Louth County Council

Establishment of Groundwater Source Protection Zones

Termonfeckin Water Supply Scheme

Termonfeckin Borehole

November 2011

Revision: E

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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.

Louth County Council contracted GSI to delineate source protection zones for eight groundwater public water supply sources in Co. Louth. The sources comprised Ardee, Cooley (Carlingford and Ardtullybeg), Collon, Greenore, Termonfeckin, Omeath (Esmore Bridge and Lislea Cross), Drybridge and Killineer.

This report documents the delineation of the Termonfeckin source protection zones.

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 are delineated for the Termonfeckin Borehole 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.

The Termonfeckin borehole source supplies domestic water to the town of Termonfeckin. In this report, the borehole is referred to as PWSBH01.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the source.
- To delineate source protection zones for borehole PWSBH01.
- To assist the Louth County Council in protecting the water supply from contamination.

Groundwater protection zones are delineated to help prioritise the area around the source in terms of pollution risk to groundwater. This prioritisation is intended as a guide in evaluating the likely suitability of an area for a proposed activity prior to site investigations. The delineation and use of groundwater protection zones is further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The maps produced are based largely on the readily available information in the area, a field walkover 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 METHODOLOGY

A desk study of existing data sources relevant to the source was carried out prior to a site visit. A site visit, site walk-over and field mapping of the study area were conducted on 29/04/2010. An interview relating to the source was carried out on 29/04/2010 with the source caretaker. A depth to bedrock drilling programme was carried out by the GSI during May 2007 to investigate the subsoil geology, the hydrogeology and vulnerability to contamination of the study area. The locations of the point features investigated during the site visits and identified during the desk study are shown in Figure 4. A summary table of the point data collected during the site visits and field mapping is provided in Appendix 1.

3 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

Borehole PWSBH01 is located approximately 300 m south of Termonfeckin village centre, adjacent to the R167 road inside the compound of the Termonfeckin supply water tower (Figure 1).

The water tower compound is approximately 25 m by 25 m and is enclosed by a 1.5 m high post and wire-mesh fence with a gate onto the R167. The ground surface within the compound comprises hardcore at the borehole, with grass and sycamore saplings beyond. The borehole and rising main are located in a 1 m^2, concrete block lined chamber approximately 0.9 m deep (Figure 2). The top of the chamber is flush with ground level and is covered by a securely-fitting and bolted metal cover.

Figure 1 Termonfeckin PWS site location map

An untreated-water sampling tap is located in an adjacent chamber of similar construction, which also houses a shut off valve.

The mouth of the borehole is formed by concentric 125 mm, 150 mm and 200 mm diameter steel casings. These are cut off at a level 0.75 m below the base of the steel rim on the top of the chamber wall (Figure 3). There is no indication that a grout seal was installed in the upper borehole annulus. The base of the borehole chamber was observed to be flooded with between 5 to 10 cm of ponded water during visits in November 2006 and April 2010. This water may derive from drainage out of service ducts which enter through the northern face of the chamber. The mouth of the borehole casing is located slightly above the level of the ponded water.

Figure 2 Covered chamber for borehole PWSBH01

Figure 3 Mouth of borehole PWSBH01 inside borehole chamber.

4 SUMMARY OF BOREHOLE DETAILS

A copy of the driller's borehole log for PWSBH01 was provided by Louth County Council and is included in Appendix 1. The borehole was drilled to a depth of 122 mbgl between the 8th and 12th of February 2003 by Dunnes Water Services Ltd.

Currently, the source contributes an average of 96 m^3/d to the Termonfeckin public water supply, which is augmented by water piped in from Drogheda. The borehole has a pumping test proven capacity of 363 to 398 m^3/day. The source typically pumps at 8 m^3/hr for approximately 12 hours per day. The water is chlorinated at a treatment plant adjacent to the Termonfeckin River, 200 m north of the source.

The water level in the borehole is monitored by a pressure transducer linked to Louth County Council telemetry for continuous measurement and logging. Water level data from this monitoring record are shown in Appendix 1. Pumping tests were carried out to assess the potential yield of the source in 2003 and 2006 and details of the tests are provided in Appendix 2.

Table 1 provides a summary of the well details.

Table 1 Summary of Source Details

Monitoring Code	n/a
GSI Well Database Reference No.	n/a
Borehole Name	PWSBH01
Grid reference	E 314051 N 280067
Townland	Termonfeckin
Source type	Borehole
Drilled	8 – 12 February 2003
Owner	Louth County Council
Elevation (Ground Level)	approx. 22.6 mAOD (i)
Depth	122 mbgl
Depth of casing	59.4 mbgl
Depth of Well Screen	150 mm diameter steel casing slotted between 39.6 and 42.1 mbgl. 125 mm diameter steel casing slotted (2 rows of slots) between 36.6 and 59.4 mbgl. A 3rd row of slots on 125 mm casing between 48.8 and 54.9 mbgl.
Diameter	200 mm steel casing 0 to 15.2 mbgl 150 mm steel casing 0 to 42.7 mbgl 125 mm steel casing 0 to 59.4 mbgl
Depth to rock	38.1 m
Static water level (SWL)	13.69 mbtc(ii) (29/04/2010 @ 11:04 pm; Pressure Transducer) 15.9 mbtc (12/12/2006 @ 7:43 am; GSI Pumping Test)
Pumping water level (PWL)	30.73 mbtc (29/04/2010 @ approx. 11 am); (Pumping Rate = 96 m^3/day)
Drawdown at current pumping rate	approx 17.04 m (PWL minus SWL on 29/04/2010)
Depth of pump	39 m
Consumption (Co. Co. records)	96 m^3/d (average rate for 2009)
Pumping test summary (iii):	
(i) abstraction rate m^3/d	363 m^3/d & 398 m^3/d
(ii) specific capacity	15.1 m^3/d/m @ 363 m^3/day 13.1 m^3/d/m @ 398 m^3/day
(iii) transmissivity (T)	4 to 41 m^2/d , average 12 m^2/d
(iv) hydraulic conductivity	0.05 to 0.48 m/d (iv)

Note i: From spot elevation on 25" historical map located 37 m NNE of source.
Note ii: 'mbtc' denotes "metres below the top of the 125 mm diameter steel casing"
Note iii: 3 day variable rate pumping test at 363 m^3/day (0 to 42 hrs) & 398 m^3/day (42 to 72 hrs) started on 17/06/2003.
Note iv: Hydraulic conductivity based on T/b, where 'b' is the aquifer thickness based on borehole depth minus overburden thickness, i.e. 122 – 38.1 ~ 84 m.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The land surrounding the borehole is generally low-lying, ranging between 0-30 mAOD. The ground elevation decreases from west to east, with the coastal high water mark located 1.5 km to the east. Higher ground (up to 90 mAOD) is found to the north and northwest of the source in the Almondstown area.

Drainage is generally towards the sea to the east. The Termonfeckin River flows west to east approximately 200 m north of the source, and occupies a steep-sided, flat-bottomed valley. To the southwest of the source, streams and field drains drain southeastwards towards Baltray, and to its east they drain northwards into the Termonfeckin River. An obsolete hydrometric river gauging station (Station No. 06037) is located on the Termonfeckin River 400 m east-northeast of the source. Historical data indicate a 95 percentile flow of 0.005 m^3/sec (432 m^3/day).

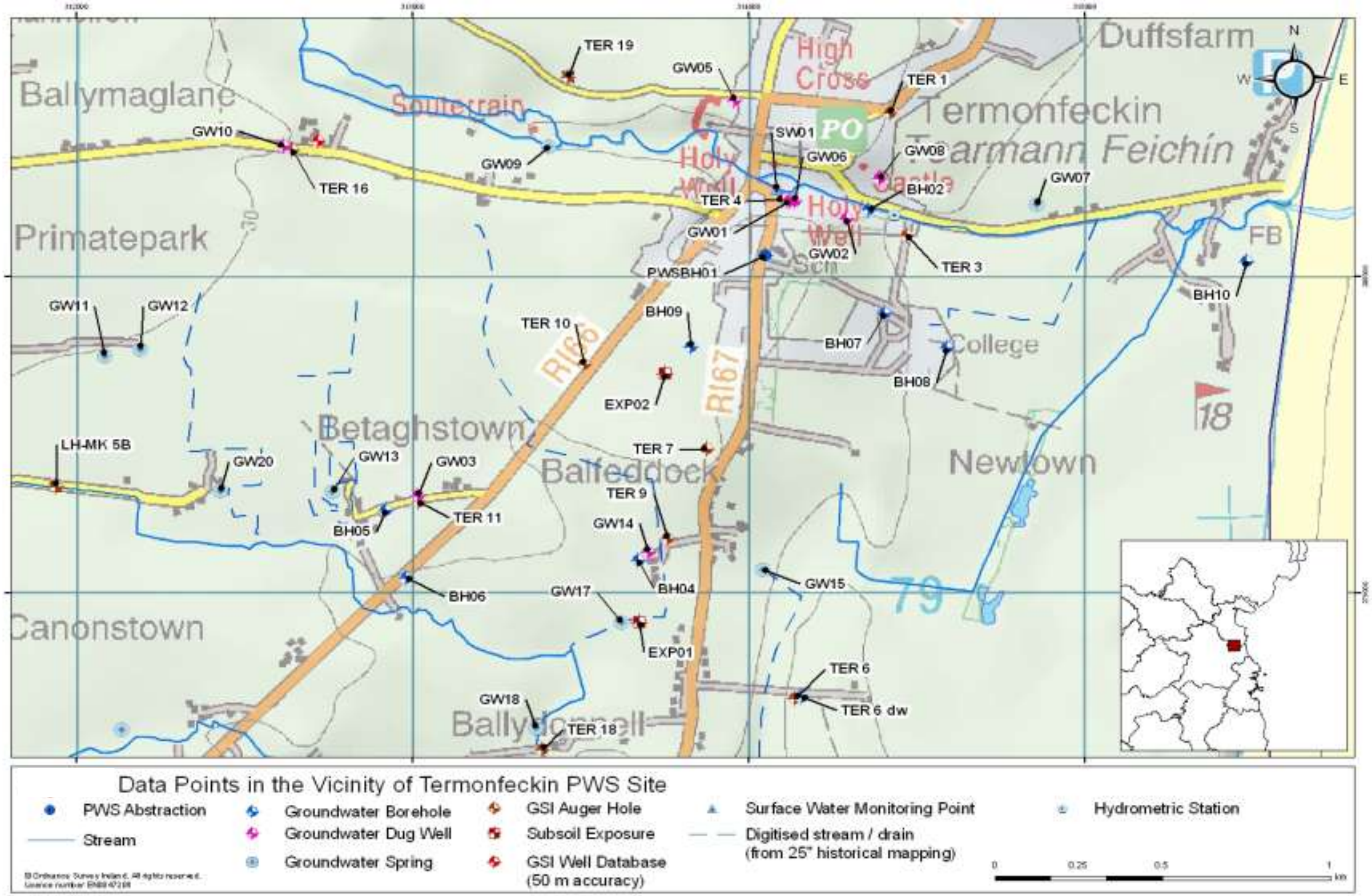

Figure 4 Data points in the vicinity of Termonfeckin PWS site

The borehole is located near a local topographic high overlooking the river, at the northern edge of a NNE-SSW oriented ridge. To the north and west respectively, the ground elevation decreases sharply (gradients 0.05-0.08) to the river valley and a dry valley. To the east and south, the ground elevation decreases more gently (at gradients of 0.03-0.008 and 0.02 respectively).

Drainage density in the area is high, in excess of 1 km per 1 km^2. During site visits the topographic ridges south and east of the source were observed to be generally well drained. Troughs between ridges and the flatter, undulating ground to the west showed evidence of heavy, poorly drained soils with frequent artificial drainage ditches and rushes.

To the west, south and east of the borehole, arable agriculture is the main land use, with wheat and root vegetables dominating. The An Grianán Agricultural College is situated 450 m to the southeast. To the north lies the village of Termonfeckin, which comprises a large area of concrete cover and made ground. The entire area has mains drinking water, and houses near the source are serviced by mains sewerage.

6 HYDRO-METEROLOGY

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

Annual rainfall: 800 mm. The closest meteorological station to the Termonfeckin Source is Clogher Head, located 5 km north northeast of the source, where the annual average rainfall from 1961 to 1983 is recorded as 751 mm (Fitzgerald and Forrestal, 1996). The next closest station to the source is Drogheda (Killineer) at Killineer Reservoir, 7.7 km to the west southwest where the average rainfall between 1970[1] and 1990 was 800 mm/a (Fitzgerald and Forrestal, 1996). The source location is topographically similar to the Drogheda station, being on the south facing northern margin of the Boyne Valley. Clogher Head on the other hand is topographically situated in the lee of the mid-Louth ridges (Robbie Meehan, pers comm., 2010). As such, the rainfall value for Drogheda has been selected as most representative of the Termonfeckin area.

Annual evapotranspiration losses: 532 mm. The closest synoptic weather station to the study area is Dublin Airport 35 km to the south. Average potential evapotranspiration (P.E.) at Dublin Airport between 1961 and 1990 was 560 mm, based on Met Éireann data. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 532 mm.

Annual Effective Rainfall: 268 mm. This is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is equivalent to this.

7 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the area around the Termonfeckin 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 on the bedrock geological map of Meath, Sheet 13, 1:100,000 Series (Geraghty & McConnell, 1999) and accompanying memoir (McConnell et al, 2001), historical geological mapping by the GSI at the 6-inch to 1 mile scale, the GSI Well and Borehole Databases and on bedrock outcrop and subsoil exposures encountered during site visits. The bedrock geology of the area is shown in Figure 5.

[1] Note: Drogheda (Killineer) rainfall station opened in 1970.

7.1 BEDROCK GEOLOGY

The bedrock map indicates that the area surrounding the source is underlain by limestone bedrock of Lower Carboniferous age with older Silurian aged rocks to the north. Regionally the limestones extend southwards from a line joining Old Bridge (4 km west of Drogheda) and Termonfeckin and continue under the Boyne River to the south of Drogheda. The bedrock types in the area are summarised in stratigraphic order in Table 2. Limestone of the Tullyallen Formation is mapped underlying borehole PWSBH01 on Map Sheet 13.

The limestones are described as strongly jointed vertically, fissured, karstified sparitic limestones which have had their fractures infilled by a variety of sands, silts and clays (as encountered during the drilling at Drybridge in 1979; NERDO, 1981). The limestones have been dolomitised and decalcified locally along major joint and bedding planes (NERDO, 1981).

Table 2 Bedrock Geology and descriptions around Termonfeckin Public Supply

Bedrock Formation	Generalised Rock Unit Group	Geological Description	Max thickness[2] (m)
Mornington Formation (MT)	Dinantian upper impure limestones (DUIL)	Limestone: Thickly to thinly bedded, dark grey packstones, wackestones, micrites, and occasional grainstones & shales. Turbidites common in upper part.	-
Tullyallen Formation (TA)	Dinantian pure bedded limestones (DPBL)	Limestone: Pale grey, thickly bedded, micritised grainstones, packstones and-wackestones	>500
Glaspistol Formation (GP)	Silurian Metasediments and Volcanics (SMV)	Black mudstones, Grey to buff coloured quartzose greywackes, and occasional green bentonites. Interbedded mudstone-sandstone packages are 10-30m thick. Note: The boundary between the GP and the TA/MT formations is an unconformity, i.e. some of the intervening rocks were eroded away before the younger rocks were deposited.	>200

In the Termonfeckin area, at Betaghstown, NERDO (1981) records that a borehole penetrated 54.5 m into the limestones. This may have been at the borehole labeled BH06 in this report. At this location only minor cavities were recorded, and the rock was comprised of sandy calcarenites and siltstones containing muddy bands and siliceous lenses (NERDO, 1981). Drillers logs for boreholes PWSBH01 and BH09 indicate that a “black rock” was penetrated, with zones of broken rock encountered at intervals down to depths of 122 mbgl. No cavities were recorded during the drilling of the boreholes.

The bedrock descriptions from these boreholes correlate poorly with the pale grey limestones expected of the mapped Tullyallen Formation bedrock. Mornington Formation limestones are mapped to the south of the Boyne Estuary. These limestones have a shale component and turbidites are common in the upper part of the formation, which could potentially match the bedrock descriptions in the study area borehole logs. It is considered here therefore, that these limestones may represent the bedrock beneath the study area rather than the Tullyallen Formation. This also agrees better with karst and hydrogeological indicators in the area (See Section 7.1.1 and Section 9).

2 Maximum thickness values from McConnell et al. (2005)

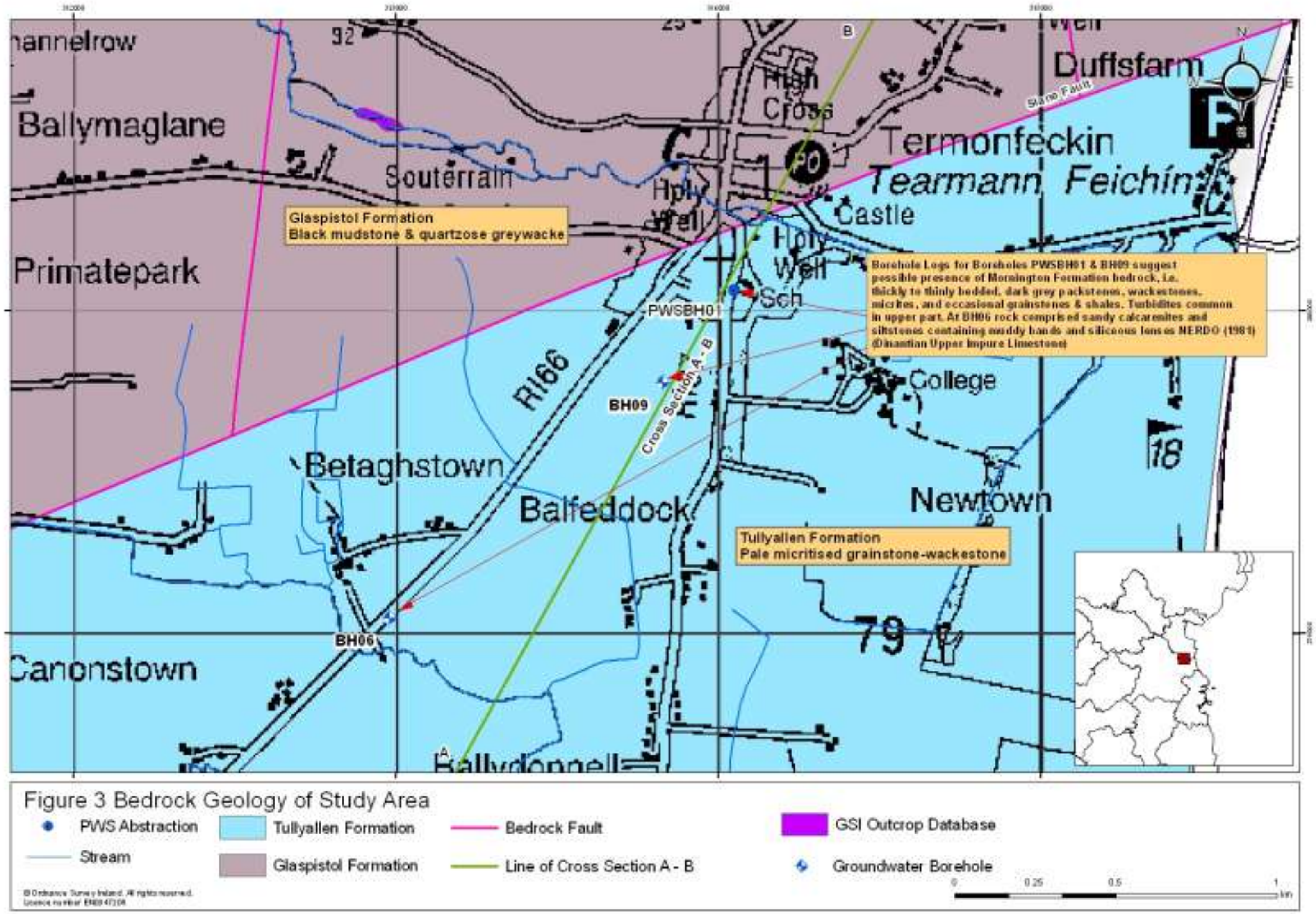

Figure 5 Bedrock geology of the study area

The Dinantian limestones are juxtaposed against the older Silurian Metasediments by the Slane fault which runs east-northeast to west-southwest between the two units, approximately 180 m north of the source. Within the limestone formations, cross faults run north northwest to south southeast, perpendicular to the Slane fault, however none have been mapped in the Termonfeckin area. The limestones are folded at their western end into a shallow syncline with a gentle plunge to the south west (NERDO, 1981). GSI historical mapping indicates that bedrock strata in the Tullyallen formation north of Drogheda dip south at approximately 5^{O}. The Silurian strata are indicated as dipping south southeast at between 80^{O} and 90^{O}, in the area 2 km to the north of the source.

A cross-section of the geology of the study area is shown in Figure 15. The line of the cross-section in Figure 15 is shown in Figure 5.

7.1.1 Karst Geology

Underground and surface karst features are known in the Tullyallen limestone to the west of the study area at Mell Quarry and Drybridge in the vicinity of Drogheda (Conroy, 2011). No karst features were identified in the study area. No evidence of karst cavities or fissures has been encountered in drilling of boreholes in the area. Minor karstification may occur in zones of broken rock such as encountered in boreholes PWSBH01 and BH09, and minor cavities were encountered at BH06 in Betaghstown; however the extent of karstification seems to be significantly less than that encountered further southwest around Drogheda. The lack of karst features agrees with the hypothesis of Mornington Formation bedrock underlying the study area.

7.2 SOILS AND SUBSOILS

According to GSI and EPA web mapping, a number of different subsoil units underlie the areas around borehole PWSBH01. Drilling and permeability mapping carried out by the GSI for this project provide additional information on the subsoils. The subsoil map of the area is shown in Figure 6. The subsoils are also depicted on the cross-section shown in Figure 15.

Several subsoil types are mapped around the source. These include raised beach sands and gravels (MGs), tills (IrSTLPSsS, TLPSsS), alluvium (A), beach sands (Mbs) and windblown sands (Ws). A significant area of built ground (Made) also occurs to the north of the source.

Raised beach sands and gravels (MGs) occupy low, north to south orientated ridges to the west, east and south of the source. The GSI Webmapping shows ridges of raised beach deposits 350 m east and approximately 460 m south-southeast of the source. Further raised beach deposits were recognized and mapped during site visits. The source itself is situated on a newly mapped raised beach ridge, which trends south-southwest to north-northeast, and extends as far as borehole BH04 along the R167 road to the southwest. Another approximately parallel ridge was mapped along the R166 road from the Termonfeckin River to dug well GW03 and borehole BH06. The newly mapped raised beach deposits were delineated based on field observation of subsoil exposures and auger sample points, as well as topography and drainage and on assessment of aerial photography of the study area. They are shown on Figure 6.

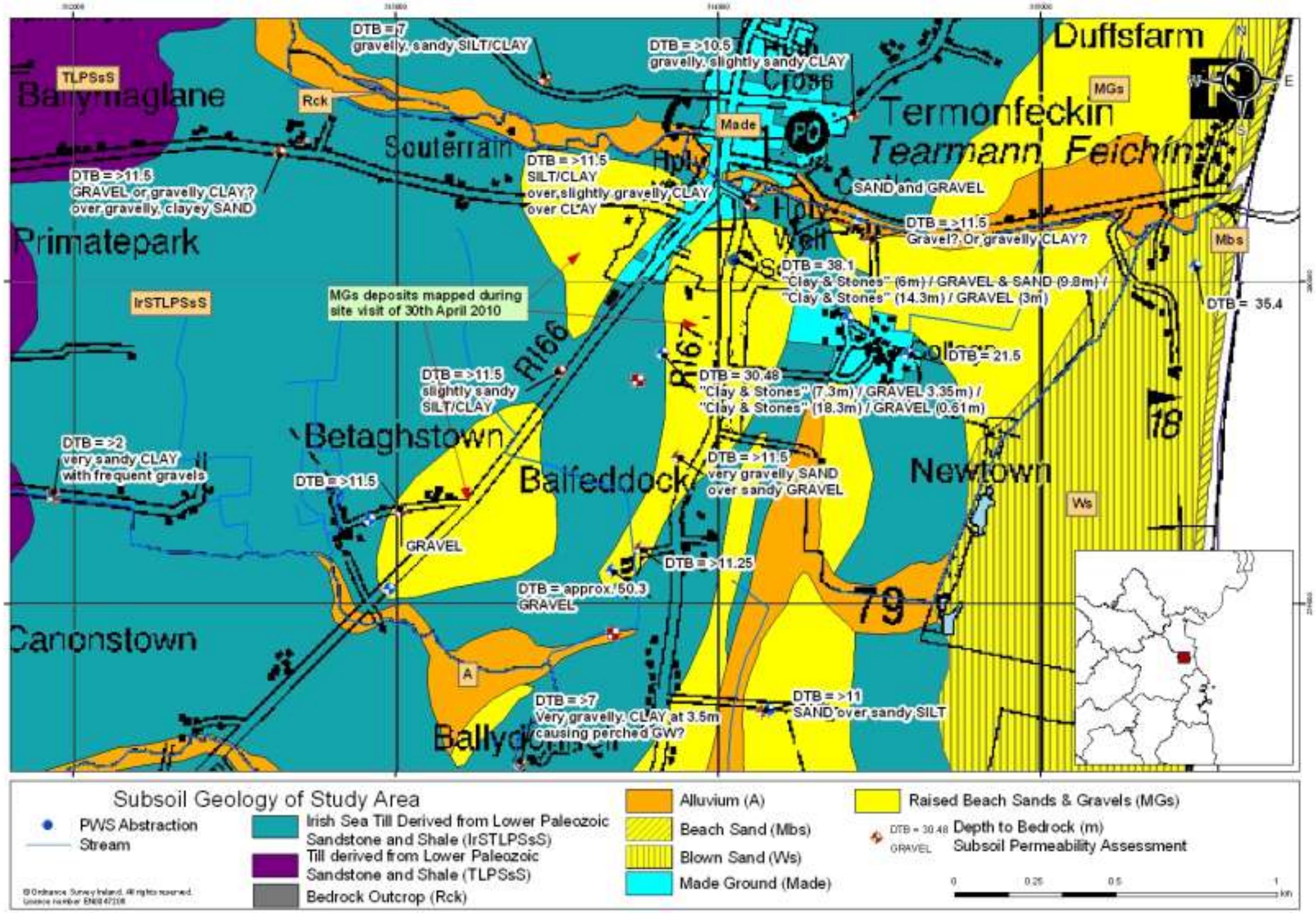

Figure 6 Subsoil geology of the study area

Irish Sea Till (IrSTLPSsS) is found in the area immediately surrounding the borehole, and dominating the area to the north, south and west. This till also occurs in between the low ridges of raised beach deposits. Borehole log data indicate that deposits recorded as “clay and stones” are present beneath the raised beach deposits across the area. These deposits may be Irish Sea Till interbedded with/underlying the raised beach deposits. These suggestions are supported by the hydrogeological indicators of a confined bedrock aquifer underlying the study area (see Section 9). Lower Paleozoic shale and sandstone till (TLPSsS), occurs about 2 km west of the borehole and extends across a large area to the west of this.

Alluvium is found primarily along the Termonfeckin River, and along its tributaries. It also occurs in narrow strips along the streams flowing southeast to Baltray from south of the source. Blown sand (Ws) and beach sand (Mbs) occupies a large area adjacent to the sea and approximately 1 km east of the source. The ‘Made’ ground around Termonfeckin village, comprised chiefly of concrete and tarmac, is assumed to be underlain by the same Irish Sea Till that surrounds it on all sides.

