Establishment of Groundwater Source Protection Zones

Ballymakenny Group Water Scheme

Ballymakenny Boreholes

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Revision A

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Project description

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

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

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

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1 Introduction

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

The Ballymakenny Group Water Scheme (GWS) is supplied from three boreholes in the townland of Yellowbatter, Co. Louth. The boreholes pumped an average of 1,100 m^3/d in 2010 but this is expected to decrease during 2011 to approximately 600 m^3/d on account of ongoing network rehabilitation and metering works.

The objectives of this report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the boreholes.
- To delineate source protection zones for the production wells in the GWS.
- To assist the Environmental Protection Agency and Louth County Council in protecting the water supply from contamination.

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

The maps produced are based largely on the readily available information in the area, a field walkover survey, water level monitoring during normal pumping operations, 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

The methodology applied to delineate the SPZ consisted of data collection, desk studies, site visits, field mapping of geological exposures, well audits, water level recording, as well as subsequent data analysis and interpretation. An initial interview with the caretaker, and site and local area inspection, was undertaken in mid-July 2010. Further interviews and site visits, including installation of data loggers (pressure transducers) in two wells, were carried out in August, 2010.

3 Location, site description and well head protection

The Ballymakenny GWS (GWS) is located on the Ballymakenny Road at the northern margin of the town of Drogheda, as shown in **Figure 1**. The GWS has been in operation since 1992 and consists of three boreholes which are situated in a secure, fenced-off area measuring approximately 50 m x 10 m. In 2010, the GWS served an estimated 560 houses, 81 farms, and 3 businesses.

The wellheads of boreholes BH1 and BH2 are both constructed inside 18-inch by 24-inch block-built chambers, each 24-inches (0.6 m) deep (below ground level). Neither BH1 nor BH2 have wellhead covers, and are therefore susceptible to inflow of surface runoff. At BH1, there is a black watermark line approximately 3.5 inches (0.1m) from the base of the chamber.

A black watermark is also seen inside the chamber at BH2 about 3-inches (0.08 m) from the base. This is significant, as this is higher than the protrusion of the 150 mm steel casing of the well (i.e., surface water can therefore ingress directly into the well. In contrast, borehole BH3 is sealed with a lockable steel cover. The GWS compound and wellhead features of BH1 through BH3 are shown in Photos 1 through 5 below.

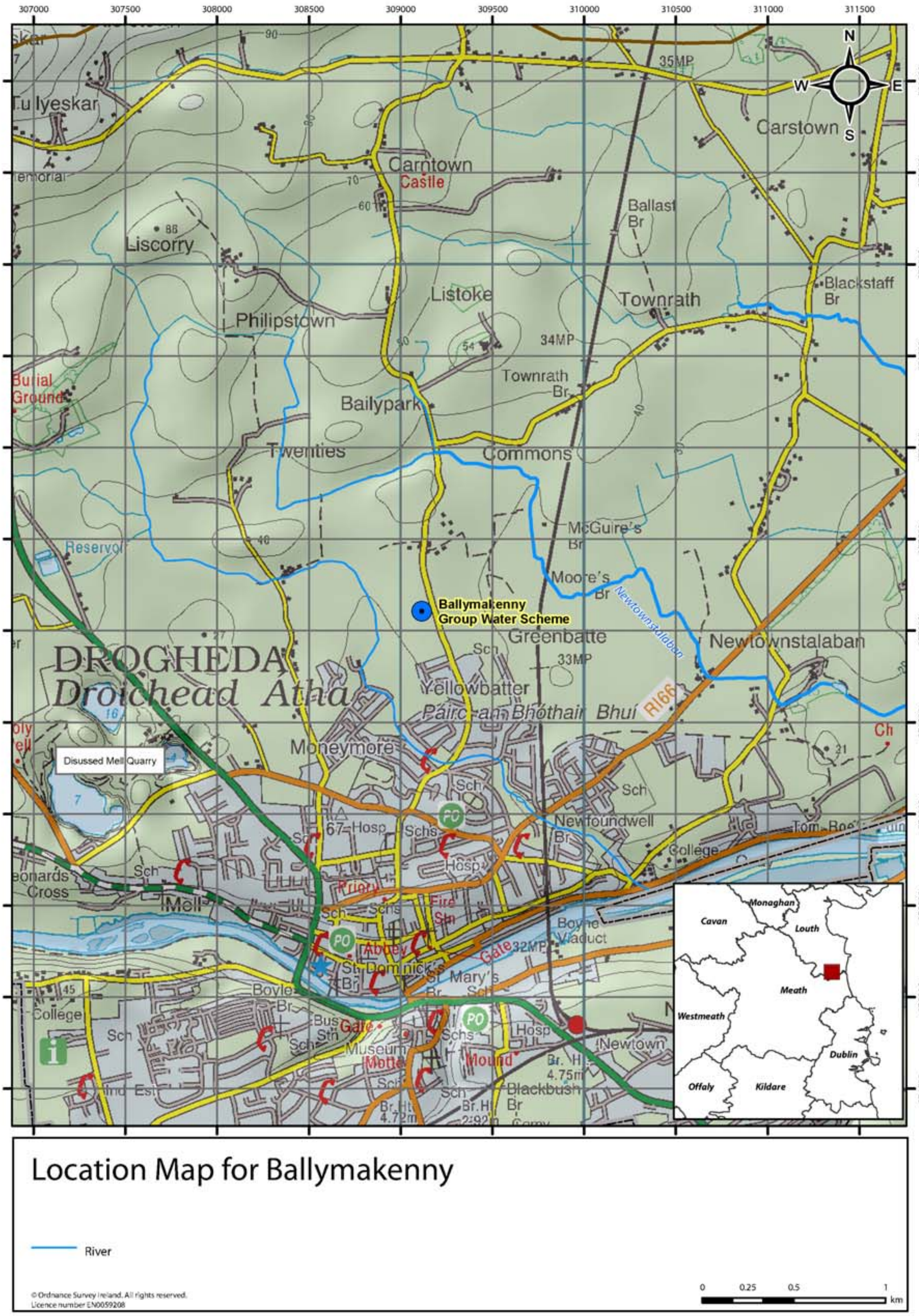


Figure 1: Location Map

Photo 1: Entrance to Ballymakenny GWS

Photo 2: Holding tank and Aquasil feed

Photo 3: BH1 Wellhead

Photo 4: BH2 Wellhead

Photo 5: BH3 Wellhead

The water is pumped from the boreholes through a 75-mm diameter pipe to a 91 m^3 (20,000 gallon) below-ground holding tank (Photo 2), where it is treated and then pumped by a booster pump to a c. 550 m^3 (120,000) gallon offsite reservoir. There is a meter recording of net flow out from the booster pump and after the reservoir. The boreholes are not metered individually.

Treatment in the holding tank is with Aquasil, rather than Chlorine, via drip-feed. There is currently no raw water sampling tap, and raw water samples would have to be collected from the jets entering the holding tank before mixing with the drip-fed Aquasil.

Each of the three boreholes is equipped with a c. 40 hp submersible pump. Usually, BH1 is pumping with BH3. BH1 is the main well abstracting approximately two-thirds of the daily total. BH2 serves as the "standby" or backup well. Recorded total abstractions for a 6-month period in 2010 are shown in **Figure 2**. The abstraction rates are based on totaliser readings from a flow meter that is installed on the pipeline that carries the water to the offsite reservoir. These readings are not typically recorded on a daily basis, but rather periodically during site maintenance activities. Each bar in **Figure 2** therefore represents the estimated average total daily abstraction for the preceding period (i.e. between totaliser readings), and not necessarily the flow record on the day the reading was taken.

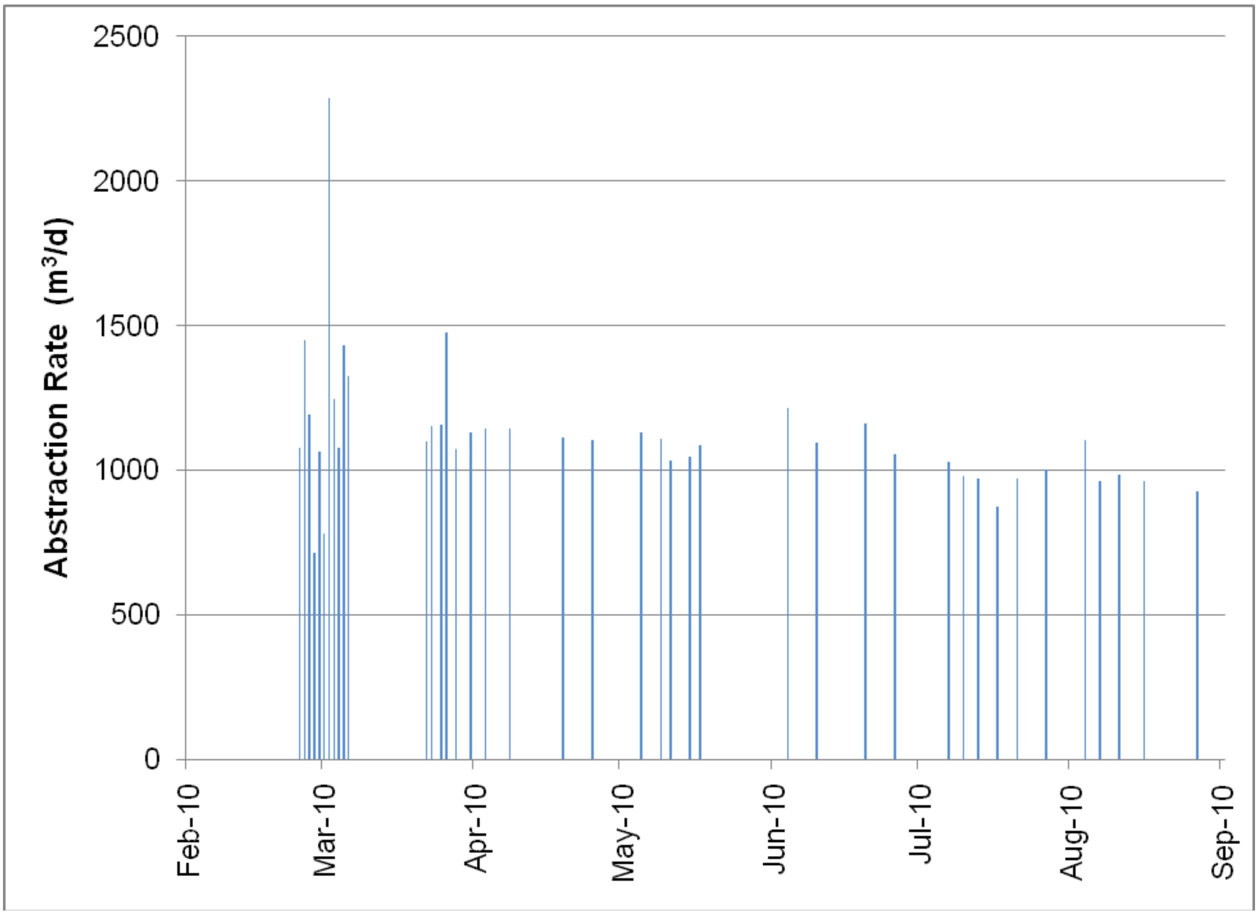


Figure 2: Recorded Abstraction, March-August, 2010

The average abstraction rate in 2010 was approximately 1,100 m^3/day. However, the average abstraction rate decreased slightly throughout the year and by August, the abstraction rate had dropped to 980 m^3/d. The reduction is expected to continue in 2011 to approximately 600 m^3/d as the water distribution network is undergoing improvement works and metres are being introduced on all water users linked to the GWS.

4 Summary of borehole details

Table 1 provides a summary of each borehole with currently known information. Boreholes BH1 and BH2 were drilled by Meehan Drilling Ltd. in 1992 but there are no construction records available. Borehole BH3 was drilled in August, 2005 by Patrick Briody & Sons Ltd., and its borehole log is provided in **Appendix 1**.

5 Topography, surface hydrology, landuse

The Ballymakenny GWS is located within the River Boyne catchment, approximately 2.5 km north of the River Boyne. The site is situated at an elevation of approximately 33 mOD, and topography generally rises to the north, reaching a maximum elevation of 160 m at Tulyeskar, some 4 km to the NW. The land immediately surrounding the site is hummocky owing to its glacial history.

Surface water drainage is to the Boyne River in the south. There are two unnamed streams within the immediate catchment. Neither stream is gauged. There are numerous field drains in the area which feed the streams. The drains are deep and cut up to 3 m into subsoil. There are no springs in vicinity of the site.

Land use surrounding the GWS is mostly agricultural and comprises arable crops and pastures. The urban footprint of Drogheda borders the GWS to the south. The GWS compound itself backs onto a bakery factory, and there is also a furniture factory and a large farmyard within 0.5 km of the GWS (both in an upslope direction). Urban development is slowly encroaching on the GWS. Planning permission was granted by Louth County Council in 2007 for a development of 600 houses in the land immediately north of the GWS. This development is currently on hold for financial reasons. Mell Quarry, a large disused limestone quarry, is located about 1.5 km to the SW of the GWS.

6 Hydro-meteorology

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

Annual rainfall: taken to be 820 mm. The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961–1990) shows that the source is located between the 800 mm and 900 mm average annual rainfall isohyets.

Annual evapotranspiration losses: 475 mm. The contoured mean annual potential evapotranspiration for Ireland shows that Tullyallen lies close to the 500 mm/yr contour. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits, giving an A.E. of 475 mm.

Annual Effective Rainfall: 345 mm. The annual effective rainfall (or potential recharge) is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore 820-475 = 345 mm/year.

See also Section 10 on recharge which estimates the proportion of effective rainfall that enters the aquifer.

