Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Longwood Water Supply Scheme

Longwood Borehole

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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.

The project "Establishment of Groundwater Source Protection Zones", led by the Environmental Protection Agency (EPA), represents a continuation of the GSI's work. A CDM/TOBIN/OCM project team has been retained by the EPA to establish Groundwater Source Protection Zones at monitoring points in the EPA's National Groundwater Quality Network.

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

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1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Longwood source according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater Source Protection Zone Delineation.

Longwood Public Water Supply is supplied by a borehole abstracting 350 m^3/day.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Longwood area.
- To delineate source protection zones for the Longwood Borehole.
- To assist the Environmental Protection Agency and Meath County Council in protecting the water supply from contamination.

The maps produced are based largely on the readily available information in the area and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The Longwood Borehole, operated by the Meath County Council since 2003, is located approximately 1.5 km to the east of Longwood, within the River Boyne catchment (See Figure 1). The intake brings the water to the pumphouse where the untreated water is chlorinated. The annulus around the borehole is not grouted (see Appendix 1 – remarks given with the log). The borehole cover and surrounding area is securely covered and locked while the site compound is securely fenced off. Photograph 1 shows the site and location of production borehole.

Photograph 1 Borehole cover and adjacent treatment works

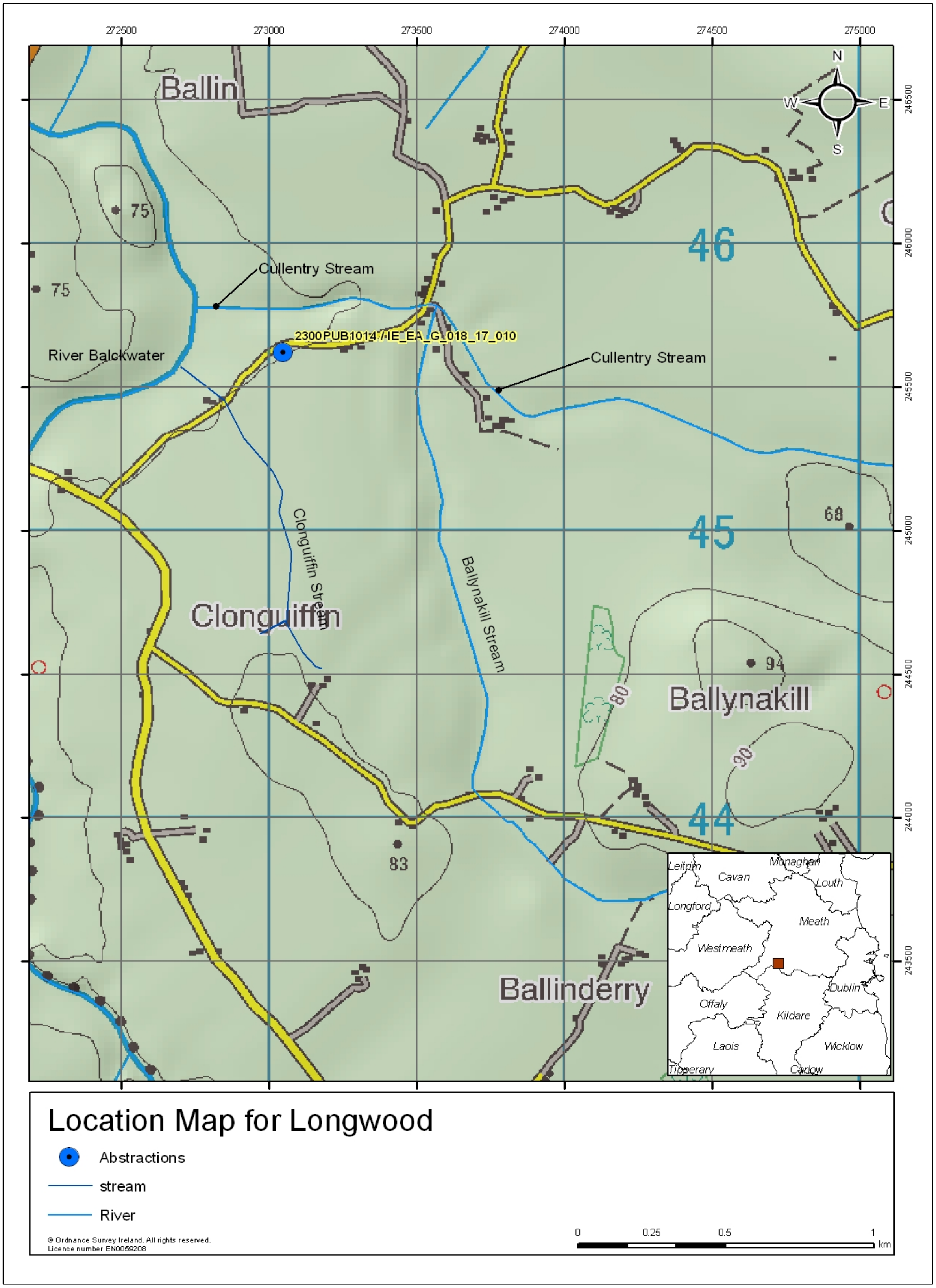


Figure 1 Location Map

3 SUMMARY OF BOREHOLE DETAILS

A trial borehole (TW2) was drilled approximately 10 m from the current location of PW1 in 1985. Subsequent to completing a pumping test on TW2 in March 2001, a production borehole PW1 was drilled in April 2001 (KT Cullen (now WYG)). Drilling encountered 7 m of till confining 5 m of saturated gravels. The underlying bedrock was fractured/weathered in the top 1 m (12-13 m bgl), becoming relatively competent with significant fractured zones encountered between 43-49 m bgl and 80 m bgl (Report of the drilling, pumping and the logs are given in Appendix I). The borehole casing was completed towards the top of the weathered bedrock, allowing water inflows from the gravels and weathered bedrock into the well. The borehole was not grout sealed to allow the significant inflows from the overburden. Table 3.1 summaries the borehole details as currently known.

Table 3.1 Summary Details of PW1

EU Reporting Code	IE_EA_G_018_17_010
Grid reference	E273050 N245620
Townland	Clonguiffin
Source type	Borehole
Drilled	2001
Owner	Meath Co. Co.
Elevation (Ground Level)	c. 70 mOD
Depth	94 m
Depth of casing	Inner Casing 94 m; Outer casing 12 m
Diameter	0.2 m
Depth to rock	11.5 m
Static water level	Artesian (Overflow estimated by well driller at 100 m^3/day)
Pumping water level	45 mbgl (17/09/2009)
Consumption (Co. Co. records)	350 m^3/d
Specific capacity	20 m^3/day/m ((767 m^3/day/36.9 m) - 7 day test 2001) 42 m^3/day/m (based on 72 hour test on TW2) **8 m^3/day/m (based on current pumping regime of 350 m^3/day with a drawdown of 45m)**
Transmissivity	80 m^2/day (confined saturated gravels & recovery data) **10 m^2/day (Bedrock and gravels together, based on Logans approximation of Specific Capacity of 8 m^3/day/m)**

4 METHODOLOGY

The methodology consisted of data collection, desk studies, site visits and field mapping. Analysis of the information collected during the studies was used to delineate the Groundwater Source Protection Zones.

The initial site visit and interview with the caretaker took place on 17/09/2009. Site walk-overs and field mapping (including measuring the electrical conductivity and temperature of streams in the area) of the study area were conducted on 17/09/2009, 22/09/2009 and 03/11/2009.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

Longwood Borehole is located 300 m southeast of the River Blackwater within the River Boyne catchment (Hydrometric Area 07). The land rises gently to the south and east of the source between the townlands of Ballynakill and Ballinderry, to the higher ground, of which Ballynakill (94 m OD) forms the highest point. The topography in the vicinity of the well is relatively flat with a gentle slope down towards the northwards-flowing River Blackwater and its tributaries. Gradients vary between 1:100 to 1:200 in the low lying areas around the source itself, becoming steeper towards the higher ground at 1:30.

According to the six inch maps, there is a moderate density of drains and springs surrounding the source. A number of smaller, unnamed streams rise on the higher ground and flow towards the River Blackwater (Refer to Figure 1). Two of the streams converge 500 m the east of the borehole and the resultant stream flows in a westerly direction, 120 m to the north of the Longwood source. Another small stream is located to the west of the borehole. For the purposes of this report, these streams are named the Clonguiffin Stream, Ballynakill Stream and Cullentry Stream, based on the townlands in which each rises (refer to Figure 1). There is a low-moderate density of drainage ditches in the area surrounding the source, with a high drainage density within alluvial areas.

Land use in the area is primarily agricultural, with lands set to pasture or used for tillage. Forestry was noted on an elevated site at Ballnakill, comprising a managed afforested site. A number of farmyards have been noted in the area, though no farmyards were identified within 250 m of the borehole. Two farmyards occur within 250-300 m of the source. The Ballynakill/Clonguiffin area has a low housing density, although a number of one-off houses have been built since 2005 (less than 10). No major industry was identified in the environs of Longwood Borehole.

6 GEOLOGY

6.1 BEDROCK GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Longwood source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based the Bedrock Geological Map of Meath Sheet 13, 1:100,000 Series (McConnell *et al*, 2001) and the GSI Karst Database.

The Bedrock Geological Map of Meath indicates that this area is principally underlain by Dinantian Pure Unbedded Limestones (Waulsortian Limestone Formation). Refer to Figure 2 for the geology map of the area. The Pure Unbedded Limestone is bounded by Dinantian Upper Impure Limestones (Lucan Formation). The contact between the two has been interpreted as a thrust fault orientated in an ESE/WNW direction.

The Dinantian Pure Unbedded Limestones (Waulsortian Limestone Formation) are comprised of relatively clean, sometimes-cherty limestones, interbedded with thin shaly bands that display a distinct wavy nodular texture.

Bedrock lithologies recorded within borehole source (PW1) consisted of dark grey to blue limestones. Highly weathered limestones were encountered at the bedrock surface 11.5 m bgl, becoming more competent at 12.5 m bgl. Fissures/fractures were encountered at 48.7 m bgl and 80 m bgl.

See the Cross section in Figure 3 for a diagrammatic view across the study area.

6.1.1 Karst Geology

As part of the development of this SPZ report, a brief karst mapping programme was undertaken in the study area by TOBIN Consulting Engineers and Robbie Meehan in September 2009. No features had previously been identified from the GSI Karst Database. The mapping identified one new karst feature (Refer to Table 6.1).