7.2.1 Subsoil Permeability

GSI analysis of subsoil samples from Irish Sea Till and Lower Palaeozoic Sandstone and Shale till in the study area indicates that the deposits are of ‘low permeability’. This classification is supported by the drainage indicators and high drainage density (see Section 8). The permeability data from GSI auger holes in the vicinity of the source are shown in Table A1.1 in Appendix 1.

Under the GSI investigations, the raised beach units in the study area have been classed as ‘High Permeability’. Borehole PWSBH01 is located on a newly mapped ridge of raised beach deposits. The borehole log for borehole PWSBH01 indicates that a 6 m thick surface cover of “clay and stones” is underlain by 9.8 m of GRAVEL and SAND subsoil. The GRAVEL and SAND is likely to be of raised beach origin. The GRAVEL and SAND deposit is underlain by 22.8 m of subsoil which is predominantly “clay and stone” and has a 5.5 m thick gravel lens close to the base. The “clay and stones” material is likely to be moderate to low permeability (possibly till). This suggests that the high permeability raised beach GRAVEL is underlain by greater than 10 m thickness of moderate to low permeability material. Similarly, at borehole BH09 on the boundary of the same raised beach unit, the borehole log indicates 25.6 m of “clay and stones” dominating a column which also contains 3.4 m of GRAVEL close to the surface. The available data suggest, therefore, that the overall permeability of the subsoil column under the newly mapped ridges is moderate to low. Nonetheless, it is possible that preferential vertical pathways of high permeability SAND and/or GRAVEL may penetrate the “clay and stones” deposits, connecting the logged high permeability GRAVEL and SAND layers to the bedrock aquifer. Recognising this possibility and taking a precautionary approach, it is therefore considered that the newly mapped ridges should be mapped as high permeability.

There are no data on the composition of subsoils at depth beneath the previously mapped raised beach deposits to the east and south of the source. It is possible that these ridges of raised beach are also underlain by moderate to low permeability deposits. Hydrogeological indicators (e.g., artesian bedrock flow at borehole BH08, see Section 9) suggest that this may well be the case. In the absence of firm data, and again allowing for the possibility of high permeability preferential vertical pathways, they have conservatively been left as high permeability as per the existing classification used for the preparation of the Louth groundwater vulnerability map.

7.3 DEPTH TO BEDROCK

Depth to bedrock (DTB) has been interpreted across the study area based on bedrock outcrops mapped by the GSI, areas mapped as extreme groundwater vulnerability under the GSI Groundwater Protection Scheme (GWPS), DTB data from the GSI Well Database, and logged evidence from drilling of GSI auger holes and private boreholes in the vicinity of the source. DTB data from GSI auger holes and from other sources is shown in Table A1.1 in Appendix 1. Data from all sources are shown in Figure 6.

The subsoil map indicates that there are no areas of outcropping limestone rock in the vicinity of the study area. A single bedrock outcrop is mapped in the bed of the Termonfeckin River to the northwest of the source; this mapping was done by the GSI in the nineteenth century. The outcrop occurs in the area mapped as Silurian metasediments and Volcanics [3].

Bedrock was at 7 mbgl in TER 19 on the Silurian bedrock to the north of the source. At all other GSI auger hole locations depth to bedrock exceeded 10 m. Available data at boreholes across the study area suggest that DTB ranges from 21.5 to 38.1 mbgl (metres below ground level).

8 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. In this area this means that 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 indicates an area of extreme vulnerability at the Silurian rock outcrop in the Termonfeckin River 1.2 km northwest of the source. This is surrounded by concentric areas of high and moderate vulnerability.

The areas underlain by beach sands, wind blown sands and the ridges of raised beach deposits to the east and south southeast of the source are mapped as high vulnerability due to the high permeability of these deposits. In the areas where newly mapped raised beach deposits have been delineated the groundwater vulnerability has conservatively been mapped as high in this report. This is because of the possibility for high permeability preferential vertical pathways to penetrate the thick low permeability subsoil deposits underlying these localities, from the ground surface down to the bedrock. The groundwater vulnerability map is shown in Figure 7.

The remainder of the area, including the area around the source, is mapped as low vulnerability due to the presence of thick, low permeability tills.

9 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 and EPA Websites and Databases (April/May 2010);
- ⇨ Louth County Council Staff and Local Authority Drinking Water returns;
- ⇨ Groundwater Resources in the N.E. (R.D.O.) Region (NERDO, 1981);
- ⇨ Response to further information request regarding proposed development at Termonfeckin, Co. Louth (Planning Ref/ No. 06/625) (OGE, 2006);

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[3] The 6-inch historical geology map of the area records this site as a "limestone boulder"

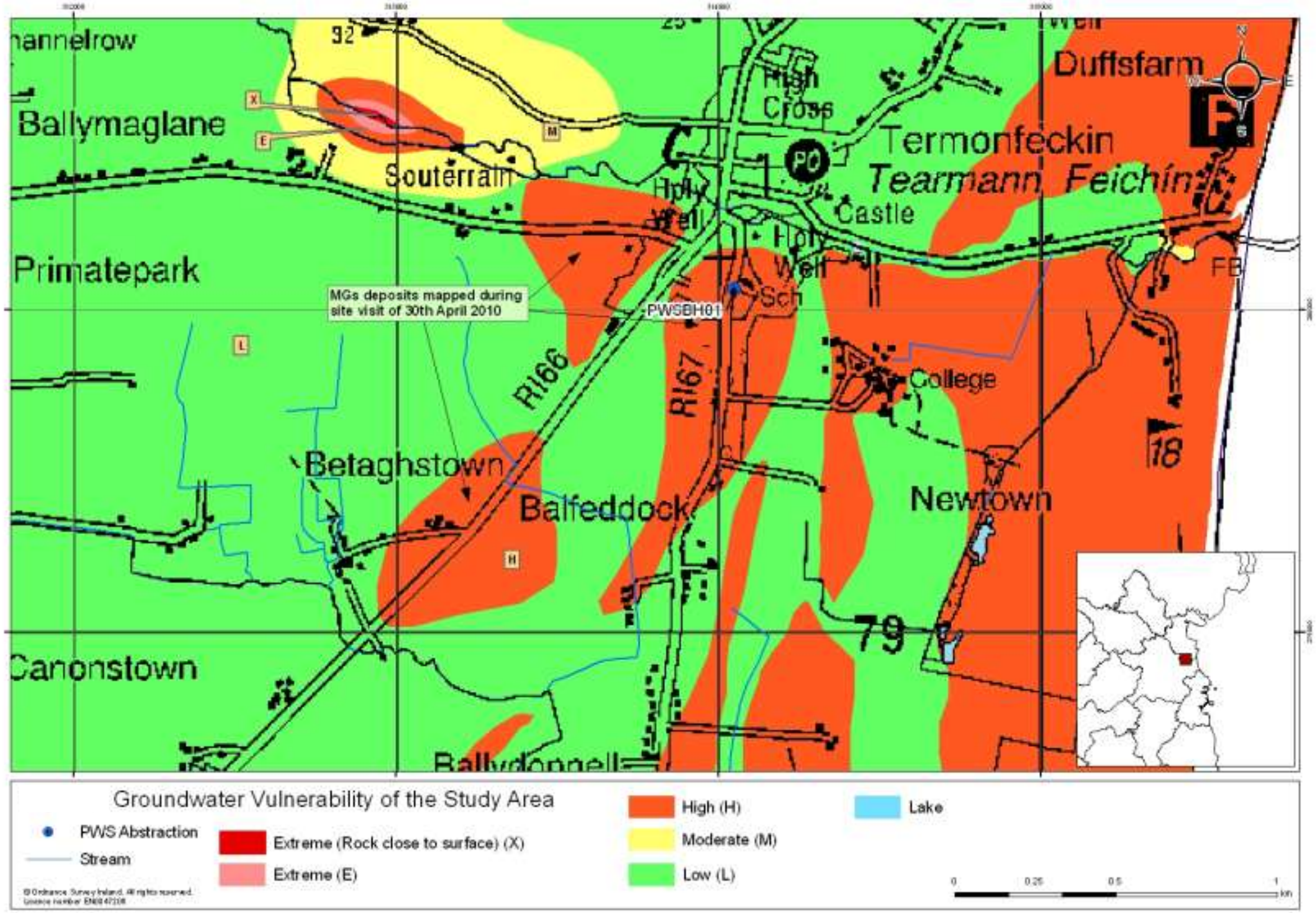

Figure 7 Groundwater vulnerability around the study area

- Drilling and permeability mapping by GSI in May 2007;
- Hydrogeological mapping by Natalya Hunter Williams (May 2007) and by Peter Conroy and Robert Meehan (April 2010);
- Louth County Council well hydrograph for Termonfeckin;
- Met Éireann rainfall and evapotranspiration data.

9.1 GROUNDWATER BODY AND STATUS

Borehole PWSBH01 is located in the Louth groundwater body (GWB). The surrounding area forms part of five separate groundwater bodies (GWBs). The various GWBs are shown in Figure A1.1 in Appendix 1, and Louth GWB description is contained in Appendix 1. The Water Framework Directive (WFD) status of Drogheda GWB is 'Poor' due to the chemical status. The WFD 'Overall' status of the other four GWBs is 'Good'. 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.

9.2 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater levels were measured at a number of boreholes across the study area on 29th April 2010. Further water level data for additional boreholes were obtained from desk study information. The elevation reference point and water level data for each location are detailed in Table A1.1 in Appendix 1. Hydrographs of water level data for borehole PWSBH01 from December 2005 to May 2010 and on 29/04/2010, from Louth County Council telemetry data, are presented in graphical format in Figure 8 and Figure 9, and summarised in Figure A1.2 in Appendix 1.

The groundwater level in borehole PWSBH01 on 29th April 2010 varied between –9.00 mAOD[4] and 8.16 mAOD for pumping at 96 m^3/day and rest conditions respectively. The minimum recorded water level on the borehole hydrograph is -27.78 mOD on 12/01/2006 (pumping rate not recorded). Until January 2007 the pumping water level was below the top of the screened section of the borehole (39 mbtc; -16.4 mAOD). This can lead to encrustation of the borehole screen and pump (reducing the borehole yield). A timer switch was fitted to the borehole pump in May 2009, which has resulted in a decrease in demand on the borehole to 96 m^3/day and a slight increase in rest water level elevation.

Measured bedrock and raised beach deposits rest groundwater levels on 29/04/2010 are shown in Figure 10. Rest groundwater levels for boreholes BH08 and BH09 for the date 17/02/2006 (OGE, 2006) and are also shown in Figure 10. Interpreted groundwater elevation contours based on these data (Figure 10) show that to the west of the source the groundwater flow direction is slightly east-southeast at a gradient of 0.017. To the east of the source the gradient decreases significantly to approximately 0.008 but continues east-southeast towards the sea, which is likely to be the main discharge zone for the bedrock aquifer.

In the Silurian bedrock flow is likely to be localised with groundwater discharging rapidly to nearby surface water features. Any groundwater crossing the Slane fault into the limestone are likely to derive from very close to the fault. The groundwater flow direction in the saturated raised beach deposits near borehole BH02 is likely to be towards the Termonfeckin River. Further east in the strip of gravels adjacent to the coast the flow direction is likely to be towards the sea.

[4] Note: The hydrograph for borehole PWSBH01 is derived from pressure transducer data. The pressure data have been converted to metres below the top of the 125 mm steel casing (mbtc) based on the dipped water level on 29/04/2010 and the corresponding pressure reading closest in time to the dipped level (27.26 m of water pressure at 11.19 am on 29/04/2009). This suggests that the pressure transducer sensor is located at approximately 58 mbtc.

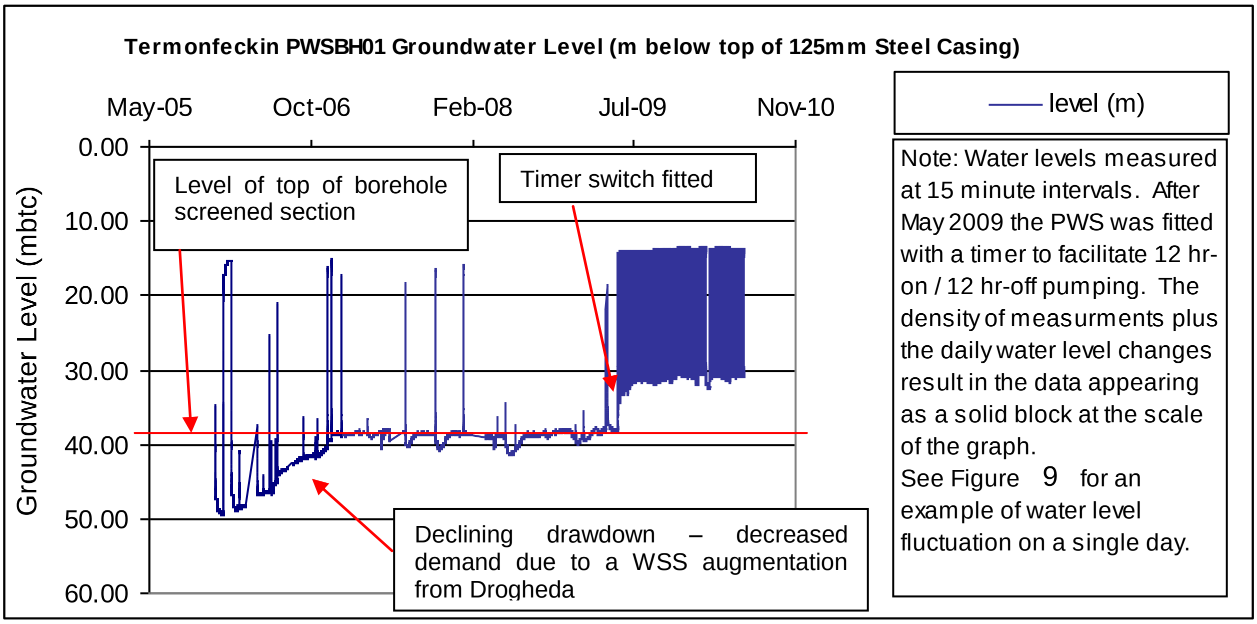

Figure 8 Borehole PWSBH01 Hydrograph December 2005 to May 2010

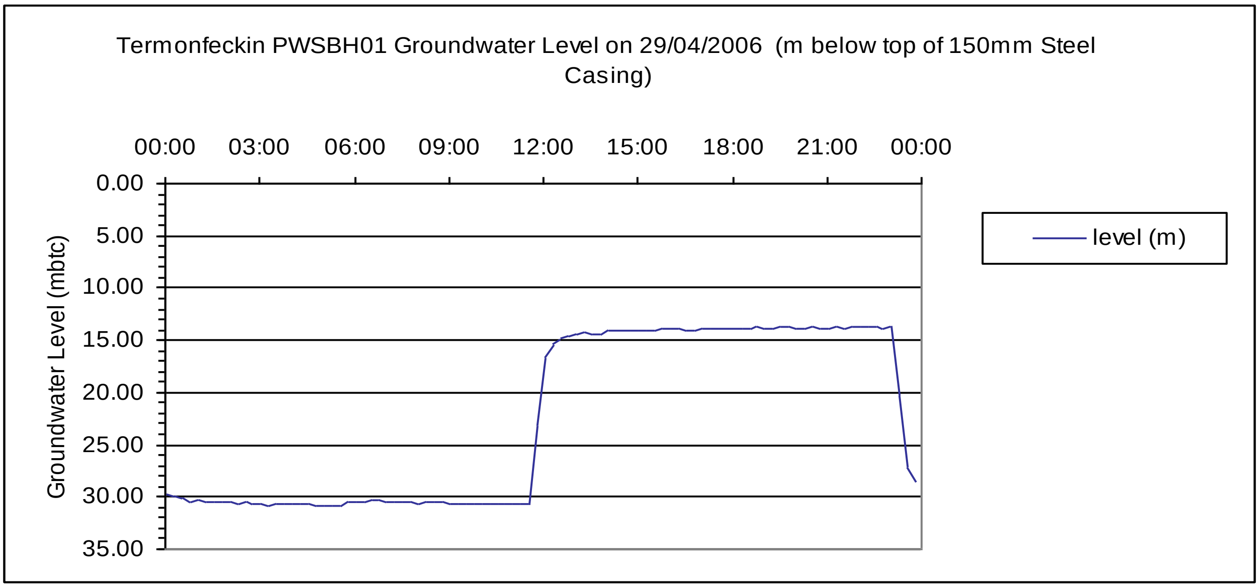

Figure 9 Borehole PWSBH01 Hydrograph on 29/04/2010

Data from borehole BH02 and dug well GW03 show that the watertable elevation in the raised beach deposits is below the piezometric level of the underlying bedrock aquifer. As such there is a vertical gradient from the bedrock aquifer up into the saturated subsoil strata. At borehole BH02 the groundwater level data suggest a hydraulic gradient from the raised beach deposits towards the Termonfeckin River. This suggests that a component of the confined groundwater flow in the bedrock aquifer is likely to discharge to the river *via* preferential pathways through the raised beach and underlying deposits. This condition may be replicated at other raised beach deposits and streams across the study area. Hydrochemistry data from groundwater seepages in the raised beach deposits support this hypothesis (see Section 9.3).

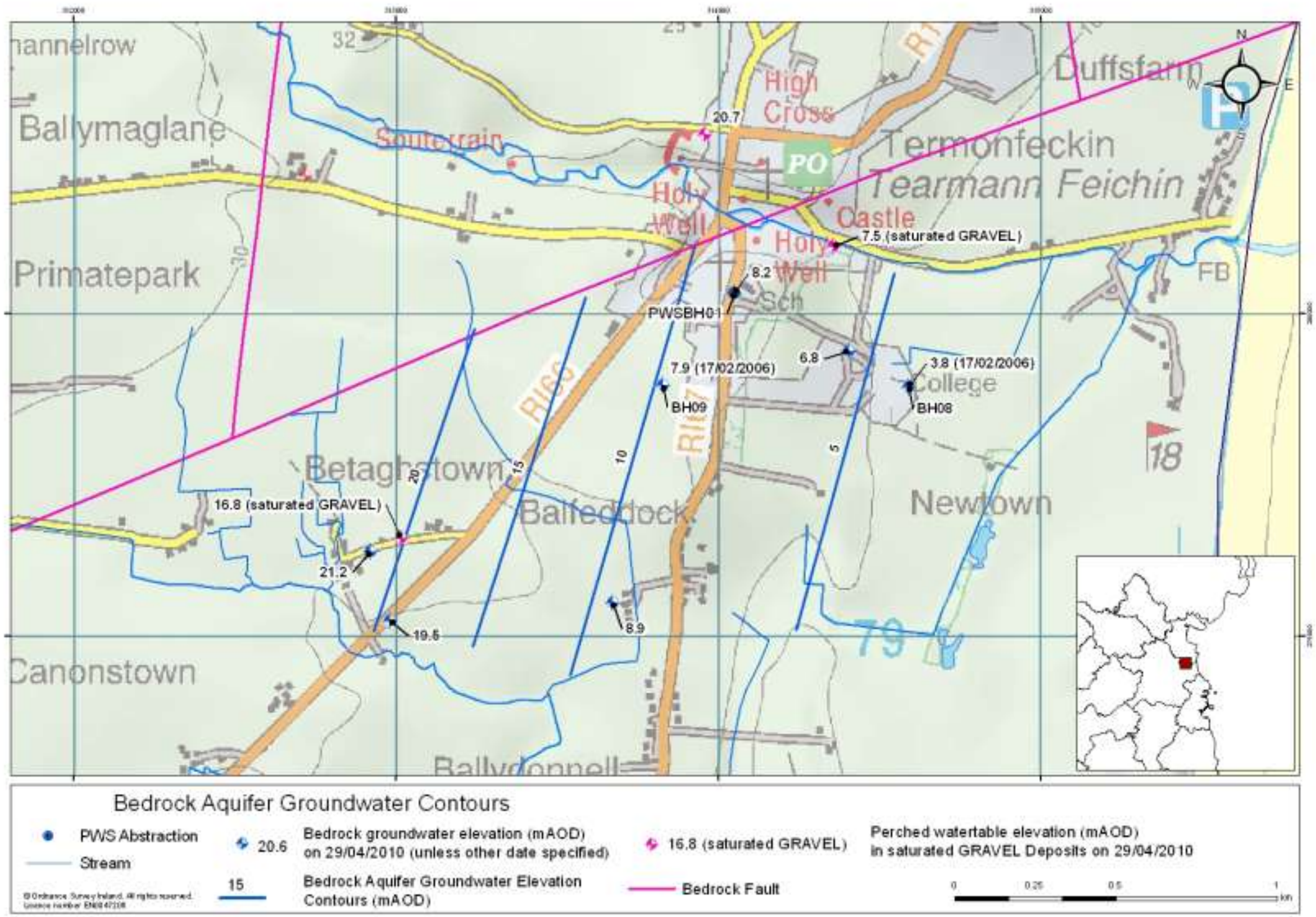

Figure 10 Bedrock aquifer groundwater contours (non-pumping)

The pumping water level at borehole PWSBH01 is -9 mAOD. This reverses the vertical gradient between the bedrock aquifer and the saturated raised beach deposits in the vicinity of the borehole. This would allow recharge of the bedrock aquifer and borehole from the raised beach deposits *via* the same preferential pathways that naturally facilitate bedrock aquifer discharge. Natural seasonal fluctuations in water levels could also result in reversed gradients.

The public water supply borehole is situated 1,500 m from the coastal high water mark shown on the 1:50,000 scale map of the area. In coastal aquifers, freshwater / saltwater density contrasts cause a wedge of saline water to intrude naturally inland into the bedrock aquifer, underneath the fresh groundwater flowing to the coast. The depth of the interface between the fresh and saline waters at any point can be estimated from the Ghyben-Herzberg relationship (de Marsily, 1986):

$z = 40h$, where: h is the fresh groundwater elevation above sea level, and
z is the depth of the interface below sea level.

In this case, assuming a bedrock aquifer thickness of 85 m at the coast (based on the depth of bedrock aquifer intersected by borehole PWSBH01), the toe of the wedge will be located at a point where the z is equal to 85 m (*i.e*. at the base of the aquifer). This implies that the toe of the wedge would be located along the 2.2 m groundwater contour ($h = z/40$). If it is assumed that the gradient from borehole PWSBH01 is directly east at 0.008, and that the groundwater elevation at the borehole is 8.2 mAOD, the toe of the wedge would lie along a line 750 m east of the source. As such, at current pumping rates, the borehole is unlikely to be affected by saline intrusion. Saline intrusion risk to the borehole should be low for pumping scenarios where the drawdown from the pumping does not extend as far as the toe of the natural saline wedge.

9.3 HYDROCHEMISTRY AND WATER QUALITY

Three groundwater samples were collected and analysed from borehole PWSBH01 between 31st March 2009 and 27th April 2010. All three of the samples were collected and analysed by the EPA on behalf of Louth County Council. Two of the samples were analysed for a limited suite of parameters. Data for three samples of groundwater from February 2006 for borehole BH09 are also available (OGE, 2006). The available data are presented in Table A1.2 in Appendix 1.

Overall the source and surrounding aquifer have a moderately high level of mineralization as indicated by the average electrical conductivity (524 µS/cm), alkalinity (227 mg/l as $CaCO_3$) and hardness (216 mg/l as $CaCO_3$). The values are lower than could be expected of a pure limestone and may further indicate the presence of DUIL bedrock in the area. The hydrochemistry is dominated by the calcium and bicarbonate ion pair. The average pH of the groundwater is 7.4. Nitrate is below detection limits, and iron and manganese concentrations are elevated, which suggests anaerobic, confined conditions. Nitrate is likely to be present in the aquifer recharge, which suggests that nitrate reduction may be occurring. There is no evidence of saline intrusion.

Field water quality data were collected on 10/05/2010 for the Termonfeckin River at location SW01, for springs emitting from the saturated raised beach deposits at location GW01, within the SAND and GRAVEL at borehole BH02, and for the bedrock aquifer at borehole BH05 (Table A1.3 in Appendix 1). The electrical conductivity and pH data for borehole BH02, the sand and gravel seepage at GW06 and the stream at SW01 are similar to the values for the bedrock borehole and to the average values for the bedrock aquifer. This supports the idea of the bedrock aquifer partially discharging via the sand and gravel deposits into the Termonfeckin River.

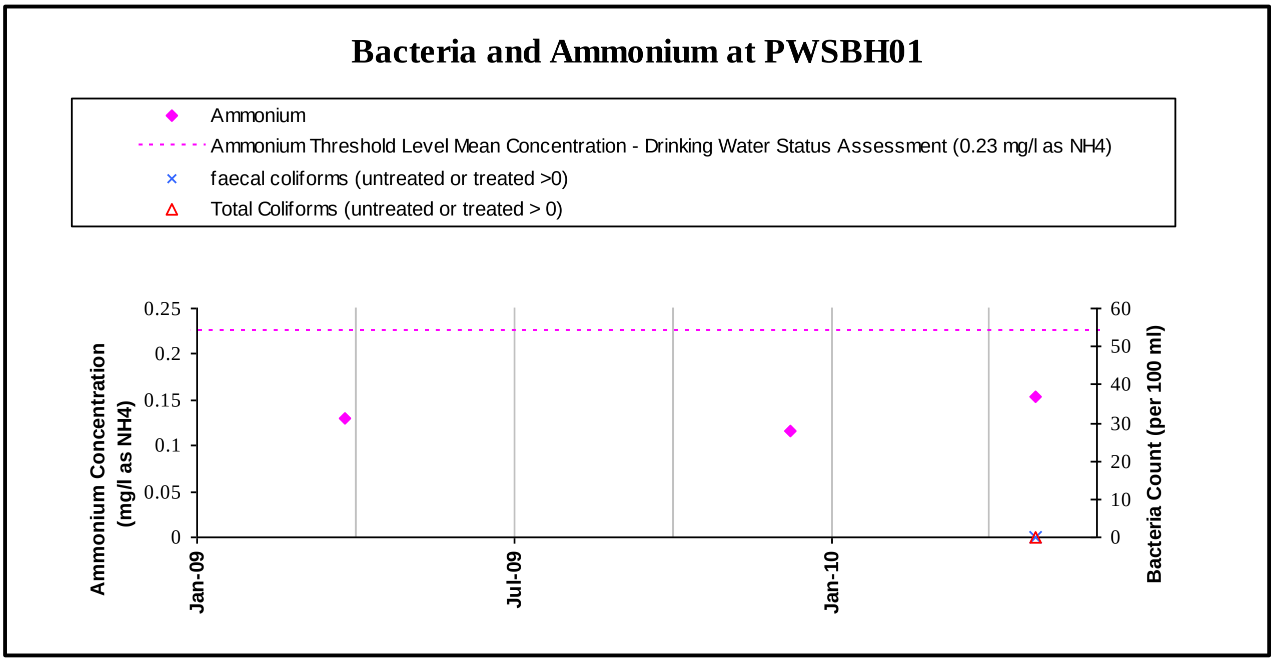

Figure 11 Graph of Bacteria and Ammonia Concentrations at Borehole PWSBH01

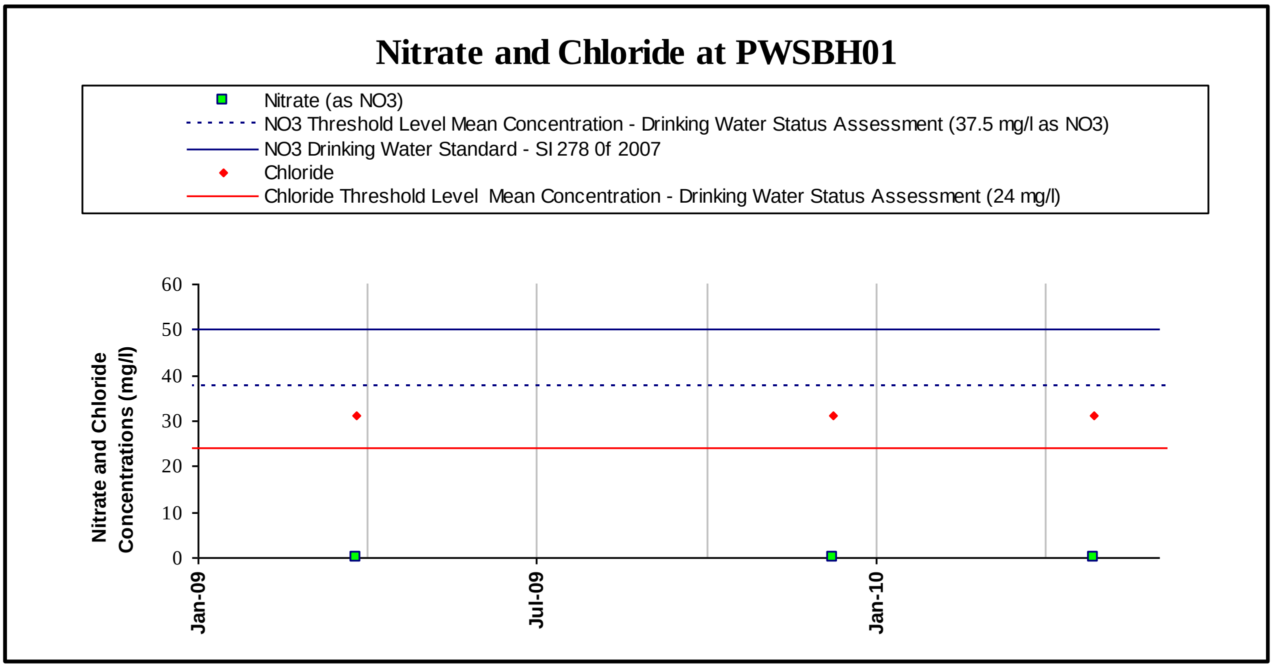

Figure 12 Graph of Nitrate and Chloride Concentrations at Borehole PWSBH01

Figure 11 shows the measured concentrations of faecal and total coliforms, and ammonium at the source. The ammonium concentrations are detectable but low. Ammonium is converted to nitrate under aerobic conditions and, as such, its presence and the absence of nitrate suggest anaerobic conditions in the aquifer. No exceedences of the ammonium drinking water standard or EPA threshold level have occurred. Coliform bacteria have not been detected at borehole PWSBH01.

