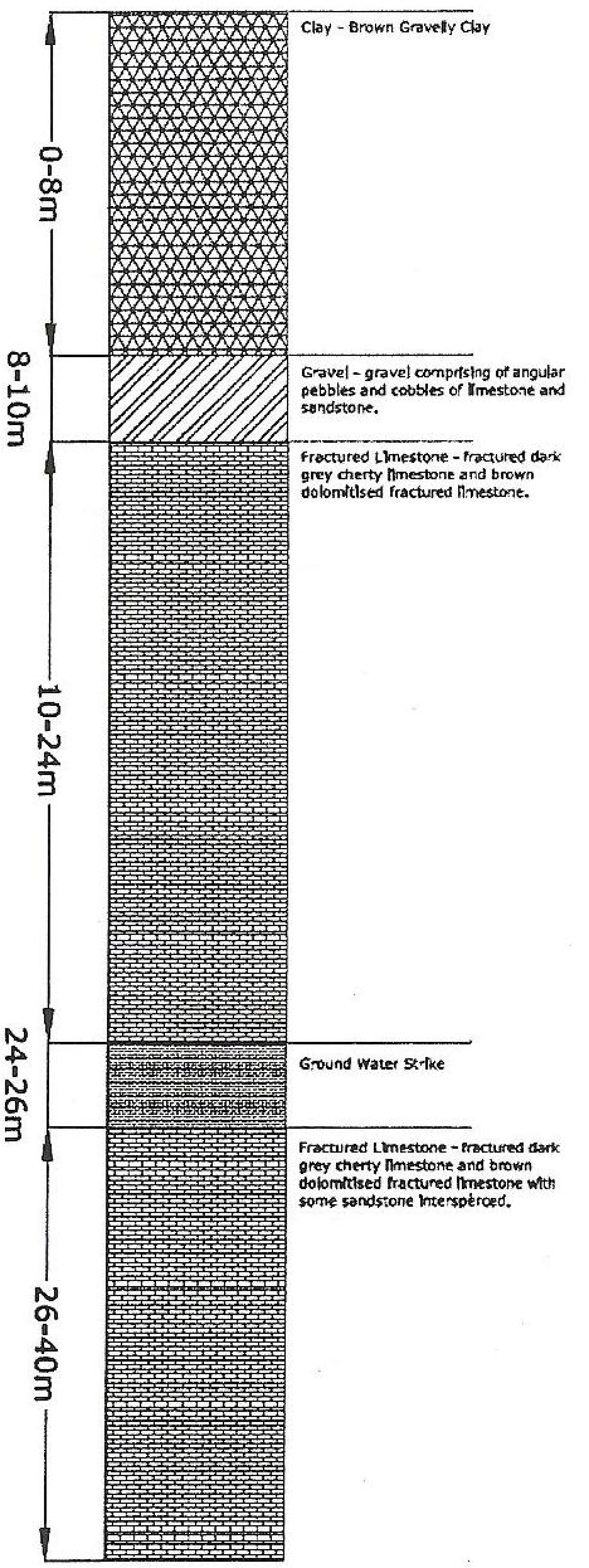
Drill Date. 13.06.08 -07.07.08

Geologist. KOD/SC

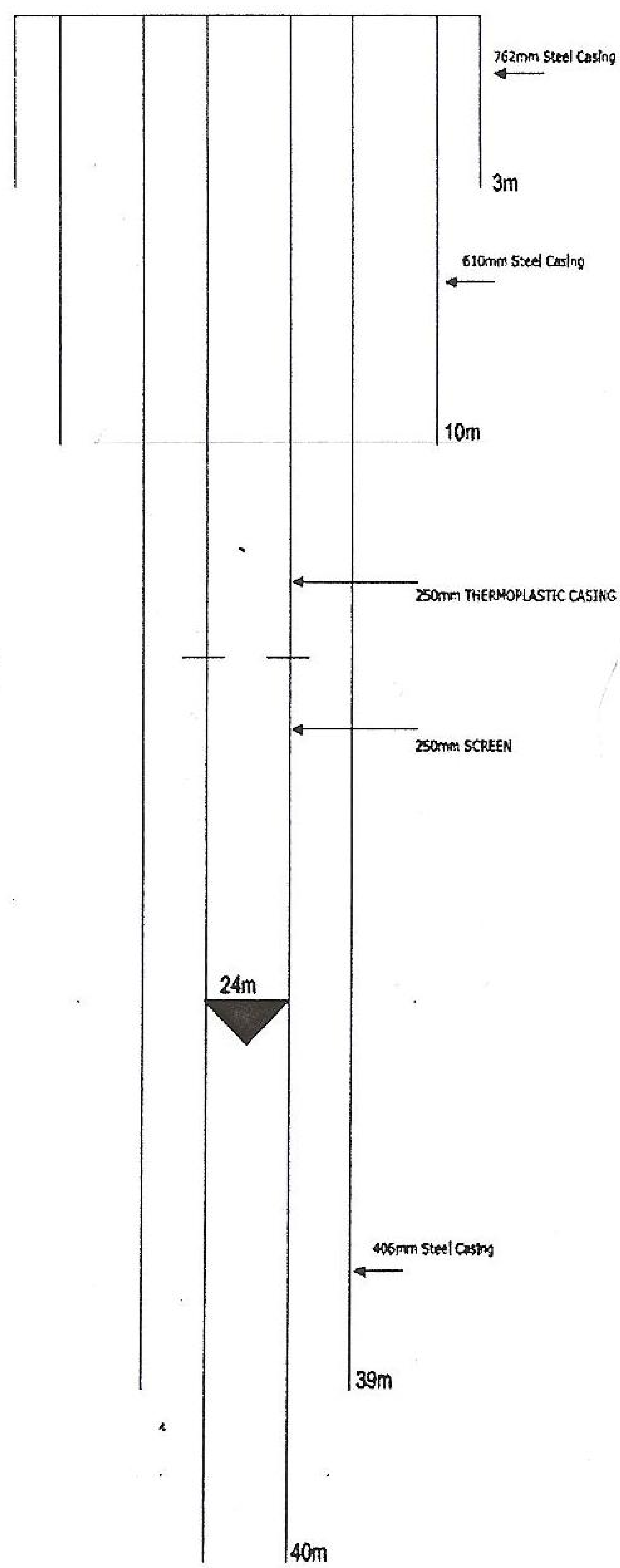
Well Type. Production Well

Location. Lough Cuillaghan Ballyconnell

SUBSURFACE PROFILE



WELL CONSTRUCTION



Drill Method. Air Rotary

Casing Length (m). 40m

Driller. Dunnes Drilling

Hole Size. 250mm

Static Water Level (bgl).

Well Log TW-1

Well No. TW-1
Grid Reference 29867, 18797

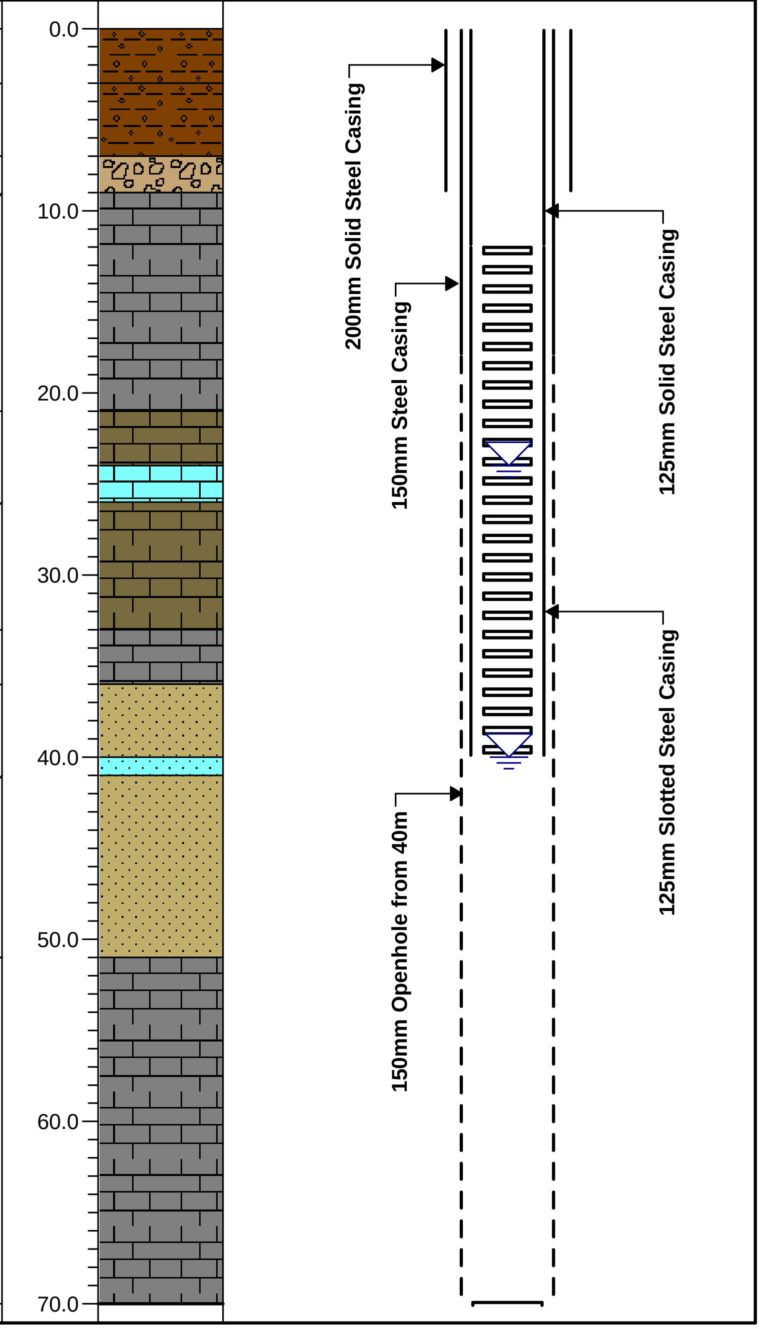
Project No. CE05339
Client JB Barry & Partners
Drill Date 16-18 January 2006

Well Type Trial Well
Location Lough Cuillaghan, Ballyconnell
Geologist Julian McDowell

SUBSURFACE PROFILE

Description	Depth (m)	Symbol
Ground Surface		
CLAY Brown slightly gravelly organic CLAY		
CLAY Brown gravelly CLAY (very wet)		
GRAVEL Gravel comprising angular pebbles and cobbles of limestone and sandstone		
FRACTURED LIMESTONE Fractured dark grey cherty limestone with calcite veining		
LIMESTONE Brown dolomitised fractured limestone with dark cherty limestone **Groundwater Strike** Groundwater inflows between 24-26mbgl		
LIMESTONE Dark grey limestone with some dolomitised limestone		
SANDSTONE Brown fractured sandstone interbedded with cherty limestone **Groundwater Strike** Groundwater inflows between 40-41m bgl		
LIMESTONE Dark grey cherty limestone		

Well Construction



Drill Method Air Rotary
Hole Size (mm) 125mm
Casing Length (m) 41m
TOC (mOD) 42mOD (not surveyed)
Driller Dunnes Drilling
Static Water Level (bgl) Artesian