7 Geology

This section briefly describes the relevant characteristics of the geological materials that underlie the area surrounding the GWS. It provides a framework for the assessment of groundwater flow and source protection zones. The geological information is based on:

Table 1: Well Details

	BH1	BH2	BH3
Reporting code	2100PRI3001 (one code for whole scheme)		
Groundwater body	EA_G_029_15_002	EA_G_029_15_002	EA_G_029_15_002
Grid reference	E309123 N277107	E309123 N277110	E309156 N277131
Townland	Yellowbatter	Yellowbatter	Yellowbatter
Source type	Borehole	Borehole	Borehole
Drilled	1992	1992	2005
Owner	Ballymakenny GWS	Ballymakenny GWS	Ballymakenny GWS
Elevation (Ground level - GPS)	c. 33 mOD	c. 33 mOD	c. 32 mOD
Total depth	Unknown (50+ m)	Unknown (50+ m)	75 m
Construction details	200 mm steel casing, presumably extending through till; borehole may have been constructed as an open borehole through limestone. No indication of a grout seal.	150 mm steel casing, presumably extending through till; borehole may have been constructed as an open borehole through limestone. No indication of a grout seal.	• 300 mm blind steel casing to 18.2 m, grouted in 375 mm nominal drilled diameter borehole; • 200 mm uPVC casing from 0.0-74.24 m; uPVC casing slotted from c. 22-24 m[1] and from 47-49 m and possibly other undefined depth intervals; • uPVC casing set in 300 m nominal diameter drilled borehole – pea gravel used in annular space from TD to 22.7 m; • Builder's sand plug apparently set above pea gravel from 22.7-20.0 m.
Depth to rock	Unknown (30+ m)	Unknown (30+ m)	36.4 m
Static water level (mbgl) at time of drilling	c. 10 mbgl	c. 10 mbgl	c. 10 mbgl
Pump intake depth (mbgl)	c. 34.1	c. 30.5	c. 60
Current abstraction rate: (GWS records)	Total estimated average in 2010[2] = 1,100 m^3/day. Reduction in total abstraction expected in 2011 to c. 600 m^3/d.		
Reported yield (m^3/d)	Information not available (n/a)		330
Estimated specific capacity (m^3/d/m)	96[3]	n/a	32[4]
Estimated transmissivity (m^2/d)	133[5]	n/a	44[5]

Note:
1 - BH3 pumps water from a limestone aquifer but also from a sand layer between 22.7-24.0 m (i.e. within the glacial till sequence).
2 – As the main well, BH1 is assumed to pump approximately two-thirds of the total in a day.
3 – Roughly estimated from transducer data of water levels and assumed abstraction rate from BH1 on August 23, 2010 (see Section 8.4).
4 – Estimated from information received from test pumping contractor.
5 – Calculated from specific capacity data, applying the Logan approximation for confined aquifers.

- Geology of Meath. Bedrock Geology 1:100,000 Scale Map Series, Sheet 13. Geological Survey of Ireland. (McConnell, Philcox, and Geraghty, 2005).
- Report 'Water Supply for a Proposed Development, Drogheda, Co. Louth' (O'Neill Groundwater Engineering, 2007)
- Borehole log of BH 3, obtained from Patrick Briody and Sons Ltd (well drillers of BH3).
- GSI well and karst database.
- Bedrock and subsoil exposures noted during site visits.

7.1 Bedrock

As shown in **Figure 3**, the area surrounding the GWS is underlain by limestone bedrock of Lower Carboniferous age, classified by the GSI as Dinantian Pure Bedded Limestones of the Tullyallen Formation. According to GSI mapping, these dip gently (< 20 degrees) to the south/southwest, with an approximate east-west strike. The Tullyallen Formation limestones are bounded to the north by Silurian metasediments and volcanics (belonging to the Glaspistol Formation). These rocks are tectonically juxtaposed by the Slane Fault which trends in an ENE-WSW direction.

Less than 1 km to the west of the GWS, a younger cross fault intersects the Slane Fault, trending in a NNW - SSE direction. Further west still, to the west of the Mell quarry, a similar cross-fault throws the Tullyallen Formation against the stratigraphically younger Platin Formation (a hydrogeologically similar limestone which extends south of the Boyne River). The faulting, notably the cross-faulting, may be significant in terms of groundwater movement in the area, as they likely impart enhanced fracture permeability on the limestone aquifer.

There are few bedrock outcrops in the immediate vicinity of the GWS. The nearest, clearly exposed limestones are found in the disused Mell quarry approximately 2 kms to the southwest of the GWS. The bedrock walls of the quarry show strong vertical jointing and incorporate clay-infilled collapse structures and solution cavities. Logs from two boreholes drilled into the Tullyallen Formation to depths of 54 and 72 m in the same area also report cavities accounting for approximately 10% of the total rock penetration (NERDO, 1981). There are no other signs of karst features at the surface in the immediate vicinity of the GWS, mainly because subsoils in the region are thick (see below) and therefore mask the potential presence of karst features in the subsurface.

Although sketchy, the geological log for BH3 (**Appendix 1**) does not suggest that solution cavities were encountered during drilling, describing the limestone as either "competent" or "fractured". Highly weathered and fractured limestone is described in the top 10 m of bedrock with additional fractured intervals (with water strikes) at 48, 58 and 60 mbgl.

7.2 Subsoils and soils

Subsoils comprise glacial tills of different types. As shown in **Figure 4,** the till in the upgradient catchment of the GWS are derived from Lower Palaeozoic shale and sandstones (TLPSsS). Closer to Drogheda and along the Boyne Valley, subsoils consist of the Irish Sea Till, derived from Irish sea basin deposits. The borehole log of BH3 at the GWS indicates "hard boulder clay" to 40 feet (12.2 m) with "tight clayey sand" from 40 to 70 feet (12.2 to 21.3 m) and "very hard clay" to 120 feet (36.6 m). Tills that are exposed in local field drains around the GWS have a characteristic clay-based matrix with variable proportions of sand, silt and cobbles.

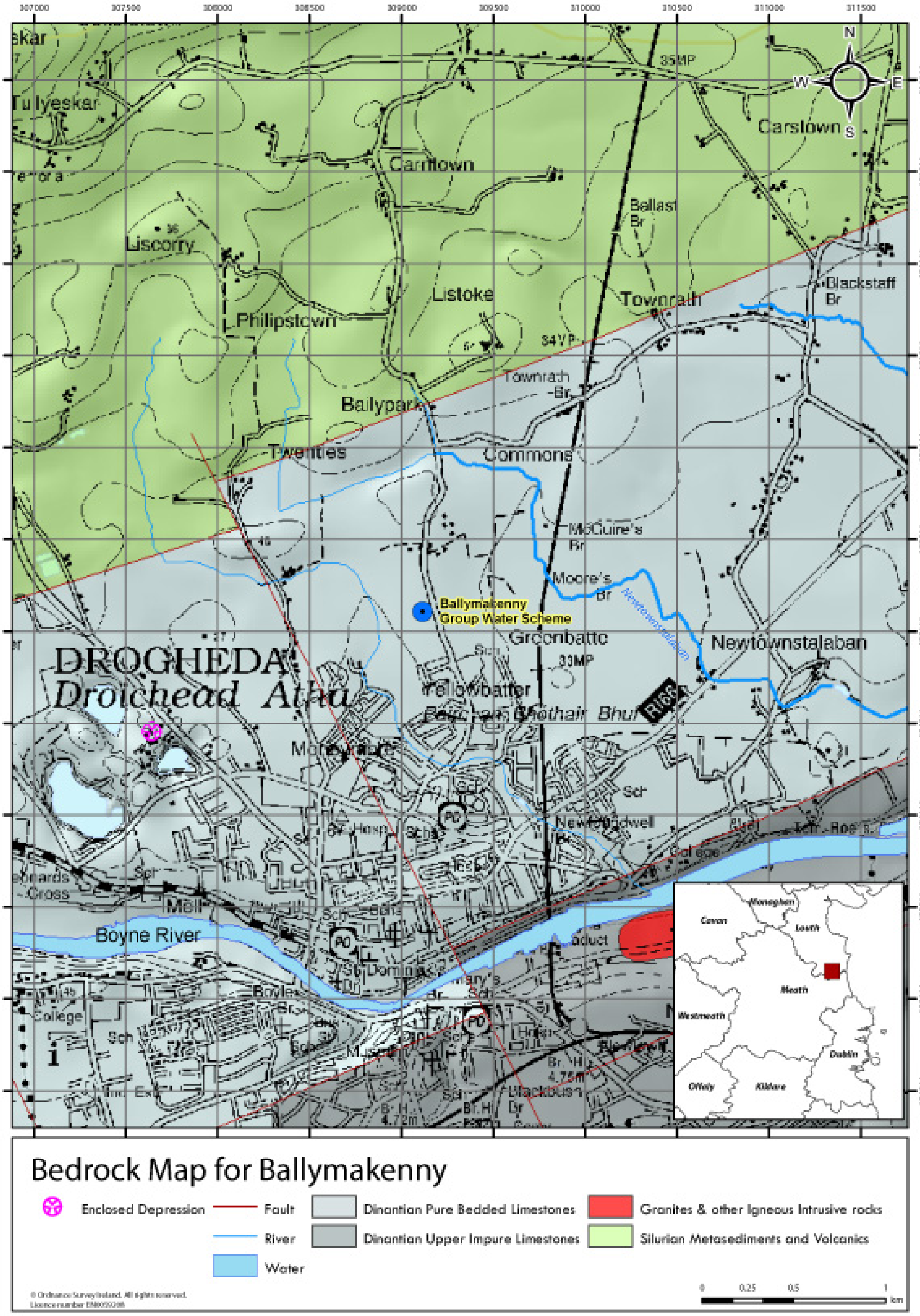


Figure 3: Bedrock/Rock Unit Map

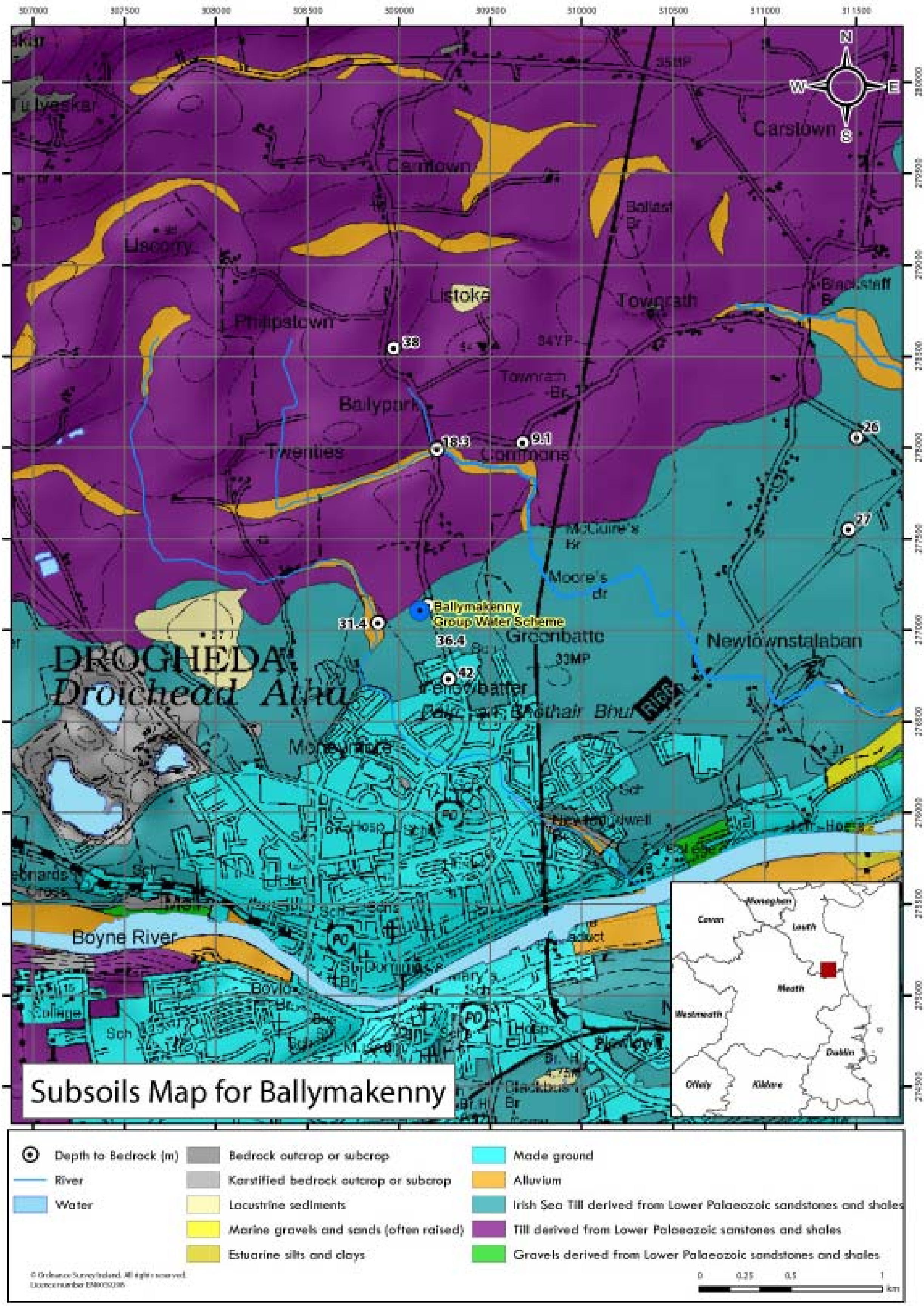


Figure 4: Subsoils Map

More sandy, alluvial-type deposits occur in localised areas along the streams and field drains to the north and east of the GWS. As part of the groundwater vulnerability mapping by the GSI across County Louth, subsoil (till) permeability has been classified as 'Low" and "Low/Moderate".