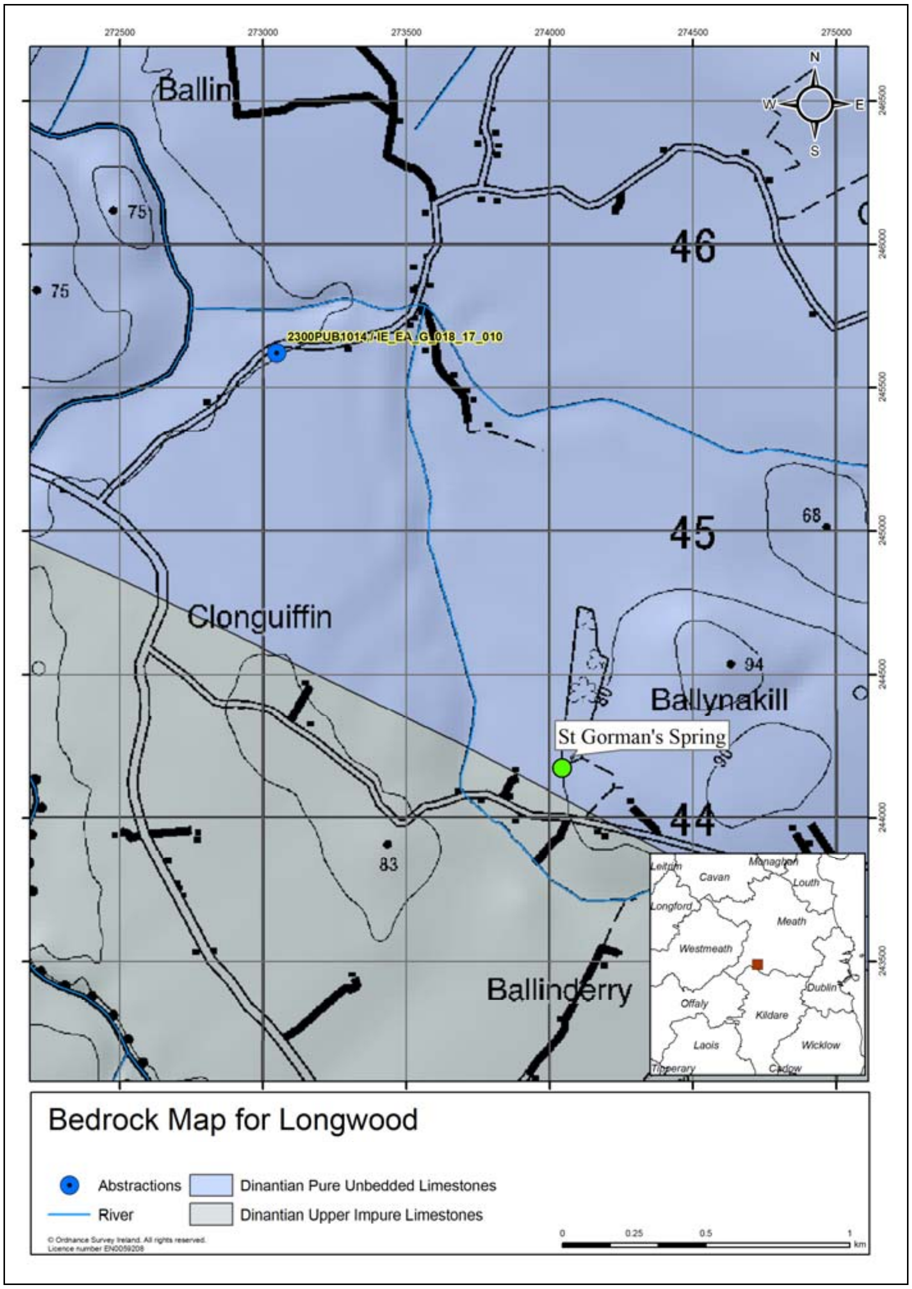


Figure 2 Geology Map

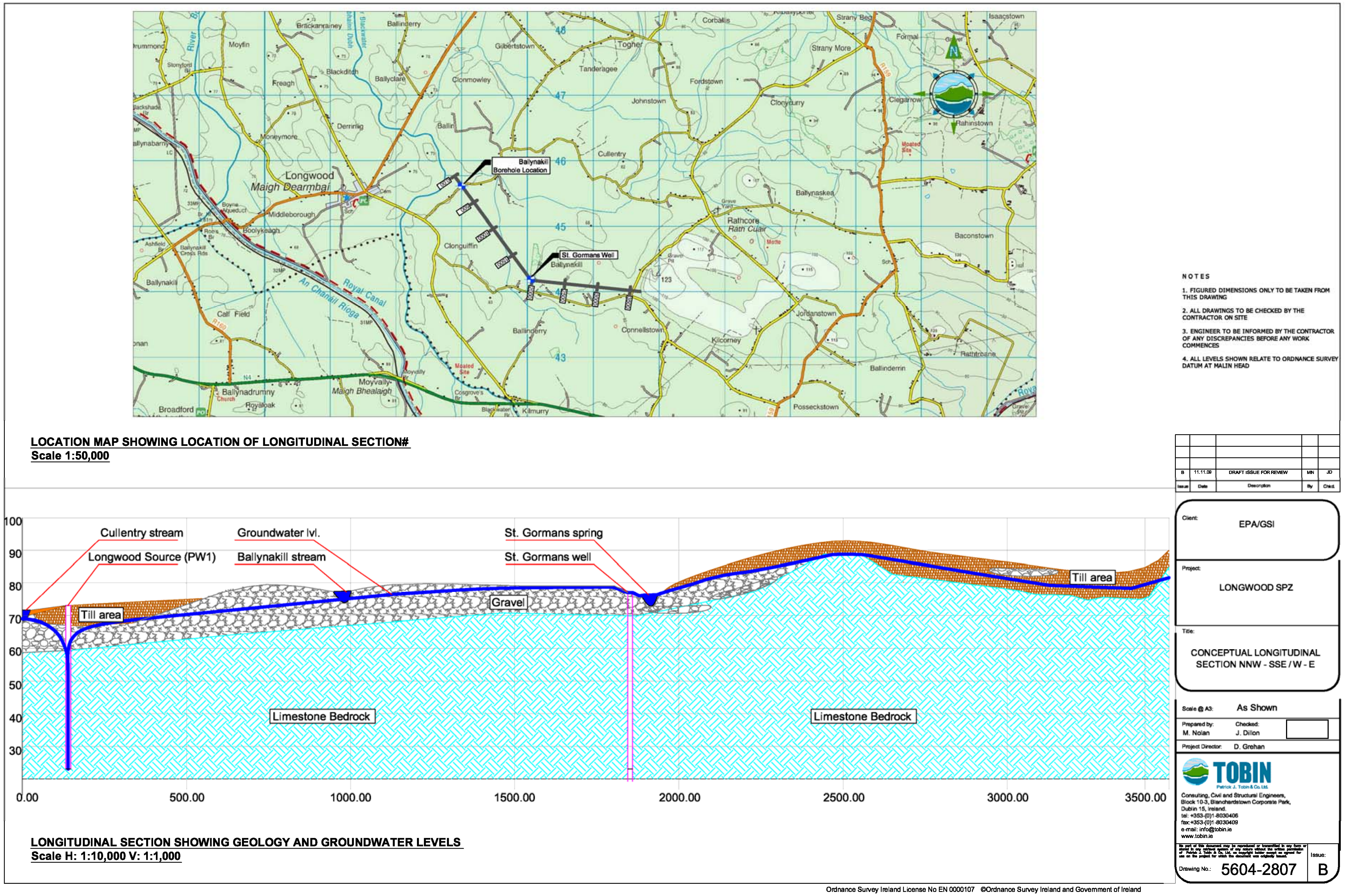


Figure 3 Cross Section

Table 6.1 Karst features within a 2 km radius of Longwood Borehole

Number	Feature type	Feature name	Easting	Northing	Distance from Borehole	Townland
SW1/SW1B	Spring	St Gorman's Well/spring	244180	274050	1.7 km SE	Ballynakill

A karstic 'geothermal' spring known as 'St Gorman's Spring' is located within the Waulsortian limestone to the southeast of the borehole. This karst feature is a warm spring potentially associated with the fault area (CSA, 2004). Based on drilling information, large karstic cavities are present underlying the geothermal spring. As part of an exploratory geothermal project, two boreholes were drilled adjacent to St Gorman's Spring to a depth of 13 m. The first borehole, 2 m from the spring, encountered very broken Waulsortian limestone and a cavity, which was connected to the spring. The second borehole, 12 m from the spring, also encountered fractured limestone. Both boreholes responded rapidly to the abstraction of water from the spring and to fluctuations in the pumping rate (1300–1800 m^3/d). Annual temperatures ranged from 12–25^oC and the conductivity from 570–585 µS/cm. The spring appears to respond to seasonal rainfall events and discharges up to 1100 m^3/day during winter months but runs dry towards the end of summer. Further drilling encountered a large cavity at 118 m in one well. The wells were drilled approximately 20 m to the west of the spring and currently act as the main groundwater discharge point for the geothermal water (see Photo 3). The majority of groundwater discharges from one well and is referred to as St Gorman's well.

Photograph 2 St Gorman's Spring

Photograph 3 St Gorman's Well

Solutionally enhanced karst features were recorded in adjacent localities at a withdrawn Planning Application for a quarry at Ballynakill Hill (Meath County Council Planning Ref. No. TA60536, 2006) and from mineral exploration drilling by BHP Billiton (1998) within the surrounding Waulsortian bedrock. Solutionally enhanced joints and cavities have been noted throughout the Waulsortian in south Meath with heavy weathering associated within the top 50 m bgl. These cavities and joints are typically clay filled or partially clay filled and have been recorded to depths of 30m bgl with occasional cavities and minor dolomitization to 100 m bgl (BHP Billiton, 1998). While many of the cavities and joints are partially or fully clay filled, iron oxide staining in some boreholes suggests water movement within these features. Based on the presence of deep karst features and thick subsoils (typically >10 m); these karst features are thought to represent palaeokarst, with some recent dissolutional activity.

6.2 SUBSOILS GEOLOGY

According to GSI and EPA web mapping, the study area is dominated by till derived from limestone (TLs) and sand and gravel deposits derived from limestone (GLs). The glaciofluvial sands and gravels form a complex boundary sequence with the till deposits to the south of the borehole. Based on the borehole log of PW1 (appendix 1), the subsoil at the borehole comprises gravelly CLAY unit approximately 7 m thick underlain by 5 m of gravels and boulders.

The number of soil and subsoil exposures is limited within the Longwood Borehole study area. Where exposures were noted, they were typically limited at <1 m. At location S1, adjacent to the Clonguiffin stream, gravel deposits were described using BS5930 as grey, loose, slightly silty, sandy, GRAVEL. Approximately 100 m to the south of the borehole, a subsoil exposure S2 was noted (1.9 m bgl) within a deepened drainage ditch. The subsoil comprised grey/yellow, very stiff, laminated CLAY. Approximately 600 m to the southeast of the Longwood borehole, a previously exploited gravel pit exists at S3. Slightly silty, sandy GRAVEL was evident within the pit. The pit is located on the apex of minor ridge running north/south to the west of Ballynakill Stream. While this had been previously mapped as till derived from limestone, based on site observations this is reclassified as sand and gravel subsoil. At location S4, adjacent to the Cullentry stream, sand and gravel deposits were described as grey, loose, silty, sandy, GRAVEL.

Based on the above information, a slightly modified subsoil map with a larger area underlain by sand and gravel is submitted as part of the SPZ Characterisation. Refer to Figure 4 for this modified subsoils map.

The area between Clonguiffin stream and Ballynakill stream is considered to be comprised of sand and gravel deposits overlain by till deposits, as encountered within TW2 and PW1. Till subsoil was encountered at location S2, 100 m south of PW1. The till area overlying the sand and gravel deposits is shown on Figure 4.

The soils on the till areas are mapped as 'dry' soil types: typically well drained deep mineral soils (BminDW) and well drained shallow soils (BminSW) (EPA webmapping). However, from field descriptions of CLAY subsoils and mapping of drainage density and vegetation around the source, pockets of gley soils are expected in the locality. Areas of alluvial deposits are mapped along the course of the Blackwater River and tributaries. In an area at the northern flank of Ballynakill Hill to the northeast/east of the source, areas of poorly drained soils are present with a large area (0.5 km^2) of lacustrine deposits, which forms the lowest point with the study area (68 m OD).