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	Ref / TC	tc magl	DTB	Exp Interval	Subsoil K
						08/07/2010	21/09/2006	23/01/2007	09/09/2010	29/09/2010	m					
PWSBH02	Groundwater	Borehole	229873	318800	PWS production well due to be commissioned by 2012. Drilled 13/6 to 07/07/2008. Driller = Dunnes. Located in Lough Cuillaghan PWS compound, approx 5 m from the edge of the lake. "tc" = top of diphole in 16" casing cover (0.31mb top of 6" stick-up tube out of the cover) Top of PVC well liner is 0.66m below top of well cover 6" tube. Concrete slab around borehole is broken in to pieces. Called PW2 in JOD (2008). ID = 250mm; Inflows 24 to 26mbgl; 7 day P Test @ 1800m3/day; Drawdown = 2.71m; Est Safe Yield = 1200m3/d 762mm SC 0-3m; 610mm SC 0-10m; 405mm SC 0-39m; 250mm PVC liner 0-approx 15m; 250mm PVC screen 15-40m; Bedrock = Fractured Lst of dk grey cherty Lst & brown dolomitised fractured Lst, with some interbedded sandstone below 26m.	0.582			0.31	0.31	40	Diphole in 16" cover	0.67	10		Brown, gravelly CLAY (0-8m) / angular GRAVEL of limestone & Sandstone pebbles and cobbles
PWSBH01	Groundwater	Borehole	229859	318789	PWS production well due to be commissioned by 2012. Drilled 19/5 to 12/062008. Driller = Dunnes. Located in Lough Cuillaghan PWS compound, approx 10 m in from PWSBH02and 10m across from TW01. "tc" = top of dip hole 16-inch steel casing. There is 10" PVC liner. JP Barry Consultants collecting 24 hr, filtered water samples for crytosporidium analysis. Called PW1 in JOD (2008). ID = 250mm; Inflows 22 to 24mbgl; 7 day P Test @ 1800m3/day; Drawdown = 4.21m; Est Safe Yield = 1200m3/d 508mm SC 0-7.3m; 406mm SC 0-17m; 305mm SC 0-26.5m; 205mm PVC liner 0-20m; 205mm PVC screen 20-34m; Bedrock = Fractured Lst of dk grey cherty Lst & brown dolomitised fractured Lst.	0.65			0.335	0.34	34	Diphole in 16" cover	0.585	10		Brown, gravelly CLAY (0-8m) / angular GRAVEL of limestone & Sandstone pebbles and cobbles
PWSSP01	Groundwater	Spring	229867	318767	Current public water supply source at Lough Cuillaghan PWS compound. Due to be phased out when PWSBH01&2 commissioned in 2012. Spring is in a chamber approx 7 m diameter. "tc" = corrugated roof of spring chamber at hole cut in roof for viewing chamber - GWL measured from trough low point of the corrugated roof. Water mark on chamber wall indicates approx winter RWL in spring ~ 0.62 mbtc. Top of chamber = 0.21magl on NW side of chamber. Chamber floor is uneven & >1.2m deep. Water level outside the chamber is the same as inside. No overflow (valve shut). 9/9/2010: EC = 284.6, pH = 7.46, T = 12.4degC. Spring flows via gravity to a sump in the compound where it is dosed with CL2 gas. Pumping from the sump could induce a siphon effect from the spring. PWS has 2 No. pumps for spring (No1 = 20m3/hr; No2 = 20m3/hr) which pump alternately for 20 hrs per day. Digital flow meter with telemetry (meter mobile phone No. 0863802109). No raw water tap, need to sample direct from spring. Estimated reliable yield = 450m3/d	1.17			0.51	0.75	0.97 to 1.2 at GWL dip ref (uneven, may be deeper elsewhere)	Lowest point of dip hole in corrugated roof	0.21			