One isolated pocket of lacustine clay-sediments occurs to the west of the source, in a topographic depression immediately to the northeast of Mell Quarry.

Mapped soils in the area, **Figure 5**, consist primarily of poorly drained mineral soils (AminDW) derived from the underlying low-permeability glacial till. The town of Drogheda is characterised by "made" ground (natural soil altered, partly with fill materials).

7.3 Depth to bedrock

The depth to bedrock in borehole BH3 is 36.4 m. As indicated in **Table 2** and on **Figure 4**, other boreholes drilled in the vicinity of the GWS indicate a depth to bedrock ranging between 9 and 42 m.

Table 2: Depth to Bedrock Information

Ref.		Location		Coordinates	Use	Bedrock Depth (m)
Ballymakenny BH3		Ballymakenny source		E309156 N277131	GWS	36.4
Louth Co Co	71507	Side gradient	250 m to the west	E308884 N277037	Trial well	31.4
Meath Co Co	TW6 (C2)	Upgradient	900 m to the north	E309206 N277986	Trial well	18.3
Meath Co Co	TW7 (C2)	Upgradient	1,000 m to the northeast	E309676 N278022	Trial well	9.1
Meath Co Co	TW11 (C1)	Upgradient	2,300 m to the northeast	E311455 N277548	Trial well	27
Meath Co Co	TW12 (C1)	Upgradient	2,500 m to the northeast	E311501 N278050	Trial well	26
GSI	2927SEW068	Upgradient	1,400 m to the north	E308970 N278540	Trial well	38
GSI	2927SEW053	Downgradient	400 m to the south	E309270 N276730	Industrial	42

There are few bedrock outcrops anywhere within the topographic catchment of the GWS. The nearest exposed bedrock is at Mell Quarry to the SW of the GWS (labelled on **Figure 1**) and at Townrath, some 2 km to the NE of the GWS.

7.4 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target', which in the case of the GWS means that vulnerability relates primarily 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).

A draft groundwater vulnerability map for Co. Louth has been developed by the GSI. As shown in **Figure 6**, the vulnerability in the region surrounding the GWS is "Low" on account of the thickness and generally low permeability nature of the till. Where bedrock is exposed (e.g., Mell quarry), or where subsoils become thinner (e.g., hilly areas to the north), vulnerability increases, with such areas mapped as high to extreme groundwater vulnerability.

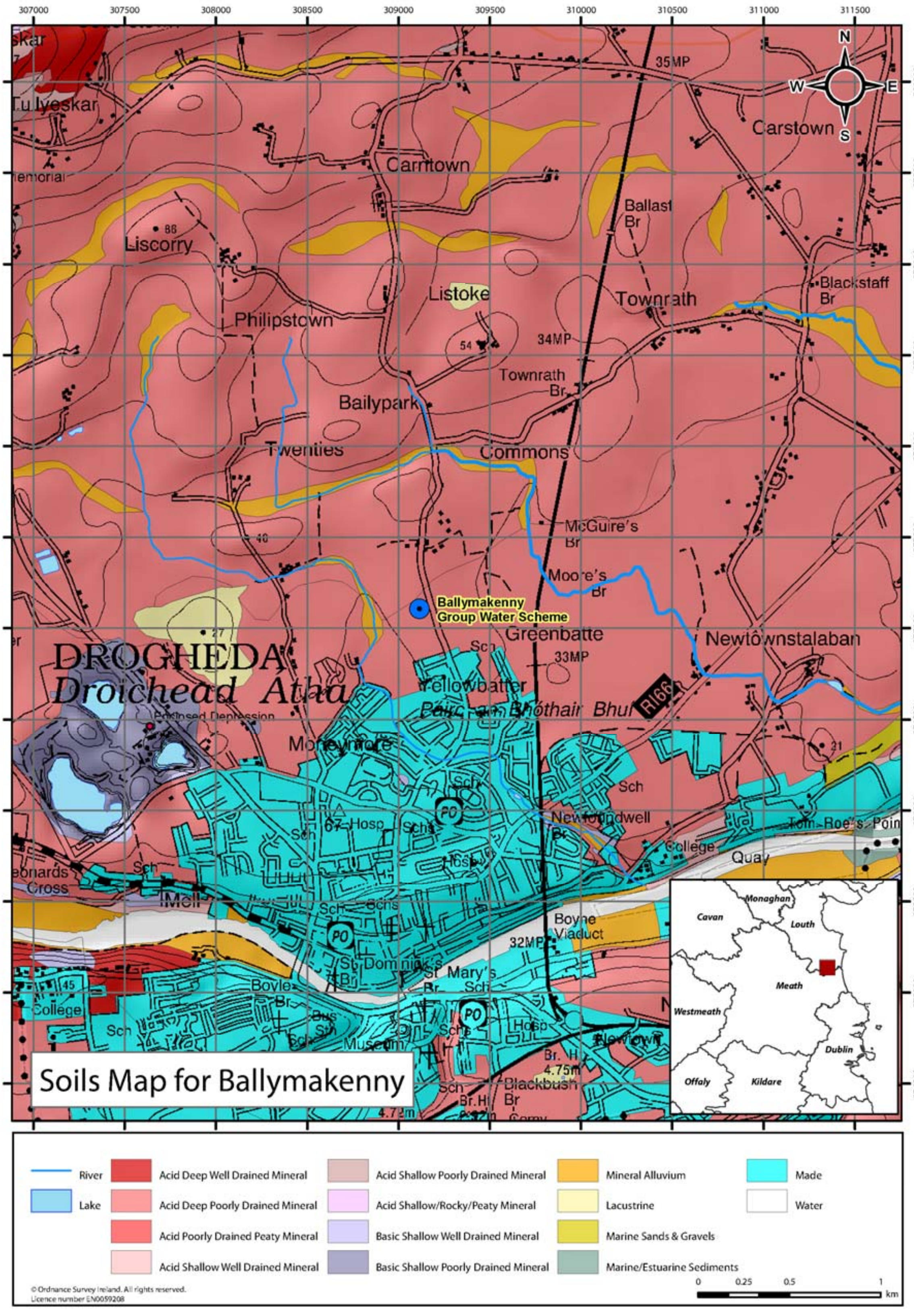


Figure 5: Soils Map

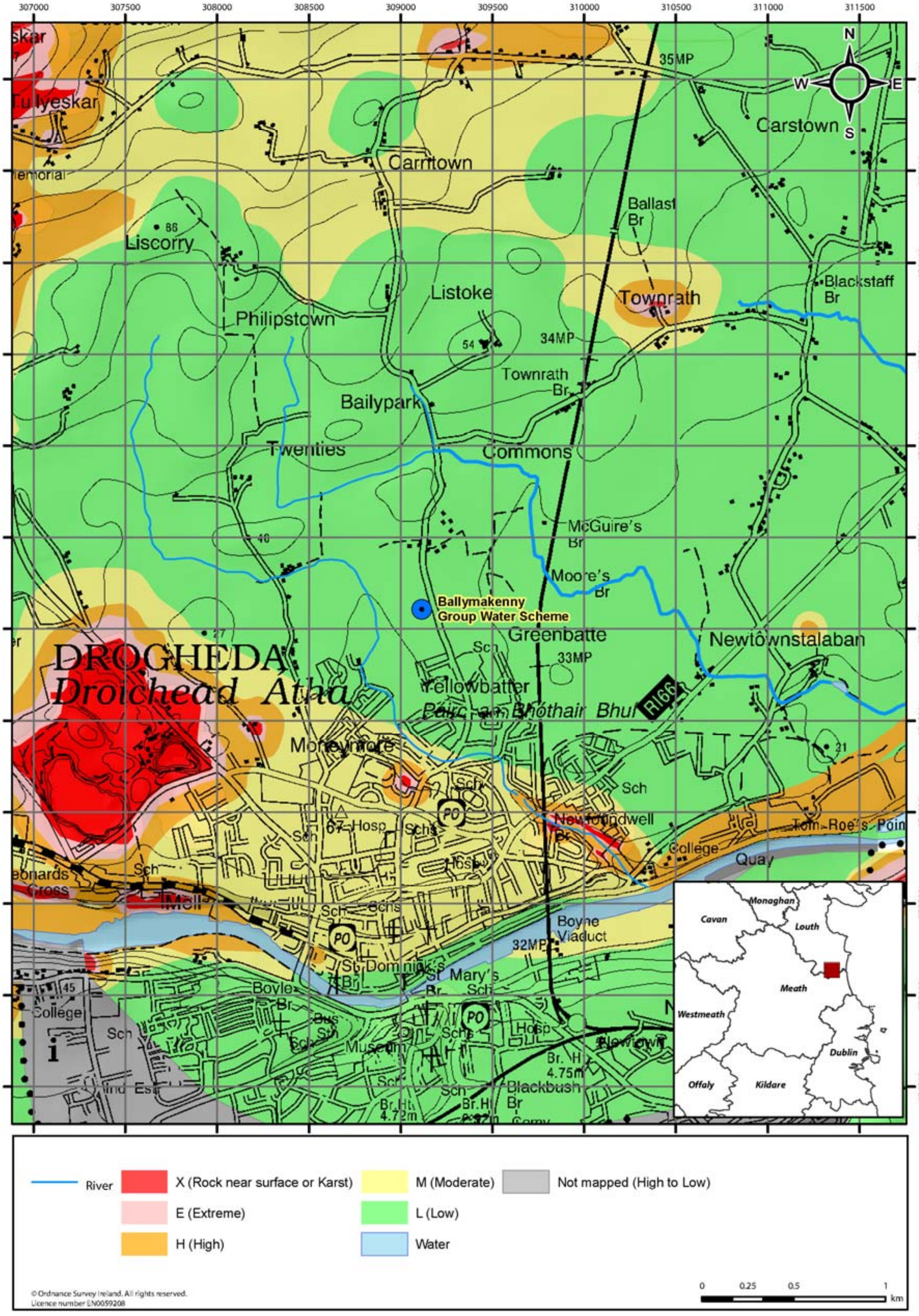


Figure 6: Groundwater Vulnerability Map

8 Hydrogeology

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

- GSI and EPA websites and databases;
- County Council Staff and drinking water returns;
- Met Eireann rainfall and evapotranspiration data;
- Reports: NERDO (1981), McCarthy Tobin (2009), Atkins (2000), and O'Neill (2007).

8.1 Groundwater body and status

The Ballymakenny GWS is located marginally within the footprint of the Drogheda Urban groundwater body (GWB). This GWB is bordered to the east, south and west by the Drogheda GWB and to the north by the Wilkinstown GWB. The Drogheda GWB has been classified as being of "Poor" status on account of elevated concentrations of phosphorus (molybdate reactive phosphorus, MRP). In contrast, the Drogheda Urban and Wilkinstown GWBs are classified as being of "Good" status. Individual GWB descriptions are available from the GSI website: www.gsi.ie and 'status' descriptions are obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

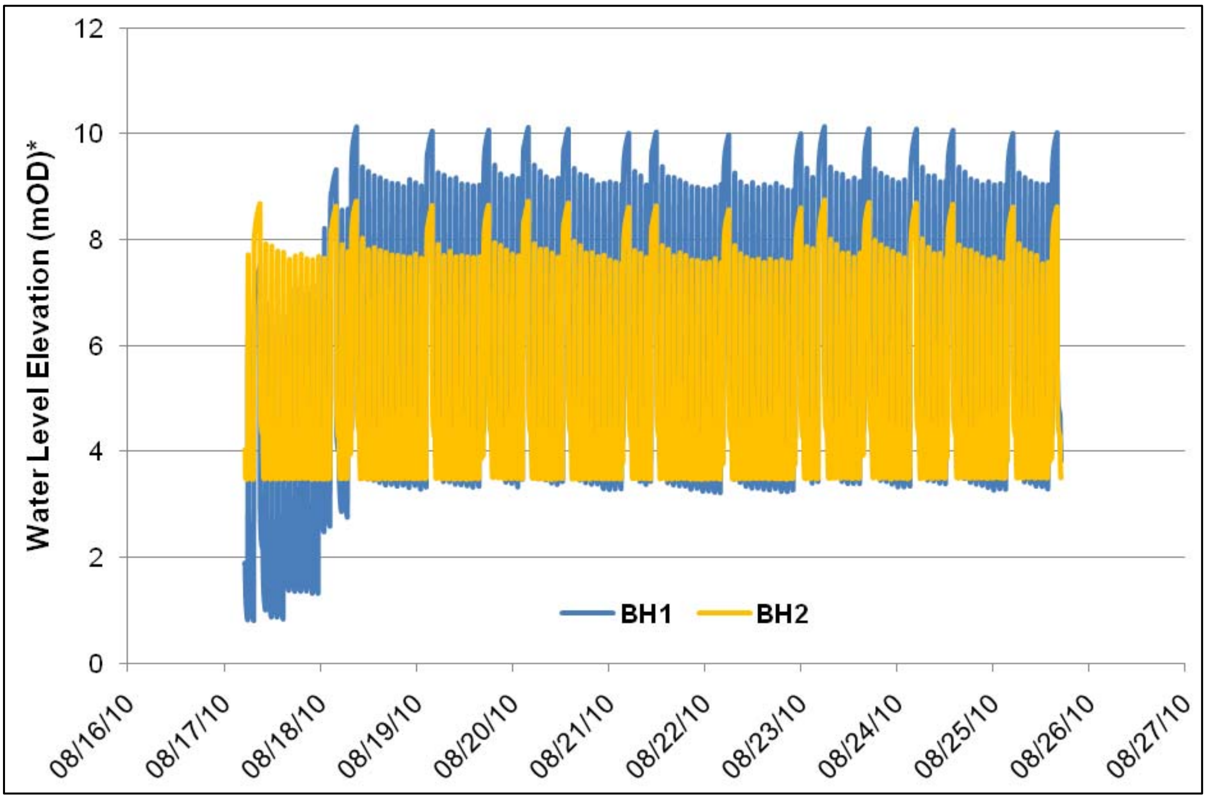
8.2 Groundwater levels, flow directions and gradients

During a site visit on August 13th 2010, measured pumping water levels in boreholes BH1, BH2 and BH3 were 28.73, 29.81 and 24.25 m bgl, corresponding to approximate elevations of 4.27, 3.19 and 7.75 mOD, respectively. At the time of measurement, the combined abstraction from boreholes BH1 and BH3 was 970 m^3/day.