The subsoils across County Meath have been classified according to British Standards 5930 in the preparation of the Groundwater Vulnerability map for Meath County Council, by the GSI. The subsoil permeability of the till unit around the source has been classed as '*Moderately Permeable*', but localized pockets of '*Low permeability*' material is expected around the source. Areas of *'High'* permeability sand and gravel deposits are located towards the north, south and east of the borehole.

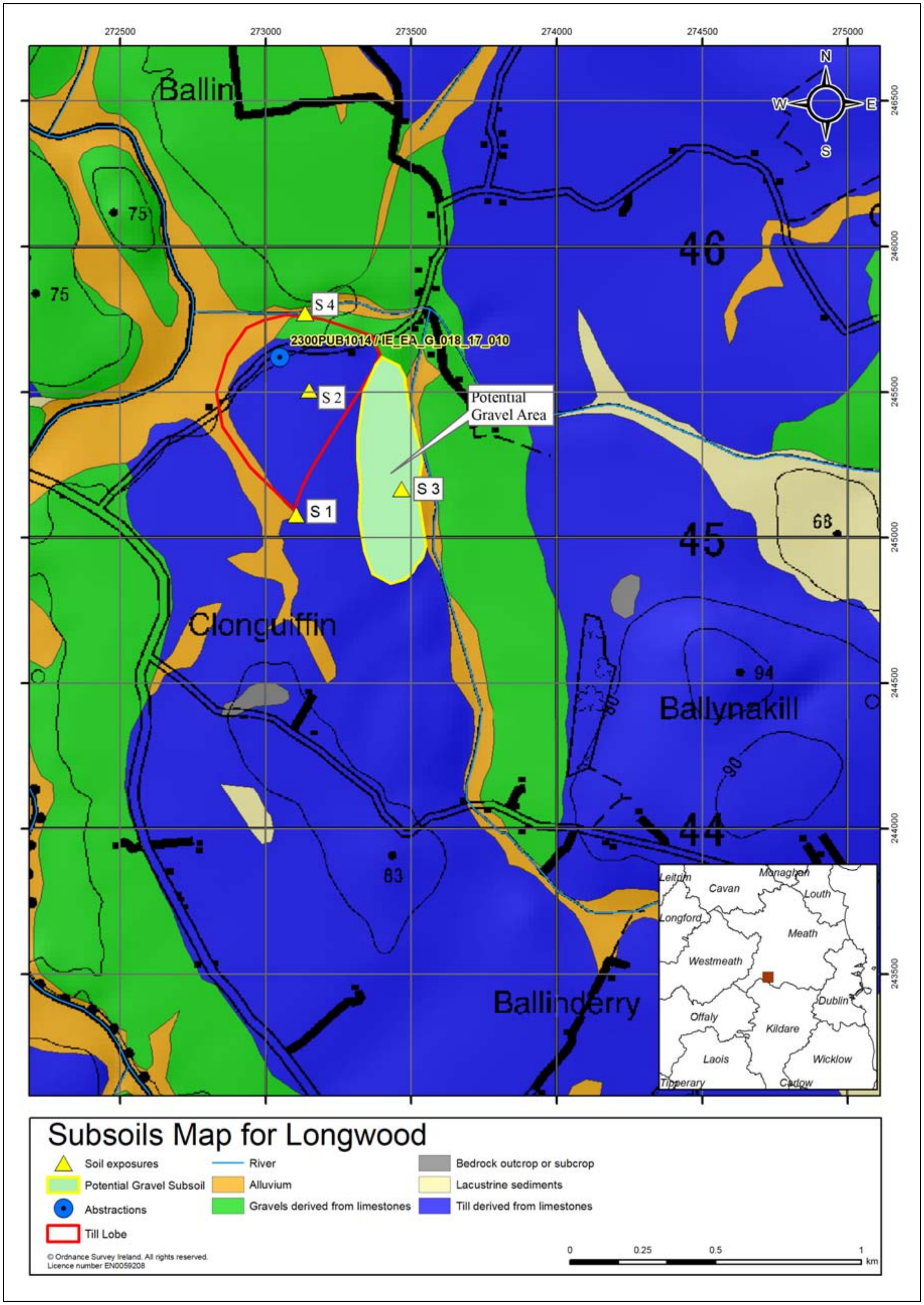


Figure 4 Subsoil Map

6.3 DEPTH TO BEDROCK

Based on the geological information acquired from the BHP Billiton report (1998), depth to bedrock in the area is in general greater than 10 m, with bedrock outcrop generally confined to the crests of hills. Depth to bedrock at the production boreholes PW1 and TW2 is 12 m.

Previous drilling on Ballynakill Hill (Meath County Council Planning Ref. No. TA60536, 2006) indicated that the subsoil thickness varied from 2.6 m towards the top of the hill, increasing quickly to 14.5 m approximately 400 m further north along the flank of the hill. Subsoil and bedrock exposures within Rathcore quarry 2 km to the east of Ballynakill, show similar depths to bedrock with shallow depths (<2 m) near the crest of the hill, quickly increasing away from the crest.

Additional information was also obtained from previous mineral exploration data (www.mineralsireland.com) by BHP Billiton investigating geophysical anomalies within the study area. Depths of subsoil from previous boreholes detailed in Table 6.1 indicates that the subsoil depths underlying the study area are generally >10 m.

Table 6.1 Summary of depth to rock information from exploration data

Location	Easting	Northing	Direction and distance from Borehole(km)	Subsoil description from GSI	Subsoil Depth
1500-98-1	272800	246700	1.1km North	TLs	9m
1500-98-2	274350	245340	1.3km East, South East	Lac	90m
1500-98-3	275650	245120	2.7km East, South East	GLs	27.5

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. This means that vulnerability relates to the thickness of the unsaturated zone in the sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. 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 for the region, as mapped by GSI, is dominated by Moderate vulnerability and is shown in Figure 5. The general subsoil permeability of the till unit around the source has been classed as '*Moderately Permeable*', but localized pockets of '*Low permeability*' material are expected around the source. As such, there are expected to be localized pockets of Low vulnerability in the vicinity of the borehole. Areas of '*High*' permeability sand and gravel deposits are located towards the north, south and east of the borehole. Based on the modified subsoils map, there is likely to be an extension of High vulnerability in the area modified as gravels.

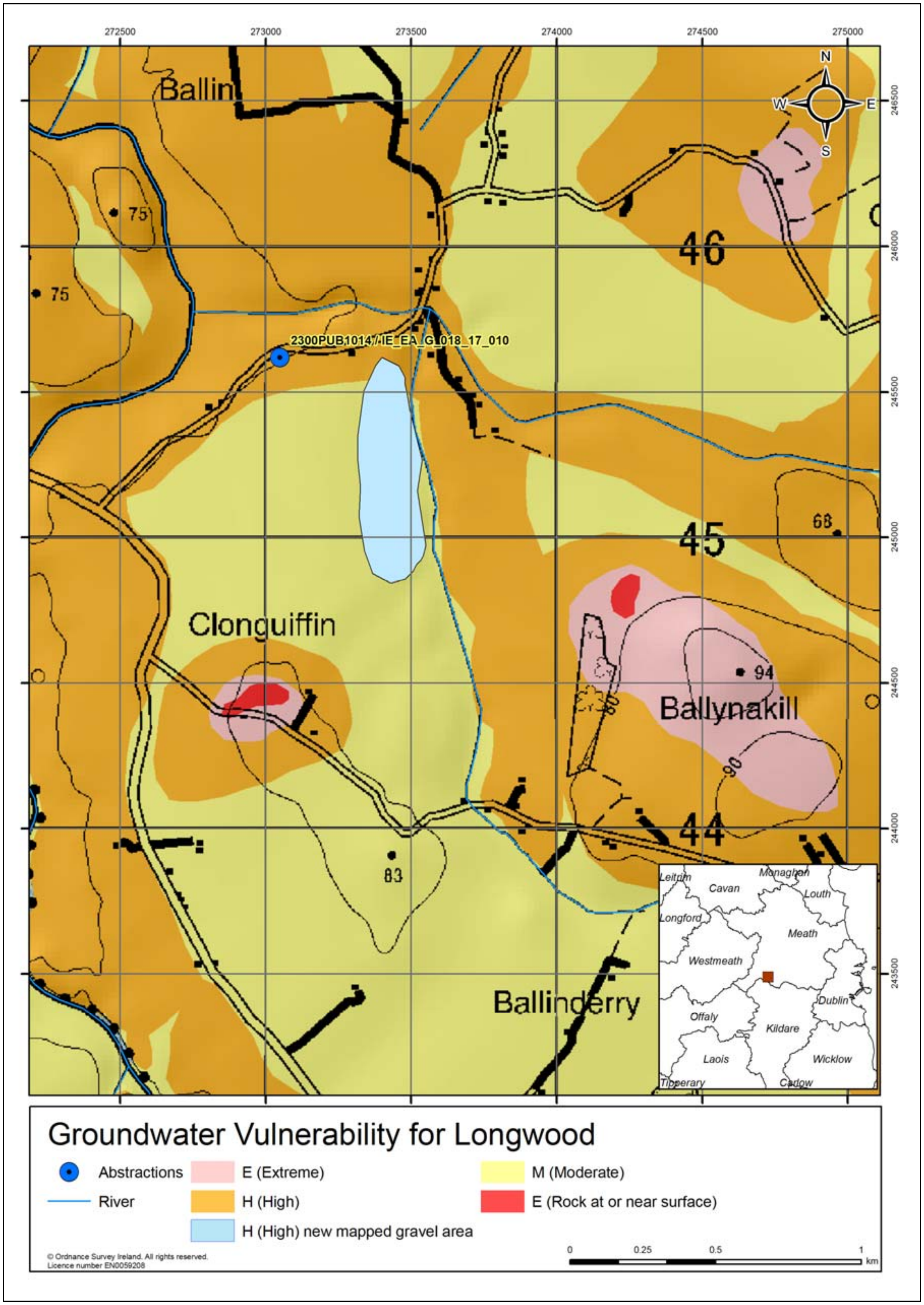


Figure 5 Groundwater Vulnerability in the area (GSI)

8 HYDROGEOLOGY

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

- GSI Website and Well Database
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan in September and November 2009.
- KT Cullen (2001). *Report on the Drilling and Testing of a Production Well at Longwood, Co. Meath.*
- Woods et al (1998) *County Meath Groundwater Protection Scheme*

8.1 GROUNDWATER BODY AND STATUS

The Longwood source is located within the Longwood Groundwater Body which has been classified as being of Good Status www.wfdireland.ie/maps.html. 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 .

8.2 METEOROLOGY

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

Annual rainfall: 843 mm. The closest meteorological station to Longwood borehole is located at Longwood Village. Data records used (Longwood Gauging Station) are based on Met Éireann data for long term annual average rainfall (Fitzgerald and Forrestal, 1996). Data from the Met Eireann website also shows that the source is located between the 800 mm and 1000 mm average annual rainfall isohyets.

***Annual evapotranspiration losses:* 428 mm.** Potential evapotranspiration (P.E.) is estimated to be 450 mm/yr (based on data from Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

***Annual Effective Rainfall: 415* mm**. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 415 mm/year. Section 8.7 following (Recharge) estimates the proportion of effective rainfall that enters the aquifer utilising other hydrogeological data for the area.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater levels in the area surrounding Longwood Borehole are close to the surface. During initial drilling at Longwood, groundwater became artesian once the gravels were encountered (Cullen, 2001).