Table A2.1 - Point Data from Desk Study Hydrogeological Mapping - Ballyconnell Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	Ref / TC	tc magl	DTB	Exp Interval	Subsoil K
						08/07/2010	21/09/2006	23/01/2007	09/09/2010	29/09/2010	m					
PWSBH03	Groundwater	Borehole	227575	319407	PWS production well, currently supplying ~336m3/day. Also called "Mucklagh Borehole". Due to be phased out when PWSBH01&2 commissioned in 2012. Drilled 1999 by Dullea Well Drilling ltd. No borehole log. Dia 150mm. Yield est = 400m3/d. Council file missing. Pumping test carried out when commissioned. Electrochlorination treatment."tc" = top of 6-inch steel casing. GWL meas at 13.46 on 8/7/10 = pumping WL. Pump depth ~ 49 m. Digital flow meter with telemetry (meter mobile phone No. 0868270640). Pumps 24 hr/d at ~14m3/hr. Well site derives from borehole for a Quinn housing development from ~ 1998.BH can be set on a timer in necessary. Informal agreement with local farmer not to landspread on surrounding land (land belongs to Quinn). Raw water tap in treatment room. Quinn data logger in well & in several local wells, contact Fintan Coyle 04867741174.	23.28					66	Top 6" SC	0.398			
TW01	Groundwater	Borehole	229870	318802	Trial well located in Lough Cuillaghan PWS compound, approx 10 m in from PWSBH02. "tc" = top of 5-inch steel casing. 8", 6" and 5" steel casings used in drilling. RWL is above GL --> seepage at ground level from outside the 8" SC. Lake flood level reached TW01 during Nov-Dec floods in 2009. Overflowing @ 1.5 l/s on 9/9/2010, pH = 7.57, EC = 386uS/cm, T = 11.4degC. Overflowing approx 1 l/s on 29/9/10.	0.26			0	0	70	Top 5" SC	0.362			
BH20	Groundwater	Borehole			GSI note - Quinn Ind Private Well, approx 500m from PWSBH03. 10 inch diameter, TD approx 52 to 61 mbtc. Assume "tc" = top of 10 inch casing. No BH log. Aka by Quinn as NCP1.		24.41									
BH21	Groundwater	Borehole	227085	319997	GSI note - Private Well (Kearns) in farm ~ 735m upgradient of PWSBH03. GWL on 21/9/06 = mbgl		35.6									
GW01	Groundwater	Spring	228355	320177	Gortawee Springs. Estimate Q ~ 4 to 5 l/s. Karst spring through acid gravels. EC = 529uS/cm, pH = 7.07 & T = 10.4degC (on 9/09/2010).				0				0			
GW02	Groundwater	Dug Well	229763	318960	GSI note - Private Well (Mary McGuire). Large Dia. Dug well in a ditch. Water level higher than surrounding ditch water ."tc" = top of concrete ring. 3 concrete rings deep, i.e. ~ 3.6m			0.65								
BH01	Groundwater	Borehole	229771	318951	Private borehole. Drilled summer 2010 to replace adjacent dug well (GW02) which dried out in summer 2010. Driller Paddy Faye (Birr/Borrisokane). "tc" = top of 6-inch steel casing.				3.22	3.08	42.062	Top 6" SC	-0.32			
BH02	Groundwater	Borehole	229833	319152	Private borehole at rear, south side of new house. House still under construction in 2010. Borehole casing likely to be cut back to below ground level when ground level is landscaped/concreted. "tc" = top 6"SC = 0.24 above current GL. Adjacent cutting shows soil/subsoil = topsoil (0.2m)/ gravel "channel" soil (0.2 to 0.4mbgl)/ gravelly mottled CLAY (0.4 to > 3mbgl).				9.69	9.26		Top 6" SC	0.23			
BH03	Groundwater	Borehole	230172	319079	Private borehole. Drilled 1980. Steel liner to rock (est at ~22mbgl due to obstruction of dipper). Pump at 30mbgl. High iron content. "tc" = top of 6" SC. Problems with water level dropping below pump during dry spells.				26.49	26.91	48.768	Top 6" SC	0.19			
BH04	Groundwater	Borehole	229110	316440	Private borehole. Slieve Russell Hotel "Car Park" Borehole. Drilled ~1998. 3 boreholes at the hotel. Caretaker says all 3 behave similarly and have similar water levels. Total Q (3 BHs) = 270 to 280 m3/d.					24.25	40	Top 9" uPVC liner	0.5	4.2672		
BH05	Groundwater	Borehole	229040	317374	Private borehole. Disused.					4.34		Top 6" SC	-0.27	<3m		
BH06	Groundwater	Borehole	229687	316024	Private borehole. In use form adjacent house and opposite farm. Drilled 1962.					10.695	~ 24	Top 6" SC	0.19			

Table A2.1 - Point Data from Desk Study Hydrogeological Mapping - Ballyconnell Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	Ref / TC	tc magl	DTB	Exp Interval	Subsoil K
						08/07/2010	21/09/2006	23/01/2007	09/09/2010	29/09/2010	m					
BH07	Groundwater	Borehole	230523	316659	Private borehole. Behind house beside school.					9.51		Top 6" SC	0.17			
BH08	Groundwater	Borehole	231055	316472	Private borehole. Beside lough Clonamullig. "tc" is top 6" SC and is 0.9m below the top of the brick chamber housing the BH.					1	24.384	Top 6" SC	-0.68	>24m?		
BH09	Groundwater	Borehole	230920	316702	Private borehole. Water strike at 18.2 to 24.4mbgl.					10.53	42.672	Top 6" SC	-0.44			
BH10	Groundwater	Borehole	231251	317310	Private borehole. Water softener on system.					7.18		Top 6" SC	-0.05			
BH11	Groundwater	Borehole	231680	319014	Private borehole. Water strike was "quite deep". Another private borehole in house to rear was sealed shut. Owner of sealed borehole said that his bored well and ones to south along road have issues with H2S odour from water & his BH also has slightly elevated Fluoride. Also his well was initially dry and only produced significant water after development & a few days standing time.					7.11		Top 6" SC	0.34			
BH12	Groundwater	Borehole	230891	319220	Private borehole. Treatment for hardness & for H2S/sulphur					23	33.528	Top 6" SC	0.09			
BH13	Groundwater	Borehole	231018	319924	Private borehole. GSI Name =					7.215		Top 6" SC	-0.06			
BH14	Groundwater	Borehole	228937	318369	Private borehole. Water has red colour and is treated with addition of "salt"					11.08		Top 6" SC	-0.22			
BH15	Groundwater	Borehole	230366	317213	Private borehole.					9.4		Top 6" SC	-0.49			
BH16	Groundwater	Borehole	229415	318234	Private borehole. Not in use.					7.65		Top 6" SC	-0.13			
BH17	Groundwater	Borehole	230199	319088	GSI note - Private Well (Paddy O'Reilly). Farmhouse well. Assume "tc" is top of casing, which is 0.15m agl. Started pumping at 11am at 300m3/d and increased to approx 545m3/d at 12.00 noon??? GWL at 12:57 = 25.52mbtc.			24.4								
KF01	Karst	Swallow Hole	226843	321084												
KF02	Karst	Swallow Hole	226935	320900												