Figure 12 shows the measured concentrations of nitrate and chloride at the source. Nitrate concentrations are below the detection limit in all samples. Average chloride concentrations measured 27.8 mg/l which exceeds the EPA threshold of 24 mg/l. Chloride is a conservative parameter and the observed concentrations suggest that inputs of organic pollutants (which typically include nitrate) to the groundwater recharge may be occurring, but only the chloride signature remains by the time the groundwater is intersected by the boreholes. Due to the location of the study area close to the coast, part of the elevated chloride may be attributable to sea spray.

Figure 13 shows the concentrations of manganese, iron and potassium, and the Potassium:Sodium (K:Na) ratio at the source. Potassium and the K:Na ratio are below their respective thresholds. Iron and manganese exceeded the drinking water standard at borehole PWSBH01 in April 2010, which is likely to be due to natural confined, anaerobic conditions.

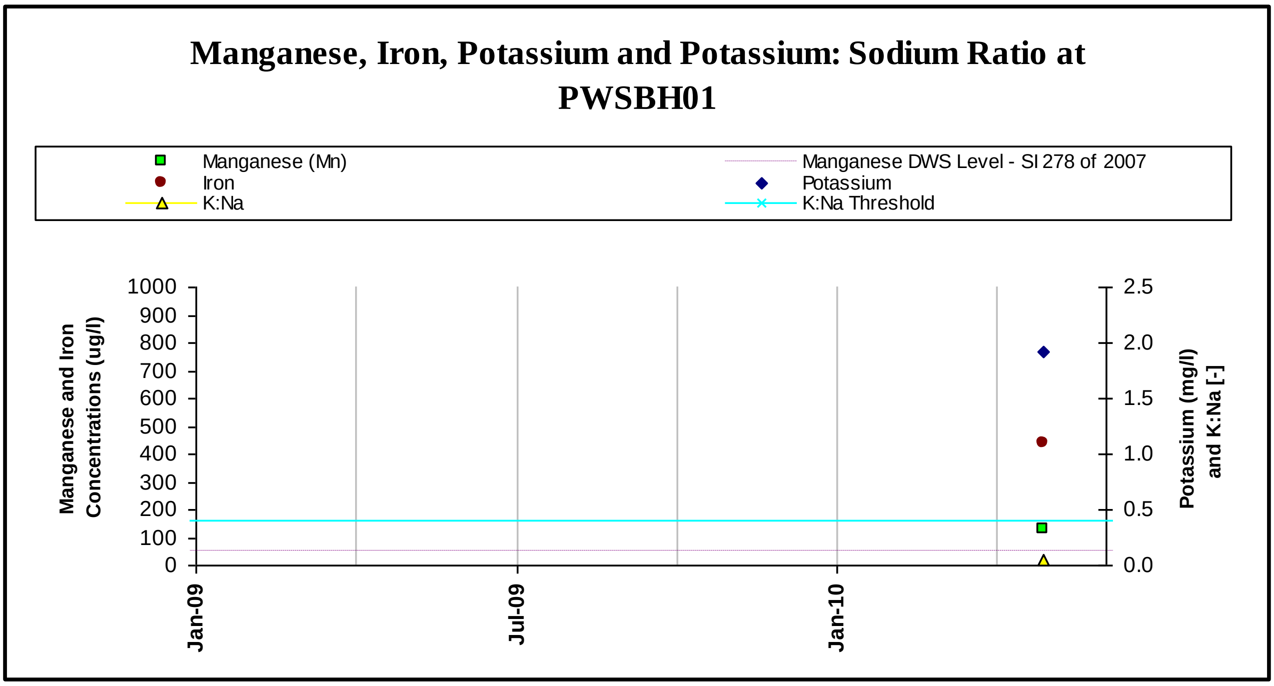

Figure 13 Graph of Manganese, Iron, Potassium and Potassium:Sodium Ratio at Borehole PWSBH01

The remaining parameters measured do not exceed their respective drinking water standard or EPA threshold. The hydrochemistry and water quality data for borehole BH09 support the conclusions drawn from the data relating to borehole PWSBH01.

In summary, recharge to the system may be slightly polluted by diffuse sources of organic matter. The majority of the contaminants except chloride and ammonia are attenuated by the subsoil cover, and the anaerobic conditions in the bedrock aquifer. The anaerobic conditions are also likely to mobilise naturally occurring iron and manganese. The field hydrochemistry data support the idea of the bedrock aquifer having a component of discharge to surface water via the saturated raised beach deposits.

9.4 AQUIFER CHARACTERISTICS

The GSI bedrock and gravel aquifer maps of the area show that various aquifer types are present in the study area. The aquifer types are summarised in Table 3.

Groundwater flow in the bedrock aquifer is largely diffuse, via fractures. Some solution enlarged fissures are likely to occur due to the limestone nature of the rock; however these are likely to be less extensive than in karstified aquifers. There is no evidence that large karst conduits or point recharge locations occur. Groundwater flow in the *Pl* aquifer is via fractures and likely to be very localised, due to the lack of regional scale fracture connectivity.

Table 3 Aquifer types around Termonfeckin Public Supply

Subsoil / Bedrock Formation	Gravel Body / Generalised Rock Unit	Aquifer Type
Mornington Formation (MT)	Dinantian upper impure limestones (DUIL)	Area underlying source mapped as DPBL, which is a *Regionally Important Aquifer – Karstified (diffuse) (Rk$_d$).* DPBL re-interpreted in this report as DUIL, which would behave in a similar way to a *Locally Important Aquifer (Lm)* – bedrock that is generally moderately productive
Tullyallen Formation (TA)	Dinantian pure bedded limestones (DPBL)	
Glaspistol Formation (GP)	Silurian Metasediments and Volcanics (SMV)	*Poor Aquifer (Pl*) – bedrock that is generally unproductive except for local zones
Wind Blown Sands & Beach Sands	Clogher Head Gravels	*Sand and Gravel (Lg)* – generally moderately productive

The geological, chemical, groundwater elevation, and available pumping test data suggest that the bedrock aquifer is of the confined-leaky type. Groundwater levels at boreholes PWSBH01 and BH09 are above the top of the bedrock (-15.5 mAOD). Boreholes BH05 and BH06 are artesian in winter. Historical records for borehole BH08 indicate that at the time of drilling the borehole was artesian (NERDO, 1981). These locations extend from west to east across the study area and suggest that the bedrock aquifer is confined. Field water quality data suggest the bedrock groundwater partially discharges *via* leakage through the overlying raised beach deposits. Pumping test data for borehole PWSBH01 and BH09 indicate that the bedrock aquifer is a confined-leaky aquifer, i.e. the data suggest downwards leakage from the subsoils into the bedrock when the upward groundwater gradient is reversed by pumping.

The decrease in groundwater gradient to the east of the source may be due to loss of water from the bedrock aquifer *via* discharge into the overlying sand and gravel deposits. An increase in aquifer transmissivity to the east of the source would also cause the observed groundwater gradients.

Pumping tests on the bedrock aquifer were carried out at boreholes PWSBH01 and BH09. The raw data from the pump tests were analysed as part of this report (Appendix 2). The results of the analysis show that transmissivity ranges from 4 m^2/d to 41 m^2/d with a geometric mean of 12 m^2/day. The specific capacity of borehole PWSBH01 ranged from 13 to 15 m^3/d/m.

A thickness of up to 100 m has been suggested for the limestone aquifer (NERDO, 1981). The thickness of the bedrock aquifer penetrated by borehole PWSBH01 is 83.9 m. The average hydraulic conductivity of the aquifer can be estimated by dividing the transmissivity by the aquifer thickness (Table 2). An average porosity of 1% was assumed for the regional scale Rk$_d$ aquifer in the NERDO (1981) report. This value is also likely to be representative of locally important aquifers in which groundwater flows through a connected fracture network.

Based on the estimated bedrock aquifer transmissivity and the aquifer hydraulic gradients, the average groundwater flow velocity can be estimated based on the equation:

$$v = \frac{T \cdot i}{b \cdot n_e},$$ where:

v = average groundwater velocity (m/day);
n_e = effective porosity (dimensionless)
b = aquifer thickness.
T = aquifer Transmissivity (m^2/day);
i = hydraulic gradient; and,

The estimated groundwater velocity range in the bedrock aquifer, based on the available data is shown in Table 4. The resulting groundwater velocity values represent an average velocity for the aquifer. Velocities in individual fissures may greatly exceed the calculated values.

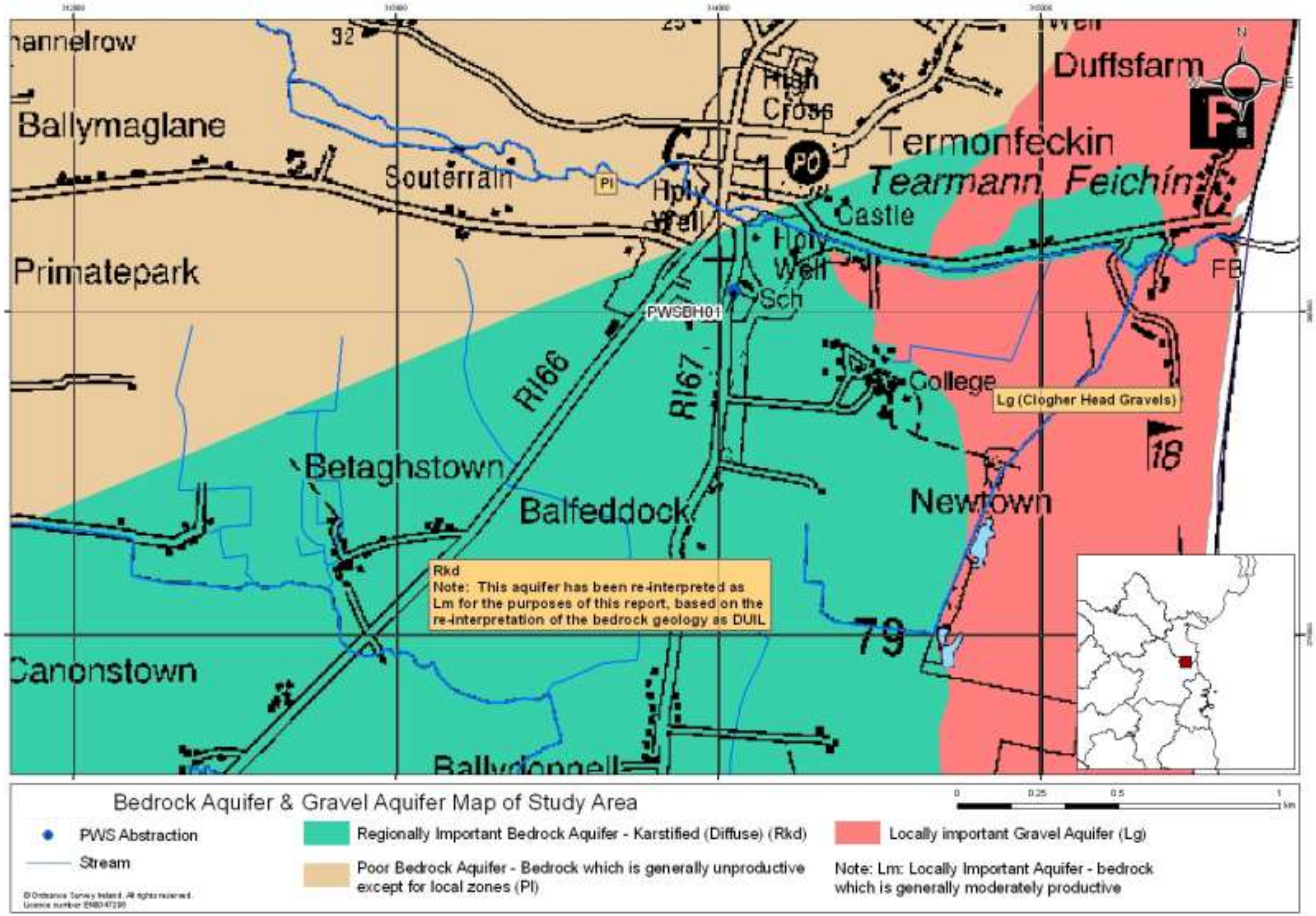

Figure 14 Bedrock aquifer and gravel aquifer map of the study area

Table 4 Estimated groundwater flow velocity (v, m/d) range in the bedrock aquifer

Parameter	Units	Minimum	Maximum	Average	Data Source
T	m^2/d	4	41	12	Pumping Test Data (Appendix 2)
i	[-]	0.008	0.017	0.012	Groundwater contours (Figure 10)
b	m	83.9	100	92	PWSBH01 borehole log, NERDO (1981)
n_e	[-]	0.01	0.01	0.01	NERDO (1981)
v	*m/d*	*0.03*	*0.83*	*0.16*	

10 ZONE OF CONTRIBUTION

10.1 CONCEPTUAL MODEL

Borehole PWSBH01 abstracts from limestone bedrock interpreted as Dinantian Unbedded Impure Limestone aquifer through which groundwater flows via fractures that are not significantly enlarged by dissolution. The bedrock aquifer is generally confined by thick, low permeability subsoil, particularly to the west of the source. The confined bedrock aquifer becomes artesian in places to the west of the source during the winter. Artesian conditions can also occur to the east of the source. In the vicinity of the source, raised beach subsoil deposits have been mapped and these are saturated with groundwater, which is perched over further low to moderate permeability subsoils. These further subsoil deposits underlie the raised beach and sit on top of the bedrock. There is an upwards vertical gradient between the limestone bedrock and the saturated raised beach deposits. A component of groundwater flow in the limestone is considered to discharge up into the raised beach deposits under the influence of the vertical gradient, *via* preferential pathways through the intervening subsoils. Groundwater in the raised beach deposits then discharges laterally into surface water courses such as the Termonfeckin River.

Pumping at borehole PWSBH01 reverses the vertical hydraulic gradient, such that perched groundwater can leak downwards into the bedrock aquifer, again *via* the preferential pathways, and subsequently flow laterally to the borehole.

Recharge to the bedrock aquifer in the vicinity of borehole PWSBH01 is of low magnitude and derives from two mechanisms. One comprises leakage from perched groundwater in the raised beach deposits, induced by groundwater abstraction from the bedrock. The other is diffuse recharge to the bedrock aquifer through the low permeability tills when seasonal water level fluctuations result in a downwards vertical gradient from the till into the bedrock, i.e. when the groundwater in the bedrock is not artesian.

Groundwater flow in the bedrock aquifer is east-southeast towards the sea, *via* a diffuse fracture network with only minor karstification thought to be present. The sea is likely to be the main discharge boundary for the bedrock aquifer, with leakage to raised beach deposits likely to be a secondary component. Saline intrusion is not considered to be a risk to the borehole at current abstraction rates.

A schematic cross section illustrating the conceptual model is shown in Figure 15. The line of cross-section is shown on Figure 5.

11 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 hydrogeological conceptual model, as described in Section 10.1.

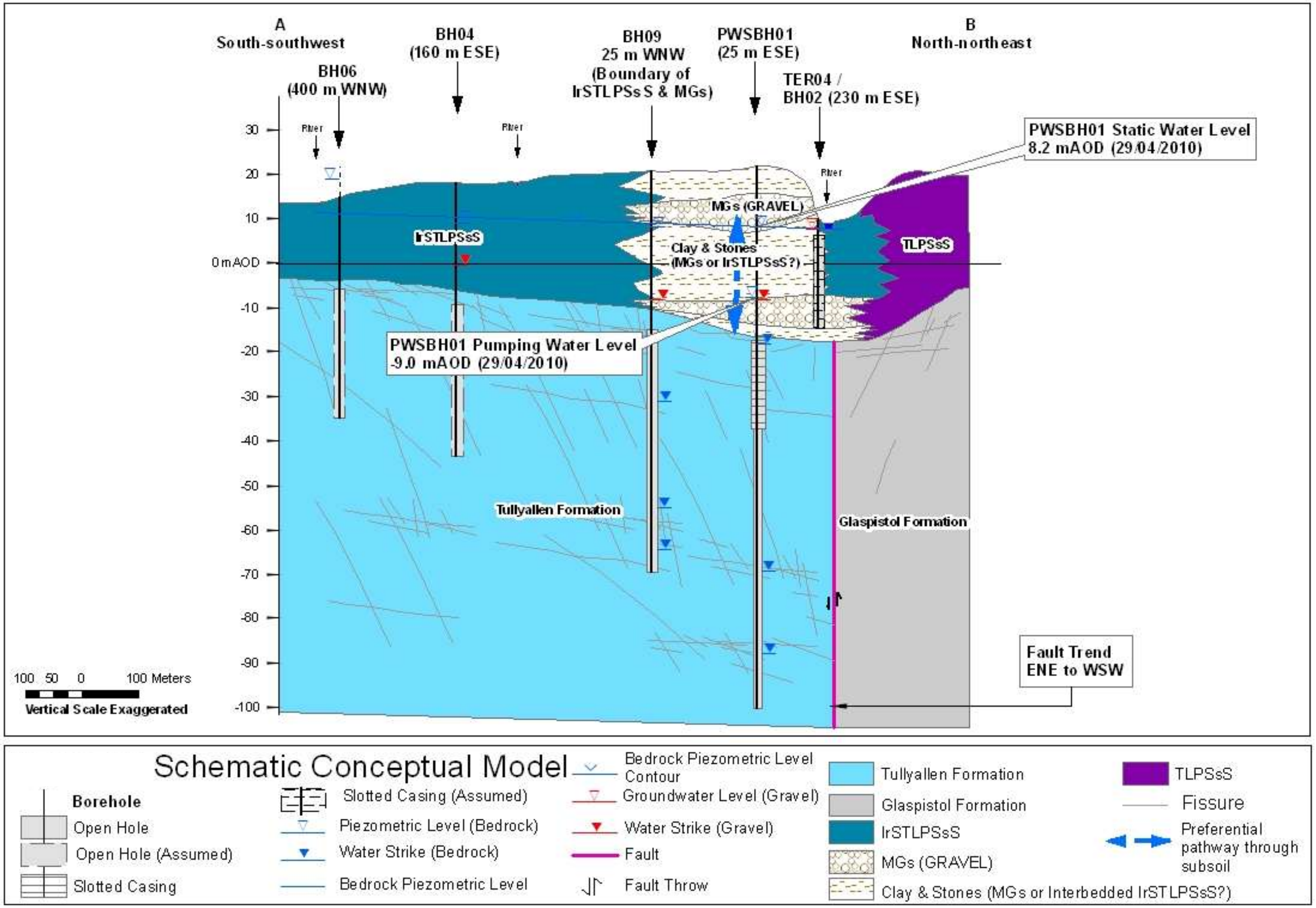

Figure 15 Schematic conceptual model of groundwater flow to Termonfeckin WSS borehole

The line of cross-section is shown on Figure 5.

Two source areas are generally delineated:

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

The delineated source protection areas are shown in Figure 16.

11.1 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 the conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

The water balance approach calculates the recharge area footprint required to supply a recharge volume equal to the public water supply abstraction. The average annual abstraction for the source is 96 m^3/day, although higher pumping rates have been achieved in the past. To provide a safety factor in delineating the ZOC, the water balance has been calculated based on 150% of the annual abstraction, which amounts to 144 m^3/day. The recharge area required to supply the source at an abstraction rate of 144 m^3/day, based on an annual recharge of 38 mm, is 1.39 km^2. The ZOC based on the water balance has been delineated as follows.

The eastern boundary is the downgradient boundary of the ZOC. This delineates the maximum downgradient distance (x_L) that the borehole can pump water from and is based on the uniform flow equation (Todd, 1980).

$x_L = Q / (2 * \pi * T * i)$ where: Q is the daily pumping rate +/- X%
T is the Aquifer Transmissivity, and
i is background non-pumping hydraulic gradient.

Using the data from Table 4 and a pumping rate of 144 m^3/d, the equation indicates that the possible down-gradient ZOC extent is approximately 380 m.

The northwestern boundary is parallel to the fault boundary between the fractured limestone aquifer on the south, and the Pl aquifers on the north side of the fault. The boundary of the fractured limestone aquifer is the practical limit of the ZOC. A 100 m buffer zone has been applied on the north side of the fault to account for limited groundwater inflow from the Pl aquifer and for direct runoff from the Pl aquifer into the fractured limestone aquifer.

The southeastern and southwestern boundaries are delineated to capture the necessary recharge footprint to satisfy the water balance requirements. The southwestern boundary begins at the northwestern boundary and extends away from the fault zone along a flow line perpendicular to the bedrock groundwater contours. From midway between the R166 and R167 roads the boundary swings to the northeast to join the downgradient boundary and capture the required recharge footprint.

This water balance delineation is supported by Darcy flow calculations for the upgradient part of the ZOC. Darcy's Law estimates groundwater flow as:

$Q = T * i * w$ where: T = aquifer transmissivity
i = hydraulic gradient, and
w = width of aquifer perpendicular to the groundwater flow direction.

Using the hydraulic gradient of 0.017 upgradient of the source, transmissivity of 12 m^2/day and a maximum upgradient ZOC width of 1200 m, gives a calculated flow through the ZOC of 247 m^3/day. This is of the same order of magnitude as the PWS abstraction and supports the positioning of the southwestern and southeastern boundaries. (It is not expected to give an exact match to the abstraction and is likely to overestimate the upgradient contribution slightly given the large downgradient capture zone.)

The northeastern corner of the ZOC passes beneath the Termonfeckin River. It is considered unlikely that borehole PWSBH01 will draw water from the river due to the buffering effect of the saturated raised beach sand and gravel deposits between the bedrock borehole and the river.

Overall the delineated boundaries describe a ZOC with an area of 1.47 km^2. This is slightly greater than the required ZOC footprint and equates to groundwater recharge sustaining an average abstraction rate of 153 m^3/d.

11.2 RECHARGE & 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 268 mm/yr i.e. (Annual Effective Rainfall, see Section 6).

Actual recharge has been estimated to be 38 mm/yr, which is 14% of potential recharge; this value is based on averaging of the recharge for the different settings outlined in Table 5.

Runoff losses: 230 mm (86% of potential recharge). Rejected potential recharge is assumed to runoff to surface water via the ground surface and interflow.

These calculations are summarised in Table 6.

Table 5 Recharge coefficients for the study area

Vulnerability	**Location in Study Area**	**Additional factors**	**% Area**	**Recharge Coefficient Guidance**		**RC**
				Inner Range	Outer Range	
Low	Till subsoils, predominantly west of source, but also in between ridges of raised beach deposits	Low slope, high drainage density. Upwards vertical hydraulic gradient from bedrock aquifer in the extreme west of the study area. Artesian conditions will reduce recharge to zero in places during the winter	64	5 – 15%	2 – 20%	8%
High Vulnerability saturated gravels, over low to moderate permeability clay, linked to bedrock aquifer by preferential pathways	Raised beach ridges surrounding the source and to extending south and further ridges to the west	Groundwater level data from April 2010 suggest upwards leakage from bedrock into sand and gravel deposits. Seasonal changes in water table may reverse this gradient at times. Also, the cone of depression around PWSBH01 during pumping conditions reverses gradient locally, suggesting leakage from gravels to bedrock & borehole will occur during pumping. Chosen coefficient allows for downwards leakage during part of the year and for induced leakage around the abstraction borehole.	36	-	-	25%

Table 6 Bedrock Recharge Calculation Summary

Parameter	**Coefficient**	**Rate**
Average rainfall (R)		800 mm/yr
Estimated P.E.		560 mm/yr
Estimated A.E. (95% of P.E.)		532 mm/yr
Effective rainfall		268 mm/yr
Potential recharge		268 mm/yr
Recharge coefficient for High Vulnerability with saturated gravels leaking across underlying low to moderate permeability clay *via* preferential pathways	0.25	67 mm/yr
Recharge coefficient for Low Vulnerability	0.08	21 mm/yr
Averaged runoff losses	(86%)	230 mm/yr
Bulk recharge coefficient	0.14	
Recharge		38 mm/yr

11.3 INNER PROTECTION AREA

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 (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the source is calculated from the velocity of groundwater flow in the bedrock. The velocity multiplied by the 100 day time period gives the distance travelled by the groundwater during the TOT. This distance gives the lateral extent of the buffer which must be applied around the source to form the SI.

Given the reinterpretation of the bedrock aquifer classification as Lm and the lack of evidence for karst flow mechanisms in the study area, the 100-day travel time approach has been used to delineate the extent of the inner protection area to the source (SI) for the Termonfeckin source.

The maximum average groundwater velocity in the bedrock aquifer is calculated as 0.825 m/d (Section 9.4). This gives a 100 day travel time distance of 82 m. A cross-check using the Thiem approach, using a pumping rate of 144 m^3/d, a predicted drawdown of 20m, well radius of 0.125 m, and a maximum average hydraulic conductivity of 0.5 m/d, gives a 100 day travel time distance of 85 m. This distance is applied around the borehole. The remainder of the ZOC is classified as the Outer Source Protection Area (SO).

12 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Figure 17 and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/H, SO/L and SO/H.