Groundwater levels at PW1 and TW2 were recorded when drilled at, or slightly above, ground level, indicating artesian conditions. The pumping test data indicates a substantial groundwater component from the subsoil (localised gravels).

Groundwater levels previously measured at Ballynakill Hill in April 2001 are between 0.2 m above ground level (St Gorman's Borehole) and 10 m bgl. Based on the presence of a number of springs towards the edge of Ballynakill Hill and poorly drained soils surrounding the base of Ballynakill Hill, it is suggested that the groundwater discharges locally towards the base of the hill. Based on the hydrochemistry (see Section 8.4), all streams are interpreted as being groundwater fed.

The regional groundwater flow direction in the vicinity of the Longwood source is from the southeast to the northwest, towards the River Blackwater. There are no well data for the area between Ballynakill Hill and Longwood PWS. Data in this area could provide more conclusive information on flow directions and subsoil conditions.

Local groundwater flow at PW1 is controlled by the pumping of the well. The natural hydraulic gradient is considered to be relatively flat, approximately 0.005 to 0.01 in the gravels but likely to be steeper in the bedrock – 0.05.

8.4 HYDROCHEMISTRY AND WATER QUALITY

To investigate the relationship of groundwater to surface water, field mapping of surface water features was carried out in September 2009 including measurement of electrical conductivity and temperature and a quantitative assessment of flow. Monitoring of flow in the Clonguiffin, Ballynakill and Cullentry streams was conducted to investigate the potential groundwater discharges to the streams. Table 8.1 provides the field data from 23rd September 2009. Refer to Figure 7 for locations.

Table 8.1 Field measurements of surface water features

SW stream ID	Flow m^3/day	Conductivity (µS/cm @ 25°C)	pH	Dissolved Oxygen %	Temperature °C	Notes
SW 1	850	590	7.5	36	20.6	At St Gorman's Borehole
SW1A	NA	590	7.5	47	14.4	St Gorman's spring
SW 1B	900	620	7.6	75	13.6	St Gorman's 400m downstream
SW 2	1289	810	7.4	72	12.1	Ballynakill Stream
SW 2A	150	818	7.3	60.8	12.0	Ballynakill Stream
SW 3	2515	820	7.4	65	12.0	Cullentry Stream
SW 4	50	910	7.5	73	11.8	Clonguiffin Stream
SW 4A	50	820	7.3	78	11.7	Clonguiffin Stream

Based on the high conductivity values, all streams are interpreted as being groundwater fed.

Electrical conductivity encountered within St Gorman's spring was appreciably lower than the surrounding area (<600 µS/cm). The very high conductivity values at the springs and streams (800–900 µS/cm @ 25°C) suggest that a component of the groundwater is derived from the gravel deposits. Due to the limited soils exposures within the catchment it was not possible to measure all spring sources. Conductivity values of 820 µS/cm were recorded at one spring SW4 along the bank of the Clonguiffin Stream. Groundwater was clearly discharging from a gravel exposure at this location.

Eleven samples were available from the EPA Groundwater Monitoring Network between 2006 and 2008. The water quality varies from hard to very hard, (324 to 396 mg/l $CaCO_3$). Alkalinity ranges from 240 to 380 mg/l $CaCO_3$. The pH ranges between 7.2 and 8.4, which is alkaline. The field electrical conductivity ranges from 557 to 818 µS/cm @25°C. The hydrochemical signature of the water is calcium bicarbonate.

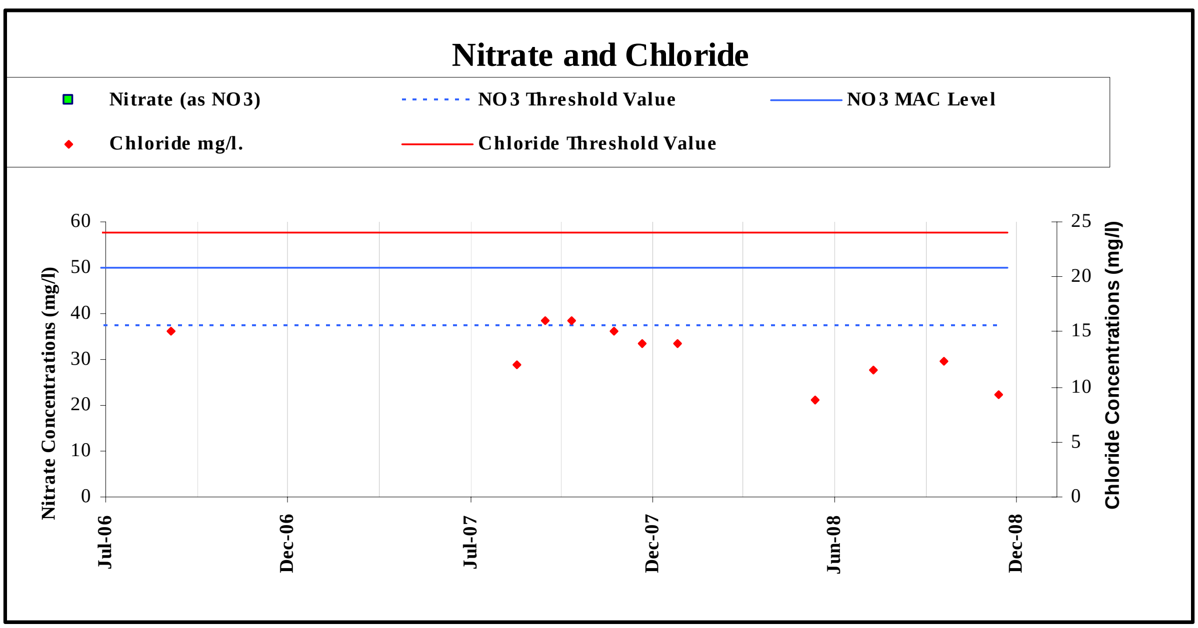
The concentration of nitrate ranges from 4.8 mg/l to 8 mg/l with an average 6.5 mg/l (as NO_3). There is no reported exceedance above the EU Drinking Water Directive maximum admissible concentration of 50 mg/l, or the groundwater threshold value (S.I. No. 9 of 2010 Groundwater Regulations) of 37.5 mg/l (see Figure 6).

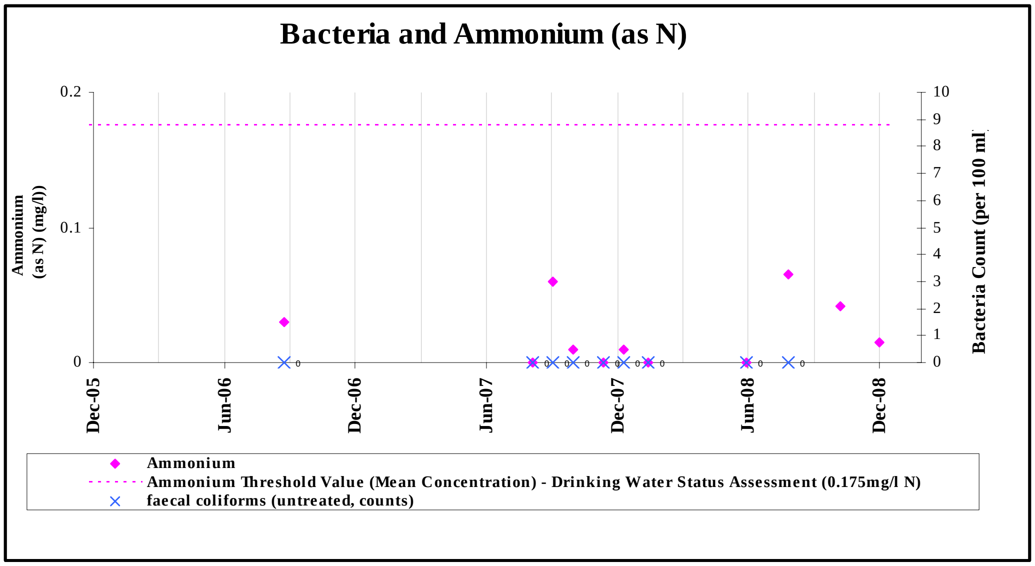
Chloride concentrations, range from 8.8 to 16 mg/l, with a mean of 12.9 mg/l which is considered to be below the mean natural background level of 18 mg/l (Groundwater newsletter 46, O'Callaghan Moran 2007) and the groundwater saline intrusion threshold value (S.I. No. 9 of 2010 Groundwater Regulations) of 24 mg/l. This is indicative of a low pollution loading at the source. Exceedance of the manganese MAC was noted in the majority of samples since November 2007. Naturally high manganese concentrations are known to occur within the gravels and limestone bedrock in Meath.

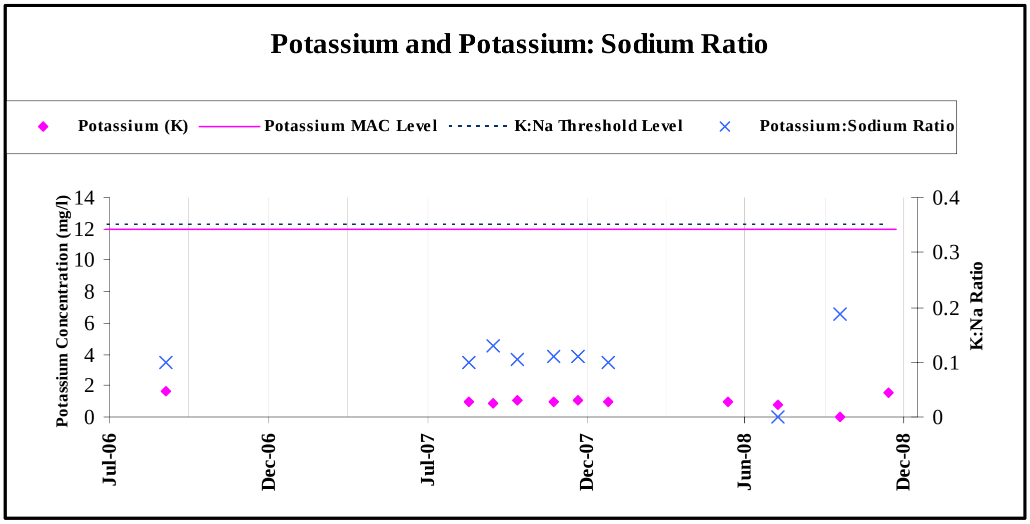
There were no faecal coliforms recorded in any of the water samples. Total coliforms were present in very low numbers on just one occasion (1 No. coliform per 100 ml on the 10/12/2008).

The concentration of sulphate, potassium, sodium, magnesium and calcium are within normal ranges. The Potassium: Sodium (K:Na) ratio is low at less than 0.2. The concentrations of all other trace metals are low and/or are below the detection limit of the laboratory. The concentration of all organic compounds and herbicides are also below the detection limits of the laboratory.

In summary, very low concentrations of nitrate, no faecal coliforms and low chloride concentrations indicate a high quality groundwater source, with minimal anthropogenic impacts. This is supported by the landuse in the area which is relatively sparsely populated rural residential with some beef and tillage farming.