Table A2.2 - Ballyconnell Groundwater Level Survey November 2010

Location	X	Y	Time	Date	GWL mOD	GWLmbDatum	Datum mOD	GWLDatum	Datum magl	TD m	Comment
NCP2	227679	319971	12:15	17/11/2010	52.88	23.54	76.42	Top 12" SC	0.145		NCP1 15m Sth was pumping
p05/07d	228075	319743	12:52	17/11/2010	48.98	2.54	51.52	Top 50mm PVC	-0.09	38	Deep
p05/07s	228069	319745	12:51	17/11/2010	48.65	2.81	51.46	Top 50mm PVC	-0.075	16	Shallow
pz02/04	227642	321393	09:31	17/11/2010	79.63	38.57	118.20	Top 50mm PVC	-0.11	90	
Q05/01d	226955	320932	10:45	17/11/2010	105.55	82.56	188.11	Top 50mm PVC	0.07	103	
Q05/04	227919	321931	09:17	17/11/2010	51.59	19.4	70.99	Top of 6" SC/Well Cover	0.515	72	
OCP1	227967.5	321730.8	09:08	17/11/2010	51.35	20.15	71.497	Top 10" SC	0.52	-	
Q05/02	227287.03	321486.353	09:45	17/11/2010	126.22	9.45	135.665	Top 50mm PVC	0.23	70	
P05/05	226576.994	321213.553	10:00	17/11/2010	199.55	25.87	225.418	Top 50mm PVC	-0.21	70	
P05/06s	227944.1	319783.7	12:37	17/11/2010	48.98	2.65	51.63	Top 50mm PVC	-0.26	15.3	Shallow
P05/06d	227944.3	319791.3	12:42	17/11/2010	48.97	2.66	51.63	Top 50mm PVC	-0.06	23.8	Deep
PWSBH02	229873	318800	12:35	16/11/2010	47.59	0.28	47.873	Diphole in 16" cover	0.67	40	
PWSBH01	229859	318789	12:47	16/11/2010	47.61	0.3	47.907	Diphole in 16" cover	0.585	34	
PWSSP01	229861	318767	12:40	16/11/2010	46.53	0.63	47.162	Lowest point of dip hole	0.21	1.2	
TW01	229864	318798	12:44	16/11/2010	47.55	0	47.545	Top 5" SC	0.362	70	
BH01	229770	318942	12:30	16/11/2010	48.51	2.68	51.194	Top 6" SC	-0.32	42.062	
BH02	229832	319153	12:20	16/11/2010	50.42	8.84	59.263	Top 6" SC	0.23		
BH03	230167	319078	11:45	16/11/2010	47.75	26.025	73.773	Top 6" SC	0.19	48.768	
BH04	229110	316434	09:25	16/11/2010	50.13	23.37	73.498	Top 9" uPVC liner	0.5	40	Slieve Russell Hotel, not pumping
BH05	229047	317368	09:44	16/11/2010	52.58	3.75	56.327	Top 6" SC	-0.27		
BH06	229686	316021	10:00	16/11/2010	48.26	12.44	60.698	Top 6" SC	0.19	~ 24	
BH07	230525	316654	10:11	16/11/2010	49.34	9.005	58.348	Top 6" SC	0.17		
BH08	231052	316468	10:29	16/11/2010	49.43	0.839	50.269	Top 6" SC	-0.68	24.384	
BH09	230919	316700	10:20	16/11/2010	49.20	10.085	59.289	Top 6" SC	-0.44	42.672	
BH10	231244	317310	10:50	16/11/2010	48.57	7.02	55.588	Top 6" SC	-0.05		
BH11	231685	319010	11:05	16/11/2010	50.40	7.005	57.407	Top 6" SC	0.34		
BH12	230889	319216	11:20	16/11/2010	52.38	22.91	75.29	Top 6" SC	0.09	33.528	
BH13	231015	319923	11:30	16/11/2010	51.45	7.06	58.511	Top 6" SC	-0.06		
BH14	228935	318371	11:50	16/11/2010	50.35	10.67	61.019	Top 6" SC	-0.22		
BH15	230361	317208	12:10	16/11/2010	49.24	8.91	58.145	Top 6" SC	-0.49		
BH16	229412	318229	12:00	16/11/2010	50.30	7.265	57.562	Top 6" SC	-0.13		
PWSBH03	227573	319401	13:21	16/11/2010	48.90	22.17	71.073	Top 6" SC	0.398	66	
TW02	226694	318639	09:05	16/11/2010	53.26	2.605	55.862	GL	0.125		
GW01	228350	320175	13:05	16/11/2010	48.63	0	48.633	GL	0		

Table A2.2 - Ballyconnell Groundwater Level Survey November 2010

Location	X	Y	Time	Date	GWL mOD	GWLmbDatum	Datum mOD	GWLDatum	Datum magl	TD m	Comment
Woodford R @ P05/08	228315	319774	13:40	16/11/2010	45.15	0	45.153	River Water Level	0		
Woodford R @ Cloncoohy	229720	319630	14:20	16/11/2010	45.33	0	45.333	River Water Level	0		
Canal @ Cloncoohy Bridge	229224	320139	14:10	16/11/2010	45.13	0	45.127	Canal Water Level	0		
Lough Cuillaghan @ PWS compound Sample Site	229873	318790	12:55	16/11/2010	46.56	0	46.557	Lake Shore adj to PWS Compound	0		
Lough Clonamullig beside BH08	231106.73	316431.3	10:35	16/11/2010	48.55	0	48.552	Lake Shore near BH08	0		