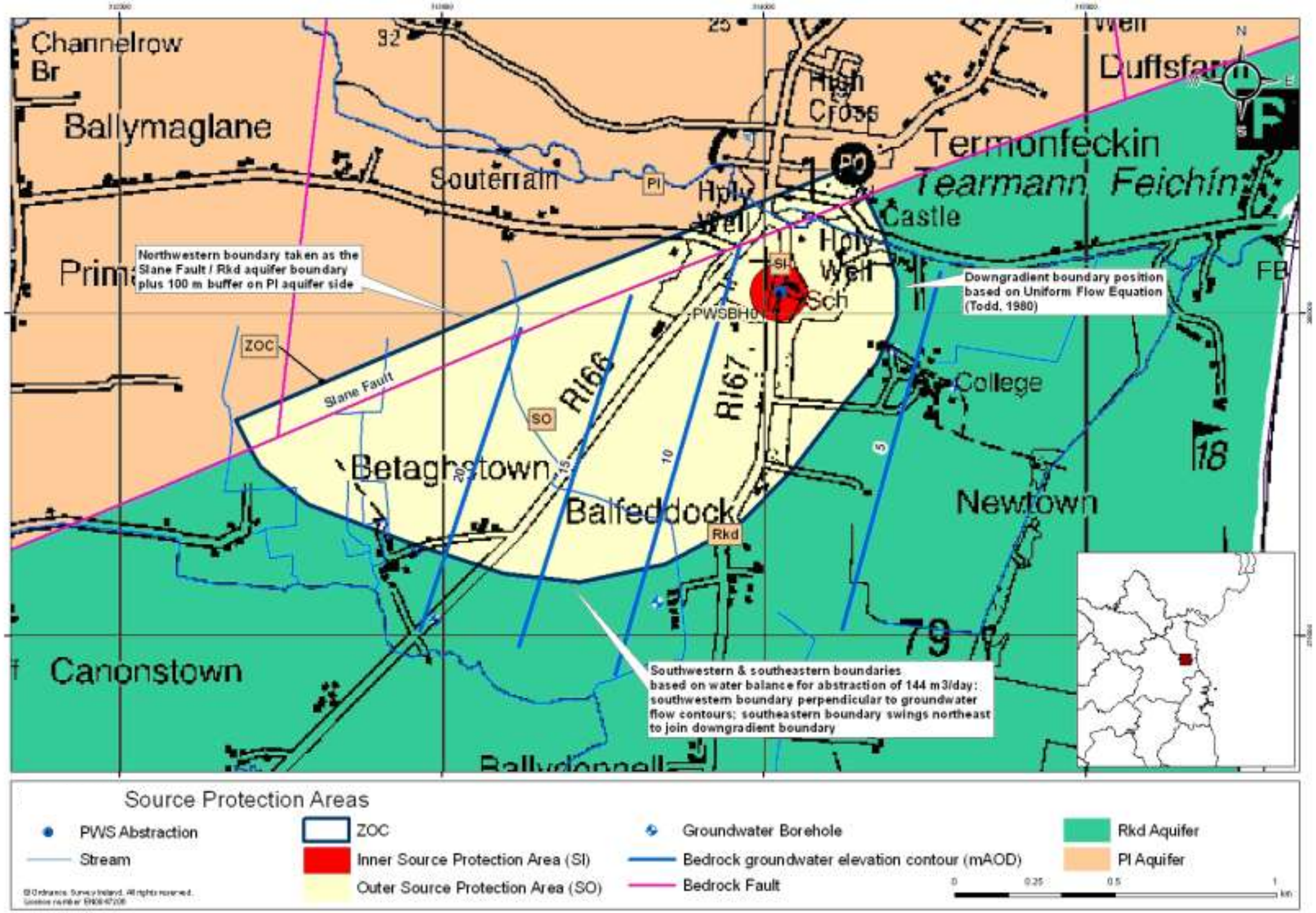

Figure 16 Source Protection Areas around Termonfeckin WSS borehole

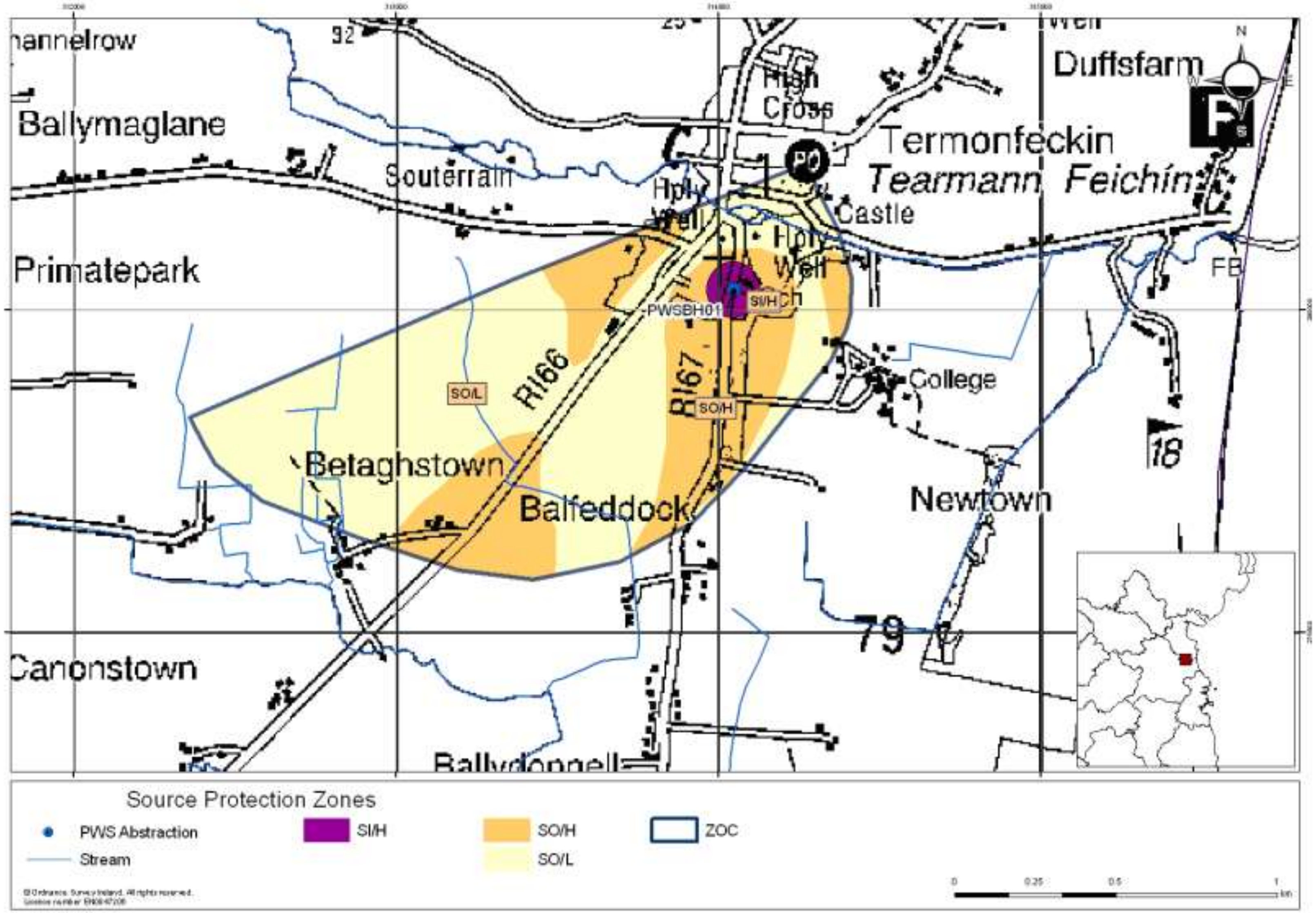

Figure 17 Source Protection Zones around Termonfeckin WSS borehole

13 POTENTIAL POLLUTION SOURCES

The bedrock aquifer is generally well protected from contamination by its thick subsoil cover. However, poorly constructed boreholes may provide localised preferential pathways through the protective subsoil cover. The main potential sources of contamination within the ZOC are:

- Direct microbial contamination of the source from ponded water within the well head chamber. The ponded water may derive from drainage along service ducts. This water may be contaminated by animals and birds. The main potential contaminants from these sources are faecal bacteria, viruses and cryptosporidium.
- The area is serviced by mains sewerage. Leakage from the mains sewer could give rise to groundwater contamination. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium.
- Agricultural landuse comprising a mix of pasture and arable uses occupies a significant part of the zone of contribution. It is likely that landspreading of organic matter from agricultural sources (*e.g*. cattle slurry) takes place within the delineated ZOC. The main potential contaminants from these sources are the same as for sewerage, plus pesticides.
- Private home heating fuel tanks are likely to be located within the catchment area. The main potential contaminants from this source are hydrocarbons.
- Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

14 CONCLUSIONS

The untreated groundwater is currently impacted by chloride. Other potential contaminants such as nitrate appear to be removed naturally by denitrification in the confined bedrock aquifer or, in the case of microbial pollutants, prevented from accessing the aquifer by the thick subsoils. The source of the chloride may be groundwater pollution by organic matter. It is most likely, however, that the chloride derives from coastal sea spray. The groundwater has naturally elevated concentrations of iron and manganese, most likely due to the reducing conditions in the bedrock aquifer.

A conservative ZOC for the source has been delineated based on 150% of the current abstraction rate of 96 m^3/day. The conceptual model assumes that the abstraction comes from diffuse recharge to the limestone bedrock aquifer together with a component of leakage of groundwater from overlying saturated sand and gravels deposits. A zone of 85 m has been delineated around the source as the inner source protection zone. The source protection zones delineated in this report are SI/H, SO/L and SO/H.

The conclusions and recommendations of the report are based on current understanding of groundwater conditions and bedrock geology as inferred from the available data. The report should not be used as the sole basis for site-specific decisions. Additional data obtained in the future may necessitate amendments to the protection zone boundaries.

15 RECOMMENDATIONS

Improvement works at the source might usefully include:

- Prevention of water ponding in borehole chamber.

Should further groundwater studies on the source be necessary in the future, it is recommended that:

- Accurate determination of the depth of the borehole PWSBH01 pressure transducer below the top of the 125 mm diameter steel casing at the well-head.
- Monitoring of groundwater levels in the bedrock aquifer and in the saturated sands and gravels of the raised beach deposits to determine seasonal fluctuations in the vertical hydraulic gradient.
- Drilling of a number of bedrock exploration boreholes to accurately determine the location of the mapped bedrock boundary between the Dinantian limestones underlying the source and the Silurian Metasediments and Volcanics to the north. This would also allow the actual limestone bedrock Formation under the source to be determined.

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APPENDIX 1

POINT DATA, WATER QUALITY DATA & BOREHOLE DATA

- Borehole Logs – PWSBH01 & BH09
- Table A1.1 – Point Data from Desk Study & Hydrogeological Mapping
- Table A1.2 – Subsoil data from Auger Drilling in Vicinity of Borehole PWSBH01
- Table A1.3 –Water Quality Data For boreholes PWSBH01 & BH09
- Table A1.4 – Field Water Quality Data
- Figure A1.1 – Mapped Groundwater Bodies in Vicinity of Source
- Figure A1.2 – Borehole PWSBH01 Monthly Maximum and Minimum Water Levels

Nº 03409

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TERMONFECKIN PWSBH01

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DRILLERS LOG

Borehole for Louth Co. CoL.

at Termonfeckin Baltray Road
Beside water Tower. WELL No(2) Co Louth

Date	Depth ~~metres~~/ft.	Diam.	Conditions
8/2 2003	0 – 18 6m	8 3/4"	Clay + stones.
	18 – 40	8"	Gravel.
	40 – 50 9.2m	8"	Sand.
10/2	50 – 97 14.3	8"	Clay + stones.
	97 – 115 5.5	6"	Gravel Water at 97ft 1500 + G.P.H at 100ft.
11/2	115 – 125 3m 38.1	6"	Clay + stones.
	125 38.1 – 140 42.67	6"	Broken Rock 1000 + G.P.H at 130ft.
	140 – 160 48.8	6"	Black Rock
	160 – 170 51.8	6"	Broken Rock 1000 + G.P.H at 160ft
	170 – 200	6"	Black Rock.
12/2	200 – 300	6"	Black Rock 1800 G.P.H at 300ft
	300 – 400	6"	Black Rock. 4000 G.P.H at 360ft.

Total Depth of well 400ft 121.92.

Estimated yield 4000 G.P.H at 400ft.

Depth to Rock 125ft 38.10

Steel casing installed 50ft of 8" 15.2m + 140ft of 6" Steel 42.7m

P.V.C. casing installed

Well screen

Other remarks Sealed off Top water with 6" Steel Casing.
Slotted 6" Steel at 130ft 39.6 to 138ft 42.1

Operator A Keegy

DUNNES WATER SERVICES LTD. № 03533

Well Drilling and Horizontal Drilling Engineers

DRILLERS LOG

DUBLIN ROAD,
DROMISKIN,
DUNDALK.
Tel.: (042) 72188

Borehole for McCabe Builders

at Balfeddock, Termonfeckin, Co Louth

Date	Depth ~~metres~~/ft.	Diam.	Conditions
8/6/06	0 – 5	8cc	Clay
	5 – 24	8cc	Clay + stones
	24 – 35	8cc	Gravel Water at 24ft 100GPH at 30ft
	35 – 50	8cc	Clay + stones
	50 – 95	8cc	Clay + stones
	95 – 97	8cc	Gravel Water at 95ft 500GPH at 95ft
	97 – 120	8cc	Black rock
8/6/	120 – 190	6cc	Black rock Water at 170ft 30GPH at 190ft
	190 – 200	6cc	Grey rock
	200 – 245	6cc	Black rock
	245 – 260	6cc	Grey rock Water at 250ft 1000+GPH at 250ft
	260 – 300	6cc	Grey rock Water at 280ft

Total Depth of well 300ft 91.44

Estimated yield 2700 GPH

Depth to Rock 100ft 30.48

Steel casing installed 12.19 40ft of 8cc + 120ft of 6cc steel 36.58

P.V.C. casing installed No

Well screen

Other remarks Airlift 6c well for 1 hour

Operator A Keey

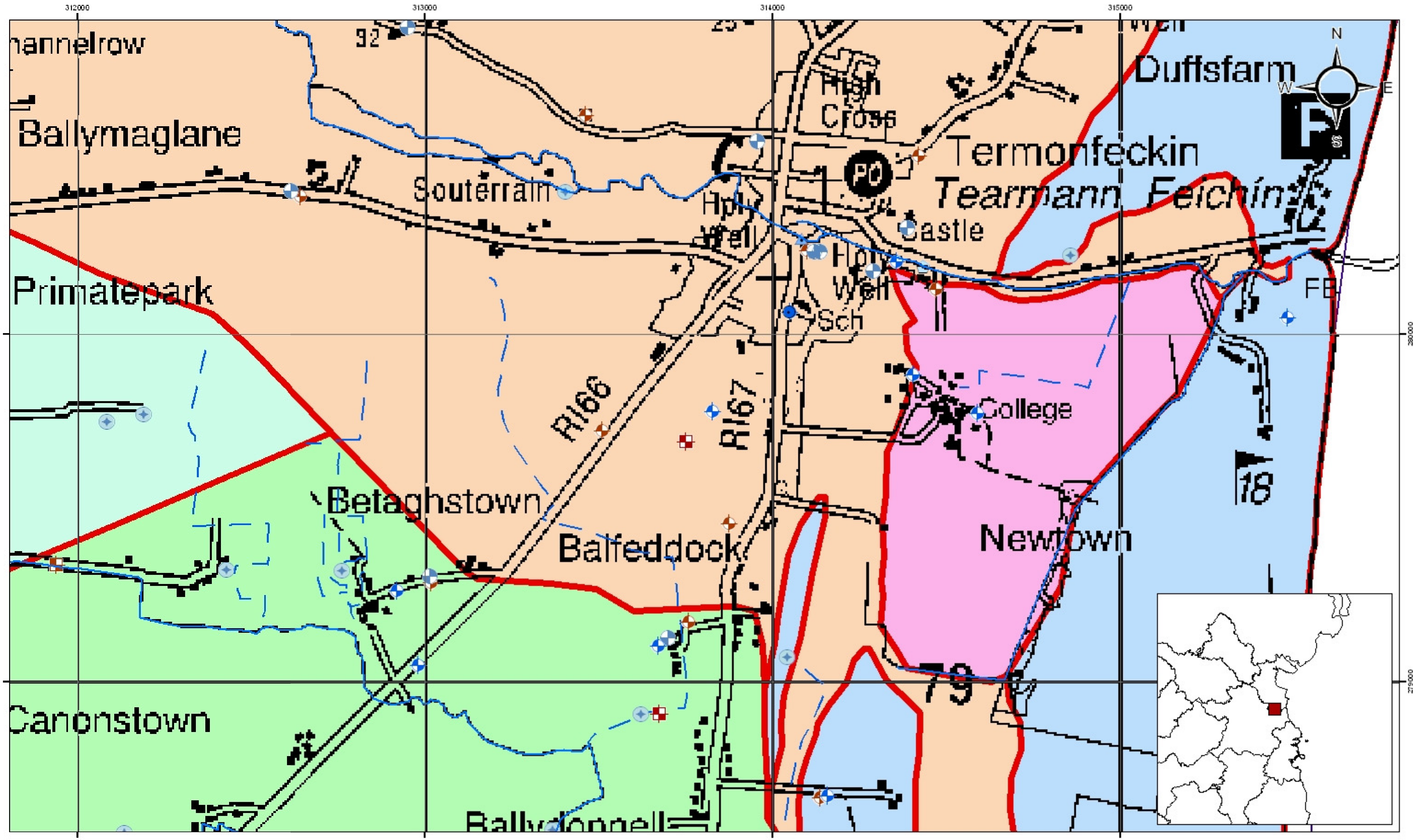


Figure A1.1 Mapped Groundwater Bodies in Vicinity of Source

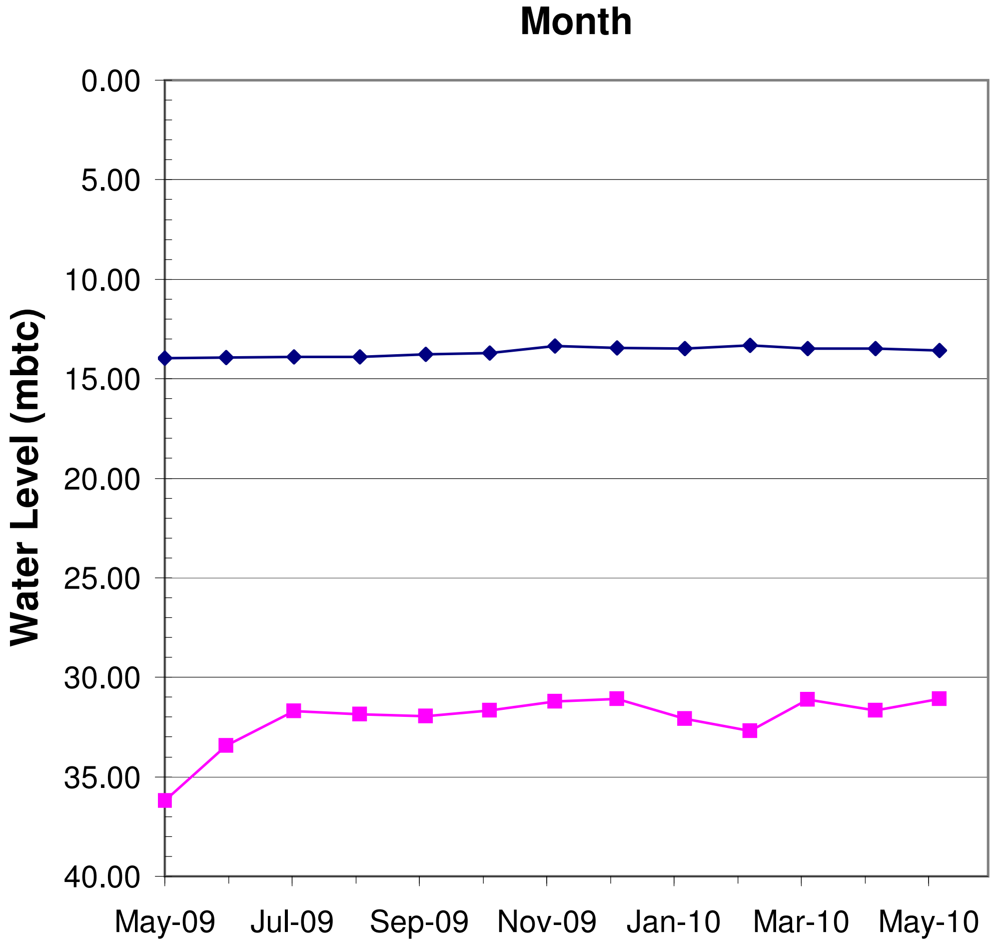
PWS Abstraction
Stream
Digitised Stream/Drain

Drogheda
Louth
Wilkinstown

Clogher Head Gravels
Newtown

0 0.25 0.5 1 km

Figure A1.2. Monthly Maximum Rest Water Levels and Minimum Pumping Water Levels at borehole PWSBH01



	Highest RWL (mbtc)	Highest RWL (mAOD)	Lowest PWL (mbtc)	Lowest PWL (mAOD)
May-09	13.97	7.88	36.19	-14.34
Jun-09	13.95	7.90	33.45	-11.60
Jul-09	13.91	7.94	31.71	-9.86
Aug-09	13.89	7.96	31.87	-10.02
Sep-09	13.77	8.08	31.97	-10.12
Oct-09	13.71	8.14	31.67	-9.82
Nov-09	13.35	8.50	31.23	-9.38
Dec-09	13.45	8.40	31.09	-9.24
Jan-10	13.47	8.38	32.09	-10.24
Feb-10	13.33	8.52	32.69	-10.84
Mar-10	13.49	8.36	31.13	-9.28
Apr-10	13.49	8.36	31.67	-9.82
May-10	13.59	8.26	31.09	-9.24
Minimum	13.33	8.52	31.09	-9.24
Maximum	13.97	7.88	36.19	-14.34

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL source	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						14/02/2006	12/12/2006	29/04/2010	NERDO 1979								
BH02	Groundwater	Borehole	314358	280212	Private borehole on floor of outwash channel close to the river bank on south side of Termonfeckin river. tc = top of 8" steel casing, which is 0.69m above the borehole chamber floor. Chamber floor = 0.38mbgl. Borehole water level rising on arrival, assume pump just switched off. Min water level = 1.35mbtc. Rest water level after 2 mins = 1.07mbtc. No rock encountered. Screened in Sand and gravel. Yield 1000 gph (108 m3/d). Monitored during GSI PWS pumping test on 12/12/2006. GL from handheld GPS = 10mAOD. GL from EPA 20m grid DTM = 10.56mAOD		2.35	1.07		24.384	0.31	25" Map Bench Mark 50m NE = 35.4' OD Poolbeg	8.22	7.46			SAND and GRAVEL
BH04	Groundwater	Borehole	313671	279104	Private well in field just west and uphill of a farmyard. Drilled 2004 by Briody. Steel casing installed to bedrock. Owner not sure of DTB…approx 150 to 180ft (assume = 165ft). Yield 600 to 900 gph (97.2m3/d). GRAVEL above bedrock had water at 60 to 70 ftbgl. tc = top of 6" SC = 0.28mbgl (in a small chamber 0.42m deep with top flush to ground level)			7.77		61	-0.28	25" Map Benchmark 200m East = 64.4' OD Poolbeg	16.93	8.88	50.3		GRAVEL (18.3 to 21.3)??
BH05	Groundwater	Borehole	312921	279263	Private borehole into bedrock. Owner of BH05 reported that its was drilled recently (assume since 2005) and overflows in winter, i.e. artesian. tc = top of 125mm PVC liner = 1.53magl. PVC liner sticks up approx 1.13m above top of 8" steel casing. Annulus between 7" & PVC is bentonite grout sealed. Slight seepage over top of 8" SC through the bentonites seal. Adjacent house has a bioflow OWWTS.			0.115			1.53	25" Map Spot Height 226m East = 74' OD Poolbeg	19.8	21.22			
BH06	Groundwater	Borehole	312981	279049	Unused, old borehole in field adjacent to R166 road. Owner of GW03 reports that the borehole was drilled in the 1970s and is artesian. It was not possible to seal the artesian flow when drilled. A 2" steel casing stick up of 1.22magl installed to reduce the over flow. BH overflows every winter. tc = invert level of steel casing stick up = 1.22magl. Highly likely that this is the Trial borehole drilled in Bethaghstown referenced in NERDO (1981) report. DTB not reported. 54.5m of limestone penetrated with minor cavities. Rock = sandy calcarenites and silstones containing muddy bands and siliceous lenses.			0.33		>54.5	1.22	25" Map Spot Height 15m NW = 69' OD Poolbeg	18.59	19.48			
BH07	Groundwater	Borehole	314405	279886	Borehole at An Grianan Agricultural College. tc = top of 4" steel casing. Surrounding land is poorly drained with rushes where unmanaged. Based on collar elevation & water level from Table K5 of NERDO (1981) assume this is well L22/16b. Well depth and yield from NERDO (1981). Yield = 17.28m3/d from limestone bedrock.			2.55	0.6	45	0.28	25" Map Bench Mark 68m east = 38.6' OD Poolbeg	9.07	6.8			

Table A1.1 - Point Data from Desk Study Hydrogeological Mapping - Termonfeckin Public Water Supply