To measure the hydraulic response to pumping at the GWS, water levels were measured continuously in boreholes BH1 and BH2 between August 17 and 25, 2010. Attempts to lower a pressure transducer in BH3 were unsuccessful due to insufficient clearance in the borehole. **Figure 7** shows the measured response in BH1 and BH2 for the one-week period. Heads of water above respective pressure transducers were converted to elevations in order to depict the pumping water levels in relation to mean sea level. The water levels are shown as elevations, referenced to Ordnance Datum (as metres OD, or mOD). It should be noted, however, that because the wellheads and the reference points used have not been accurately surveyed, the elevations shown are approximations and are probably correct to within 0.5 m.

Water levels in BH1 fluctuated between approximate elevations 10 mOD and 3.5 mOD, and the total drawdown is roughly 6.5 m for each pumping cycle. The corresponding water levels in idle well BH2 ranged between 8.5 and 3.5 mOD, for a total drawdown of 5 m in each pumping cycle. These drawdowns do not represent full ranges of water level changes as the full recovery responses are interrupted during each cycle. Extrapolations of the asymptotic drawdown and recovery curves indicate that the range would be closer to 10 m in BH1 if the borehole was allowed to fully recover.

During August 17 (first day of continuous monitoring), it is noted that measured water levels in BH1 are slightly lower than on August 18 and subsequent days, which could suggest that the wells were pumping at higher rates on August 17 than on August 18. However, BH2 does not show a similar response. The available pumping records are not sufficiently detailed to verify if a reduction in abstraction took place, and the initial data therefore have to be regarded with care. The caretaker believes the pumping in mid- to late-August was relatively stable, around 980 m^3/d. It is noteworthy that the relative magnitude of drawdown during pumping cycles on August 17 and 18 are similar, which would not be expected if there was a big change in pumping rates between the two days.



**- approximate*

Figure 7: Measured Water Levels in BH1 and BH2, August 17-25, 2010

Figure 8 shows a close-up of the measured data for the two-day period of August 22 and 23, 2010. The close-up demonstrates how the pump in BH1 trips on/off every 1.5 hours, which suggests a very inefficient pumping operation (note - the pump in BH3 burnt out on August 27).

Both BH1 and BH2 show a consistent hydraulic response to pumping. Each pumping cycle includes an initial drawdown, followed by a sudden flattening of water levels, followed again by a second phase of drawdown. Highlighted in **Figure 9**, this produces a "stepped" appearance of the measured water levels. In BH1, the step occurs at an approximate elevation of 4.2 mOD (equivalent depth of c. 28.4 m bgl). The precise cause for this characteristic response is not known. The sudden flattening could indicate that a source of water becomes readily available (karst conduit?). The second drawdown phase is likely caused by BH3 whose pump kicks in slightly later than BH1. It is not believed to represent dewatering of a water-bearing fracture or conduit. Unfortunately, borehole construction logs are not available for BH1 and BH2. In nearby BH3, the corresponding elevation occurs within a blind section of casing through glacial till.

A regional groundwater level map was produced for the Drogheda area in 1979 (NERDO, 1981). This map, reproduced in **Appendix 2**, shows a general flow direction from the north towards the Boyne River and its estuary. The reported water level near the Ballymakenny GWS was 12 mOD. From the interpolated positions of the 20 mOD and 10 mOD contours, the map suggests that a hydraulic gradient of approximately 0.01 can be expected under non-pumping conditions in vicinity of the GWS. An average value of 0.085 for the region was reported by NERDO. Based on an extrapolated rest water level in borehole BH1 of 11 mOD (from Figure 9) and an estimated groundwater elevation of 1 mOD for the Boyne River some 1.5 km to the south, the hydraulic gradient between the GWS and the river is approximately 0.007. The actual gradient in the active groundwater system intersected by the boreholes in the GWS could potentially be very different from this, especially if karst exerts a hydraulic influence on the system. The NERDO reported gradient of 0.085 remains arguably the most "representative" average for the region, mainly because it is derived from regional data. .

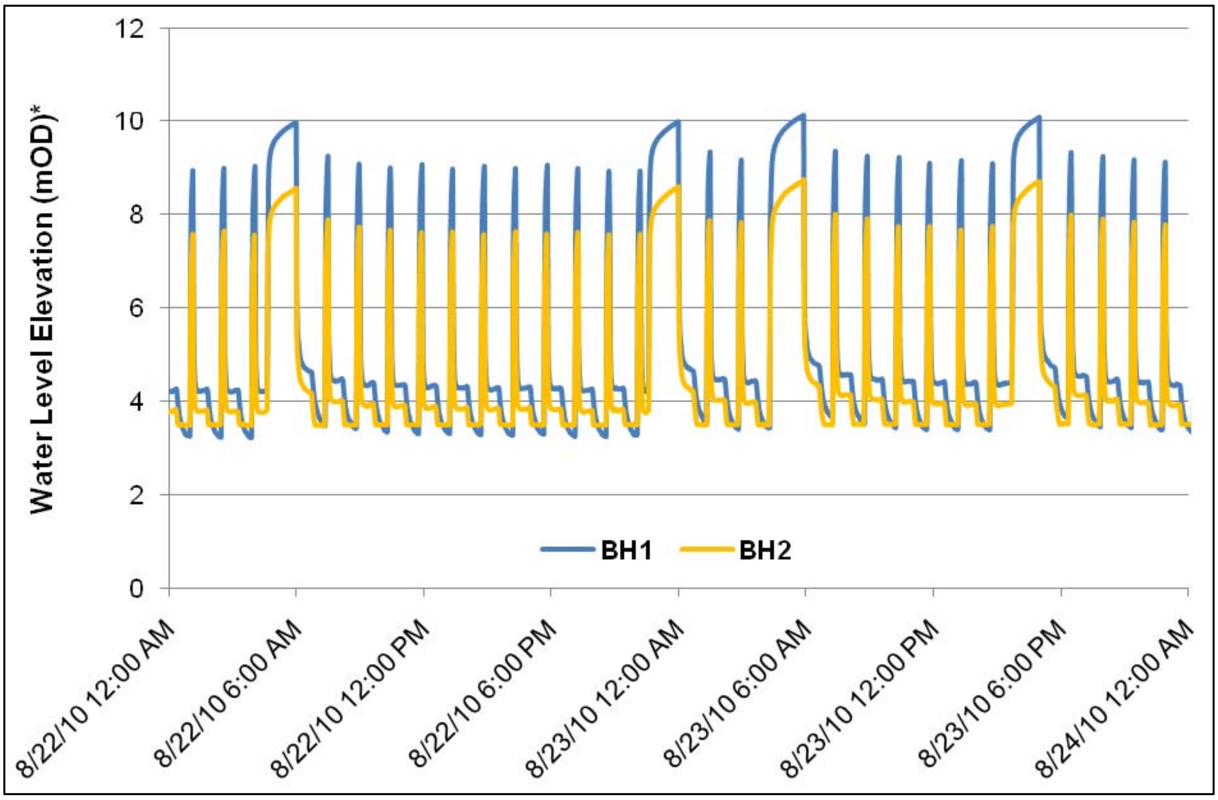


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Figure 8: Individual Pumping Cycles over a 48 Hour Period

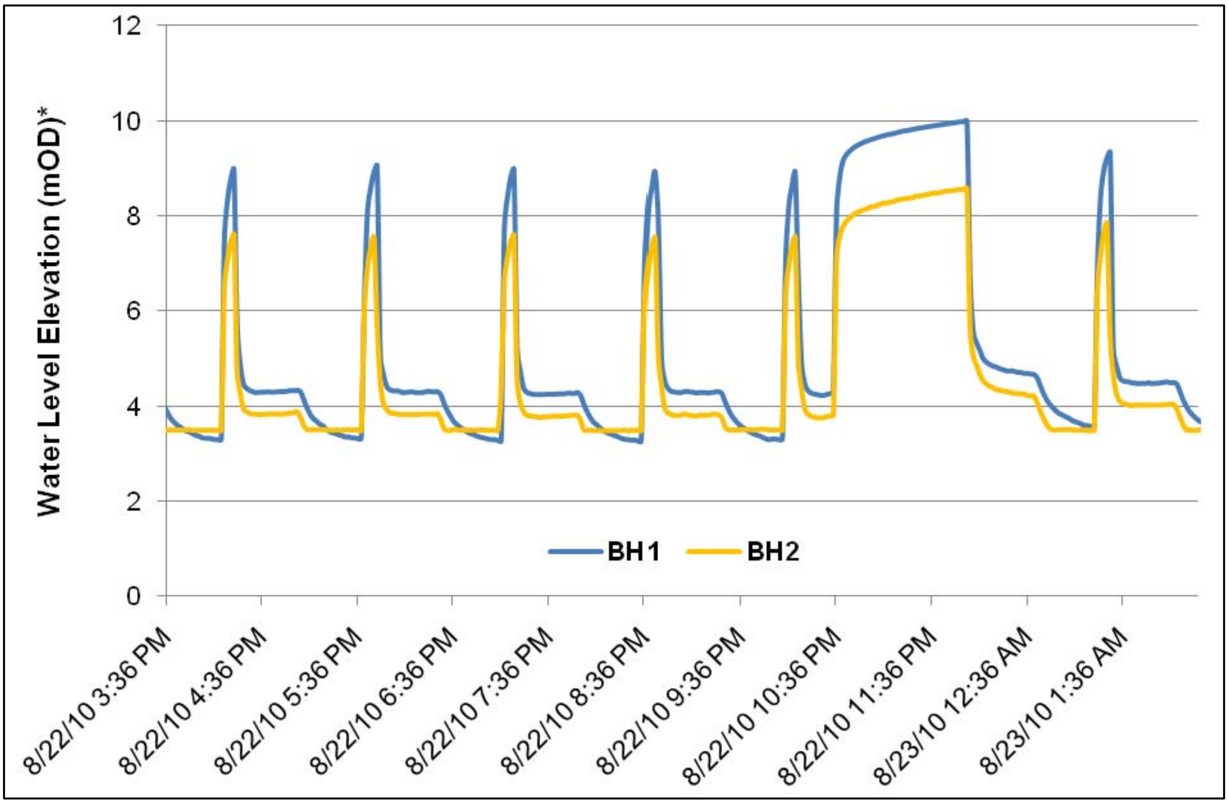

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Figure 9: Stepped Drawdown Response over a 10 Hour Period

It should be pointed out that the NERDO contour map for 1979 shows a water level at Mell Quarry of 8 mOD, reportedly influenced by dewatering operations at the time. Using a water balance approach, Conroy (2010) estimates that post-quarrying, it would have taken up to 13 years to recover to pre-pumping water levels in the quarry pits (assuming that no groundwater inflow or outflow from the pits occurred during the water balance period). Supported by hydrograph data from borehole PWSBH1 at Drybridge, less than 1 km west of the quarry, Conroy further demonstrates that the water levels in the quarry may exercise a regional control on groundwater levels in the limestone aquifer in the Drogheda area. This is of significance to the Ballymakenny GWS, and the present role of the quarry pits as a potential groundwater divide is further described in Section 10.

There are no large springs along the Boyne River, and it is possible that groundwater from the limestone aquifer discharges diffusely into and through the overlying tills and river gravels, or emerges as subsea groundwater discharges (SGDs) in the estuary. The cross-faults referred to in Section 7.1 may also exert a hydraulic influence on groundwater levels, especially if they act as hydraulic sinks, channelling groundwater towards the Boyne River.

8.3 Hydrochemistry and water quality

The Ballymakenny GWS has been monitored by the EPA since 1993, and was included in EPA's national WFD monitoring network in 2006 as an operational groundwater monitoring point (due to the poor status classification of the Drogheda GWB mentioned earlier). The current sampling point is from the holding tank which contains the combined supply of water from BH1, BH2 and BH3. Based on the treatment history of the water in the holding tank, water samples pre-2008 represent post-treatment water, whereas testing of untreated water only commenced in 2008.

Existing laboratory results have been compared to these thresholds or standards: EU Drinking Water Council Directive 98/83/EC Maximum Admissible Concentrations (MAC); the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were recently adopted in Ireland under S.I. No. 9 of 2010. The data are summarized graphically in **Figures 10 to 13**, representing 38 samples in total. Results are highlighted as follows:

- The water is moderately hard to hard (average 244 mg/l $CaCO_3$). The average field conductivity is 546 µS/cm and the average pH is around 7.3. The hydrochemical signature of the water is calcium bicarbonate.

- There were no faecal coliforms recorded in any of the water samples to date.

- There are no ammonium concentrations greater than EPA's status Threshold Value of 0.175 mg/l. Ammonium concentrations post-2006 appear slightly elevated compared to detections pre-2006, but this is believed to be a result of changing analytical protocols with the start-up of EPA's WFD-related monitoring programme at the end of 2006.