PARAMETER	Units	POTABLE M.A.C. (SI 278 of 2007)	PWSBH03	L Cuillaghan	TW01	TW01	TW02	L Cuil Spring	PWSBH02	PWSBH02	PWSBH02	PWSBH01	PWSBH01	PWSBH01			
	Date		17/11/2010	16/11/2010	16/11/2010	24/01/2007	24/01/2007	24/01/2007	12/02/2009	20/03/2009	22/04/2009	27/05/2009	25/06/2009	21/07/2009	PW2 (27/10/09)	PW2 (20/11/09)	PW2 (17/12/09)
pH	-	6.5-9.5	7	-	-	8.26	8.3	8.32	7.87	7.55	7.63	6.47	7.63	7.58	7.97	7.5	7.46
Conductivity	µS/cm at 25°C	2500	402	-	-	389	436	344	387	334	408	360	376	354	348	352	361
Fluoride	mg/l	1.5	<0.15	<0.15	<0.15	0.3	0.3	0.2	0.1	-	-	<0.5	-	-	<0.5	-	-
Colour	Hazen Units	-	<5	-	-	1	1	6	0	<5	<5	<1	<5	<5	<1	<5	<5
Turbidity	NTU	-	<0.5	-	-	1	1.2	0.4	<0.1	<0.5	0.86	0.3	<0.5	<0.5	0.129	<0.5	<0.5
TOC	mg/l	-	42.9	-	-	2	<2	2	<2	-	-	<3	-	-	<3	-	-
Ammoniacal Nitrogen	mg/l N	0.23	<0.023	<0.023	<0.023	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	0.211	<0.1	<0.1
Cyanide	mg/l	0.05	<0.01	-	-	<50	<50	<50	<0.05	-	-	<0.05	-	-	<0.05	-	-
Nitrate	mg/l NO_3	50	0.8	1.3	1.3	5.8	8.6	5.4	8.8	<8.77	<8.77	2.9	<8.77	<8.77	7.13	<8.77	<8.77
Nitrite	mg/l NO_2	0.5	<2	2	<2	<0.05	<0.05	<0.05	<0.05	<0.07	<0.07	<0.05	<0.07	<0.07	<0.05	<0.07	<0.07
Chloride	mg/l	250	13	12	12	12	21	12	13	<10	<10	12	<10	<10	11.8	<10	10.11
Sulphate	mg/l	250	23.5	11.2	10.8	11	10	11	12	<20	<20	11	<20	<20	10.4	<20	<20
Hardness (as CaCO3)	mg/l	-	-	-	-	186	201	169	-	199.29	198.49	-	197.5	199.23		197.54	196.46
Alkalinity (as CaCO3)	mg/l	-	155	147	146	180	190	170	-	178	187	-	172	172		176	184
Total suspended solids	mg/l		-	-	-	<10	14	<10	-	-	-	-	-	-			
Total Dissolved Solids	mg/l	1000	-	-	-	190	198	177	-	-	-	-	-	-			
Aluminium	mg/l	0.2	<0.005	-	-	<0.002	<0.002	<0.002	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.052
Copper	mg/l	2	0.036	-	-	0.002	<0.001	<0.001	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Iron	mg/l	0.2	-	-	-	0.707	0.956	1.021	0.0299	<0.02	<0.02	<0.02	0.026	<0.02	<0.02	<0.02	<0.02
Dissolved Iron	mg/l	-	<0.010	-	-	0.036	0.026	0.038	<0.02	-	-	<0.02	-	-	<0.02	-	-
Total Manganese	mg/l	0.05	-	-	-	0.071	0.062	-	<0.005	<0.005	<0.005	0.042	0.034	0.023	<0.005	<0.005	<0.005
Dissolved Manganese	mg/l	0.05	<0.001	-	-	0.017	0.029	0.012	<0.005	-	-	0.04	-	-	<0.005	-	-
Calcium	mg/l	200	-	-	-	-	-	-	67.1	65.6	65.6	62.8	62.4	63.4	65.7	64.9	64.4
Dissolved Calcium	mg/l	200	-	60.41	61.33	60.2	59.9	55.5	-	-	-	-	-	-			
Potassium	mg/l	12	-	<2.5	<2.5	0.8	1.7	1	<5	<5	<5	<5	<5	<5	<5	<5	<5
Magnesium	mg/l	50	-	8.73	8.99	-	-	8.9	8.9	8.6	8.6	10.8	10.1	9.9	8.7	8.6	8.6
Sodium	mg/l	200	9.42	6.94	7.3	7	10.5	6.5	7.6	7.48	7.48	7.24	6.95	6.84	7.43	7.47	7.68
Arsenic	ug/l	10	<0.5	-	-	<1	<1	<1	<0.37	-	-	<0.37	-	-	<0.37	-	-
Cadmium	ug/l	5	<0.1	-	-	<0.4	<0.4	<0.4	<0.5	-	-	<0.5	-	-	<0.5	-	-
Chromium	ug/l	50	<0.5	-	-	4	4	4	<5	-	-	<5	-	-	<5	-	-
Nickel	ug/l	20	<0.5	-	-	1	1	2	<2	-	-	<2	-	-	<2	-	-
Lead	ug/l	10	<0.5	-	-	<1	<1	<1	<2.5	-	-	<2.5	-	-	<2.5	-	-
Antimony	ug/l	5	<0.5	-	-	5	2	<1	0.4	-	-	0.45	-	-	0.13	-	-
Boron	mg/l	1	0.0137	-	-	0.076	0.072	0.068	<0.1	-	-	0.1	-	-	<1	-	-
Barium	mg/l	-	-	-	-	4	9	5	<0.02	-	-	0.02	-	-	<0.02	-	-
Phosphorous	ug/l	-	-	-	-	-	-	-	<100	-	-	<100	-	-	<100	-	-
Dissolved Phosphorous	ug/l	-	-	-	-	11	<10	11	-	-	-	-	-	-			
Selenium	ug/l	10	<0.5	-	-	<1	<1	<1	0.24	-	-	<0.22	-	-	0.24	-	-
Tin	ug/l	-	-	-	-	-	-	-	<0.9	-	-	<0.9	-	-	3	-	-
Dissolved Tin	ug/l	-	-	-	-	<1	<1	<1	-	-	-	-	-	-			
Uranium	ug/l	-	-	-	-	-	-	-	0.62	-	-	1.1	-	-	0.62	-	-
Dissolved Uranium	ug/l	-	-	-	-	<1	<1	<1	-	-	-	-	-	-			
Mercury	ug/l	1	<0.05	-	-	<0.05	<0.05	0.06	<0.015	-	-	<0.015	-	-	<0.015	-	-
Zinc	mg/l	5	-	-	-	-	-	-	<0.02	-	-	<0.02	-	-	<0.02	-	-
Dissolved Zinc	mg/l	5	-	-	-	0.012	0.013	0.01	-	-	-	-	-	-			
Faecal Coliforms	cfu/100ml	0	0	-	0	<1	2	2	<1	0	0	<1	0	0	<1	0	0
Faecal *Streptococci*	cfu/100ml	-	-	-	-	<1	<1	-	<1	0	0	<1	0	0	0	0	0
Clostridium perfringens	cfu/100ml	0	-	-	-	2	2	-	<1	0	0	<1	0	0	0	0	0
Total Coliforms	cfu/100 ml	0	0	-	-	<1	2	30	<1	<1	<1	<1	<1	<1	0	<1	<1
TVC 22ºC	cfu/ml	-	-	-	-	<1	<1	-	6	3	2	2	0	0	50	100	379
TVC 37ºC	cfu/ml	-	-	-	-	<10	40	-	<1	6	0	5	0	0	6	0	1
Crypto Sample Volume Filtered	l	-	-	-	-	-	-	-	1787	2648	1675	1437	1572	1461	1794	1853	1815
Crypto Filter Appearance	-	-	-	-	-	-	-	-	Clean	Clean	Loaded	Loaded	Loaded	Clean	Clean	Loaded	Clean
Cryptosporidium	Oocysts/10l	0	-	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Giardia	Cysts/10l	0	-	-	-	-	-	-	-	-	-	<0.01	<0.01	<0.01			
PESTICIDES Total	µg/l		<0.02			<0.1	<0.1										
Diazinon	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Dichlorvos	µg/l	1	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Ethion	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-