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL source	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						14/02/2006	12/12/2006	29/04/2010	NERDO 1979								
BH08	Groundwater	Borehole	314592	279775	Borehole at An Grianan Agricultural College. Monitored by GSI during PWS pumping test on 12/12/06. tc = edge of casing adjacent to blue rope --> assume = ground level. Based on collar elevation & water level from Table K5 of NERDO (1981) assume this is well L22/16a. Well depth, yield, etc. from NERDO (1981). NERDO Table K5 yield = 25.9m3/d from limestone bedrock. Iron in the water. Drilled by Dunnes. 21.5m of liner installed. DTB in NERDO = 2m but 6" Geol Map says 70ft (21.3m). 6" Geol Map says overflow rate = 300gph (32m3/d) & drilled 1977. 3 hour Pumping test carried out by NERDO on 8/6/1979. Yield = 34.6m3/d for 18.7m of drawdown. RWL at start test was recorded as 0 mbref, i.e. artesian. BH was monitored during pumping test on BH09 on 14/02/2006. Assume WL ref = edge of casing(assume this = GL). WL measured at 3:25pm on 14/2/06	1.98	0.45		Artesian	30	0	25" Map Spot Height 20m N = 28' OD Poolbeg	5.83	3.85	21.5		
BH09	Groundwater	Borehole	313829	279779	Private well drilled in support of Louth CoCo planning application No. 06265 to provide temporary water supply for proposed Balfeddock Housing Dev. Of 144 houses. Hydrogeological Report on the borehole & GW resource by O'Neill GW Eng. Drilled by Dunnes in Feb 2006. 72 hour Pumping test by Kellys 14 to 17 Feb 2006. Pumping test SWL ref point = 0.8magl. RWL at start test (2.25pm) = 13.35mbref. Some monitoring at PWSBH01 & BH08 during test. Pumping test Q = 225m3/d. Final Drawdown = 19.41m. Qs = 11.6m3/m/d. Initial Q of 294m3/d generated 29.25m of ddn after 12 hrs and was cut back to 225m3/d. BH log indicates 8" SC to 12.2mbgl; 6" SC to 36.58mbgl. Driller est of yield = 291m3/d. Water strike in GRAVEL at 7.32mbgl, Q = 10.8m3/d at 9.1mbgl (sealed off by 8"SC). Water strike in gravel at 29mbgl, Q = 54m3/d (sealed off by 6" casing). Water strike at 51.8m, Q = 3.2m3/d, increase to 108m3/d at 76.2m, increase to 291m3/d at 85mbgl.	13.35				90	0.8	25" Map Spot Height 200m NE = 76' OD Poolbeg	20.47	7.92	30.48		Clay + Stones (7.3m) / GRAVEL 3.4m) / Clay + stones (18.3m) / GRAVEL over bedrock (0.6m)
BH10	Groundwater	Borehole	315484	280050	Data from 6"Geol map. Exact location not marked. Rck @ 116ft in Bored well										35.4		
PWSBH01	Groundwater	Borehole	314051	280067	Termonfeckin PWS Borehole. Drilled Feb 2003 by Dunnes. Diameter 8" to 15.2m then 6" to total depth. 8" steel casing (SC) to 15.2m. 6" SC to 42.7m. 6" SC slotted 39.6 to 42.1mbgl. Water strikes at: 162m3/d @ 29.5m (GRAVEL on broken limest rock), sealed off; 108m3/d @ 39.6m; no increase by48.8m; 194m3/d @ 91.4m; 432m3/d @ 109.7m. Slotted steel 39.6m to 42.1m. Further work on 28/5 to 4/6/2003: 125mm dia steel liner installed 36.6m to 59.4m with 2 rows of slots made by perforator after installation. 3rd row of slots between 48.8 and 54.9m. Airlift for 5hrs gave yield est = 389m3/d. Pumping test by Kellys 17 to 20/6/03 at 367m3/d (0-42hrs) then 418m3/d (42-72hrs). Final drawdown = 30.37m (45.51mbgl). Qs at end test = 13.8m3/d/m. RWL = 15.14mbref (ref = 0.8magl). Pumping test by GSI on 12/12/2006, 9hrs @ approx 362m3/d. Final Drawdown = 22.2m. Qs = 16.3m3/d/m. RWL = 15.9mbref (assume ref = top 6" SC). WL on 29/4/2010 = pumping level, ref = top 6" SC. GL from handheld GPS = 27mAOD. GL from EPA 20m grid DTM = 22.6mAOD. Water level on 14/02/06 from Pumping test on BH09, level rec	40.89	15.9	30.73		122	-0.75	25" Map Spot height 38m NNW = 83' OD Poolbeg = DTM elevation	22.6	5.95	38.1		Clay & stones (6m)/GRAVEL & SAND (9.8m)/ Clay & Stones (14.3m)/GRAVEL (5.5m)/ Clay & Stones (3m)

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	GWL mbtc	Total Depth (m)	tc magl	GL source	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						14/02/2006	12/12/2006	29/04/2010	NERDO 1979								
GW01	Groundwater	Dug Well	314122	280240	Small Dug Well near PWS treatment plant. Seepage of approx 1 l/s from pure sand lenses adjacent to the well. Perched water in sand lenses above low K material diverting recharge away from bedrock. Called "Trinity Well" on 25" historical map.							DTM	14.27				
GW02	Groundwater	Dug Well	314291	280185	Private dug well. Disused. Replaced by BH02. Owner reported that well had high lime content when in use.							DTM	12.72				
GW03	Groundwater	Dug Well	313015	279307	Private dug well in Sand and gravel. Located in field approx 75m west of farmyard. Very secure wellhead, raised above ground level. Diameter = 1.2m, lined with concrete rings. tc = top of uppermost concrete ring = 0.23magl. Owner indicated that: Excavated by hand by undermining concrete rings in 1970s/80s. Transmissivity low enough to dewater gravels around well to facilitate excavation to 1.2m below RWL. Water level doesn't fluctuate much seasonally; water quality is good --> used for dairy and domestic residence.			3.28		4.23	0.23	25" Map Spot Height 148m ESE = 74' OD Poolbeg	19.8	16.75			GRAVEL (probably over till as bedrock groundwater confined in nearby BH05)
GW04	Groundwater	Dug Well	312953	280887	Hand pump in cul-de-sac. Location recorded by GSI during pumping test on 12/12/2006. Not working.												
GW05	Groundwater	Dug Well	313958	280557	Wide diameter well. Location recorded by GSI during pumping test on 12/12/2006. Stagnant water in ditch on opposite end of made ground in at the location, stagnant water level approx same as well. tc = top edge of casing (assume = ground level). On north side of Termonfeckin River.		1.95				0	DTM. 25" Map Tile not obtained	22.62	20.67			
GW06	Groundwater	Dug Well	314137	280240	Seepage from Sand and Gravel embankment 15m east of GW01. Water quality measured at 16:10 on 10/5/10. EC = 649uS/cm, pH = 6.7, T = 9.7C												
GW08	Groundwater	Dug Well	314390	280310	From 25-inch Hist. Map. Castle Well												
GW10	Groundwater	Dug Well	312616	280415	From 25-inch Hist. Map. Pump												
GW14	Groundwater	Dug Well	313702	279129	From 25-inch Hist. Map. Pump												
GW16	Groundwater	Dug Well	314579	278266	From 25-inch Hist. Map. Cowan Well												
GW21	Groundwater	Dug Well	314428	277990	From 25-inch Hist. Map. Pump												
GW07	Groundwater	Spring	314859	280229	From 25-inch Hist. Map.												
GW09	Groundwater	Spring	313405	280412	From 25-inch Hist. Map.												
GW11	Groundwater	Spring	312084	279751	From 25-inch Hist. Map.												
GW12	Groundwater	Spring	312189	279772	From 25-inch Hist. Map.												
GW13	Groundwater	Spring	312762	279321	From 25-inch Hist. Map.												
GW15	Groundwater	Spring	314042	279074	From 25-inch Hist. Map.												
GW17	Groundwater	Spring	313623	278909	From 25-inch Hist. Map.												
GW18	Groundwater	Spring	313369	278575	From 25-inch Hist. Map.												
GW19	Groundwater	Spring	312135	278568	From 25-inch Hist. Map.												
GW20	Groundwater	Spring	312104	278134	From 25-inch Hist. Map.												
GW20	Groundwater	Spring	312428	279324	From 25-inch Hist. Map.												
GW22	Groundwater	Spring	312458	277892	From 25-inch Hist. Map.												
GW23	Groundwater	Spring	312352	277708	From 25-inch Hist. Map.												
GW24	Groundwater	Spring	313188	277803	From 25-inch Hist. Map.												
GW25	Groundwater	Spring	313720	278108	From 25-inch Hist. Map.												
EXP01	Subsoil	Exposure	313675	278909	Drain in till field at edge of alluvial flat to south of BH04. At edge of raised marine deposits.There is another drain running parellel to the road from the farmhouse. Indicates that ridges are permeable with till between and possible underneath.												
EXP02	Subsoil	Exposure	313752	279693	From 25-inch Hist. Map. Sand or Clay Pit noted on 6" Geol Map. Now site of Lou CoCo Planning App 06265 (see BH09)												
SW01	Surface Water	Stream	314082	280277	Termonfeckin River adjacent to the PWS pumping/treatment compound. Stream water quality measured 16:40 on 10/5/10: EC 539uS/cm, pH 8.44, T = 10.1C												

Table A1.2 - Louth County Council EPA Water Quality Data for Termonfeckin PWS Source

			mg/l NO3	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l NO2	mg/l SO_4	mg/l $CaCO_3$	mg/l $CaCO_3$	uS/cm	ug/l Al
GSI Name	**Date**		**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**
	Jan-82	**Threshold**	**37.5**				**150**	**24**	**0.375**	**187.5**			**800**	**150**
	Jan-82	**DWS**	**50**				**200**	**250**	**0.5**	**250**			**2500**	**200**
GSI Name	**Date**		**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**
TermonfeckinPWS (LOUCoCo)(LHS18)	31-Mar-09		<0.35*					31.0			216		555	
TermonfeckinPWS (LOUCoCo)(LHS18)	09-Dec-09		<0.35*					31.0			224		555	
TermonfeckinPWS (LOUCoCo)(LHS18)	27-Apr-10		<0.009	73.35	12.08	1.92	27.08	31		17.5	242	220	566	<10
BH09	15-Feb-06								<0.003			212	485	
BH09	16-Feb-06		<0.4				31.1	22.0	<0.01	7.0			492	<11
BH09	17-Feb-06		<0.4				29.8	24.0	<0.01	6.0			489	<11
	Average	mg/l	<0.4	73.4	12.1	1.9	29.3	27.8		10.2	227	216	524	<11
		mmol/l		1.83	0.48	0.05	1.28	0.78		0.11	2.27	mmol of CaCO3 = mmol of CO3--		
		MW		40	25.31	39.1	22.99	35.45	47	96.066	100			
		charge		2	2	1	1	1	1	2	2			
		meq/l		3.67	0.95	0.05	1.28	0.78		0.21	4.55	meq of CO3-- = meq of HCO3-		
											4.55	mmol HCO3-		
		meq cations	5.95								277.35	mg/l as HCO3-		
		meq anions	5.54											

Red colour denotes result in excess of Drinking Water Standard (DWS)

Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.2 - Louth County Council EPA Water Quality Data for Termonfeckin PWS Source

		ug/l Fe	ug/l Mn	mg/l NH4	No./100ml	No./100ml	ug/l Ba	ug/l Ni	mg/l P	mg/l P	mg/l Se	mg/l Ag	mg/l Sr
GSI Name	**Date**	**Fe**	**Mn**	**NH4**	**TC**	**F. coli**	**Ba**	**Ni**	**PO4**	**P**	**Se**	**Ag**	**Sr**
	Jan-82			**0.23**				**15**	**0.035**				
	Jan-82	**200**	**50**	**0.3**	**0**	**0**		**20**			**0.01**		
GSI Name	**Date**	**Fe**	**Mn**	**NH4**	**TC**	**F. coli**	**Ba**	**Ni**	**PO4**	**P**	**Se**	**Ag**	**Sr**
TermonfeckinPWS (LOUCoCo)(LHS18)	31-Mar-09			0.129					0.020				
TermonfeckinPWS (LOUCoCo)(LHS18)	09-Dec-09			0.116					<0.02				
TermonfeckinPWS (LOUCoCo)(LHS18)	27-Apr-10	**436.7**	**127.6**	0.154	0	0	71.1	<1	0.02	0.008	<1	<1	
BH09	15-Feb-06	**934**		0.090	0	0							
BH09	16-Feb-06	101	**69**	0.080	**1**	0		1.0			0.001		
BH09	17-Feb-06	168	**67**	0.080	**1**	0		1.0			0.001		
	Average	135	**88**	0.108	**1**	0		1.0	0.020		0.001		

Red colour denotes result in excess of Drinking Water Standard (DWS)
Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.2 - Louth County Council EPA Water Quality Data for Termonfeckin PWS Source

		mg/l Zn	mg/l Sb	mg/l As	[-]	%	deg C	mg/l C	mg/l O2	mg/l O2	mg/l O2	mg/l O_2
GSI Name	Date	Zn	Ant	As	K/Na Ratio (using meq)	DO (% Sat)	pH	Temp	TOC	COD	BOD	DO
	Jan-82			0.0075	0.4							
	Jan-82		0.005	0.001			>6.5 & < 9.5					
GSI Name	Date	Zn	Ant	As	K/Na Ratio							
TermonfeckinPWS (LOUCoCo)(LHS18)	31-Mar-09					24.0	7.5	11.40	<1.5	<10	<1.5	
TermonfeckinPWS (LOUCoCo)(LHS18)	09-Dec-09					36.0	7.5	11.20	<3.0	<10	<1.5	
TermonfeckinPWS (LOUCoCo)(LHS18)	27-Apr-10	18	<0.001	<0.001	0.04		7.5		<1.5			
BH09	15-Feb-06						7.3					
BH09	16-Feb-06			0.002			7.4		<1.0			
BH09	17-Feb-06			0.001			7.2		<1.0			
	Average			0.002		30.00	7.4	11.3	<1.5	<10	<1.5	

Red colour denotes result in excess of Drinking Water Standard (DWS)
Orange Colour denotes result in excess of EPA Threshold

Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

Source: available Louth County Council EPA data.

Table A1.3 – Field Water Quality Data
for Termonfeckin PWS Source

Location	Time	Date	X	Y	pH	T^oC (pH meter)	EC uS/cm
GW01	16:20	10/05/2010	314122	280240	6.77	10.1	927
GW06	16:10	10/05/2010	314137	280240	6.7	9.7	649
SW01	16:40	10/05/2010	314082	280277	8.44	10.1	539
BH02	17:20	10/05/2010	314358	280212	7.77	10.2	506
BH05	17:45	10/05/2010	312921	279263	7.45	11.8	681

Louth GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
Hydrometric Area 06 Louth Co. Co. Monaghan Co. Co. Meath Co. Co. NI	***Rivers:*** Blackwater, Castletown, Clarebane, County Water, Cully, Fane, Flurry, Garra, Kilcurry, Killary Water, Kilmainham, Longfield, Dee, Glyde, Lagan, Ryland, White, Ballykelly, Ballymascanlan, Big, Proules, Raskeagh, Termonfeckin. ***Lakes:*** Altiduff, Alina, Ballingarry, Black, Bileady, Blaney Castle Lake, Cappagh, Carrickaslane, Carrigan's, Coogan's, Cashel Upper, Clare, Coolcair, Corliss, Corrinsigo, Cornamucklagh, Corrawaddy, Cortial, Drumaavarn, Drumacon, Drumboy, Drumcah, Drumcrew, Drumganny, Drumgeeny, Drumgristan, Drumilland, Drummacavoy, D'umgrististin, Ervey, Ghost, Iassan, Killarus, Killycracken, Killygola, Kilmurry, Lackagh, Laragh, Letterbane, Limagunshin, Lismagunshin, Mhucnu, Nagarnaman, Nahinch, Moybane, Muff, Muckro, Mullaghbane, Mullaghduff, Philip's, Ross, Shilties, Smiley, St Peters, Tapagh, Toprass, Tullynahttina.	Dundalk Bay, Boyne Coast and Estuary and Carlingford Shore (O'Riain, 2004).	1621

Topography		Comprising a large proportion of Hydrometric Area 06, the northern, western and south-eastern boundaries of this GWB are topographic divides (Rivers Dee, Glyde, Fane, Castletown and Flurry). The east is bounded by coastline and the southwest is bound by more productive aquifers. Elevations generally increase moving inland, ranging from sea level in the flatter coastal areas, to c.600 mAOD along the more mountainous north/northeast boundaries. Drumlins are a topographic feature of the western portion of the GWB. The large number of lakes are the predominant surface water features and the general surface water flow direction is to the eastwards towards the coasts.
Geology and Aquifers	**Aquifer categories**	The majority of the GWB comprises **Pl:** Poor aquifer which is generally unproductive except for local zones (just under 90%). There are two significant SW-NE trending bands of **Pu:** Poor aquifer which is generally unproductive. A small isolated area in the southeast is categorised as $\mathbf{Rk^d}$**:** Regionally important karstified aquifer dominated by diffuse flow, and there are two small zones of **Lm:** Locally important aquifer which is moderately productive (<1% in total). There are also a few thin bands of **Ll:** Locally important aquifer which is moderately productive only in local zones.
	Main aquifer lithologies	The main rock group in this GWB is the Silurian Metasediments and Volcanics (82.56%) although Granites & Other Igneous Intrusive Rocks dominate the northeast portion (12.34%). Smaller areas of other rocks (c.1% each) are also recorded in the GWB (Dinantian Limestones, Sandstones and Shales; Ordovician Metasediments, Namurian Shales) with other minor areas (<1%) of Permo-Triassic Mudstones and Gypsum, Basalts and other Volcanic rocks, Ordovician Volcanics, and Westphalian Shales. The rocks are detailed in Table 1.
	Key structures	Deformation in this part of the county has resulted in rocks dipping steeply (up to 80°) in a predominantly SE direction, and a large number of faults with associated perpendicular faults: SW-NE trending in the south of the GWB (e.g. Tinure Fault); variable directions in the Dinantian rocks; N-S in the Granites.
	Key properties	Yields from 36 wells in this GWB range from 13-2688 m^3/d. Just under half of these wells have <200 m^3/d, and 9 of the 11 wells with yields >250 m^3/d are located near fault zones along the boundaries of more productive GWBs (e.g. Carrickmacross, Kingscourt and Dundalk). The 8 available specific capacity values range from 0.9-470 $m^3/d/m$, although the highest 5 values (15.6-470 $m^3/d/m$) are associated with the boreholes adjacent more productive GWBs. No local transmissivity data area available for the Silurian rocks and Granites although national data generally reflect low (<20 m^2/d) to moderate (20-80 m^2/d) transmissivity values. The higher values may be achieved in faulted zones (e.g. south of the GWB), and/or in the coarser-grained rocks. Specific dry weather flows from 6 stations in the Silurian rocks and 1 station in the Granites are low: 0.01-0.69 $l/s/km^2$. These values suggest that this aquifer does not make a significant baseflow contribution to streamflow. Storativity is also expected to be low. Of the c.270 wells, two-thirds have groundwater levels 0-10 m below ground level (c.50% <5 mbgl). Groundwater levels deeper than 30 m bgl are recorded in 13 wells (up to 115 mbgl) although these are mainly along the boundaries of more productive GWBs (e.g. Carrickmacross, Kingscourt and Dundalk). Due to the low permeability of the rocks, groundwater gradients are expected to be relatively steep. *(Ordovician Aquifer Chapter; Silurian Aquifer Chapter; Granites Aquifer Chapter*)

	Thickness	Most groundwater flux is likely to be in the uppermost part of the aquifer comprising a broken and weathered zone typically less than 3 m thick, a zone of interconnected fissuring 10-15 m thick (mainly <10 m), and a zone of isolated poorly connected fissuring typically less than 150 m. Deeper water strikes are noted between 30-91 m bgl in 7 borehole although 6 of these appear to be in highly faulted areas.
Overlying Strata	**Lithologies**	Subsoil data are only available for c.70% of the GWB (RoI). Of this area, till is the predominant subsoil (c.72%), with small proportions of other subsoil types, such as peat (5%) and alluvium (5%). Approximately 11% of the mapped area (8% of the total GWB) is recorded as rock outcrop/shallow subsoil.
	Thickness	The available outcrop and borehole data indicate that the higher areas to the northwest, northeast and along the southern boundary have thin subsoil cover (<3 m). Lower-lying valley areas and drumlins appear to have thicker subsoil.
	% area aquifer near surface	*[Information will be added at a later date]*
	Vulnerability	From the Monaghan and Meath GWPSs, the vulnerability is predominantly Extreme in the northwest and very south of the GWB, and mainly High in the southwest. The drumlins in the northwest are categorised as Moderate, due to their thickness. No data are available for Louth or NI.
Recharge	**Main recharge mechanisms**	Diffuse recharge occurs via rainfall percolating through the subsoil and rock outcrops. Due to the low permeability of some subsoil deposits (e.g. thicker till) and the aquifers, a high proportion of the effective rainfall will quickly discharge to the streams in the GWB. In addition, steeper slopes in the mountainous and drumlin areas and promote surface runoff. The relatively high stream density reflecting the higher proportion of surface runoff as opposed to aquifer recharge.
	Est. recharge rates	*[Information will be added at a later date]*
Discharge	**Large springs and high yielding wells (m^3/d)**	Sources: None identified. Excellent Wells: Kingscourt WWS (2688 m^3/d, 1824 m^3/d, 1027 m^3/d, 800 m^3/d, 500 m^3/d), Louth Co.Co. (1091 m^3/d, 1090 m^3/d), Meath Co.Co. (610m^3/d), Drumgoosat (605 m^3/d), Channonrock (518 m^3/d). Good Wells: Dundalk (390 m^3/d, 218m^3/d*2), Glenmore (218 m^3/d), Almondstown (216 m^3/d), Togher (207 m^3/d), Fairhill (153 m^3/d), Mullagharlin (160 m^3/d), Marshes Upper (190 m^3/d), Collops (130 m^3/d), Philipstown (130 m^3/d), Analog (109 m^3/d), Avalbane (109 m^3/d), Ballymakellett (109 m^3/d*2), Brachagh (109 m^3/d), Collon (109 m^3/d), Hitchestown (109 m^3/d), Port (109 m^3/d*2), Shanmullagh (109 m^3/d). Springs: None identified.
	Main discharge mechanisms	The main groundwater discharges are to the rivers and streams crossing the GWB, which reflect short groundwater flow paths. Small springs and seeps are likely to issue at the stream heads and along their course. Seepages will also develop on the coastal cliff faces. A proportion of groundwater may also discharge to adjacent GWBs that comprise more permeable aquifers (e.g. Carrickmacross).
	Hydrochemical Signature	***National classification:*** Ordovician/Silurian Metasediments Non-calcareous. $CaMgHCO_3$ signature. However, Cavan and Monaghan also have $CaMgSO_4$ record a signature. Alkalinity (mg/l as $CaCO_3$): range of 9-470; mean of 172 (445 'non limestone subsoils' data points) Total Hardness (mg/l): range of 5-481; mean of 222 (389 'non limestone subsoils' data points) Conductivity (μS/cm): range of 80-477; mean of 490 (477 'non limestone subsoils' data points) ***National classification:*** Granites & Other Igneous Intrusive Rocks Non-calcareous rocks. Alkalinity (mg/l as $CaCO_3$): range of 43-298; mean of 179 (22 'non limestone subsoils' data points) Total Hardness (mg/l): range of 103-304; mean of 183 (10 'non limestone subsoils' data points) Conductivity (μS/cm): range of 317-1017; mean of 495 (24 'non limestone subsoils' data points) As minerals present in granite are generally acidic, corrosion and leaching of metals such as iron and manganese may present a problem. Radon and Uranium are also associated with granitic bodies. *(Calcareous/Non calcareous classification of bedrock in the Republic of Ireland report)*
Groundwater Flow Paths		In the absence of inter-granular permeability, groundwater flow is expected to be concentrated in upper fractured and weathered zones and in the vicinity of fault zones. Available groundwater levels are mainly 0-10 m below ground level (c.50% <5 mbgl). Flow paths are likely to be short (30-300 m) with groundwater discharging rapidly to nearby streams and small springs. Water strikes deeper than the estimated interconnected fissure zone suggest a component of deep groundwater flow, however shallow groundwater flow is dominant. Groundwater flow directions are expected to follow topography – overall in a easterly direction.
Groundwater & Surface water interactions		Groundwater will discharge locally to streams and rivers crossing the aquifer and also to small springs and seeps. Owing to the poor productivity of the aquifers in this body it is unlikely that any major groundwater - surface water interactions occur. Baseflow to rivers and streams is relatively low.

Conceptual model	• Western, northern and south-eastern boundaries are topographic divides. The southwest boundary of the GWB is marked by more productive aquifers and the eastern boundary comprises coastline. Drumlins are noted in the west of the GWB. • The GWB is composed primarily of low transmissivity rocks. Most of the groundwater flux is likely to be in the uppermost part of the aquifer comprising: a broken and weathered zone typically less than 3m thick; a zone of interconnected fissuring typically less than 10m; and a zone of isolated fissuring typically less than 150m. • Recharge occurs diffusely through the subsoil and rock outcrops, although can be limited by thicker till, and the low permeability bedrock. Therefore, most of the effective rainfall is not expected to recharge the aquifers. • Flow paths are likely to be short (30-300 m) with groundwater discharging rapidly to the streams crossing the aquifer, and to small springs and seeps. Overall, the flow direction is expected to be to the east, as determined by the topography.
Attachments	Figure 1. Figure 2. Table 1.
Instrumentation	**Stream gauges:** 06011*, 06012, 06013, 06014*, 06016, 06021, 06023*, 06026*, 06027, 06029, 06030*, 06031*, 06032, 06033*, 06034, 06035, 06036, 06037, 06039, 06040, 06041, 06044, 06045, 06046, 06047, 06048, 06049, 06050, 06051, 06052, 06053, 06055, 06070, 06071, 06072 . * Adjusted dry water flow data available. **EPA Water Level Monitoring boreholes:** LOU009, LOU099, MEA143, MEA146 **EPA Representative Monitoring points:** CAV 18, CAV90, LOU2, LOU9, LOU11, LOU 18, LOU24, LOU25, LOU26, LOU28, LOU29, LOU30, LOU31, LOU32, LOU33, LOU35, LOU36, LOU38, LOU39, LOU41, LOU42, LOU44, LOU45, LOU47, LOU48, LOU50, LOU51, LOU52, LOU53, LOU55, LOU74, MEA9, MON 16, MON104, MEA143, MEA114.
Information Sources	Geraghty, M., Farrelly, I., Claringbold, K., Jordan, C., Meehan, R., and Hudson, M., 1997. *Geology of Monaghan-Carlingford. A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 8/9, Monaghan-Carlingford*. Geraghty, M. (ed.). Geological Survey of Ireland. 60 p. McConnell, B., Philcox, M. and Geraghty, M., 2001. *Geology of Meath: A geological description to accompany the bedrock geology 1:100,000 scale map series, Sheet 13, Meath*. With contributions from J. Morris, W. Cox, G. Wright, and R. Meehan. Geological Survey of Ireland. 77 p. O' Riain, 2004. *Water Dependent Ecosystems and Subtypes (Draft)*. Compass Informatics in association with National Parks and Wildlife (DEHLG). WFD support projects. Swartz, M and Daly, D. (2002) *County Monaghan Groundwater Protection Scheme Report*. Main Report. Final Report to Monaghan County Council. Geological Survey of Ireland Woods, L., Meehan, R. and Wright, G. R., 1998. *County Meath Groundwater Protection Scheme*. Main report. Final report to Meath County Council. Geological Survey of Ireland. 54 p.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

Figure 1. Location and Boundaries of GWB.