- The concentration of nitrate (as NO_3) ranges from 1.7 mg/l to 6.33 mg/l with a mean of 3.66 mg/l. These values are well below the groundwater quality standard of 50 mg/l or the EPA status Threshold Value of 37.5 mg/l. Low nitrate concentrations in a confined aquifer may suggest that denitrification is taking place.

- Chloride concentrations range from 16 mg/l to 38 mg/l with a mean of 22 mg/l which is marginally below EPA's status Threshold Value of 24 mg/L for "Good" chemical status. Given the proximity of the GWS to the coast, and the fact that chloride is a conservative (non-reactive) substance, the chloride concentrations are most likely natural in origin (i.e. chloride is present in rainwater given the proximity to the sea). There is no sustained upward trend in measured concentration.

- The sulphate, potassium, sodium, magnesium and calcium levels are within normal ranges. The potassium/sodium ratio is low at less than 0.1. The concentration of iron and manganese is also within normal ranges. The concentration of all other trace metals are low and/ or below laboratory detection limits. The concentrations of all organic compounds to date are also below respective laboratory limits of detection.

- The mean concentration of Molybdate Reactive Phosphate (MRP), or orthophosphate, is 0.065 mg/l (as P), which exceeds the EPA status Threshold Value for "Good" groundwater status of 0.035 mg/l P. The orthophosphate concentrations fluctuate significantly with a reported maximum of 0.13 mg/L.

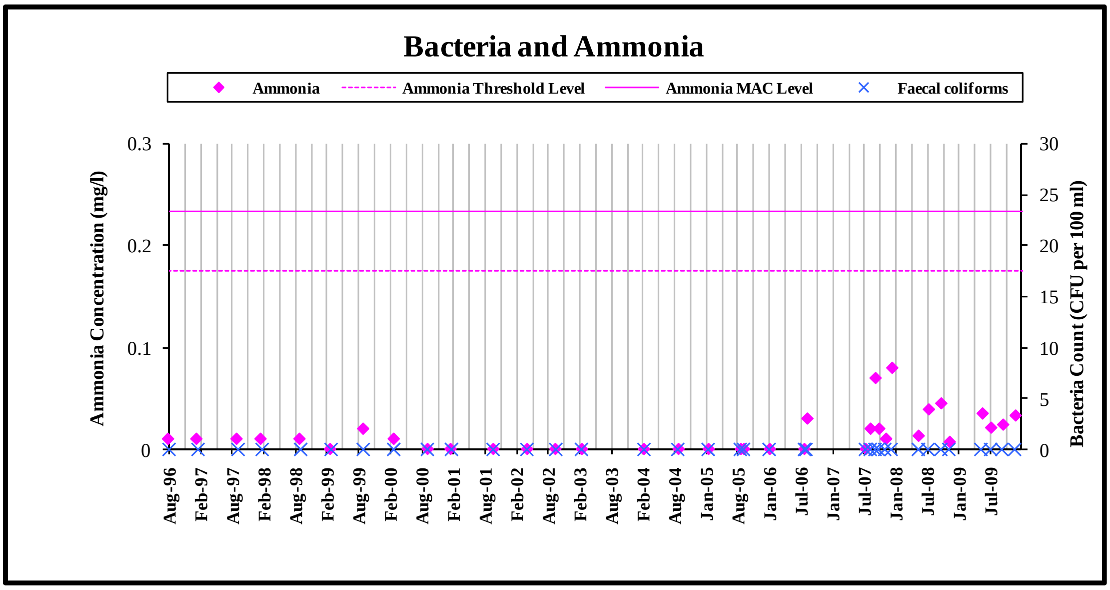

Figure 10: Bacteria Counts and Ammonium Concentrations at the Ballymakenny GWS

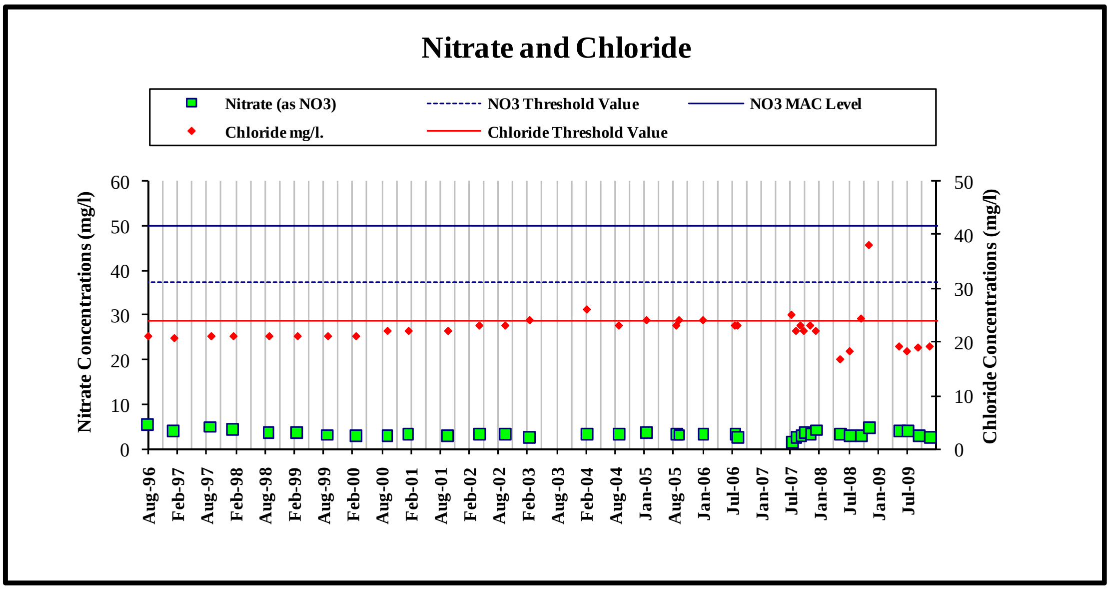

Figure 11: Nitrate and Chloride Concentrations from the Ballymakenny GWS

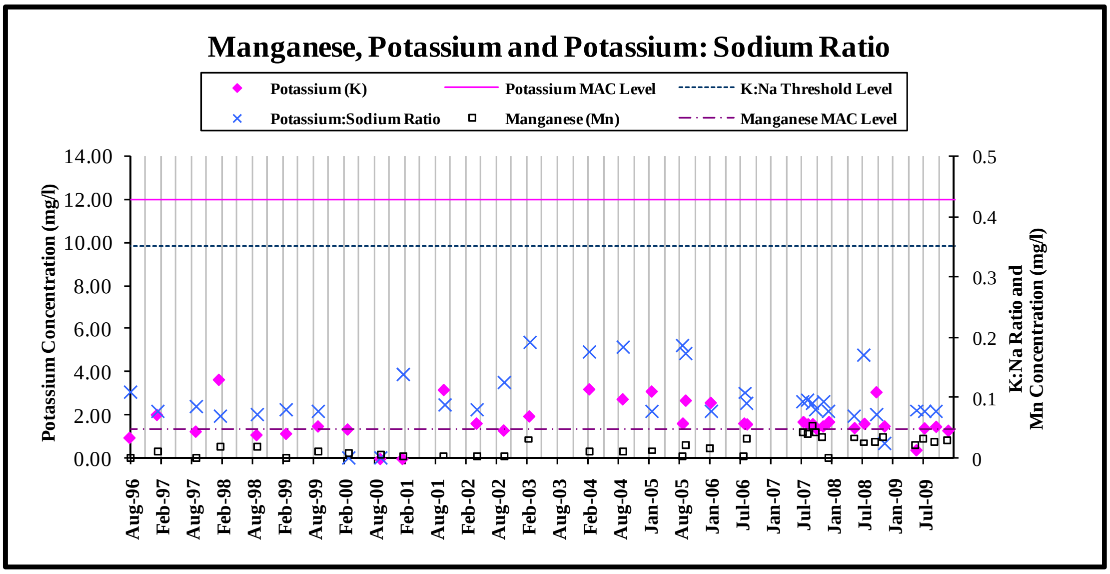

Figure 12: Manganese, Potassium and K/Na ratio at the Ballymakenny GWS

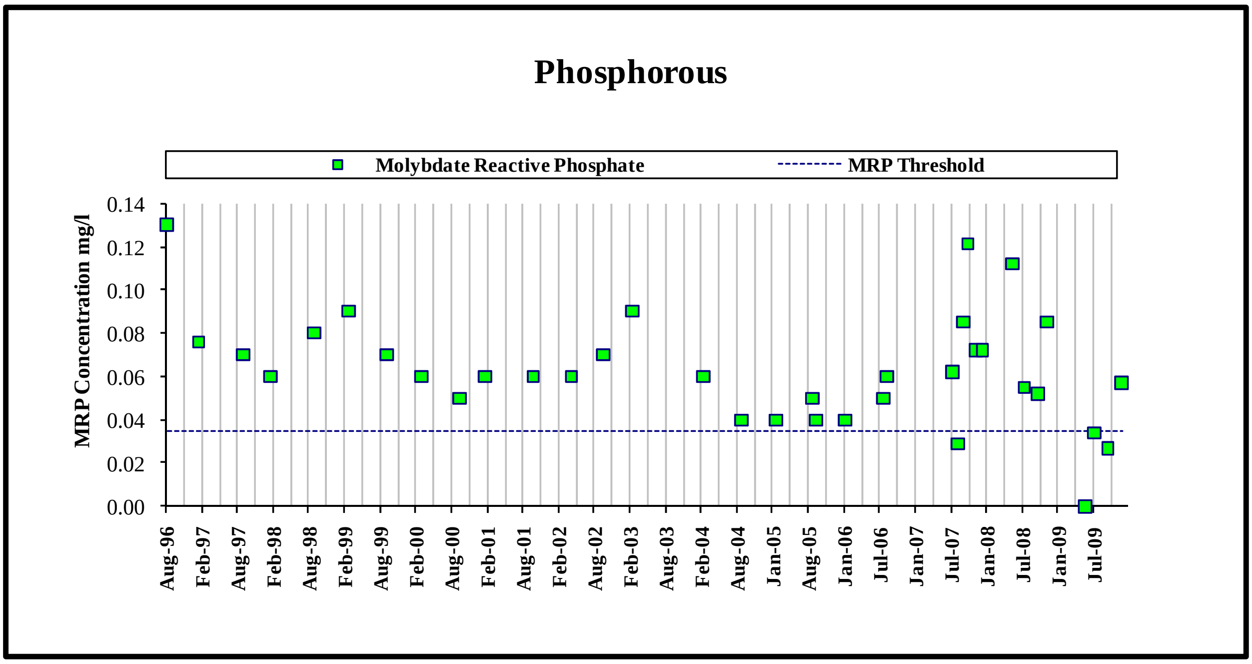

Figure 13: MRP Concentrations at the Ballymakenny GWS

There are no apparent correlations between orthophosphate to other pollutants, but the results are broadly mirrored in the supply well at Drybridge (Conroy, 2010) and trial well TW6(C2) located about 1 km north of the GWS in the same aquifer system. In trial wells TW11 and TW12, about 2.5 km east of Ballymakenny, orthophosphate concentration were lower during testing 2007, at approximately 0.02 mg/L, in the same aquifer (McCarthy/Tobin, 2009).

8.4 Aquifer characteristics

On the basis of regional mapping and general bedrock characteristics, the GSI has classified the limestones around Drogheda as an Rk_d aquifer – i.e. a regionally important karstified limestone aquifer in which groundwater flow is believed to be dominantly diffuse through fractures, fissures and joints rather than solution cavities and conduits. As indicated by **Figure 14**, the Rk_d aquifer is adjoined to the north by Silurian age bedrock which is considered a Pl aquifer – a poor aquifer, generally unproductive except for local zones.

The Rk_d aquifer in the region of the Ballymakenny GWS has been subject to several exploration drilling activities, including the East Meath, South Louth and Drogheda Water Improvement Scheme (McCarthy Tobin, 2009). Results of test pumping associated with relevant and known exploration activities are summarised in **Table 3**.

For the Ballymakenny GWS, pumping test data from the time of drilling and original testing of boreholes BH1 and BH2 have been researched but not obtained (found). Indicative results for BH3, as received from the test pumping contractor (Michael Kearney & Sons Ltd), are included in **Appendix 3**. BH 3 was pumped at 650 m^3/day for 72 hours. The pumping water level reportedly "levelled off" after only 2 hours at 43.6 mbgl Assuming a static water level of about 23 mbgl (elevation of 10 mOD, see Section 8.2), this corresponds to a specific capacity of 32 m^3/d/m of drawdown. The driller's estimated yield of BH3, from airlifting during well development, was reported as 330 m^3/day. The apparently quick levelling off of water levels described for BH3 hints at a response that is consistent with that described for BH1 in **Figure 9** earlier.

A proper pumping test on the GWS could not be conducted as part of this study, as pumping operations could not be interrupted and there was no immediate means of discharging the pumped water to waste.

Based on the operational data in Section 8.2, BH1 clearly cycles on/off several times in a day. Consistently, the water levels recovered to an approximate elevation of 9-10 mOD when the pump was shut off, and consistently, the water level was drawn down to an elevation of approximately 3.5 m OD during a one-hour pumping cycle. The drawdown over a single pumping cycle was about 6.5 m.

In late August, 2010, the approximate total abstraction rate for the GWS was 930 m^3/d. Of this volume, the caretaker estimates that two-thirds is abstracted from BH1. On this basis, the approximate specific capacity of BH1 is 96 m^3/d/m of drawdown. Applying Logan's approximation (for estimating transmissivity from specific capacity data in confined aquifers), the corresponding apparent transmissivity value for BH1 is 117 m^2/d. This value is considered a maximum given the fact that the hydraulic response and measured drawdown in BH1 is also a function of the water pumped from BH3, and the specific capacity represents only one hour of pumping and not a maximum, long-term drawdown (which Logan's approximation assumes). For this reason, a lower value of T is probably more representative for the limestone aquifer at Ballymakenny. From **Table 3,** the average T value of 70 m^2/d was selected.