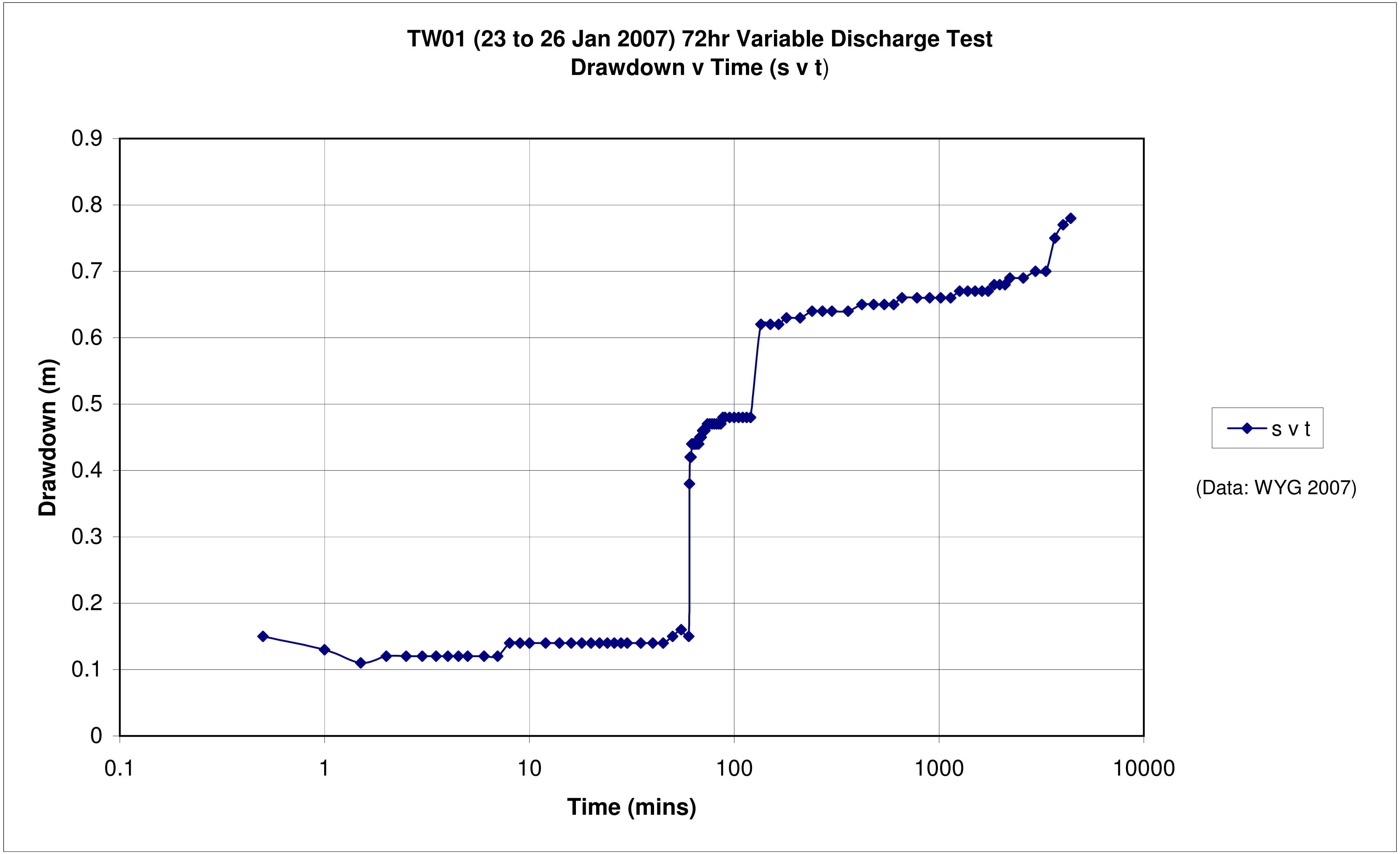
PARAMETER	Units	POTABLE M.A.C. (SI 278 of 2007)	PWSBH03	L Cuillaghan	TW01	TW01	TW02	L Cuil Spring	PWSBH02	PWSBH02	PWSBH02	PWSBH01	PWSBH01	PWSBH01			
	Date		17/11/2010	16/11/2010	16/11/2010	24/01/2007	24/01/2007	24/01/2007	12/02/2009	20/03/2009	22/04/2009	27/05/2009	25/06/2009	21/07/2009	PW2 (27/10/09)	PW2 (20/11/09)	PW2 (17/12/09)
Fenitrothion	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Malathion	µg/l	190	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Methyl Parathion	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Parathion	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Aldrin	µg/l	0.03	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Azinphos methyl	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Mevinphos	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
α-BHC	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
β-BHC	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
γ-BHC	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
4,4'-DDD	µg/l	0.01	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
4,4'-DDT	µg/l	0.01	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
4,4'-DDE	µg/l	0.01	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Dieldrin	µg/l	0.0001	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Endosulfan α	µg/l	30	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Endosulfan β	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Endosulfan Sulphate	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Endrin	µg/l	0.00004	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Heptachlor	µg/l	0.3	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Heptachlor Epoxide	µg/l	3	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
Methoxychlor	µg/l	-	-	-	-	-	-	-	<0.01	-	-	<0.01	-	-	<0.01	-	-
VOC's																	
Trihalomethanes-Total	ug/l	100	-	-	-	<4	<4	-	<1	-	-	<1	-	-	-	-	-
1,2-Dichloroethane	ug/l	3	<0.6	-	-	<0.2	<0.2	-	<0.06	-	-	<0.06	-	-	<0.06	-	-
1,1,1-Trichloroethane	ug/l	200	-	-	-	-	-	-	<0.04	-	-	<0.04	-	-	<0.04	-	-