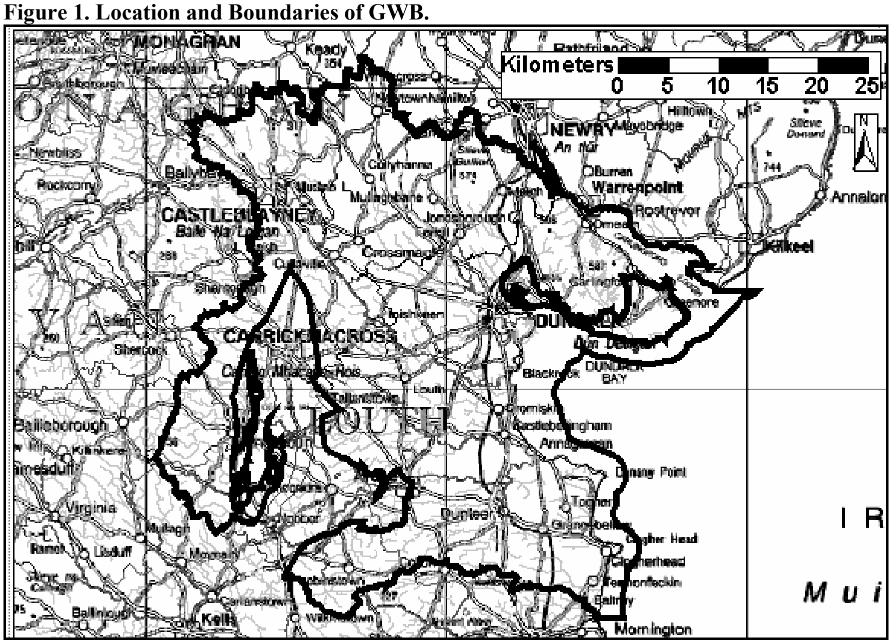
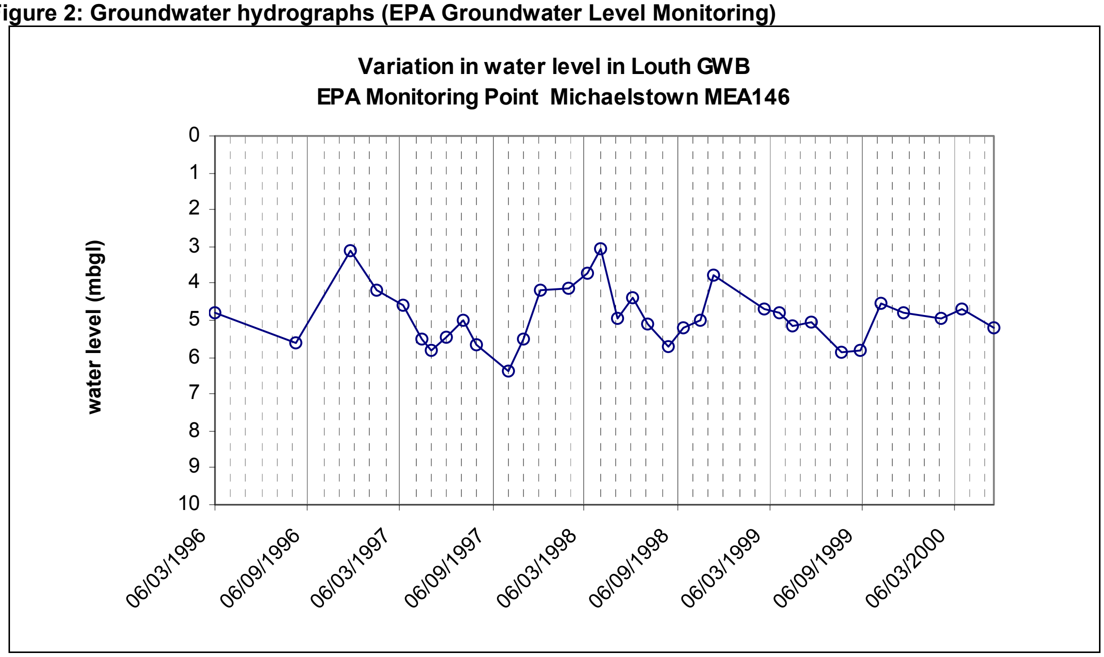
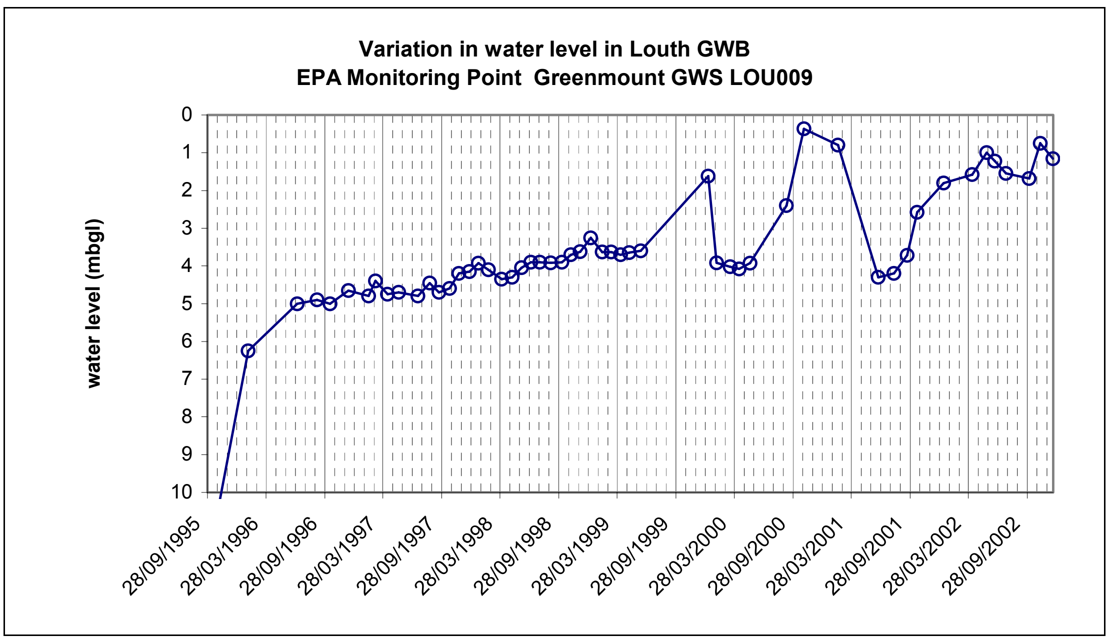


Table 1. List of Rock units in Louth GWB

Rock Unit Name	Code	Description	Rock Unit Group	Aquifer Class.	% Area
Clontail Formation	CL	Calcareous red-mica greywacke	Silurian Metasediments and Volcanics	Pl	31.72%
Central Belt (undifferentiated)	CBT	Undifferentiated turbidite & mudstone	Silurian Metasediments and Volcanics	Pl	13.69%
Salterstown Formation	bsSA	Calcareous greywacke & banded mudstone	Silurian Metasediments and Volcanics	Pu	7.45%
Castlerahan Formation	RA	Dark quartz greywacke, microconglomerate	Silurian Metasediments and Volcanics	Pl	5.59%
Lough Avaghon Formation	LA	Massive sandstone & microconglomerate	Silurian Metasediments and Volcanics	Pl	5.01%
Granophyre	Gr	Microgranite with granophyric texture	Granites & other Igneous Intrusive rocks	Pl	4.88%
Newry Granite	Ng	Granodiorite	Granites & other Igneous Intrusive rocks	Pl	4.01%
Clogherhead Formation	CV	Thickly bedded calcareous greywacke	Silurian Metasediments and Volcanics	Pu	3.08%
Shercock Formation	SK	Fine to coarse grained turbidite	Silurian Metasediments and Volcanics	Pl	3.02%
Taghart Mountain Formation	TM	Turbidite, massive sandstone & siltstone	Silurian Metasediments and Volcanics	Pl	2.57%
Little Harbour Formation	LT	Calcareous greywacke & mudstone	Silurian Metasediments and Volcanics	Pl	2.33%
Magoney Bridge Formation	MB	Medium to thick turbidite & sandstone	Silurian Metasediments and Volcanics	Pl	2.04%
Glaspistol Formation	GP	Black mudstone & quartzose greywacke	Silurian Metasediments and Volcanics	Pl	1.91%
Rathkenny Formation	RK	Black mudstone, siltstone, greywacke	Silurian Metasediments and Volcanics	Pl	1.79%
Inniskeen Formation	IN	Turbidite with red mica & red shale	Silurian Metasediments and Volcanics	Pl	1.08%
Layered Gabbro	Ex	Undifferentiated, or layered gabbro 1-4	Granites & other Igneous Intrusive rocks	Pl	1.03%
Porphyritic granophyre	Pg	Porphyritic granophyre	Granites & other Igneous Intrusive rocks	Pl	0.94%
Dolerite	Do	Dolerite	Granites & other Igneous Intrusive rocks	Pl	0.93%
Ardagh Shale Formation	AD	Black shale	Namurian Shales	Pu	0.92%
Taghart Mountain Formation	TM	Greywacke, massive sandstone & siltstone	Silurian Metasediments and Volcanics	Pl	0.89%
Dinantian Limestones (undiff.)	DIN	Limestone	Dinantian Mixed Sandst., Shales and Limest.	Lm	0.89%
Kingscourt Gypsum Form.	KG	Mudstone with gypsum & anhydrite	Permo-Triassic Mudstones and Gypsum	Pl	0.56%
Kehernaghkilly Formation	KY	Black shale & minor rhyolitic tuff	Ordovician Metasediments	Pl	0.42%
Porphyritic Felsite	Pf	Porphyritic Felsite	Granites & other Igneous Intrusive rocks	Pl	0.39%
Tullyallen Formation	TA	Pale micritised grainstone-wackestone	Dinantian Pure Bedded Limestones	Rkd	0.34%
Carrickatee Formation	CK	Black shale, mafic volcanics & tuffs	Ordovician Metasediments	Pl	0.32%
Red Mans Cove Formation	RD	Red, green, black mudstone	Silurian Metasediments and Volcanics	Pl	0.26%
Laragh Formation	LH	Pyritic, graptolitic, black shale	Ordovician Metasediments	Pl	0.26%
White Island Bridge Form.	WI	Tuff, tuffaceous siltstone, mudstone	Ordovician Volcanics	Pl	0.22%
Westphalian (undiff.)	WES	Grey shale, thin siltstone & sandstone	Westphalian Shales	Pu	0.20%
Vent agglomerate	Va	Vent agglomerate	Basalts & other Volcanic rocks	Ll	0.17%
Cam Lough Breccia	Bc	Slieve Gullion outer ring crush breccia	Basalts & other Volcanic rocks	Ll	0.16%
Early Gabbro	Eg	Basic intrusive	Granites & other Igneous Intrusive rocks	Pl	0.16%
Black shale & chert	bs	Black shale & chert	Silurian Metasediments and Volcanics	Pl	0.12%
Hawaiite Lava	Ha	Basaltic lava	Basalts & other Volcanic rocks	Ll	0.11%
Collon Formation	CM	Andesite breccia/conglomerate/sandstone	Ordovician Volcanics	Pl	0.10%
Knockerk Formation	KC	Tuffaceous sandstone, shale	Ordovician Volcanics	Pl	0.08%
Cruicetown Group (undiff.)	CRT	Argillaceous bioclastic limestone	Dinantian Lower Impure Limestones	Ll	0.07%
Bryanstown Formation	BF	Crystal & lithic tuff	Ordovician Volcanics	Pl	0.06%
Navan Group (undiff.)	NAV	Limestone, mudstone and sandstone	Dinantian (early) Sandst., Shales and Limest.	Ll	0.05%
Basal Beds	BAS	Calcareous sandstone	Dinantian Sandstones	Ll	0.03%
Broomfield Formation	BO	Black shale with chert	Ordovician Metasediments	Pl	0.03%
Fieldstown Formation	FI	Olive to grey mudstone, tuff	Ordovician Metasediments	Pl	0.03%
Basalt & Trachyte Lava	Bt	Basalt & Trachyte Lava	Basalts & other Volcanic rocks	Ll	0.03%
Fingal Group (undiff.)	FNG	Dark limestone, shale and micrite	Dinantian Upper Impure Limestones	Ll	0.02%
Slieve Glah Formation	SG	Siltstone, mudstone & thin turbidite	Silurian Metasediments and Volcanics	Pl	0.01%
Brittstown Formation	BW	Coarse- to fine-grained tuff	Ordovician Volcanics	Pl	0.01%
Hill Of Slane Formation	HS	Massive lapilli tuff	Ordovician Volcanics	Pl	0.01%
Volcanics	mv	Mafic & felsic volcanic tuff	Ordovician Volcanics	Pl	0.0029%
Diorite	Di	Diorite	Granites & other Igneous Intrusive rocks	Pl	0.0025%
Vent Agglomerate	Vg	Vent agglomerate & granophyric fragments	Basalts & other Volcanic rocks	Ll	0.0017%
Milverton Group (undiff.)		Milverton Group (undifferentiated)	Dinantian Pure Bedded Limestones	Rk	0.0001%

Figure 2: Groundwater hydrographs (EPA Groundwater Level Monitoring)





APPENDIX 2

PUMPING TEST ANALYSES

- Pumping Test Analyses Report
- Pumping Test Data

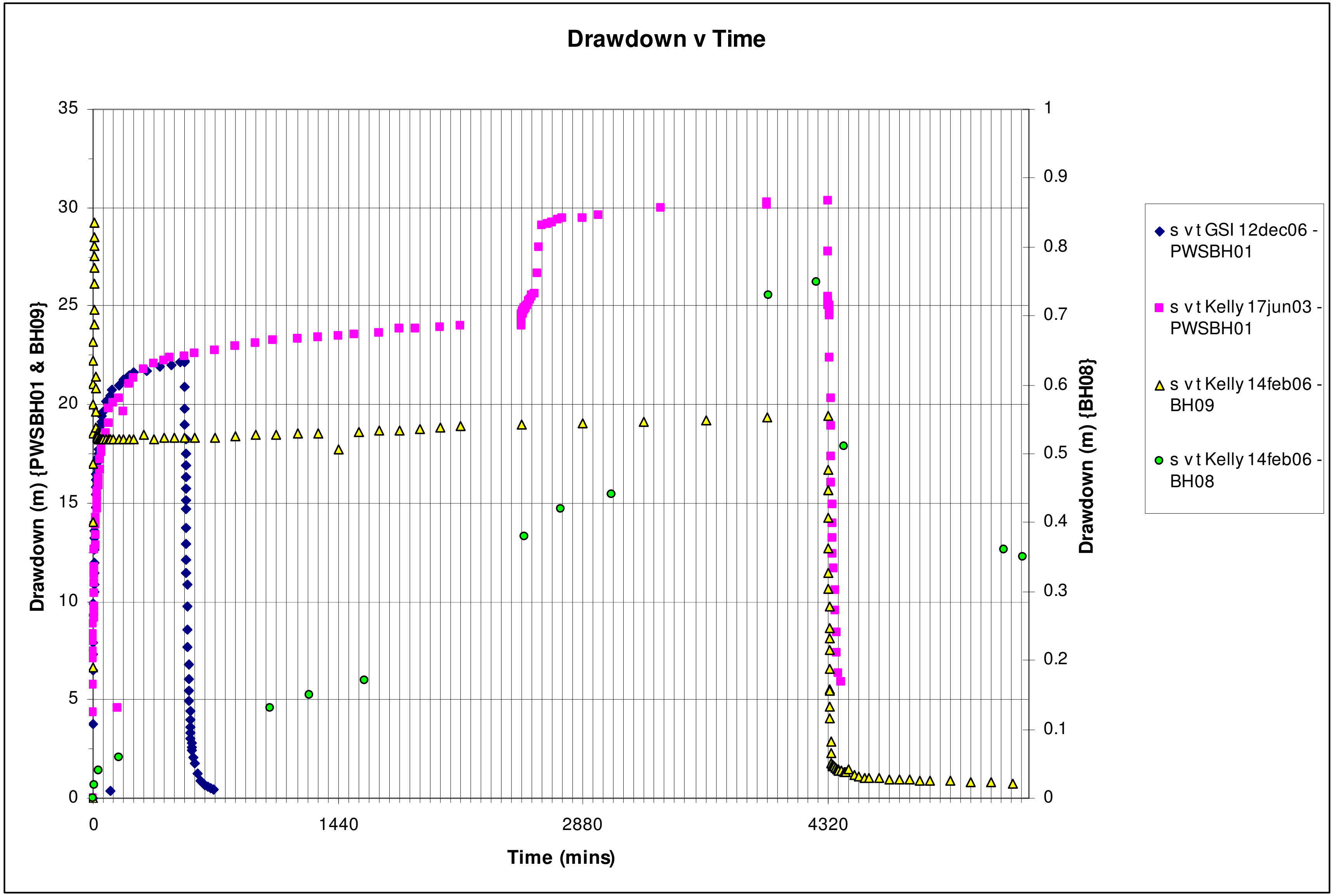
1 Introduction

Data from three pumping tests have been analysed in order to enhance the conceptual model of the Termonfeckin PWS source. Two of the tests were carried out on the source itself (PWSBH01) and the third was carried on BH09, located 200m south southwest of the source. The tests carried out were as follows:

- GSI – 12/12/2006 - 9 hour constant discharge test (CDT) followed by recovery on PWSBH01. Monitoring of drawdown in the pumping well. Monitoring of water levels in observation wells (BH08 and BH02) did not show drawdown which correlated with the test pumping.
- Kellys Ltd. – 17/06/2003 – 72 hour variable discharge test (VDT) followed by recovery on PWSBH01. Monitoring of drawdown in the pumping well. Monitoring of water levels in observation wells (GW01 and 2 sites at unspecified locations) did not show drawdown which correlated with the test pumping.
- Kellys Ltd. – 14/02/2006 – 72 hour variable discharge test (VDT) followed by recovery on BH09. Monitoring of drawdown in the pumping well. Monitoring of water levels in observation wells (BH08 & PWSBH01). Data for observation well BH08 has been analysed. Data from observation well PWSBH01 did not show drawdown which correlated with the test pumping.

Pumping tests where drawdown data are only available for the pumping well are known as single well tests.

The time-drawdown data from the three tests are shown in Figure A2.1. The details and results of the three tests are presented in Table A2.1. The monitoring data from the various tests are presented in Tables A2.2 (a), (b) and (c).


Drawdown v Time
Drawdown (m) {PWSBH01 & BH09}
Drawdown (m) {BH08}
Time (mins)
35
30
25
20
15
10
5
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1440
2880
4320
s v t GSI 12dec06 - PWSBH01
s v t Kelly 17jun03 - PWSBH01
s v t Kelly 14feb06 - BH09
s v t Kelly 14feb06 - BH08

2 Conceptual Model For Pumping Test Analysis

The test data were analysed to determine aquifer hydraulic properties for the bedrock aquifer. Analytical solutions for hydraulic property analysis were selected based on the type of pumping test carried out (i.e. CDT, VDT, Recovery Test) and on the conceptual model of the bedrock aquifer. The conceptual model of the bedrock aquifer was developed based on the desk study data collected, hydrogeological mapping of the study area, analysis of borehole logs and water level data for the study area and on the shape of the time-drawdown curves for the various pumping tests.

The desk study data, hydrogeological mapping, borehole logs and water level data for the study area indicate that boreholes PWSBH01 and BH09 intersect a confined-leaky limestone aquifer (see Section 8 of the Main Report). Given the Rk_d classification of the bedrock aquifer it is assumed that the aquifer is sufficiently fractured and broken to behave in a manner hydraulically equivalent to a porous aquifer. This assumption is not likely to be entirely accurate. The borehole logs for PWSBH01 and BH09 show that during drilling groundwater inflows to the borehole occurred in discrete zones logged as broken rock with the intervening strata logged as "black rock" and presumably not broken. The zones of broken rock are assumed to be equivalent to a porous medium and are assumed to be sufficiently interconnected to behave as a single unit.

The NERDO (1981) report indicates that the limestone bedrock aquifer is approximately 73 m thick and possibly up to 100 m thick. PWSBH01 penetrates 83.9 m of bedrock while BH09 penetrates 53.4 m. For the purposes of the analysis both wells are assumed to fully penetrate the aquifer. This may not be the case for BH09. Partial penetration of the aquifer generates vertical flow of groundwater from beneath the well up into the well. This requires the generation of a vertical hydraulic gradient which results in larger drawdown in the well compared to a fully penetrating well (which would be assumed to only induce horizontal flow).

Graphs of time versus drawdown have been compared with characteristic time-drawdown curves as presented in Kruseman and deRidder (1990). Log-log and semi-log plots of the data are shown in Figure A2.2 and Figure A2.3 respectively.

In the log-log plot the early time data and the mid time data from PWSBH01 follow the characteristic (Theis) curve (not shown). The mid and late time data from BH09 are difficult to interpret due to the change in the discharge rate. The mid to late time data for PWSBH01 show a slight flattening with respect to the Theis curve. This indicates that the bedrock aquifer is leaky rather than completely confined. The leakage takes place through the high and low permeability subsoils overlying the aquifer (see cross-section in Figure X of main report) and derives from direct recharge through tills and leakage of perched groundwater stored in the raised beach sand and gravel deposits.

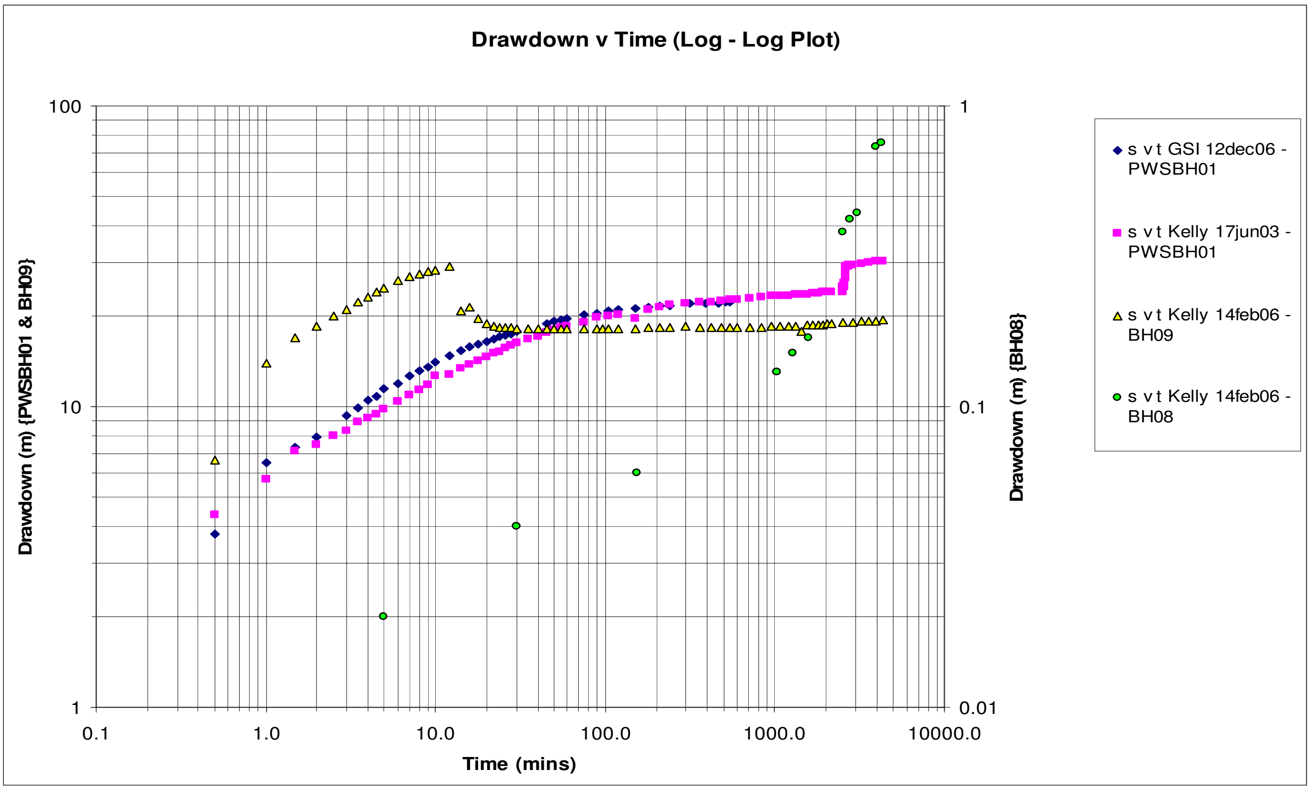


Figure A2.2. Log – log plot of drawdown versus time

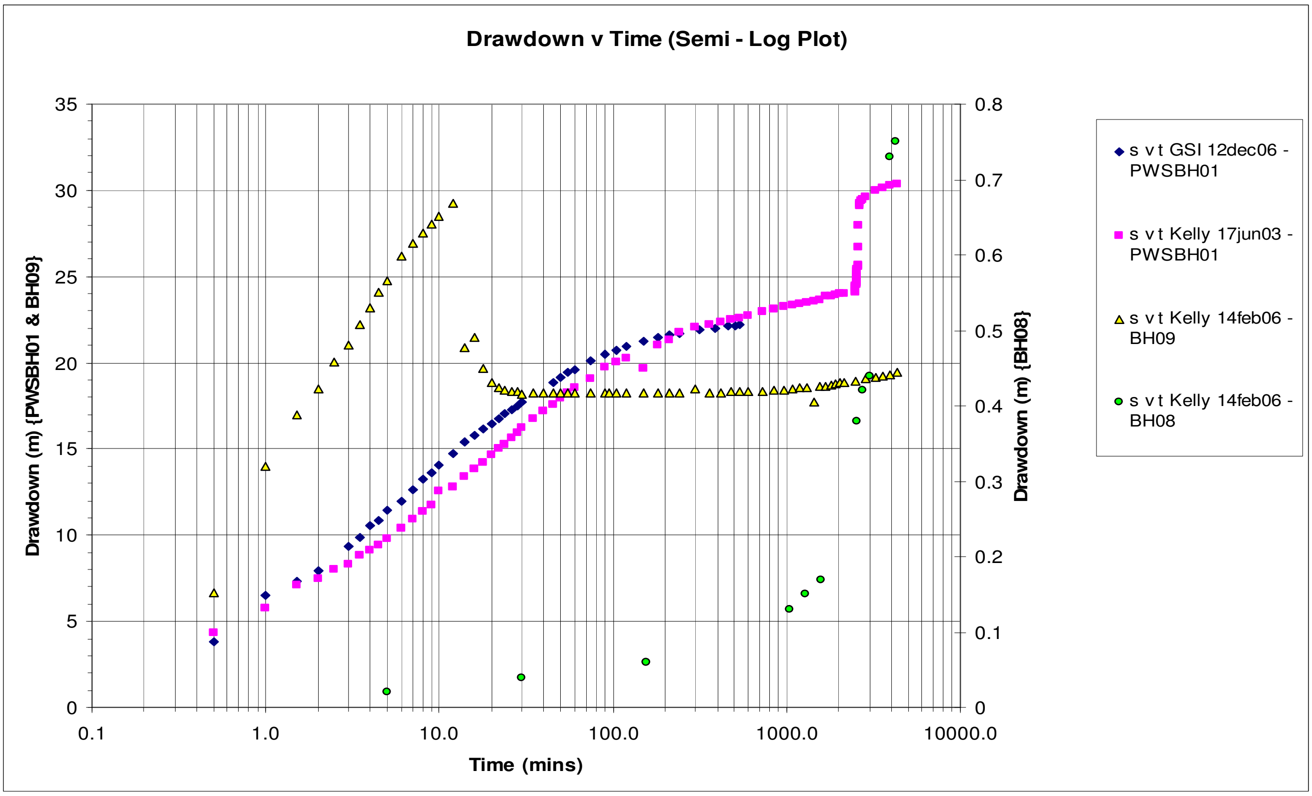


Figure A2.3. Semi – log plot of drawdown versus time

The leakage increasingly reduces the pumping test drawdown compared to a confined aquifer as pumping continues, such that eventually all of the abstraction derives from leakage rather than from storage in the aquifer.

In the semi – log plot the time drawdown curve of a confined aquifer plots as a straight line. The data for BH09 are difficult to interpret due to the change in the discharge rate. The data from PWSBH01 show a flattening of the line after approximately 200 minutes of pumping, which again indicates the effect of leakage from overlying strata on the pumping test drawdown.

The data from BH08 are difficult to interpret. It is likely that water level changes from before 200 minutes are related to natural fluctuations in the borehole water level rather than to the pumping test. Subsequent data are roughly linear, but no leakage impacts are visible.

3 Pumping Test Analysis Summary

The pumping test analyses are presented in turn below. The analysis of the CDT and CDT Recovery on PWSBH01 at PWSBH01 is presented first, followed by the VDT and VDT Recovery on PWSBH01 at PWSBH01, the VDT and VDT Recovery on BH09 at BH09 and finally the VDT on BH09 at observation well BH08.

3.1 CDT on PWSBH01 – Drawdown in PWSBH01 (GSI 12/12/2006)

Drawdown data are only available for the pumping well (single well test). The test type is a constant discharge test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Jacob's Straight Line Method as per Kruseman and deRidder (1990).

The transmissivity is determined from drawdown differences, which are not influenced by well losses as long as the discharge remains constant. Table A2.2(a) shows that the instantaneously measured discharge fluctuated between 347 and 349 m^3/day. This fluctuation does not appear to have significantly impacted on the "straight-line" analysis of the semi-log plot of drawdown versus time. The average discharge over the test period was 358 m^3/day.