The corresponding bulk permeability (K) of the aquifer can be estimated by dividing the transmissivity by the saturated thickness of the aquifer. The saturated thickness at BH1 is not known, but for calculation purposes, this is taken to be 50 m (which is the approximate water-producing depth interval of BH1, based on the log of nearby BH3). On this basis, the apparent bulk K is estimated to be 1.4 m/d.

Using the K value, the approximate velocity of water moving through the aquifer to the borehole can also be estimated from the following equation:

$$\text{Velocity (V)} = (\text{K x Groundwater Gradient (i)}) / \text{effective porosity } (n_e)$$

The natural gradient is approximately 0.0085 (Section 9.2) and the effective porosity is taken to be 0.02, a reasonable value for productive, fractured bedrock aquifers in Ireland. The bulk groundwater velocity is therefore estimated to be 0.6 m/d or 219 m/yr.

The estimated groundwater velocity range in the bedrock aquifer, based on the available data, is shown in **Table 4.** The 0.6 m/d derived above is a bulk average velocity for the aquifer, and it should be noted that velocities in fault zones or conduits may greatly exceed the calculated values.

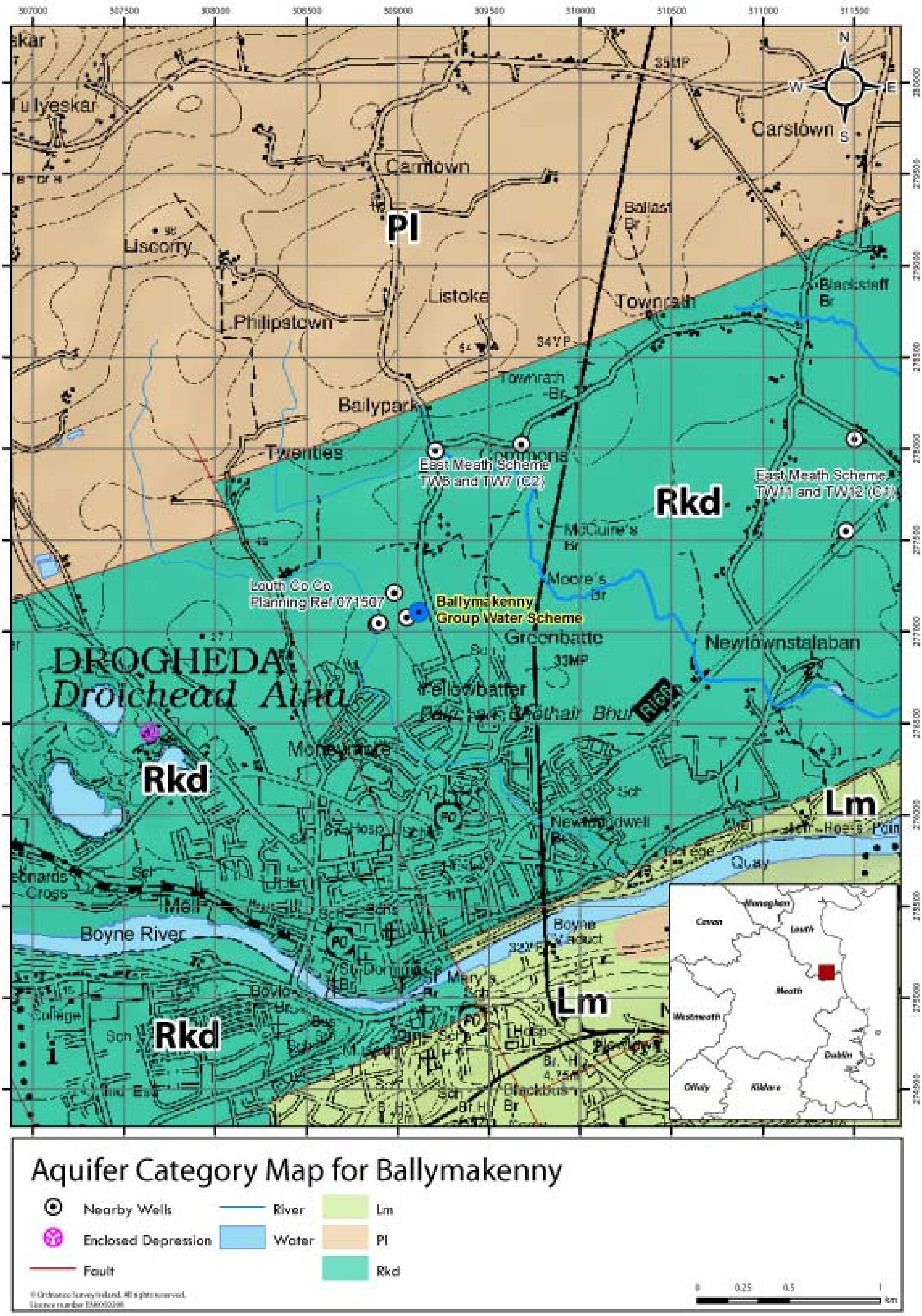

Figure 14: Aquifer Category Map

Table 3: Summary of Transmissivity Values from Wells in the North Drogheda Area

Trial Well/ Borehole	Location	Test Type	Reference	Reported Yield (m^3/d)	Reported Transmissivity (T) (m^2/d)	Reported Drawdown (m)	Estimated Specific Capacity (SC) ($m^3/d/m$)	Apparent T from SC (m^2/d)[1]
BH1	309123E 277107N	Operational data	CDM, 2010	--	--	--	96	117
BH2	309123E 277110N	--	--	--	--	--	--	--
BH3	309156E 277131N	72-hrs @ 650 m^3/d	Kearney, 2005	330	--	20.6[2]	32[2]	39
GW1	308884E 277037N	72-hrs @ 442 m^3/d	OGE, 2007	>442		4.5	99	121
Well 1	Mell quarry	--	GSI, 2008	1,600[3]	140	36[3]	44[3]	54
TW6 (C2)	308407E 273501N	Airlifting	McCarthy/Tobin, 2009	26	--	--	--	--
TW7 (C2)	307080E 277268N	Airlifting	McCarthy /Tobin, 2009	11	--	--	--	--
TW11 (C1)	311455E 277543N	24-hrs @ 1,690 m^3/d	McCarthy /Tobin, 2009	1,200 when pumping with TW12	--	29.6	57 (43)[4]	70 (53)[4]
TW12 (C1)	311501E 278057N	24-hrs @ 926 m^3/d	McCarthy /Tobin, 2009	500 when pumping with TW11	--	33.1	28 (20)[4]	34 (24)[4]

Note:
1 – Converted from Logan's approximation for confined aquifers;
2 – Estimated from pumping and drawdown information;
3 – From information reported by GSI (2008) - borehole yield of 1600 m^3/d estimated for a drawdown of 36 m;
4 – Values in parenthesis from 7-day dual well test of TW11 (@1,400 m^3/d) and TW12 (@ 600 m^3/d);

Table 4: Estimated Groundwater Velocity Range

Parameter	Units	Min. Input Values	Max. Input Values	Average	Comment
T	m^2/d	24	121	70	From Table 3
i	[-]	0.0071	0.01	0.0085	From NERDO (1981)
b	m	50	50	50	Average estimated from logs, plus approximate average reported in NERDO (1981)
n_e	[-]	0.01	0.03	0.02	Typical values for fractured bedrock in Ireland
v	m/d	0.34	0.8	0.6	Calculated

9 Zone of contribution

9.1 Conceptual model

Illustrations of the conceptual model of the Ballymakenny GWS are provided in **Figures 15 and 16.** The GWS includes three production wells pumped an average of 1,100 m^3/d in 2010. The wells produce water from a limestone bedrock aquifer which is classified by the GSI as a *Regionally Important Aquifer (Rk_d)*. The limestone aquifer is overlain and confined by glacial till which, in the immediate vicinity of the GWS, is nearly 40 m thick. There are three immediate implications:

- Streams in the vicinity of the GWS are unlikely to be in hydraulic connection with the limestone aquifer;
- The groundwater vulnerability in the area is “Low”; and
- Recharge to the limestone aquifer will be impeded, resulting in relatively low recharge rates across much of the study area.

The depth to the limestone aquifer decreases westward in the direction of the former quarry at Mell, approximately 2 kms west of the GWS. At Mell, the limestone aquifer is exposed at the surface and accordingly, groundwater vulnerability is mapped as “Extreme”. Karst features are visible on the disused quarry walls.

Since the quarry became inactive and dewatering activities ceased in 1979, groundwater levels in the pits have recovered to approximately 11 to12 mOD. This is of hydrogeological significance, as the filled pits may act as recharge mounds and, therefore, as hydraulic divides between the pumping operations at the GWS and the Drybridge public supply well to the west. Pumping water levels at the GWS are lower than the groundwater levels in the quarry pits, indicating an easterly flow component towards the GWS during pumping.

The regional and natural groundwater flow gradient in the limestone aquifer under non-pumping conditions is southerly towards the Boyne River and its estuary. Existing pumping water level data at the GWS indicate that a positive hydraulic gradient is maintained between the GWS and the estuary, even under pumping conditions. Groundwater is believed to flow predominantly through fractures and fissures rather than conduits and solution cavities. However, the potential presence and hydraulic influence of karst features in the immediate vicinity of the GWS cannot be ruled out.

Other features that may influence groundwater flow patterns and rates in the region are a series of faults that may enhance the fracture permeability of the limestone aquifer locally, whereby groundwater flow converges on the higher permeability zones. One such fault has been mapped by the GSI less than 1 km to the west of the GWS, trending NNW-SSE. If the zone of contribution (ZOC) of the GWS extends westward to include the fault, the higher permeability fault zone could act as a source of groundwater to the GWS (see Section 9.2).