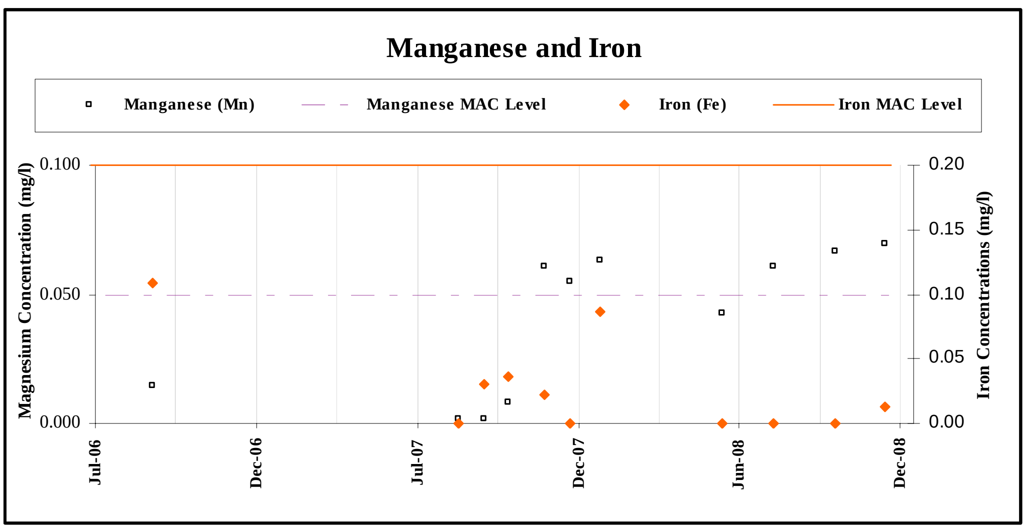


Figure 6 Water Quality Graphs

St Gorman's Well

The water chemistry of the St Gorman's Well on Ballynakill Hill is somewhat different to the Longwood Source. Water quality samples taken (planning application No. TA60536) are shown below and compared to the Longwood source.

Table 8.2 Groundwater Chemistry for the Well in Longwood Borehole and St Gorman's Spring

Parameter	Units	St Gorman's Well	Longwood PWS
Sample Taken		April 2001	June 2008
pH		7.2	7.6
Total Organic Carbon	mg/l	2	1.71
Conductivity	µS/cm@25⁰C	-	618
Ammonium as N	mg/l	0.3	<0.007
Nitrate as N	mg/l	10.5	7.5
Alkalinity	mg/l	290	298
Calcium	mg/l	96.11	106
Chloride	mg/l	66	8.8
Magnesium	mg/l	16.1	16
Potassium	mg/l	1.3	0.9
Sulphate	mg/l	15	26
Sodium	mg/l	26	9.4
Total Hardness	mg/l	292	330
Iron (Total)	µg/l	<50	<5
Manganese (Total)	µg/l	<50	43

The main contrast in water quality parameters are the concentrations of Sodium and Chloride, with higher concentrations occurring in the geothermal water. This can be typical of older groundwater with longer residence times whereas shallow groundwater in limestone areas tends to be dominated by $CaCO_3$. However there is evidence to suggest that the deeper geothermal waters are also being mixed with shallower groundwater before discharging at the surface. For example, 10.5 mg/l of nitrate could be considered high, and a conductivity of <600 µS/cm low for a purely geothermal source. The seasonal variations in spring discharge and temperature also point towards a connection with the near surface system.

8.5 AQUIFER CHARACTERISTICS

The GSI bedrock aquifer map of the area indicates that the Dinantian Pure Unbedded Limestones (Waulsortian Limestones) are classified as a *Locally Important Aquifer which is moderately productive only in local zones (Ll*). A potential Locally Important Sand and Gravel Aquifer (Lg) is located north of the borehole, shown in Figure 7.

The main inflow to the borehole is from both the gravels and the fractured zone at the top of the bedrock – which together are approximately 5-6 m thick. This is confined by a 7 m unit of gravelly CLAY. Smaller inflows enter the borehole at 50 m bgl and 80 m bgl. The subsoils and fractured bedrock at the top of the limestone unit were not grouted out to allow the significant inflows to enter the borehole.

A 3-day pumping test was initially carried out on TW2 in March 2001 with a 7-day pumping test of PW1 completed in April 2001 by KT Cullen (now WYG). As evident in the time drawdown graph of the pumping test given in Appendix 1, the drawdown response increases sharply at 12.5 m bgl (approximately 40 minutes into the test), which corresponds to the base of the fractured rock. Despite subsequent reductions to the pumping rate steady state conditions do not appear to have been reached. The initial sustainable yield was estimated to be approximately 700 m^3/day. Whilst there has been no data obtained over the pumping period from 2001 to date, anecdotal evidence and associated large drawdown recorded during the initial site visit suggest that the current abstraction of 350 m^3/day cannot be maintained. Further the standard approach to increase the abstraction rate by 50% to establish the source protection zones is not being done for this borehole as the data suggests that the long term abstraction rate could not be increased to 525 m^3/day. The data suggest that both the limestones, including the fractured zone and the gravels are limited.

Specific Capacity is estimated to be 8 m^3/day/m based on current abstraction rate and drawdown. Based on the original 7-day test the specific capacity is 20 m^3/day/m. The yield of Longwood Borehole (PW1) is 'moderate' and the productivity is Class III, though close to the boundary with Class IV, according to GSI classification. The yield and productivity is representative of the gravels and bedrock combined, and is based on the current specific capacity estimates.

The apparent transmissivity of the gravels based on the recovery data from the pumping test at PW1 using the Theis recovery method is 80 m^2/day.

However, the apparent transmissivity of the productive zones, represented by the gravels and the fractured limestones is much smaller. Using the Logan method of approximation: apparent transmissivity is 10 m^2/day.

The gravels are unlikely to be laterally extensive over a large area. It is likely to be a combination of the position in the landscape, proximity to the river and the occurrence of a relatively poor aquifer that allows for the gravels to be saturated. Permeability is in the order of 10-20 m/day based on a saturated thickness of 5 m, and porosity is assumed to be in the order of 20%. Therefore, assuming a gradient of 0.01 and a permeability of 16 m/day, the groundwater flow velocity is in the order of 0.8 m/day – this is used to calculate the inner protection area.

In the bedrock, groundwater flow tends to be concentrated in the upper fractured and weathered zone. Bulk permeability, estimated from a transmissivity of 10 m^2/day, an aquifer thickness of 20 m based on the log, a gradient of 0.01, and a porosity of 0.01 is 0.5 m/d. Accordingly groundwater velocities are 0.5 m/d.

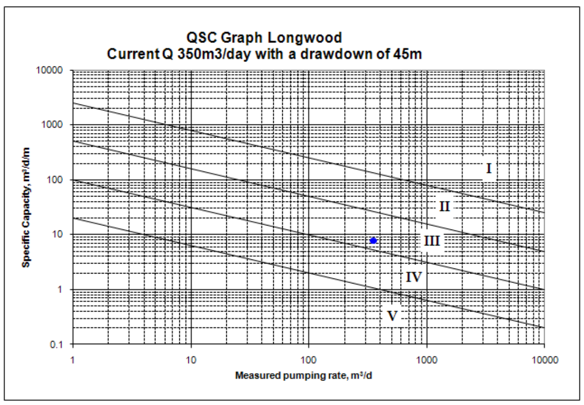


Figure 7 QSC Graph

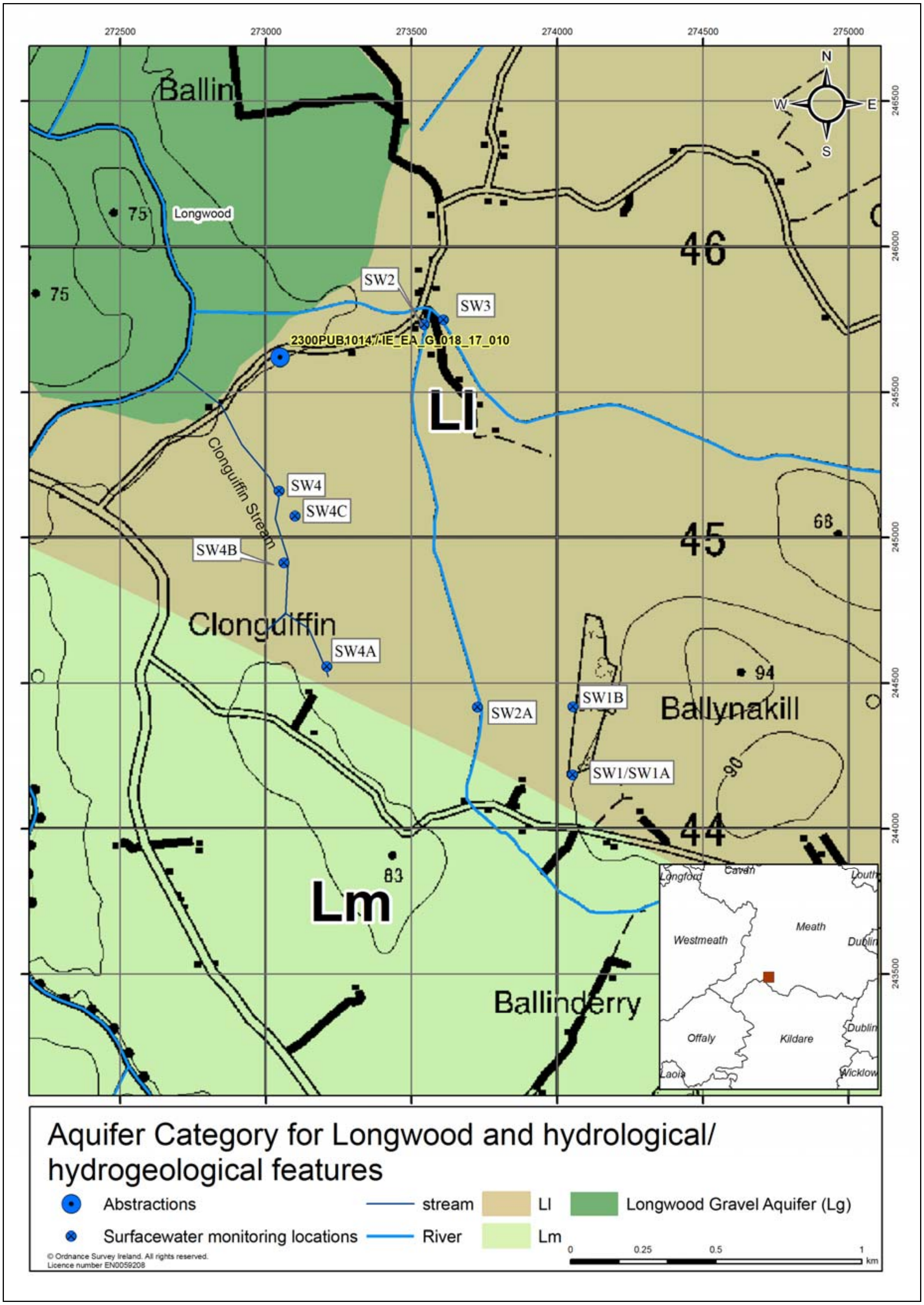


Figure 8 Aquifer Map in the vicinity of Longwood

8.6 RECHARGE

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

At Longwood, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

Runoff losses: *195* mm. Runoff losses are assumed to be 47% of potential recharge. This value is based on an assumption of *c*. 15% runoff for 35% of the area (high vulnerability), and 65% runoff over 65% of the area due to moderate vulnerability subsoil.

The bulk ***recharge coefficient*** for the area is therefore estimated to be 53%. (Guidance Document GW5, Groundwater Working Group 2005).