Drawdown data for single well test are affected by well-bore storage. This is where water stored the well itself is abstracted initially in place of water stored in the aquifer, such that drawdown in the aquifer is initially reduced. Analysis of the data indicates that drawdown data after 28 minutes should not be impacted by well-bore storage effects.

Drawdown data in leaky aquifers are affected by leakage of water into the aquifer from over or underlying strata during the test period. This reduces drawdown compared to the ideal drawdown anticipated by the analytical solution for calculation of hydraulic properties, resulting in an overestimation of aquifer transmissivity. Data on aquifer storage and the leakage from the overlying aquifer are required to determine the time after which leakage effects significantly impact on the data. These data are not available for the study area. Typical leakage and storativity literature values indicate that leakage might become significant after 28 minutes. This would imply that there is no period in the test where drawdown data are completely free of both well-bore-storage and leakage effects. Studying the semi-log plot for the test indicates that leakage becomes significant after approximately 100 minutes.

The straight line has been matched to data between 28 and 100 minutes. The resulting bedrock aquifer transmissivity is 8.1 m^2/day. The relevant semi-log plot is shown in Figure A2.4.

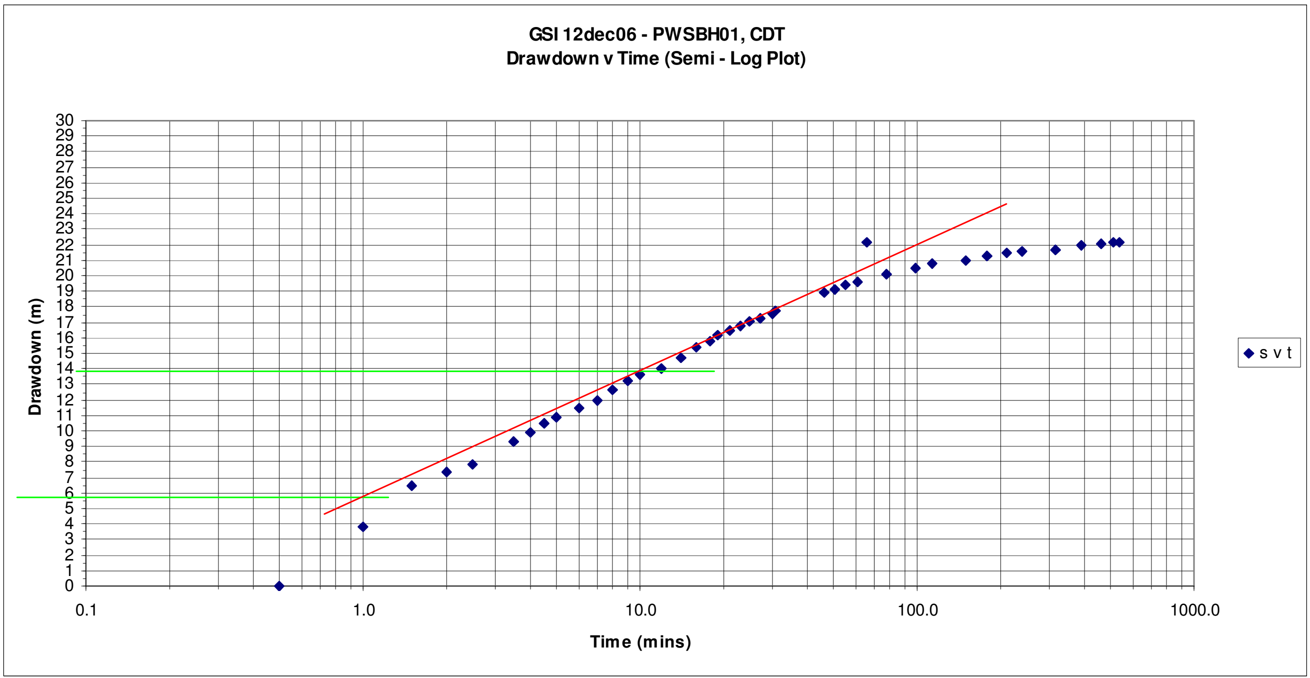


Figure A2.4. PWSBH01 CDT (12/12/06), Semi – log plot of drawdown versus time.

3.2 CDT Recovery on PWSBH01 – Drawdown in PWSBH01 (GSI 12/12/2006)

Residual drawdown data are only available for the pumping well (single well test). The test type is a constant discharge recovery test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Theis Recovery Method as per Kruseman and deRidder (1990).
The limitations of the analysis are the same those outlined in Section 3.1 except with respect to well losses. Recovery data are not affected by well losses.

The straight line has been matched to data after 50 minutes (end of well-bore storage effects for this data set). The resulting bedrock aquifer transmissivity is 4.1 m^2/day. The relevant semi-log plot is shown in Figure A2.5. In the graph the x-axis represents t/t' where "t" is the time since the start of pumping and "t' "is the time since cessation of pumping.

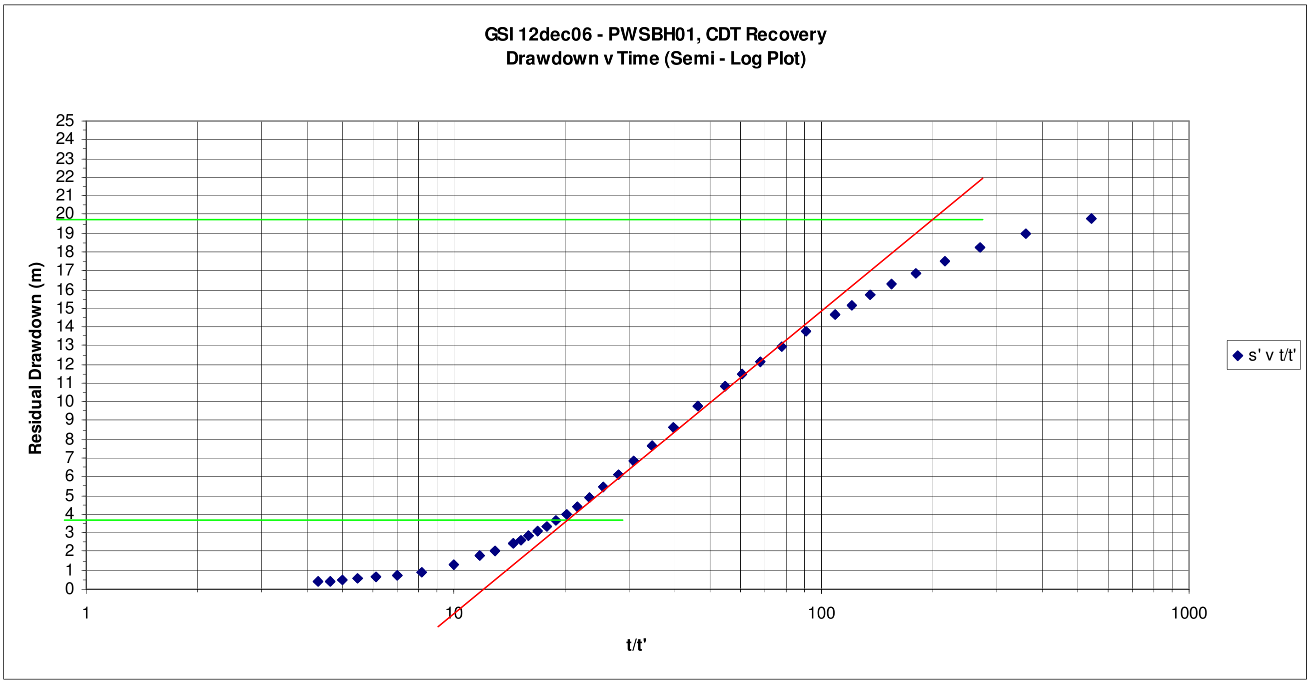


Figure A2.5. PWSBH01 CDT Recovery (12/12/06), Semi – log plot of residual drawdown versus time.

3.3 VDT on PWSBH01 – Drawdown in PWSBH01 (Kelly Ltd. 17/06/2003)

Drawdown data are only available for the pumping well (single well test). The test type is a variable discharge test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Birsoy-Summers Method as per Kruseman and deRidder (1990).

The Birsoy-Summers Method is for a confined aquifer analysis rather than a leaky aquifer as is the case here. This may result in over-estimation of the bedrock aquifer transmissivity.

The transmissivity is determined from drawdown differences, which are not influenced by well losses as long as the discharge remains constant. Well losses increase as the discharge rate increases. Because this is a variable discharge test the drawdown data at different discharge rates will be affected by different magnitudes of well loss. Well-losses result in larger drawdown in the well than in the surrounding aquifer, due to inefficiency in transmitting water from the borehole-aquifer interface to the pump. Drawdown data uncorrected for well-losses can therefore lead to underestimation of aquifer transmissivity and this may be the case in this analysis. No step test data are available to calculate well-loss parameters from which corrected drawdown data could be derived. Well loss effects may be responsible for the deviation of the initial data from the second (increased) discharge period from the straight line used in the analysis (see Figure A.2.6).

Well-bore storage and leakage effects are applicable as described in Section 3.1.

The straight line has been matched to data after 18 minutes (end of well-bore storage effects for this data set) from the first discharge period (S1/Q1) and to the late data, which fall on the same straight line, from the second discharge period. The resulting bedrock aquifer transmissivity is 11 m^2/day. The relevant semi-log plot is shown in Figure A2.6. The graph x-axis represents adjusted time to account for the impact of the variable discharge rate.

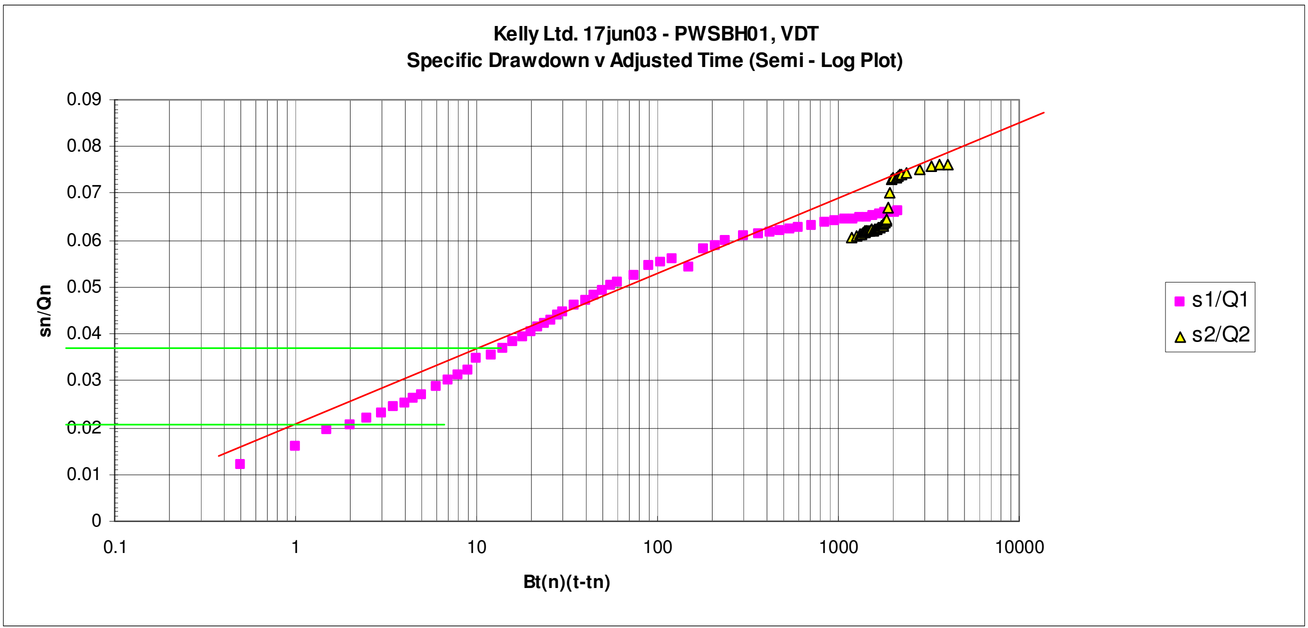


Figure A2.6. PWSBH01 VDT (17/06/03), Semi – log plot of specific drawdown versus adjusted time.

3.4 VDT Recovery on PWSBH01 – Drawdown in PWSBH01 (Kelly Ltd. 17/06/2003)

Residual drawdown data are only available for the pumping well (single well test). The test type is a variable discharge recovery test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Birsoy-Summers Method as per Kruseman and deRidder (1990).

The Birsoy-Summers Method is for a confined aquifer analysis rather than a leaky aquifer as is the case here. This may result in over-estimation of the bedrock aquifer transmissivity.

The limitations of the analysis are the same as those outlined in Section 3.3 except with respect to well losses. Recovery data are not affected by well losses.

The straight line has been matched to values of adjusted time corresponding to recovery data after 48 minutes (end of well-bore storage effects for this data set). The resulting bedrock aquifer transmissivity is 4.2 m^2/day. The relevant semi-log plot is shown in Figure A2.7. The graph x-axis represents adjusted time to account for the impact of the variable discharge rate.

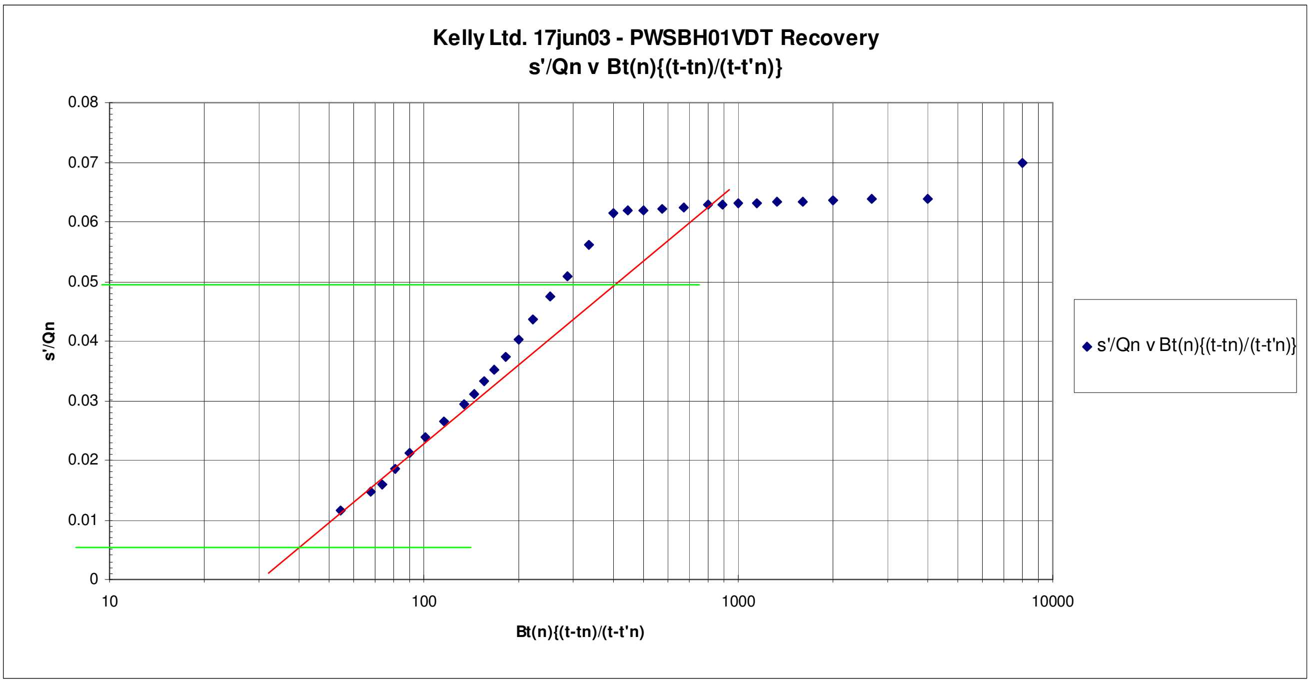


Figure A.2.7. PWSBH01 VDT Recovery (17/06/03), Semi – log plot of residual specific drawdown versus adjusted time.

The recovery test adjusted time data plot in the inverse direction to normal time, such that the early time recovery data plot at the high end of the adjusted time scale. The data are expected to give a straight line under ideal conditions. Figure A.2.7 shows that the early time recovery data have a lower slope than the later data which have been used in the analysis. The slope of the early data indicate a high transmissivity, however this is considered to be spurious. The drawdown in the borehole corresponding to these data are the maximum drawdown data following cessation of pumping. The borehole log indicates that at this drawdown level the upper water bearing zone of the bedrock aquifer in the vicinity of the borehole is dewatered. Furthermore the GSI pumping test data (12/12/2006) indicate that when drawdown recovered in this zone during that test a "gurgling" sound was heard, which was taken to indicate the re-filling of a de-watered fracture. As such the early data correspond to a time when the actual aquifer transmissivity intersected by the borehole is reduced due to dewatering, rather than increased as might be believed based on the slope of the data in Figure A.2.7. The analytical solution does not account for variable transmissivity during the test period, as such these early recovery data have been ignored.

3.5 VDT on BH09 – Drawdown in BH09 (Kelly Ltd. 14/02/2006)

Drawdown data for the pumping well (single well test) are analysed in this section. The test type is a variable discharge test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Birsoy-Summers Method as per Kruseman and deRidder (1990).

The Birsoy-Summers Method is for a confined aquifer analysis rather than a leaky aquifer as is the case here. This may result in over-estimation of the bedrock aquifer transmissivity.

Borehole BH09 may only partially penetrate the bedrock aquifer. Partial penetration is not accounted for in the analysis. As such, the analysis may underestimate the bedrock aquifer transmissivity.

The limitations of the analysis with respect to well losses, well-bore storage and leakage are the same those outlined in Sections 3.1 and 3.3.

Well bore effects for this data set are estimated to finish after 8 minutes. Nearly all of the data for the first discharge rate occur before 8 minutes (s1/Q1). As such the data from the first discharge period have been ignored in the calculation of hydraulic properties. The deviation of the early data from the second discharge period from the ideal straight line may be due to well loss effects. The straight line has been matched to the late time data of the second discharge period. These data may be effected by leakage, which may lead to an overestimation of the aquifer transmissivity. The resulting bedrock aquifer transmissivity is 20 m^2/day. The relevant semi-log plot is shown in Figure A2.8.

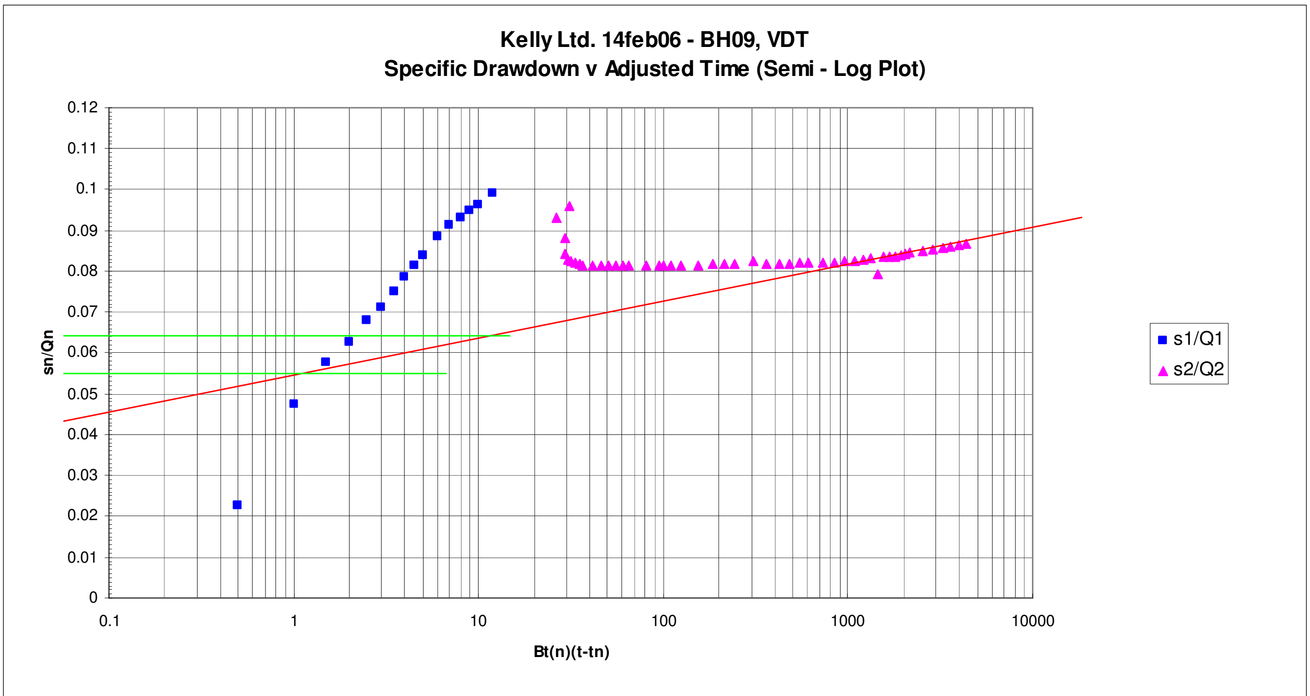


Figure A2.8. BH09 VDT (14/02/06), Semi – log plot of specific drawdown versus adjusted time.

3.6 VDT Recovery on BH09 – Drawdown in BH09 (Kelly Ltd. 14/02/2006)

Residual drawdown data for the pumping well (single well test) are analysed in this section. The test type is a variable discharge recovery test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Birsoy-Summers Method as per Kruseman and deRidder (1990).

The Birsoy-Summers Method is for a confined aquifer analysis rather than a leaky aquifer as is the case here. This may result in over-estimation of the bedrock aquifer transmissivity.

Borehole BH09 may only partially penetrate the bedrock aquifer. Partial penetration is not accounted for in the analysis. As such, the analysis may underestimate the bedrock aquifer transmissivity.

The limitations of the analysis with respect to well-bore storage and leakage are the same those outlined in Sections 3.1 and 3.3. Recovery data are not affected by well losses.

The estimated duration of well bore effects depends on the calculated transmissivity. In this case matching the straight line to the high-slope, early recovery data (which corresponds to the late adjusted time) gives a low transmissivity with a corresponding long duration of well-bore effects, which renders the early recovery data irrelevant. Matching to the low-slope mid to late recovery data gives a higher transmissivity and corresponding shorter duration of well-bore effects, which brings some of the early data back into play. For this analysis the mid to late recovery data have been used, which gives a duration of well-bore effects of 5 minutes. The high slope, early data after five minutes (i.e. adjusted time less than 860) have been discarded as possibly affected by well-bore storage. The mid to late recovery data may be effected by leakage, which may lead to an overestimation of the aquifer transmissivity. The resulting bedrock aquifer transmissivity is 40.7 m^2/day. The relevant semi-log plot is shown in Figure A2.8.

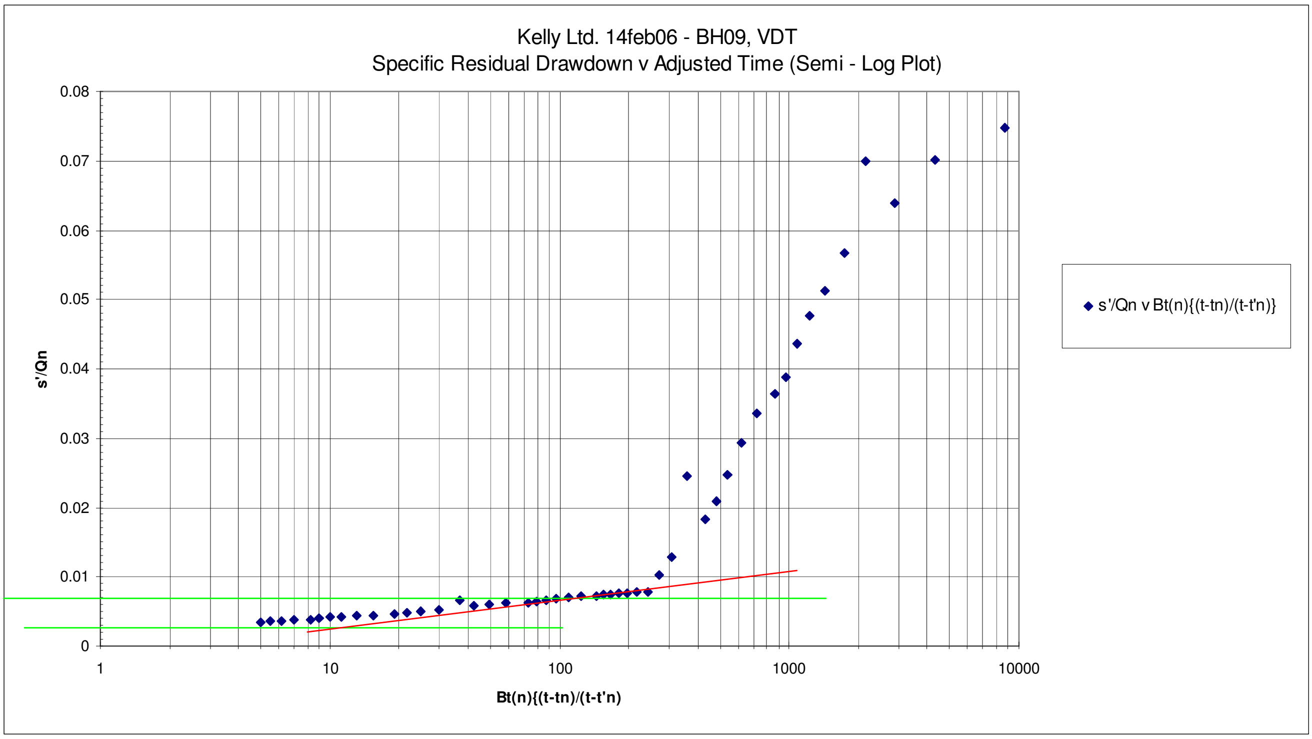


Figure A2.8. BH09 VDT (14/02/06), Semi – log plot of specific drawdown versus adjusted time.

3.7 VDT on BH09 – Drawdown in BH08 (Kelly Ltd. 14/02/2006)

Drawdown data for the observation well BH08 are analysed in this section. The borehole is located 780 m east of the pumping well BH09. The test type is a variable discharge test in a leaky aquifer for a fully penetrating well. The data have been analysed using the Birsoy-Summers Method as per Kruseman and deRidder (1990).

The Birsoy-Summers Method is for a confined aquifer analysis rather than a leaky aquifer as is the case here. This may result in over-estimation of the bedrock aquifer transmissivity.

Borehole BH09 may only partially penetrate the bedrock aquifer. Partial penetration is not accounted for in the analysis. As such, the analysis may underestimate the bedrock aquifer transmissivity.

The limitations of the analysis with respect to leakage are the same those outlined in Sections 3.1 and 3.3. Well losses and well-bore storage should not affect observation well drawdown data.

The low-slope early monitoring data are considered to represent natural variation of the observation well water level before the impact of abstraction at the pumping well has reached the observation well. The straight line has been matched to the high-slope data after 1500 minutes. These data may be effected by leakage, which may lead to an overestimation of the aquifer transmissivity. The resulting bedrock aquifer transmissivity is 30 m^2/day. The relevant semi-log plot is shown in Figure A2.9.