Tetrachloromethane	ug/l	2	-	-	-	-	-	-	<0.06	-	-	<0.03	-	-	<0.03	-	-
Benzene	ug/l	1	<0.6	-	-	<0.05	<0.05	-	<0.024	-	-	<0.024	-	-	<0.024	-	-
MTBE	ug/l	30	-	-	-	-	-	-	<0.1	-	-	<0.1	-	-	<0.1	-	-
Trichloromethane	ug/l	200	<0.7	-	-	-	-	-	<0.21	-	-	<0.21	-	-	<0.21	-	-
TAME	ug/l	-	-	-	-	-	-	-	<0.09	-	-	<0.09	-	-	<0.09	-	-
Trichloroethene	ug/l	70	-	-	-	-	-	-	<0.07	-	-	<0.07	-	-	<0.07	-	-
Dichlorobromomethane	ug/l	-	-	-	-	-	-	-	<0.13	-	-	<0.13	-	-			
Dibromochloromethane	ug/l	-	-	-	-	-	-	-	<0.15	-	-	<0.15	-	-	<0.15	-	-
1,2-Dibromomethane	ug/l	-	-	-	-	-	-	-	<0.16	-	-	<0.16	-	-			
Tetrachlorethene	ug/l	10	-	-	-	-	-	-	<0.06	-	-	<0.06	-	-	<0.06	-	-
Tribromomethane	ug/l	-	-	-	-	-	-	-	<0.17	-	-	<0.17	-	-	<0.17	-	-
Tetra + Trichloroethene	ug/l	40	<0.7	-	-	<0.4	<0.4	-	<0.4	-	-	<0.4	-	-	-	-	-
PAH's - Total	ug/l		<0.002			<0.0034	<0.0036										
Benzo (a) pyrene	ug/l	0.01	<0.001	-	-	<0.004	<0.004	-	<0.0004	-	-	<0.0011	-	-	0.0011	-	-
Benzo (b) fluoranthene	ug/l	0.5	-	-	-	-	-	-	<0.0007	-	-	<0.0014	-	-	0.0014	-	-
Benzo (k) fluoranthene	ug/l	0.05	-	-	-	-	-	-	<0.0006	-	-	<0.0015	-	-	0.0015	-	-
Benzo (g,h,i,) perylene	ug/l	0.05	-	-	-	-	-	-	<0.0013	-	-	<0.0016	-	-	0.0016	-	-
Indeno (1,2,3-cd)pyrene	ug/l	0.05	-	-	-	-	-	-	<0.0007	-	-	<0.001	-	-	0.0010	-	-
Fluoranthene	ug/l	1	-	-	-	-	-	-	<0.0024	-	-	<0.0067	-	-	0.0067	-	-
Bromate ug/l	ug/l		<0.6	-	-	-	-	-	-	-	-	-	-	-			
Field pH			7.23	7.6	7.56	-	-	-	-	-	-	-	-	-			
Field Conductivity @ 25°C			395	389	395	-	-	-	-	-	-	-	-	-			
Ortho-phosphate (P) mg/l	mg/l P		-	<0.02	<0.02	-	-	-	-	-	-	-	-	-			
Temperature	deg C		9.9	9.4	11.2	-	-	-	-	-	-	-	-	-			

Bold Red Text indicates exceeedance of MAC

Bold Orange Text indicates exceeedance of EPA Threshold (ammonium threshold = 0.175 mg/l as N)

APPENDIX 3

- Pumping Test Analysis for borehole TW01


TW01 (23 to 26 Jan 2007) 72hr Variable Discharge Test
Drawdown v Time (s v t)
Drawdown (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Time (mins)
0.1
1
10
100
1000
10000
s v t
(Data: WYG 2007)

TW01 (23 to 26 Jan 2007) 72hr Variable Discharge Test - Birsoy Summers Analysis Specific Drawdown v Adjusted Time (Semi - Log Plot)