These calculations are summarised as follows:

Average annual rainfall (R)	843 mm
estimated P.E.	450 mm
estimated A.E. (95% of P.E.)	427.5 mm
effective rainfall	416 mm
potential recharge	195 mm
runoff losses	47%
bulk recharge coefficient	53%
Recharge	**221 mm**

A recharge cap of 200mm is typically applied to *Locally Important Aquifer (Ll*). Since the majority of groundwater flow to the well is from the gravel subsoil, the recharge cap is not applied in this instance.

8.7 CONCEPTUAL MODEL

The current understanding of the geological and hydrogeological situation is given as follows:

- Longwood Borehole currently abstracts 350 m^3/day from a combination of a relatively thin gravel and the top fractured zone of limestone unit – together approximately 6 m. A localised 7 m thick low permeability till appears to confine the groundwater flows system around the borehole. Significantly smaller inflows are present at depth.
- A large drawdown within the well was measured in September 2009 during a site visit at 45 m bgl. The yield drops once the water level goes below the base of the gravels and the top of the rock. Anecodotal evidence and the associated large drawdown currently being observed suggest that the borehole suggests that 350 m^3/day is unsustainable.
- The gravel deposit is not laterally extensive in the direction of groundwater flow that provides the water to the source and the bedrock aquifer is also limited.
- Groundwater flow is likely to be from the land to the south, northwards towards the Borehole source. Groundwater recharge is primarily through the gravels where they are exposed. A smaller quantity recharges through the till to the bedrock and is abstracted at the borehole.

- Over the region, an average recharge rate of 208 mm/year is used, which is approximately 50% of the total potential recharge. The remaining 50% of potential recharge is rejected and discharge may be via land overflow during the winter months. Recharge is predominantly diffuse. This estimate is likely to be conservative because some of the rainfall that runs off the tills in the upper parts of the ZOC, may indirectly recharge into the newly mapped gravels in lower part of the ZOC.
- The groundwater is of calcium bicarbonate signature and hard. Nitrate concentrations are below their respective MAC. Manganese concentrations are elevated. The microbial analysis of the water samples indicates that the groundwater does not appear to be impacted by contamination from human or agricultural sources. A zero count for faecal coliforms was recorded in 11 samples of the 11.

9 DELINEATION OF SOURCE PROTECTION AREAS

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow, as described in Section 8.7 Conceptual Model and presented in Figure 3.

Two source areas are delineated:

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

9.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. **the zone of contribution (ZOC)**, which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

The **Northern Boundary** is based on a combination of hydrogeological mapping, the uniform flow equation and an assumption that in general the River Blackwater Tributary (Cullentry Stream) is in hydraulic connection with groundwater.

The uniform flow equation (Todd, 1980) is:

> $xL = Q / (2\pi * T * I)$ where Q is the daily pumping rate; T is Transmissivity (taken from aquifer characteristics); and, I is the background non-pumping gradient.

The Uniform flow equation suggests the wells could pump from 70 m down gradient (based on an approximate transmissivity of 80 m^2/day, and a natural groundwater gradient of 0.15). It is unlikely given the distance and the presence of permeable sand and gravel deposit along the stream that water could be drawn from the river. Given the position of the river 120m north and a degree of uncertainty in relation to gradients, the northern boundary is conservatively extended to the Cullentry stream.

The **Southern Boundary** is based on the estimated groundwater flow direction which is considered to be to the northwest and flow paths lengths which are likely to be relatively short in this bedrock type. The water table is likely to be a subdued reflection of topography. Given that the aquifer is a *Locally Important aquifer which is moderately productive only in Local Zones (Ll)*, it is likely that the groundwater flow paths are short, thus the southern boundary is extended to where flow lines extend downgradient toward the borehole. Further south, the flow lines are likely to be east and west toward the surface water streams.

The **Eastern Boundary** is based on the presence of the gravels to the east and the Ballynakill Stream. The Ballynakill stream is considered to be in hydraulic connection with groundwater. It is unlikely given the distance and the presence of permeable sand and gravel deposit along the stream that water could be drawn from the other side of the river. Groundwater at Ballynakill Hill is considered to flow towards the Cullentry and Ballynakill streams and towards St Gorman's well/spring. It is unlikely, given the difference in physio-chemical properties and the large groundwater discharges from St Gorman's well, that water could be drawn from the other side of St Gorman's Well.

The **Western Boundary** is based on topography, the presence of the Clonguiffin stream and the aquifer type. It is a very small stream and it is considered that flow paths extend beneath it.

Water balance: Based on an abstraction of 350 m^3/day on average and the estimated recharge of 221 mm/year, a zone of contribution of 0.6 km^2 in area is required. Hydrogeological field mapping and the conceptual model determined an area of 0.5 km^2 – less that the area required. Current GSI guidance state that ZOC delineation should conservatively account for 150% of the abstraction volume, however, the borehole cannot support long term abstraction of 350 m^3/day, thus the 150% is not applied in this case. The limited gravels and bedrock and confining nature of the subsoils are the principal reasons for this.

9.2 INNER PROTECTION AREA

This area is designed to protect against the effects of human activities that might have an impact on the quality of the groundwater source. The Inner Source Protection Area is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source. The 100-day time of travel is chosen in Ireland as a conservative limit to allow for the heterogeneous nature of Irish aquifers. The 100-day horizontal time of travel to the abstraction boreholes is calculated from the velocity of groundwater flow in the gravels - estimated to be approximately 0.80 m/day (see aquifer characteristics). Therefore the 100-day horizontal time of travel, and therefore the Inner Protection Area, is calculated as a radius extending 80 m around the source. There is an area around the borehole that is confined however, it is not known how far this extends, thus the inner protection area is mapped.

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in 8, and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/H, SO/M SO/H. The majority of the area is designated SO/M.

Table 10.1 Source Protection Zones

Source Protection Zone	% of total area (0.5km^2)
SI/High	4%
SO/High	24%
SO/ Moderate	72%

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- Private residences within the ZOC are serviced by septic tank systems or similar wastewater treatment discharging percolation areas. The main potential contaminants are ammonia, nitrates, phosphates, chloride, potassium, faecal bacteria, viruses and cryptosporidium.

- The majority of land within the zone of contribution is primarily grassland with areas of tillage land. A number of farming operations are located within the source protection zone. The main potential contaminants from these sources are ammonia, nitrates, phosphates, chloride, potassium, pesticides, faecal bacteria, viruses and cryptosporidium.

- Private home heating fuel tanks are located within the catchment area. The main potential contaminants from this source are hydrocarbons.

12 CONCLUSIONS

The untreated groundwater is currently of good microbial quality, with no observable impact associated with human activities. However naturally elevated concentrations of manganese have been detected in the raw groundwater samples, above permissible levels under Potable Water Standards (SI 278 of 2007).

The borehole is a moderately yielding borehole that abstracts from a 5 m thick sand and gravel deposit overlying a pure unbedded limestone. The sand and gravel deposit is an extension of an unproven Locally Important Sand and Gravel Aquifer. It provides much of the water to the borehole, but is not laterally extensive in the direction of groundwater flow. The yield drops significantly when the water level drops below the base of the gravels and the top of the rock.

The Outer Source Protection Area or the Zone of Contribution is calculated to extend to 1km^2.

The Inner Source Protection Area or the 100-day horizontal travel time is calculated to extend 80 m from the abstraction source.

13 RECOMMENDATIONS

Continued monitoring of water levels during the operation of the scheme should be collated to develop a real-time database of hydrogeological information.

The source site is the area immediately around the groundwater abstraction borehole. Protection in this area is paramount to ensure that direct intentional or accidental interference is not caused to the borehole, particularly as the borehole is not grouted. The protection of the source site involves prevention of access and prevention of activities in the immediate proximity of the abstraction boreholes.

Further investigations into the nature of the hydraulic connection between the gravels, the underlying limestones, the streams and the fault, under pumping conditions, would help to better constrain the ZOC.

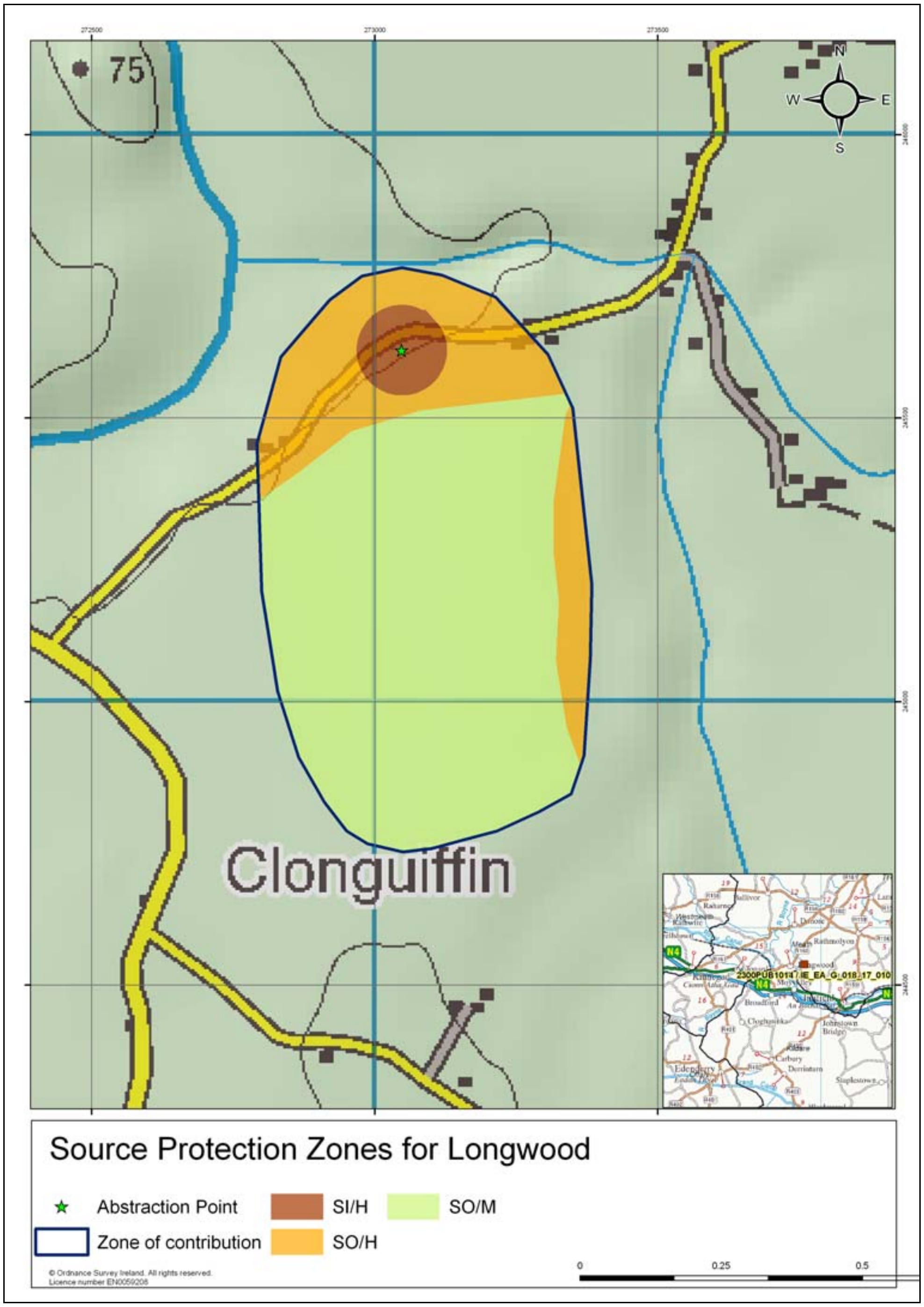


Figure 9 Source Protection Zones around Longwood Borehole

14 REFERENCES

An Foras Talúntais and Geological Survey of Ireland, (1981). Soil map of Ireland

Clarke, A, Parkes. M, Gately. S, (2007) Geological Heritage of Meath

C.W. Fetter 4th Ed. (2001) Applied Hydrogeology

Collins, J.F. and Cummins, T. (1996) Agroclimatic Atlas of Ireland. AGMET – Joint working group on Applied Agricultural Meteorology, Dublin.