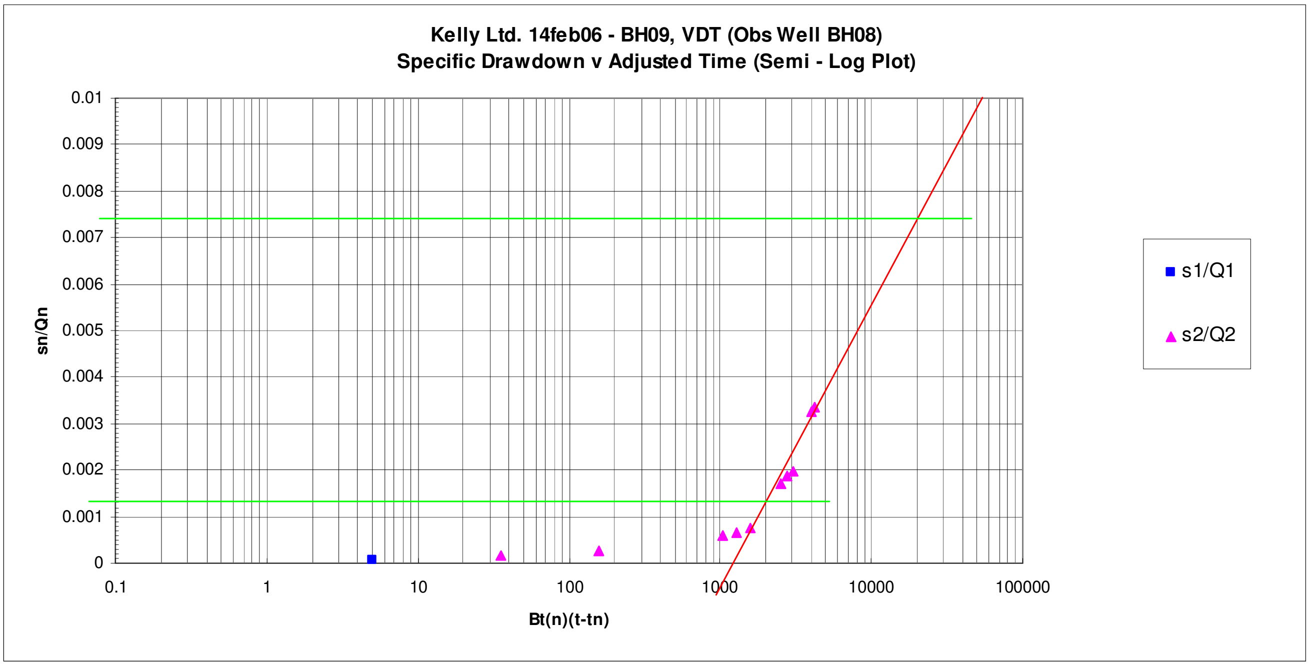


Figure A2.9. BH09 VDT (14/02/06), Semi – log plot of specific drawdown versus adjusted time observation well BH08.

Table A.2.1 Summary Table Of Test Details And Results

Pumping Test	Borehole	Test Type	Duration	Discharge Rate	Max Drawdown / % Recovery	Specific Capacity	Transmissivity	Analytical Solution	Comment
			(Hours)	(m^3/day)	(m)	(m^3/d/m)	(m^2/day)		
GSI (12/12/2006)	PWSBH01	CDT	9	358	22.195	16.1	8.1	Jacob's Straight Line Method	Single Well Test
		Recovery	2.75	0	87.2 %	-	4.1	Theis Recovery Method	Single Well Test
Kelly Ltd. (17/06/2003)	PWSBH01	VDT	72	Q_1 = 363	24.06	15.1	11	Birsoy Summers Method	Single Well Test. Q_1 lasted 42 hrs
				Q_2= 398	30.37	13.1			Q_2 lasted 30 hrs
		Recovery	1.25	0	85%		4.2	Birsoy Summers Method	Single Well Test
Kelly Ltd. (14/02/2006)	BH09	VDT	70.8	Q_1 = 295	29.25	10.1	20	Birsoy Summers Method	Single Well Test. Drawdown still increasing at end of step. Step 1 lasted 12 mins
				Q_2= 223	19.41	11.5			Step 2 lasted 70.6 hrs
		Recovery	19.1	0	96%	-	40.7	Birsoy Summers Method	Single Well Test
	BH08	VDT	70.8	Q_1 = 295	0	-	30	Birsoy Summers Method	Observation Well at 610 m from pumping well
				Q_2= 223	0.75	-			

Start test on 12/12/2006 @ 7.43am. Water level Ref not recorded.

DATE	t min	Pump Well Level	log t	Drawdown	Flow METER Meter (m3)	del t (min)	vol (m3)	Rate (m3/d)	Flow Meter Instantaneous Q (m3/hr)	Q (m3/d)
12/12/2006	0.0	15.9		0	130179.25	0	0	0	0	
	0.5	19.68	0.00	3.78					16.22	389
	1.0	22.4	0.00	6.5						
	1.5	23.22	0.18	7.32						
	2.0	23.79	0.30	7.89						
	2.5		0.40							
	3.0	25.22	0.48	9.32						
	3.5	25.8	0.54	9.9					25.8	619
	4.0	26.42	0.60	10.52						
	4.5	26.74	0.65	10.84					15.71	377
	5.0	27.37	0.70	11.47						
	6.0	27.87	0.78	11.97						
	7.0	28.52	0.85	12.62					15.53	373
	8.0	29.1	0.90	13.2						
	9.0	29.49	0.95	13.59	130181.88	9.0	2.63	421	15.47	371
	10.0	29.95	1.00	14.05						
	12.0	30.65	1.08	14.75						
	14.0	31.31	1.15	15.41	130182.92	5.0	1.04	300	15.49	372
	16.0	31.675	1.20	15.775	130183.42	2.0	0.5	360	14.46	347
	18.0	32.06	1.26	16.16						
	19.0		1.28		130184.2	3.0	0.78	374	15.33	368
	20.0	32.37	1.30	16.47						
	21.0		1.32		130184.7	2.0	0.5	360	15.2	365
	22.0	32.66	1.34	16.76						
	23.0		1.36		130185.26	2.0	0.56	403	15.29	367
	24.0	32.965	1.38	17.065						
	25.0		1.40		130185.75	2.0	0.49	353	15.26	366
	26.0	33.185	1.41	17.285						
	27.0		1.43		130186.25	2.0	0.5	360	15.34	368
	28.0	33.42	1.45	17.52						
	30.0	33.625	1.48	17.725						
	31.0		1.49		130187.33	4.0	1.08	389	15.13	363
	32.0	33.83	1.51							
	33.0		1.52		130187.76	2.0	0.43	310	15.16	364
	34.0	34.015	1.53							
	35.0		1.54		130188.34	2.0	0.58	418		
	36.0		1.56							
	37.0		1.57							
	38.0	34.315	1.58							
	39.0		1.59		130189.35	4.0	1.01	364	15.16	364
	40.0	34.46	1.60							
	41.0		1.61		130189.8	2.0	0.45	324	15.16	364
	45.0	34.78	1.65	18.88	130191.08	4.0	1.28	461		
	46.0		1.66						15.14	363
	50.0	35.055	1.70	19.155						
	50.5		1.70		130192.23	5.5	1.15	301	15.14	363
	55.0	35.31	1.74	19.41						
	55.5		1.74		130193.52	5.0	1.29	372	15.23	366
	60.0	35.52	1.78	19.62						
	61.0		1.79		130194.85	5.5	1.33	348	15.14	363
	75.0	36.035	1.88	20.135						
	78.0		1.89		130199.94	17.0	5.09	431	14.98	360
	90.0	36.38	1.95	20.48						
	99.0		2.00		130202.16	21.0	2.22	152	15.07	362
	105.0	36.65	2.02	20.75						
	114.0		2.06		130208.28	15.0	6.12	588	15	360
	120.0	36.835	2.08	20.935	130209.68	6.0	1.4	336	15	360
	150.0	37.155	2.18	21.255	130216.75	30.0	7.07	339	15.07	362
	180.0	37.375	2.26	21.475	130224.63	30.0	7.88	378	15.01	360
	210.0	37.505	2.32	21.605	130232.47	30.0	7.84	376	14.97	359
	240.0	37.615	2.38	21.715	130240.36	30.0	7.89	379	14.95	359
	315.0	37.845	2.50	21.945	130258.56	75.0	18.2	349	14.9	358
	390.0	37.92	2.59	22.02	130275.92	75.0	17.36	333	14.77	354
	465.0	38.03	2.67	22.13	130295.07	75.0	19.15	368	14.84	356
	510.0	38.065	2.71	22.165	130306.31	45.0	11.24	360	14.84	356
	540.0	38.095	2.73	22.195	130313.5	30.0	7.19	345	14.88	357
Recovery	540.5	36.79	2.73	20.89		Average Q1 (m3/d)		358		371
	541.0	35.715	2.73	19.815						
	541.5	34.9	2.73	19				152		
	542.0	34.17	2.73	18.27				588		
	542.5	33.4	2.73	17.5						
	543.0	32.79	2.73	16.89						
	543.5	32.185	2.74	16.285						
	544.0	31.6	2.74	15.7						
	544.5	31.02	2.74	15.12						
	545.0	30.57	2.74	14.67						
	546.0	29.64	2.74	13.74						
	547.0	28.825	2.74	12.925						
	548.0	28.04	2.74	12.14						
	549.0	27.365	2.74	11.465						
	550.0	26.77	2.74	10.87						
	552.0	25.64	2.74	9.74						
	554.0	24.5	2.74	8.6						
	556.0	23.55	2.75	7.65						
	558.0	22.7	2.75	6.8						
	560.0	21.99	2.75	6.09						
	562.0	21.35	2.75	5.45						
	564.0	20.815	2.75	4.915						
	566.0	20.31	2.75	4.41						
	568.0	19.9	2.75	4						
	570.0	19.55	2.76	3.65						
	572.0	19.225	2.76	3.325						
	574.0	18.96	2.76	3.06						
	576.0	18.725	2.76	2.825						
	578.0	18.51	2.76	2.61						
	580.0	18.34	2.76	2.44						
	585.0	17.94	2.77	2.04						
	590.0	17.67	2.77	1.77						
	600.0	17.19	2.78	1.29						
	615.0	16.8	2.79	0.9						
	630.0	16.66	2.80	0.76						
	645.0	16.54	2.81	0.64						
	660.0	16.46	2.82	0.56						
	675.0	16.39	2.83	0.49						
	690.0	16.345	2.84	0.445						
	705.0	16.3	2.85	0.4						

Recovery Prior to CDT on 12/12/2006

Pumping at 14.77m3/h (354m3/d) before shut down

t min	Pump Well Level	log t	Drawdown
0	39.995		24.095
0.25	39.4		23.5
0.5	39.3		23.4
2	39.25		23.35
3.333	39.15		23.25
4.167	39.11		23.21
5.5	39.02		23.12
8.83	37.5		21.6
10	35.7		19.8
12.75	33.25		17.35
14.33	31.87		15.97
17.33	29.67		13.77
20.33	27.75		11.85
28.33	24.23		8.33
30.5	23.27		7.37
80	17.79		1.89
234	16.89		0.99
332	16.695		0.795
433	16.53		0.63
1022	15.905		0.005

Appendix 2 - Table A2.2
Kelly Ltd VDT Data PWSBH01 - 17/06/2003

Pump intake @ 60mbgl; Discharge distance = 15m; Water level measurement ref = 0.8m agl RWL = 14.34
Start Test on 17/06/2003 @ 3.54pm

DATE		Pump Well	Pump house Obs Well		Pump Well	Pump house Obs Well	Flow METER				Flow Meter Instantaneous	
	t	Level mbref	Level mbref	log t	Drawdown		Meter (m3)	del t (min)	vol (m3)	Rate (m3/d)	Q (l/m)	Q (m3/d)
17/06/2003	0.0	15.14	2.33		0		152058.3	0	0	0	0	
	0.5	19.5		0.00	4.36						262	377.28
	1.0	20.87		0.00	5.73							
	1.5	22.24		0.18	7.10							
	2.0	22.62		0.30	7.48							
	2.5	23.12		0.40	7.98							
	3.0	23.45		0.48	8.31							
	3.5	24		0.54	8.86							
	4.0	24.26		0.60	9.12							
	4.5	24.6		0.65	9.46							
	5.0	24.9		0.70	9.76							
	6.0	25.54		0.78	10.40							
	7.0	26.05		0.85	10.91							
	8.0	26.48		0.90	11.34							
	9.0	26.89		0.95	11.75							
	10.0	27.74		1.00	12.60							
	12.0	27.96		1.08	12.82							
	14.0	28.5		1.15	13.36							
	16.0	28.99		1.20	13.85							
	18.0	29.38		1.26	14.24							
	20.0	29.82		1.30	14.68							
	22.0	30.18		1.34	15.04							
	24.0	30.42		1.38	15.28							
	26.0	30.74		1.41	15.60							
	28.0	31.04		1.45	15.90							
	30.0	31.4		1.48	16.26							
	35.0	31.86		1.54	16.72							
	40.0	32.31		1.60	17.17							
	45.0	32.69		1.65	17.55							
	50.0	33.07		1.70	17.93							
	55.0	33.37		1.74	18.23							
	60.0	33.67		1.78	18.53		152074	60.0	15.7	376.8	260	374.4
	75.0	34.22		1.88	19.08							
	90.0	34.9		1.95	19.76							
	96.0		2.35	1.98		-0.02						
	105.0	35.21		2.02	20.07							
	120.0	35.42		2.08	20.28		152089.4	60.0	15.4	369.6	256	368.64
	150.0	34.81		2.18	19.67							
	180.0	36.18		2.26	21.04		152104.5	60.0	15.1	362.4	255	367.2
	210.0	36.48		2.32	21.34							
	240.0	36.92		2.38	21.78		152119.7	60.0	15.2	364.8	255	367.2
	300.0	37.21		2.48	22.07		152134.8	60.0	15.1	362.4	255	367.2
	360.0	37.35		2.56	22.21		152150.2	60.0	15.4	369.6	255	367.2
	420.0	37.49		2.62	22.35		152165.3	60.0	15.1	362.4	255	367.2
	456.0		2.36	2.66		-0.03						
	480.0	37.62		2.68	22.48		152180.4	60.0	15.1	362.4	255	367.2
	540.0	37.75		2.73	22.61		152195.6	60.0	15.2	364.8	255	367.2
	600.0	37.89		2.78	22.75		152210.8	60.0	15.2	364.8	255	367.2
	720.0	38.08		2.86	22.94		152241.2	120.0	30.4	364.8	255	367.2
	840.0	38.23		2.92	23.09		152271.9	120.0	30.7	368.4	253	364.32
	960.0	38.4		2.98	23.26		152302.3	120.0	30.4	364.8	253	364.32
	1056.0		2.09	3.02		0.24						
	1080.0	38.49		3.03	23.35		152332.1	120.0	29.8	357.6	253	364.32
	1200.0	38.58		3.08	23.44		152362.3	120.0	30.2	362.4	252	362.88
	1320.0	38.63		3.12	23.49		152392.3	120.0	30	360	251	361.44
	1440.0	38.67		3.16	23.53		152421.9	120.0	29.6	355.2	250	360
	1536.0		2.41	3.19		-0.08						
	1560.0	38.79		3.19	23.65		152452.1	120.0	30.2	362.4	251	361.44
	1680.0	38.96		3.23	23.82		152482.2	120.0	30.1	361.2	252	362.88
	1800.0	39.02		3.26	23.88		152512.3	120.0	30.1	361.2	251	361.44
	1896.0		2.46	3.28		-0.13						
	1920.0	39.1		3.28	23.96		152542.4	120.0	30.1	361.2	252	362.88
	2040.0	39.12		3.31	23.98		152572.5	120.0	30.1	361.2	252	362.88
	2160.0	39.13		3.33	23.99		152602.6	120.0	30.1	361.2	252	362.88
42	2520.0	39.2		3.40	24.06		152692.9	360.0	90.3	361.2	252	362.88
	2520.5	39.31		3.40	24.17							
	2521.0	39.45		3.40	24.31							
	2521.5	39.52		3.40	24.38							
	2522.0	39.59		3.40	24.45							
	2522.5	39.65		3.40	24.51							
	2523.0	39.71		3.40	24.57							
	2523.5	39.76		3.40	24.62							
	2524.0	39.8		3.40	24.66							
	2524.5	39.82		3.40	24.68							
	2525.0	39.84		3.40	24.70							
	2526.0	39.86	3.01	3.40	24.72	-0.68						
	2527.0	39.88		3.40	24.74							
	2528.0	39.89		3.40	24.75							
	2529.0	39.91		3.40	24.77							
	2530.0	39.84		3.40	24.70							
	2532.0	39.92		3.40	24.78							
	2534.0	39.98		3.40	24.84							
	2536.0	40.01		3.40	24.87							
	2538.0	40.03		3.40	24.89							
	2540.0	40.06		3.40	24.92							
	2542.0	40.09		3.41	24.95							
	2544.0	40.11		3.41	24.97							
	2546.0	40.13		3.41	24.99							
	2548.0	40.15		3.41	25.01							
	2550.0	40.18		3.41	25.04							
	2555.0	40.29		3.41	25.15							
	2560.0	40.41		3.41	25.27							
	2565.0	40.49		3.41	25.35							
	2570.0	40.58		3.41	25.44							
	2575.0	40.69		3.41	25.55							
	2580.0	40.78		3.41	25.64							
	2595.0	41.83		3.41	26.69							
	2610.0	43.09		3.42	27.95							
	2625.0	44.2		3.42	29.06							
	2640.0	44.28		3.42	29.14							
	2670.0	44.39		3.43	29.25							
	2700.0	44.5		3.43	29.36							
	2730.0	44.57		3.44	29.43							
	2760.0	44.58		3.44	29.44							
	2880.0	44.78		3.46	29.64		152797.6	360.0	104.7	418.8	290	417.6
	2976.0		2.62	3.47		-0.29						
	3240.0	45.1		3.51	29.96		152902	360.0	104.4	417.6	290	417.6
	3336.0		2.51	3.52		-0.18						
	3600.0	45.28		3.56	30.14		153006.4	360.0	104.4	417.6	290	417.6
	3960.0	45.44		3.60	30.30		153111.2	360.0	104.8	419.2	290	417.6
	3966.0		3.11	3.60		-0.78						
	4320.0	45.51		3.64	30.37		153190.1	360.0	78.9	315.6	290	417.6
Recovery	4320.5	42.93		3.64	27.79			Average Q1 (m3/d)		363		366
	4321	40.6		3.64	25.46			Average Q2 (m3/d)		398		418
	4321.5	40.52		3.64	25.38					398		
	4322	40.46		3.64	25.32							
	4322.5	40.4		3.64	25.26							
	4323	40.34		3.64	25.20							
	4323.5	40.28		3.64	25.14							
	4324	40.24		3.64	25.10							
	4324.5	40.2		3.64	25.06							
	4325	40.16		3.64	25.02							
	4326	40.01		3.64	24.87							
	4327	39.92		3.64	24.78							
	4328	39.83		3.64	24.69							
	4329	39.74		3.64	24.60							
	4330	39.64		3.64	24.50							
	4332	37.5		3.64	22.36							
	4334	35.41		3.64	20.27							
	4336	34.01		3.64	18.87							
	4338	32.51		3.64	17.37							
	4340	31.15		3.64	16.01							
	4342	30.02		3.64	14.88							
	4344	29.1		3.64	13.96							
	4346	28.39		3.64	13.25							
	4348	27.52		3.64	12.38							
	4350	26.81		3.64	11.67							
	4355	25.72		3.64	10.58							
	4360	24.63		3.64	9.49							
	4365	23.59		3.64	8.45							
	4370	22.53		3.64	7.39							
	4375	21.5		3.64	6.36							
	4380	21.03		3.64	5.89							
	4395	19.74		3.64	4.60							

Appendix 2 - Table A2.3
GSI VDT Data BH09 - 11/02/2006

Pump intake @ 60mbgl; Pump type = GZS-75/7.5 kW; Well Dia = 0.150m; Discharge distance = 50m; Water level measurement ref = 0.8m agl
Start Test on 14/02/2006 @ 2.55pm; Stopped pumping on 17/06/2006 @ 2.57pm (i.e. 72hr 02min)
Data in red are estimated to assist with analysis

DATE		Pump Well	An Grianan (BH08)		Pump Well	An Grianan (BH08)	Flow METER				Flow Meter Instantaneous	
	t	Level mbref	Level mbref	log t	Drawdown		Meter (m3)	del t (min)	vol (m3)	Rate (m3/d)	Q (l/s)	Q (m3/d)
14/02/2006	0.0	13.35	1.94		0	0	27169	0	0	0	0	
	0.5	20		0.00	6.65		27169.12	0.5	0.12	333	3.85	333
	1.0	27.35		0.00	14.00							
	1.5	30.35		0.18	17.00							
	2.0	31.85		0.30	18.50							
	2.5	33.39		0.40	20.04							
	3.0	34.4		0.48	21.05							
	3.5	35.56		0.54	22.21							
	4.0	36.52		0.60	23.17							
	4.5	37.4		0.65	24.05							
	5.0	38.13	1.96	0.70	24.78	0.02						
	6.0	39.52		0.78	26.17							
	7.0	40.3		0.85	26.95							
	8.0	40.87		0.90	27.52							
	9.0	41.41		0.95	28.06							
	10.0	41.84		1.00	28.49							
	12.0	42.6		1.08	29.25		27171.46	11.50	2.35	294	3.4	294
	14.0	34.18		1.15	20.83							
	16.0	34.8		1.20	21.45							
	18.0	33.01		1.26	19.66							
	20.0	32.2		1.30	18.85							
	22.0	31.87		1.34	18.52		27172.97	10.0	1.51	218	2.52	218
	24.0	31.75		1.38	18.40							
	26.0	31.68		1.41	18.33							
	28.0	31.65		1.45	18.30							
	30.0	31.56	1.98	1.48	18.21	0.04	27174.20	8.0	1.22	220	2.55	220
	35.0	31.57		1.54	18.22							
	40.0	31.57		1.60	18.22							
	45.0	31.57		1.65	18.22		27176.50	15.0	2.30	221	2.56	221
	50.0	31.57		1.70	18.22							
	55.0	31.57		1.74	18.22							
	60.0	31.57		1.78	18.22		27179	15.0	2.50	240	2.61	226
	75.0	31.57		1.88	18.22							
	90.0	31.57		1.95	18.22							
	96.0	31.57		1.98	18.22							
	105.0	31.57		2.02	18.22							
	120.0	31.57		2.08	18.22		27188	60.0	9	216	2.6	225
	150.0	31.57		2.18	18.22						2.6	
	155.0		2	2.19		0.06						
	180.0	31.58		2.26	18.23		27198	60.0	10	240	2.6	225
	210.0	31.59		2.32	18.24						2.6	
	240.0	31.59		2.38	18.24		27207	60.0	9	216	2.59	224
	300.0	31.81		2.48	18.46		27218	60.0	11	264	2.59	224
	360.0	31.61		2.56	18.26		27226	60.0	8	192	2.58	223
	420.0	31.63		2.62	18.28		27235	60.0	9	216	2.59	224
	456.0			2.66								
	480.0	31.64		2.68	18.29		27244	60.0	9	216	2.59	224
	540.0	31.66		2.73	18.31		27254	60.0	10	240	2.59	224
	600.0	31.66		2.78	18.31		27263	60.0	9	216	2.59	224
	720.0	31.68		2.86	18.33		27281	120.0	18	216	2.59	224
14	840.0	31.73		2.92	18.38		27300	120.0	19	228	2.59	224
16	960.0	31.78		2.98	18.43		27318	120.0	18	216	2.59	224
17.33333333	1040.0		2.07	3.02		0.13						
17.6	1056.0			3.02								
18	1080.0	31.81		3.03	18.46		27337	120.0	19	228	2.59	224
20	1200.0	31.88		3.08	18.53		27356	120.0	19	228	2.59	224
21.25	1275.0		2.09	3.11		0.15						
22	1320.0	31.9		3.12	18.55		27374	120.0	18	216	2.59	224
24	1440.0	31.06		3.16	17.71		27393	120.0	19	228	2.58	223
25.6	1536.0			3.19								
26	1560.0	31.98		3.19	18.63		27412	120.0	19	228	2.57	222
26.58333333	1595.0		2.11	3.20		0.17						
28	1680.0	32		3.23	18.65		27431	120.0	19	228	2.55	220
30	1800.0	32.04		3.26	18.69		27449	120.0	18	216	2.57	222
31.6	1896.0			3.28								
32	1920.0	32.1		3.28	18.75		27467	120.0	18	216	2.58	223
34	2040.0	32.17		3.31	18.82		27486	120.0	19	228	2.58	223
36	2160.0	32.22		3.33	18.87		27504	120.0	18	216	2.58	223
42	2520.0	32.3		3.40	18.95		27561	360.0	57	228	2.58	223
42.25	2535.0		2.32	3.40		0.38						
45.83333333	2750.0		2.36	3.44		0.42						
48	2880.0	32.39		3.46	19.04		27618	360.0	57	228	2.58	223
49.6	2976.0			3.47								
50.83333333	3050.0		2.38	3.48		0.44						
54	3240.0	32.51		3.51	19.16		27673	360.0	55	220	2.57	222
55.6	3336.0			3.52								
60	3600.0	32.57		3.56	19.22		27729	360.0	56	224	2.57	222
66	3960.0	32.66		3.60	19.31		27784	360.0	55	220	2.57	222
66.1	3966.0			3.60								
66.25	3975.0		2.67	3.60		0.73						
70.83333333	4250.0		2.69	3.63		0.75						
72.03	4322.0	32.76		3.64	19.41		27840	362.0	56	223	2.6	225
Recovery	4322.5	30.04		3.64	16.69			Average Q1 (m3/d)		295		313
1	4323	29		3.64	15.65			Average Q2 (m3/d)		223		223
1.5	4323.5	27.61		3.64	14.26							
2	4324	28.98		3.64	15.63							
2.5	4324.5	26.03		3.64	12.68							
3	4325	24.82		3.64	11.47							
3.5	4325.5	23.97		3.64	10.62							
4	4326	23.09		3.64	9.74							
4.5	4326.5	22		3.64	8.65							
5	4327	21.46		3.64	8.11							
6	4328	20.87		3.64	7.52							
7	4329	19.92		3.64	6.57							
8	4330	18.89		3.64	5.54							
9	4331	18.03		3.64	4.68							
10	4332	17.44		3.64	4.09							
12	4334	18.83		3.64	5.48							
14	4336	16.22		3.64	2.87							
16	4338	15.64		3.64	2.29							
18	4340	15.11		3.64	1.76							
20	4342	15.09		3.64	1.74							
22	4344	15.06		3.64	1.71							
24	4346	15.04		3.64	1.69							
26	4348	15.02		3.64	1.67							
28	4350	15		3.64	1.65							
30	4352	14.98		3.64	1.63							
35	4357	14.95		3.64	1.60							
40	4362	14.92		3.64	1.57							
45	4367	14.88		3.64	1.53							
50	4372	14.84		3.64	1.49							
55	4377	14.79		3.64	1.44							
60	4382	14.76		3.64	1.41							
75	4397	14.72		3.64	1.37							
90	4412.0	14.7		3.64	1.35							
	4415.0		2.45	3.64		0.51						
105	4427.0	14.67		3.65	1.32							
120	4442.0	14.81		3.65	1.46							
150	4472.0	14.53		3.65	1.18							
180	4502.0	14.47		3.65	1.12							
210	4532.0	14.41		3.66	1.06							
240	4562.0	14.38		3.66	1.03							
300	4622.0	14.36		3.66	1.01							
360	4682.0	14.32		3.67	0.97							
420	4742.0	14.3		3.68	0.95							
480	4802.0	14.28		3.68	0.93							
540	4862.0	14.25		3.69	0.90							
600	4922.0	14.22		3.69	0.87							
720	5042.0	14.2		3.70	0.85							
840	5162.0	14.17		3.71	0.82							
960	5282.0	14.15		3.72	0.80							
	5355.0		2.3	3.73		0.36						
1080	5402.0	14.12		3.73	0.77							
	5465.0		2.29	3.74		0.35						