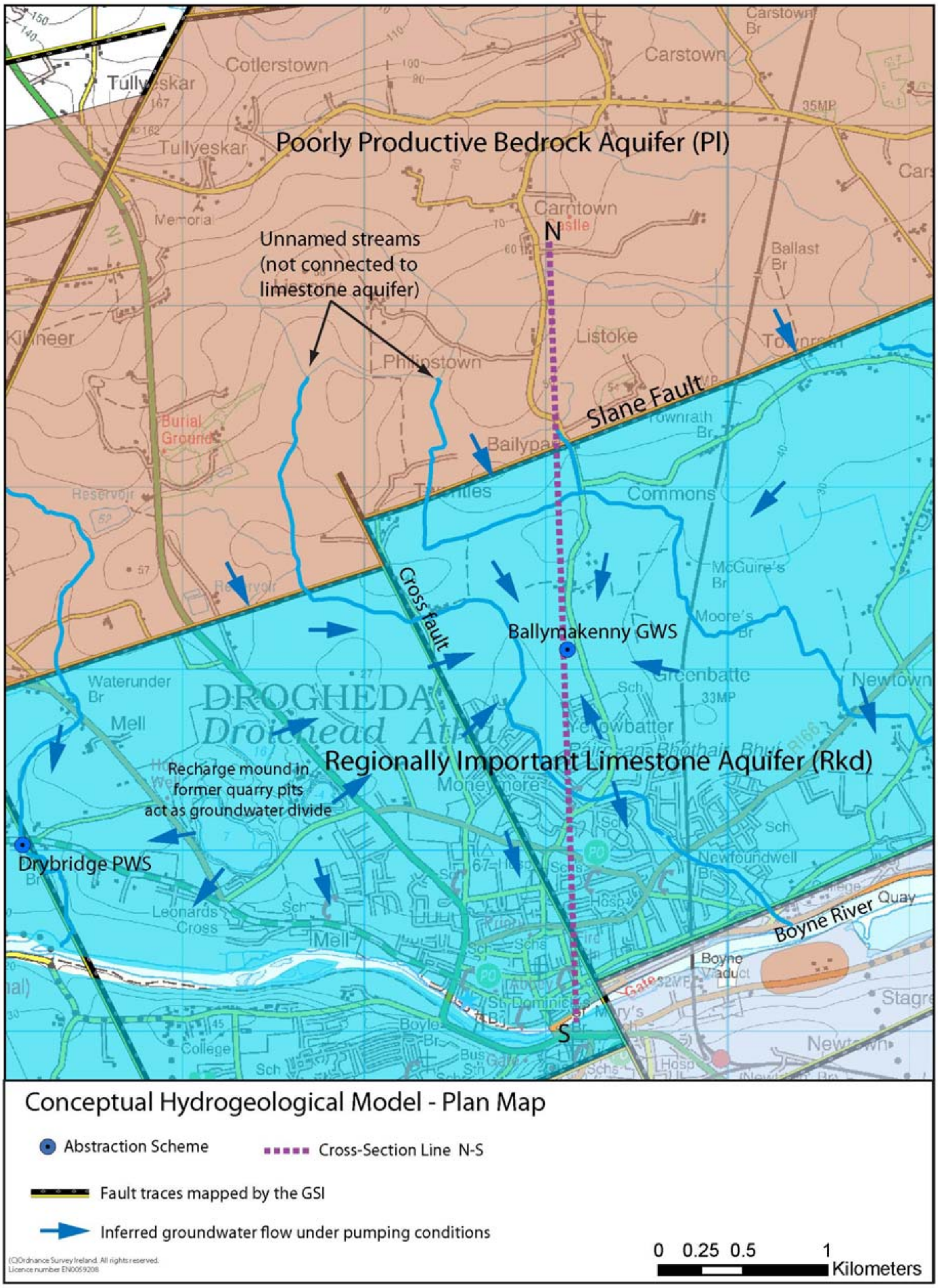

Figure 15: Conceptual Hydrogeological Model – Plan Map

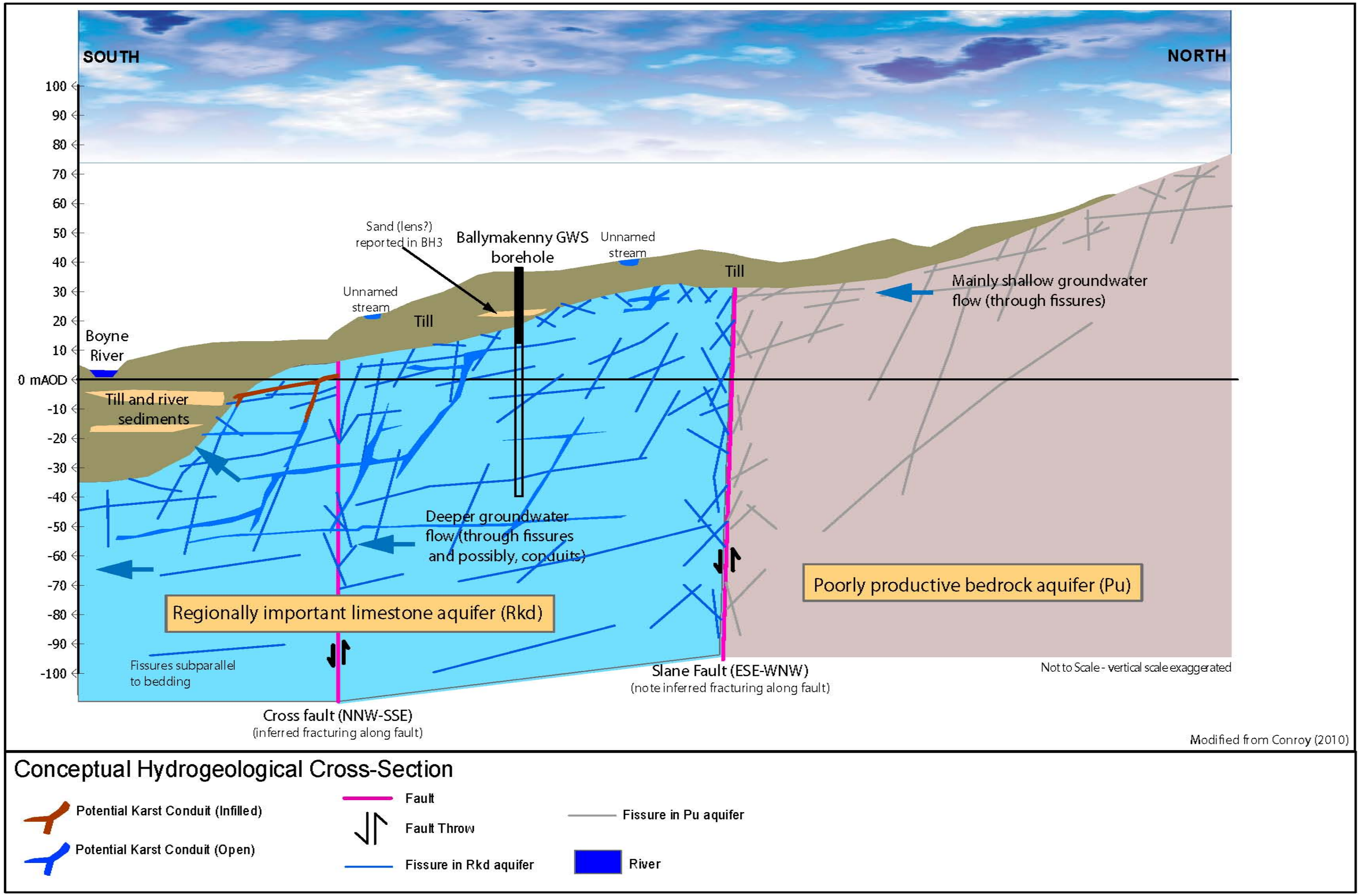

Figure 16: Conceptual Hydrogeological Model – Cross-Section

The combination of relatively high abstraction rates with relatively low recharge rates results in a ZOC that is appreciably large. The ZOC is constrained by the presence of poorly productive bedrock to the north. Runoff from the Wilkinstown GWB to the north of the GWS is expected to drain quickly to surface water courses due to the low permeability of the till cover and the Silurian bedrock aquifer. A very small component of groundwater from the Silurian bedrock aquifer is expected to discharge along (and into) the Slane Fault which subsequently passes into the Rk_d aquifer.

As the ZOC expansion is constrained to the north, the ZOC is interpreted to expand laterally to the east, west and south. Although evidential data do not exist, it is reasonable to infer that the groundwater mound at Mell acts as a recharge source for the GWS, directly or indirectly via the fault zone described earlier. As such, the mound can be considered to function more or less like a fixed head boundary.

An easterly flow component from Mell exists, but the relative quantity of water that flows towards the GWS is unknown. The quantity will depend on the degree of hydraulic connection between Mell and the GWS. If the aquifer transmissivity between the quarry and the GWS is small, the volumes of water transmitted would also be small, and visa versa. If karst conduits extend eastwards from the quarry, then the volumes transmitted could be significant. Unfortunately, there are no geological or groundwater data in the area between the quarry and the GWS that can directly prove or disprove the hydraulic connection between groundwater at Mell and the GWS.

9.2 Boundaries

The ZOC for the GWS is estimated using a water balance approach, i.e. by considering the recharge area needed to supply a volume of water equivalent to the abstraction rate of the GWS. Although the aquifer may in part be karstified, there is no direct means of verifying the extent to which karst features (notably conduits) are present and exerting hydraulic controls on groundwater flow patterns and rates. Given the Rkd designation of the regional aquifer, it is assumed, for the purpose of this report, that groundwater flow is primarily "diffusive" through fractures and fissures.

When delineating ZOCs, the GSI generally recommends that actual abstraction rates be increased by 50% to be conservative in the mapping. The 50% increase is intended to allow for variations in abstractions (e.g. increases in demand) and for the expansion of the ZOC during dry weather periods.

The ZOC for the Ballymakenny GWS is delineated on the basis of an expected abstraction rate in 2011 of 600 m^3/d in 2011, plus 50%, for a total abstraction rate of 960 m^3/d. At the beginning of February 2011, the reported abstraction rate was already lower at 640 m^3/d. Because the GWS is proven capable of pumping at rates in excess of 1,100 m^3/d (see **Figure 2**), the added 50% can be sustained. The recharge area required to supply 960 m^3/d from the GWS, based on a bulk annual recharge rate of 69 mm (see Section 10.3), is 5 km^2.

As a first approximation, the ZOC was delineated by applying the Uniform Flow Equation (Todd, 1980), as follows:

Width of upgradient boundary:

$$Y_L = Q / (2 * T * i)$$

where,

Y_L is the half-width of the upgradient boundary;

Q is the daily pumping rate (m^3/d);

T is Transmissivity (m^2/d); and

i is the non-pumping hydraulic gradient (m/m).

For the average transmissivity of 70 m^2/d and a gradient of 0.0085, Y_L is 807 m. For the range of transmissivity from 24 to 121 m^3/d indicated in **Table 3**, the corresponding range of Y_L would be 468–2,347 m.

Similarly, the maximum downgradient distance (X_L) that the borehole can pump water from under prevailing hydraulic gradients is defined by:

$x_L = Q / (2\pi * T * i)$ where Q, T and i have the same definition as above.

For the average transmissivity of 70 m^2/d and a gradient of 0.0085, X_L would be 257 m. For the range of transmissivity from 24 to 121 m^3/d indicated in **Table 3**, the corresponding range of X_L would be 148–750 m.

Delineating the ZOC on this basis captures a ZOC with an area of approximately 2.0 km^2, which falls significantly short of the area required to supply the target abstraction rate of 960 m^3/d (at 4.54 km^2). For this reason, the ZOC has to be expanded, and the expansion can only take place in three directions – east, west and south. The ZOC cannot be expanded in a northerly direction beyond its natural physical boundary which is represented by the poorly productive bedrock aquifer to the north of the Slane Fault.

The **northern boundary** is therefore considered to be Slane Fault which separates the Rk_d and Pl aquifers. The ZOC includes a buffer of 100 m into the Pl aquifer to account for a limited contribution from the Pl aquifer as well direct runoff from the Pl aquifer onto the Rk_d aquifer area (negligible overall contribution to the limestone aquifer).

The southern boundary is the approximate downgradient boundary of the ZOC as calculated from the Uniform Flow Equation. Minor adjustment of the downgradient extent was judged on the basis of the expansion of the eastern and western boundaries (described below). Further expansion south is possible but is not favoured overall because measured pumping water levels at the GWS during the dry summer or 2010 remained up to 3 metres above mean sea level. This infers that a southerly flow gradient from the GWS towards the Boyne River and its estuary is maintained, even under pumping conditions.

To accommodate the area required, the ZOC was mainly extended to the east and west as shown in **Figure 17**. The primary justification for this lies in the geology whereby the main geological structures (strike of bedding and faults) are oriented in an approximate east-west direction. Importantly, the **western boundary** was extended to include the cross-fault that runs NNW-SSE between the GWS and the disused quarry at Mell. This fault is likely to impart greater fracture permeability to the limestone aquifer and may act as a recharge source for the GWS. The path of the cross-fault is interpreted based on a few control points in the area, and it is possible that it could even pass closer to the GWS than indicated by existing mapping.

The ZOC has also been extended to the west beyond the cross fault to include the inferred groundwater mound at Mell. The groundwater levels in the pits are higher than the pumping water levels of the GWS. As such, the mound would represent a groundwater divide between flow to the east and flow to the west towards the Drybridge public supply well (note – the respective ZOCs of the GWS and the Drybridge public supply well (Conroy, 2010) do not overlap).

Whether and how far the ZOC should be extended to the west of the cross-fault is debatable. From a water balance consideration, recharge from the Mell area is helpful to satisfy the pumping rate at the GWS. The alternative is to extend the ZOC further south, which is not preferred for reasons described above. Incorporating the quarry pits is precautionary with respect to groundwater protection, as the quarry area is extremely vulnerable to groundwater pollution.

The adjusted ZOC boundaries describe an area of c. 5.0 km^2 which satisfies the water balance. The ZOC is large but reflects the low recharge that applies to the thick tills across much of the GWS catchment. The ZOC area could be reduced if karstic groundwater flow takes place, e.g. from the Mell area.

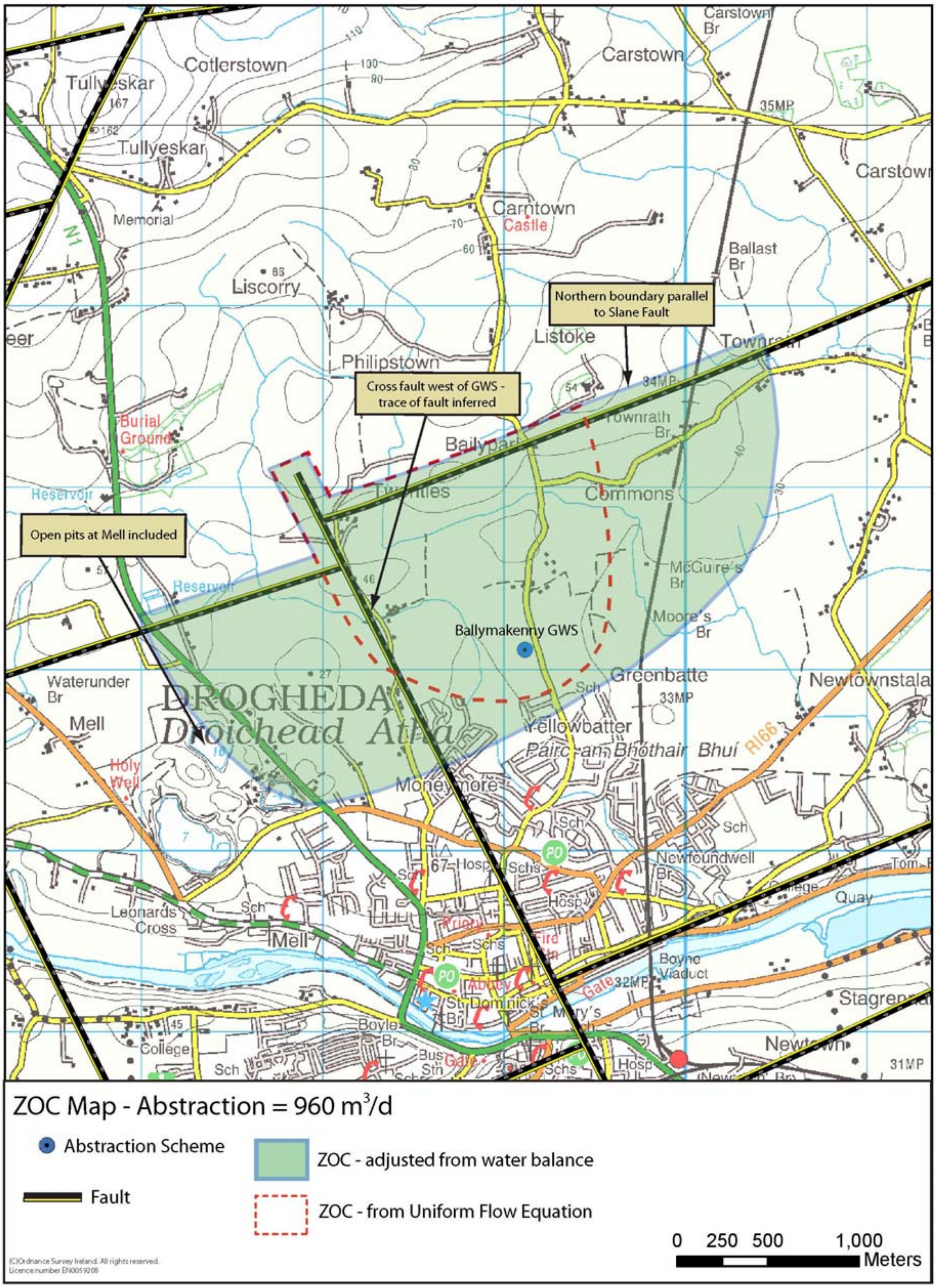

Figure 17: Estimated Zone of Contribution, Abstraction = 960 m^3/d

9.3 Recharge and water balance

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

At Ballymakenny, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient. The recharge coefficient is estimated using Guidance Document GW5 (Groundwater Working Group 2005). There are two primary settings involved:

- Low groundwater vulnerability across much of the study area, with generally low permeability subsoil and poorly drained soils, occasionally “cut” by alluvial sediments in narrow gullies along stream courses;.