Fitzgerald D., and Forrestal, F. (1996) Climatological Note No. 10. Monthly and Annual Averages of Rainfall 1961-1990. Meteorological Service

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

Kevin Cullen & Company (2001). *Report on the Drilling and Testing of a Production Well at Longwood, Co. Meath*. Unpublished report prepared for Meath County Council.

Kilsaran Groundwater monitoring, Rathcore (2006-2009)

Longwood GWB: Summary of Initial Characterisation. CDM

McConnell, B., Philcox, M.E. and Geraghty, M., Morris, J., Cox, W., Wright, G.R. and Meehan, R.T., (2001) Geology of Meath. Geological Survey of Ireland. *1:100,000*

Meehan, R. (1999) Directions of ice flow during the last Glaciation in counties Meath, Westmeath and Cavan Irish Geography, Volume 32(1), 1999, 26-51.

Planning Application Meath No. TA60536 (2006)

Todd, D.K., (1980) Groundwater Hydrology. Wiley and Sons 535pp

Woods L, Meehan R & Wright G R, 1998. *County Meath Groundwater Protection Scheme*. Report to Meath County Council. Geological Survey of Ireland.

www.wfdireland.ie/maps.html (2008) Longwood GWB status

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

APPENDIX 1

Borehole Log & Pumping Test

046 9243610

TOM BRIODY & SON LTD
WELL DRILLING & WATER SERVICES

Shinco
Cressakiel
Kells Co Meath
Phone: 046 9243614
Fax: 046 9243610
Email: info@briodydrilling.ie

Fax

To:	JOHN DILLON	From:	Hugh Briody
Fax:	(01) 8030410	Date:	21/4/09
Cc:		Pages:	2
Re:	WELL LOG.		

☐ Urgent ☐ For Review ☐ Please Comment ☐ Please Reply ☐ Please Recycle

Comments:

JOHN,

HOPE THIS HELPS YOU OUT

REGARDS

Hugh Briody.

046 9243610

TOM BRIODY & SON

Well drilling specialists since 1960

WELL LOG

Customer Name: K T Cullen

Site Address: Meath County Council
Longwood
Co. Meath

Date Work Completed: April 2001

FINISHED 200MM DIAMETER WELL

FINISHED DEPTH OF WELL: 94.5mts

DESCRIPTION	DIAMETER	DEPTH
Drill	300mm	0 – 12.2mts
Supply & Install Steel Casing	300mm	12.2mts
Drill	250mm	12.2 – 94.5mts
Supply & Install Screen	200mm	40.6mts
Supply & Install Riser	200mm	52.2mts

Type of Subsoil: 0 – 11.6mts Clay & Gravel

Depth to Bedrock: 11.6mts

Type of Bedrock: Limestone

Water Entry Levels: 12.2mts
55mts
85.4mts

Supply at time of testing with drilling rig: 10,000 G.P.H

Remarks:
Cap well on completion.
Developed Well for 2 Hrs
Well not sealed due to large quantities of water in the overburden

Well Log

Well No. TW2 | **Grid Reference** 273000 246000

Project No. 2449 | **Client** Meath County Council | **Drill Date** June 1985

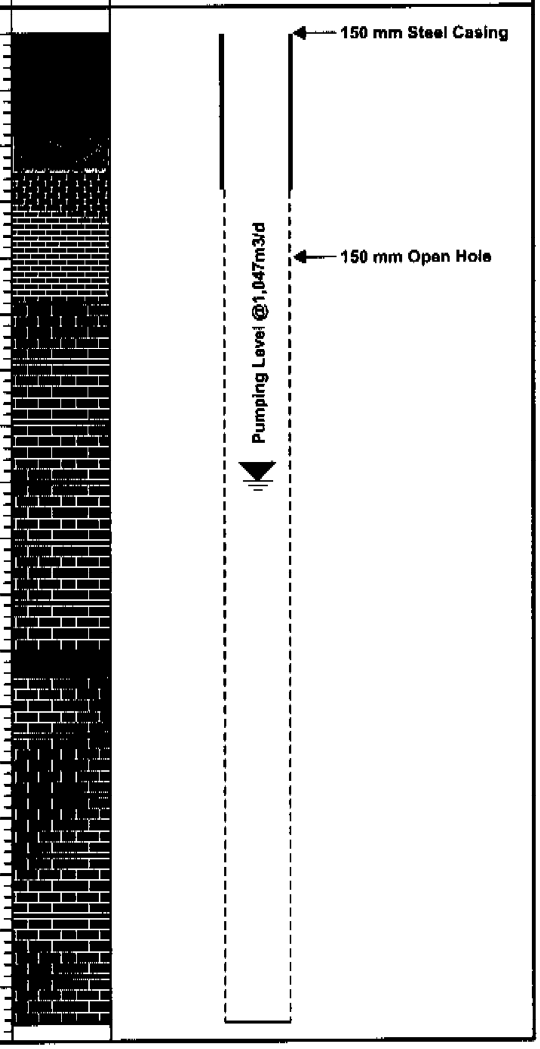
Well Type Trial | **Location** Longwood | **Geologist**

SUBSURFACE PROFILE

Description	Depth
Ground Surface	0
Stony Clay	0–9
Sand and Gravel (Inflow)	9–14.5
Soft Black Shaly Limestone	14.5–24
Hard Black Limestone	24–55
Broken Limestone (Inflow)	55–61
Black Limestone	61–88

Depth: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85

Symbol | Well Construction



K.T.Cullen & Co. Ltd.

Drill Method Air Rotary

Driller O Donohue Brothers

Hole Size (mm) 150

Ground Level (mOD)

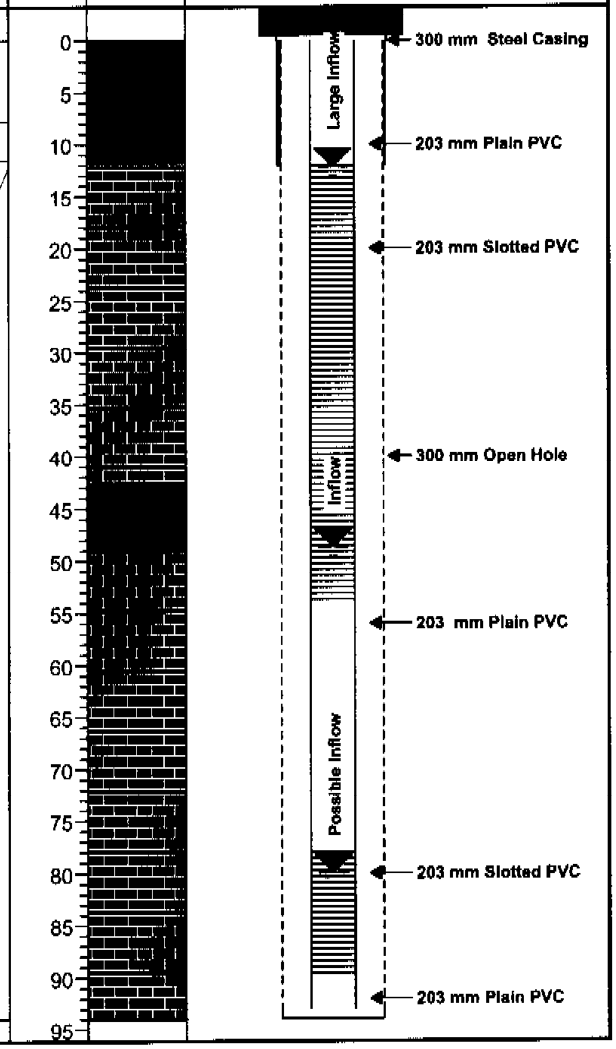
Static Water Level (bgl) Artesian

Well Log

Well No. PW1 | **Grid Reference** |
Project No. 2449 | **Client** Meath County Council | **Drill Date** April 2001
Well Type Production | **Location** Longwood | **Geologist** Justin Rutherford

SUBSURFACE PROFILE

Description	Depth	Symbol	Well Construction
Ground Surface			
Gravelly Clay			
Gravel and Boulders			
Fractured Limestone Large, artesian flow			
Dark Grey/Blue Limestone			
Fractured Limestone Inflow at 48.7 metres			
Dark Blue/Grey Limestone Possible Inflow at approximately 80 metres			



K.T.Cullen & Co. Ltd.

Drill Method Air Rotary
Driller Tom Briody & Sons

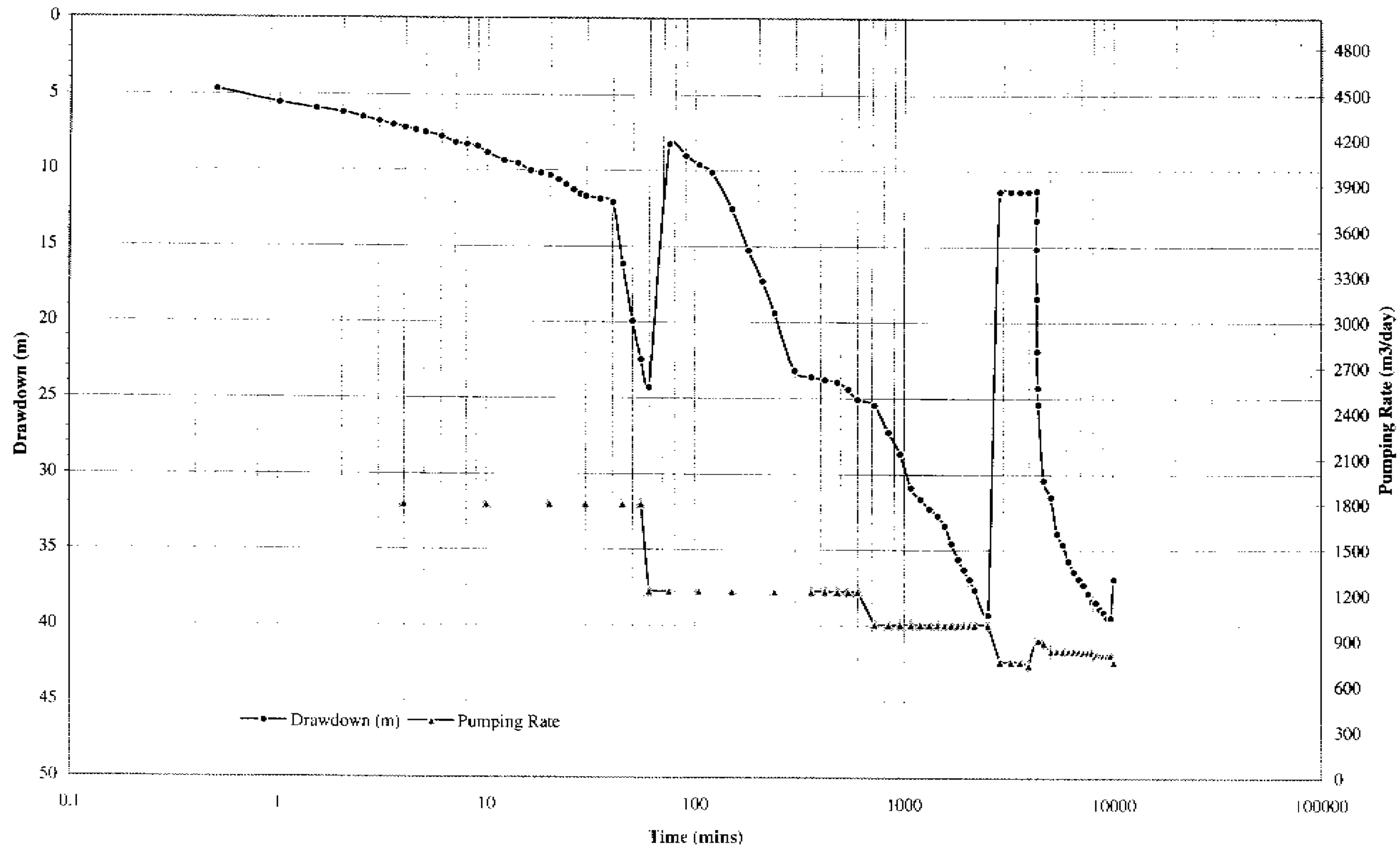
Hole Size (mm) 300
Ground Level (mOD)
Static Water Level (bgl) -0.7

TIME (MINS)	WATER LEVEL BELOW G.L. (m.)	DRAWDOWN METRES	YIELD M3/Day
0	-0.18	0	1800
0.5	4.5	4.68	
1	5.38	5.56	
1.5	5.735	5.915	
2	6	6.18	
2.5	6.3	6.48	
3	6.6	6.78	
3.5	6.8	6.98	
4	7	7.18	1800
4.5	7.15	7.33	
5	7.3	7.48	
6	7.58	7.76	
7	7.99	8.17	
8	8.09	8.27	
9	8.26	8.44	
10	8.67	8.85	1800
12	9.2	9.38	
14	9.38	9.56	
16	9.84	10.02	
18	10.01	10.19	
20	10.16	10.34	1800
22	10.45	10.63	
24	10.75	10.93	
26	11.1	11.28	
28	11.38	11.56	
30	11.5	11.68	1800
35	11.69	11.87	
40	11.9	12.08	
45	16	16.18	1800
50	19.76	19.94	
55	22.25	22.43	1800
60	24.1	24.28	1224
75	8.07	8.25	1224
90	8.85	9.03	
105	9.45	9.63	1224
120	9.93	10.11	
150	12.32	12.5	1224
180	15.07	15.25	
210	17.1	17.28	
240	19.21	19.39	1224
300	23	23.18	
360	23.4	23.58	1224
420	23.61	23.79	1224
480	23.75	23.93	1224
540	24.21	24.39	1224
600	24.88	25.06	1224
720	25.27	25.45	1008
840	27.03	27.21	1008
960	28.46	28.64	1008
1080	30.7	30.88	1008

Time Drawdown Data for 7 Day Pumping Test on PW1, Clonguiffen, Longwood, Co. Meath, April 2001.

TIME (MINS)	WATER LEVEL BELOW G.L. (m.)	DRAWDOWN METRES	YIELD M3/Day
1200	31.46	31.64	1008
1320	32.1	32.28	1008
1440	32.56	32.74	1008
1560	9.98	33.39	1008
1680	34.39	34.57	1008
1800	35.4	35.58	1008
1920	36.09	36.27	1008
2040	36.73	36.91	1008
2160	37.46	37.64	1008
2520	39.06	39.24	1008
2880	11.2	11.38	763
3240	11.2	11.38	763
3600	11.2	11.38	763
3960	11.2	11.38	741
4320	11.13	11.31	950
4325	13.06	13.24	950
4329	14.96	15.14	940
4340	18.24	18.42	920
4360	21.69	21.87	907
4390	24.1	24.28	907
4410	25.19	25.37	907
4680	30.2	30.38	890
5040	31.29	31.47	836
5400	33.72	33.9	836
5760	34.44	34.62	836
6120	35.54	35.72	836
6480	36.22	36.4	836
6840	36.7	36.88	836
7200	37.11	37.29	829
7560	37.65	37.83	829
7920	38.2	38.38	829
8280	38.27	38.45	807
8640	38.71	38.89	807
9000	38.93	39.11	807
9360	39.25	39.43	807
9720	39.25	39.43	807
10080	36.72	36.9	764

Time Drawdown Data for 7 Day Pumping Test on PW1, Clonguiffen, Longwood, Co. Meath, April 2001.



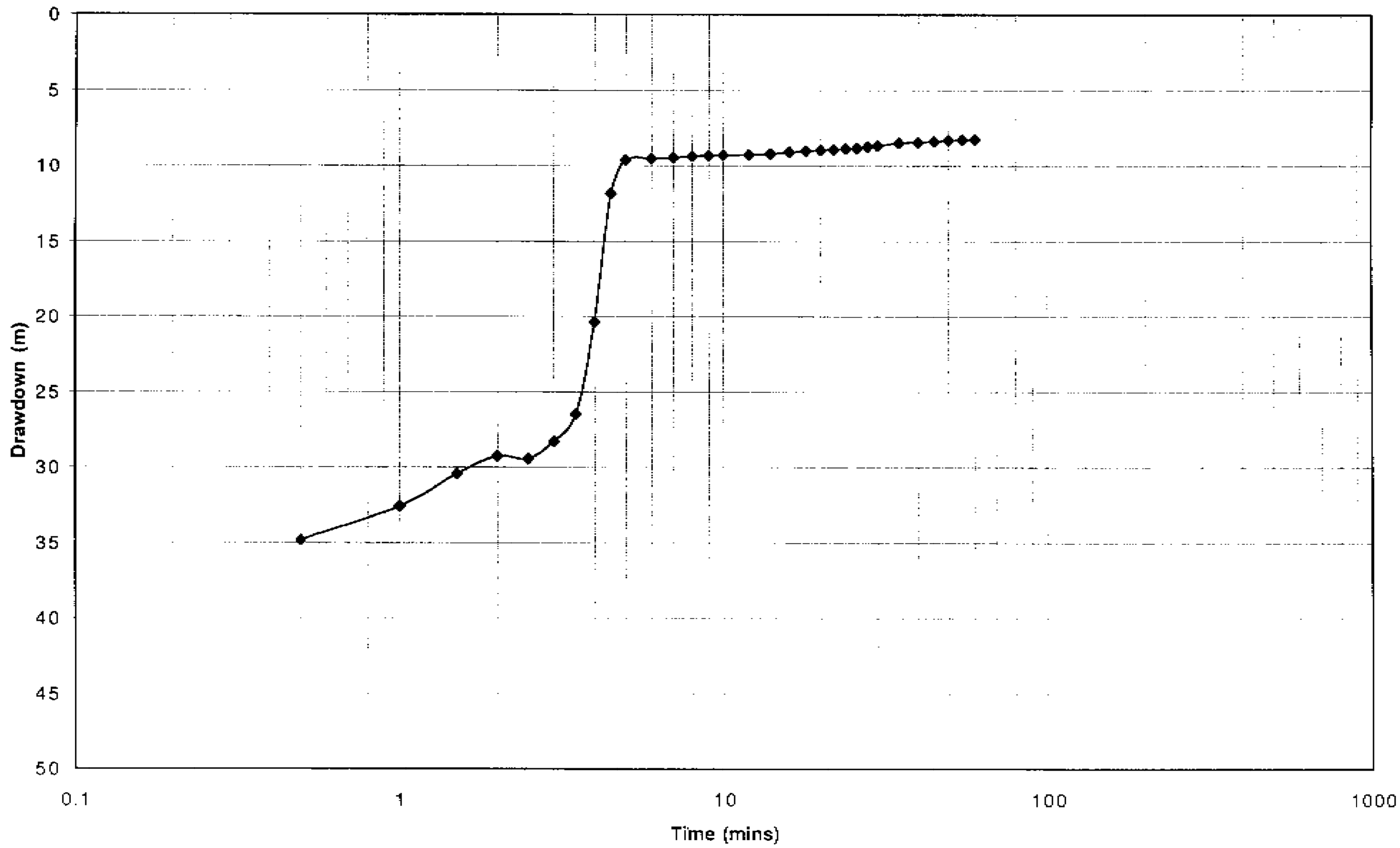
Time Drawdown Graph from 7 Day Pumping Test on PW 1, Clonguiffen,Longwood, Co. Meath, April 2001.

TIME (MINS)	Water Level TW 1	Water Level MW 1	Water Level MW 2
0	ARTESIAN	0.54	1.11
60	8.18	2.9	3.3
90	6.23		
120	7.3	3.3	3.9
180	7.93	3.86	4.25
240	8.51	4.12	4.57
300	8.91		
360	8.87	4.63	5.03
420	8.84		
480	8.82		
540	8.81		
600	8.81	5	5.66
720	8.81		
840	8.8		
960	8.8		
1080	8.8	5.63	6.31
1200	8.8		
1320	8.79	6.67	7.2
1440	8.79		
1560	8.78		
1680	8.77	6.91	7.43
1800	8.77		
1920	8.76		
2040	8.75	6.99	7.7
2160	8.74		
2520	8.74		
2880	8.05	7.03	7.8
3240	8.05	7.03	7.8
3600	8.05		
3960	8.05	7.03	7.8
4320	8.07	7.07	7.62
4680	8.09	7.1	7.68
5040	8.22	7.13	7.71
5400	8.35	7.15	7.78
5760	8.48	7.27	7.85
6120	8.68	7.46	7.96
6480	8.81	7.61	8.09
6840	8.77	7.61	8.09
7200	8.73	7.61	8.1
7560	8.7	7.61	8.1
7920	8.68	7.61	8.11
8280	8.65	7.61	8.12
8640	8.63	7.62	8.12
9000	8.64	7.63	8.12
9360	8.65	7.64	8.12
9720	8.67	7.66	8.14
10080	8.65	7.67	8.15
10140	6.86	7.44	7.87

Observation Well Data from 7 Day Pumptest on PW1, Clonguiffen Longwood, Co. Meath, April 2001.

TIME (MINS)	DRAWDOWN (METRES)	WATER LEVEL BELOW G.L. (m)
0	36.9	36.62
0.5	34.82	34.54
1	32.59	32.31
1.5	30.43	30.15
2	29.29	29.01
2.5	29.47	29.19
3	28.32	28.04
3.5	26.51	26.23
4	20.37	20.09
4.5	11.85	11.57
5	9.63	9.35
6	9.51	9.23
7	9.45	9.17
8	9.37	9.09
9	9.33	9.05
10	9.31	9.03
12	9.26	8.98
14	9.21	8.93
16	9.09	8.81
18	9.01	8.73
20	8.96	8.68
22	8.91	8.63
24	8.86	8.58
26	8.81	8.53
28	8.73	8.45
30	8.68	8.4
35	8.48	8.2
40	8.43	8.15
45	8.38	8.1
50	8.32	8.04
55	8.28	8
60	8.24	7.96

Time Drawdown Recovery Data after 7 Day Test on PW 1, Longwood, Co. Meath, April 2001.



Time Drawdown Recovery Graph after 7 Day Test on PW1, Longwood, Co. Meath, April 2001.