- Rapid transition to Extreme (outcrops) groundwater vulnerability to the west-southwest of the GWS, at the disused Mell quarry pits (now filled with groundwater).

For the two “extremes”, recharge coefficients of 0.10 and 1.00 apply, respectively. Although there is a broad range of coefficients involved to account for variations in subsoil thickness, permeability and vulnerability, the largest area is represented by:

- Low vulnerability with a Moderate permeability subsoil (till) – 53% of total area; and

- Low vulnerability with a Low permeability subsoil – 22% of the total area.

For these two dominant scenarios, recharge coefficients of 0.15 and 0.10 were assigned respectively. Higher recharge coefficients apply for smaller areas towards the Mell quarry pits, with a coefficient of 1.0 applied where the limestone aquifer is exposed and filled with groundwater (Extreme vulnerability, X, applies to c. 5% of the total ZOC area). The overall bulk recharge coefficient for the ZOC is estimated to be 20%, and the average annual recharge calculation is summarised as follows:

Average annual rainfall (R)	820 mm
Estimated P.E.	500 mm
Estimated A.E. (95% of P.E.)	475 mm
Effective rainfall	345 mm
Potential recharge	345 mm
Bulk recharge coefficient	20%
Recharge	69 mm

With a recharge of 69 mm/yrand an average abstraction rate of 960 m^3/day, the area required to supply the water is approximately 5.0 km^2.

10 Source protection zones

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

The SI is mainly the area defined by the horizontal 100 day time of travel from any point below the water table 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 suing aquifer hydraulic properties as described in Section 8.4. The SI describes the horizontal flow to the source and is independent of the vertical aquifer recharge component which is described by the groundwater vulnerability. Given the potential presence of karst conduits in the Rk_d aquifer, flow and travel times within the limestone can be very rapid, and calculations of velocity become almost irrelevant with respect to protection of the GWS from pollution, particularly micro-organisms. On this basis, it is considered appropriate to designate all of the Ballymakenny ZOC as Inner Source Protection Area (SI).

Resulting groundwater Source Protection Zones for the abstraction rate of 960 m^3/d are shown in **Figure 18.** They include SI/L, SI/M, SI/H, SI/E, and SI/X. Approximately 80% of the ZOC is designated as SI/L.

11 Accounting for potential future abstractions

As mentioned in Section 3, the total abstraction from the GWS in 2011 will be reduced as a result of network improvement works. Despite this, there is an overall growing demand for groundwater in the Drogheda region, as exemplified by plans under the East Meath, South Louth and Drogheda improvement scheme. There are also private initiatives underway to use groundwater in the immediate vicinity of the GWS. Specifically, a planning application was lodged in 2007 for a housing and retail development at "Neighbourhood 2" of the North Drogheda Environs Master Plan of 2006, within 1 km of the GWS. Drilling and pump testing has already been carried out on a trial well located c. 250 m to the NW of the GWS, with a reported yield of c. 500 m^3/d (Moylan, 2007). The total water demand on the completed development is reported as 390 m^3/d.

A combined future abstraction rate from the GWS (600 m^3/d) and the latter development (390 m^3/d) would therefore be approximately 1,000 m^3/d. From a resource point of view, the aquifer has a proven capacity to withstand this combined pumping as the pumping from the GWS alone was approximately 1,100 m^3/d in 2010. Although the two schemes can sustain respective levels of abstractions, a question arises over whether the two schemes would interfere with one another operationally, and specifically if the new development would affect the GWS operations. This not a certainty but should be tested. Therefore, prior to the start-up of any new development pumping, well interference tests should be carried out, whereby the GWS operates normally and water levels are measured continuously over several days while the new development wells are also pumped.

The resulting ZOC for a potential future combined pumping rate of 1,000 m^3/d would be similar to that shown in **Figure 17** as the two pumping centres are located relatively close to each other. Increasing the abstraction rate from either scheme would imply that ZOC boundaries would expand. The expansion would be expected to occur primarily in a southern and possibly eastern direction as a westward expansion would be limited by the inferred hydraulic function of the cross-fault and mound at Mell as recharge boundaries.

12 Potential pollution sources

The land uses within the catchment of the GWS are mainly agricultural (arable and pasture) although the urban footprint of Drogheda is marginally captured towards the west and south. Given the low vulnerability setting within most of the defined ZOC, the overall risk of microbial contamination is considered to be low.

The main potential pollution sources in immediate vicinity of the GWS are considered to be farmyard slurry storage areas, farmyard washings, and landspreading of organic fertilisers. The closest farm yard is c.350 m to the northeast of the GWS. Impacts associated with these potential sources are typically elevated concentrations of ammonia, nitrates, phosphate, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium. Only phosphates have so far been detected at elevated concentrations in the untreated water at the GWS. The precise cause is not well understood but data from the GWS are broadly supported by similar results at other locations around Drogheda. Groundwater quality may be influenced by diffuse sources of pollution. Generally low concentrations of nitrate in the confined limestone aquifer would suggest that denitrification may be an important attenuation process in the subsurface environment.

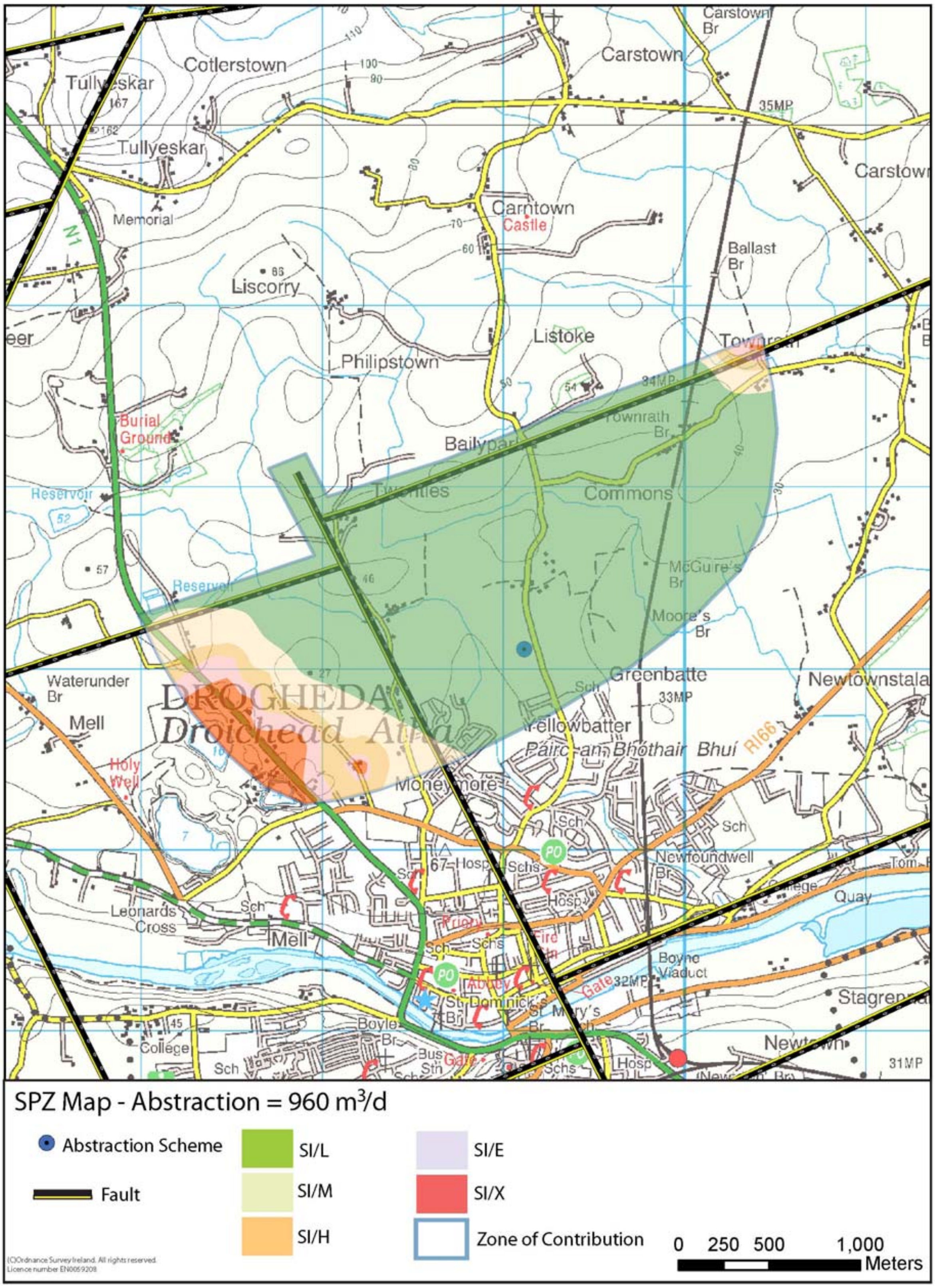

Figure 18: Source Protection Zones, Abstraction = 960 m^3/d

The expanding and encroaching urban footprint of Drogheda in higher vulnerability areas implies that greater awareness is needed in connection with the protection of the public groundwater supplies, not just for the GWS but also other public groundwater abstraction schemes in the Drogheda region.

The GWS itself is characterised by poor wellhead completions. Onsite, the wellheads of BH1 and BH2 both sit below ground in uncovered block chambers, and there is visual evidence that water occasionally ponds inside the chambers. As a result, periodic direct ingress of surface water into the wells can be expected. In contrast, BH3 is completed above ground level and secured with a locked lid.

At a site less than 250 m from the GWS, a trial well and three monitoring wells were drilled in 2005 for a planning application associated with a large housing and retail development. The wells are currently not used and sit idle at the margin of an agricultural field. Unless equal and adequate well head protection measures are taken here, the wells may act as direct pathways of surface pollutants to the limestone aquifer.

The town of Drogheda is largely sewered, but an estimated.40 houses (dwellings) within the immediate GWS catchment use onsite wastewater treatment systems (OSWTS). Given the thick tills around the GWS, percolation from OSWTS is considered a secondary issue in term of risk to groundwater quality.

12.1 Potential for seawater intrusion

There are no data to suggest that the Ballymakenny GWS is under any near-term or even longer-term threat from seawater intrusion. Nonetheless, abstraction pressures in the limestone aquifer in the Drogheda area are growing and as future new schemes come online or expand, the potential risks from seawater intrusion will increase accordingly. A future assessment of the risk of seawater intrusion would require a regional approach involving monitoring of existing abstraction schemes and at dedicated observation wells.

13 Conclusions

The Ballymakenny GWS abstracts groundwater from a confined limestone aquifer. The combination of relatively high abstraction rates from a confined aquifer that is characterised by low bulk recharge rates in vicinity of the GWS results in a ZOC that is appreciably large. For the expected abstraction rate of 600 m^3/d in 2011 and applying a 50% safety margin to the abstraction, the estimated ZOC covers an area of 4.4 km^2. Importantly, the ZOC is predicted to extend west to include a potentially important fault which likely acts as a zone of higher fracture permeability. There is some uncertainty as to the full extent of ZOC expansion, particularly to the west towards the quarries at Mell. There is also uncertainty as to the presence and influence of karst features on local hydrogeology and well operations at the GWS.

Although groundwater vulnerability within most of the ZOC is mostly Low, available groundwater quality data suggests that the aquifer may be impacted by diffuse pressures of an agricultural nature. Wellhead protection at the GWS is inadequate. Boreholes BH1 and BH2 are susceptible to direct inflow of surface runoff and ponded water. Neither BH1 nor BH2 have wellhead covers and both are located inside below-ground block-chambers that have visible watermark lines (from standing water) at their base.

14 Recommendations

Wellhead protection measures should be taken at the GWS involving extension of steel casing and the design and construction of proper wellhead chambers, preferably above ground level. This is particularly relevant at BH1 and BH2.

When the submersible pumps are removed next time from BH1, BH2 and BH3, total well depths should be confirmed and ideally, borehole geophysical logs should be carried out for each borehole. The next time pumping equipment is re-installed in BH3, downhole equipment should be installed such that groundwater levels can be measured without risk of getting level probes stuck.

Ideally, and although it is recognised it is difficult to interrupt GWS operations, new pumping tests should be carried out in BH1 and BH3, so that more reliable site-specific aquifer properties can be derived. The new data and interpretations should be used to check and/or verify the basis for estimating ZOCs and SPZs in this report.

The trial and monitoring wells that currently stand idle in a field within 250 m of the site should all be secured and capped as appropriate since they represent a potential direct pathway for surface pollutants to reach the regional aquifer. If future production pumping is implemented at the trial well location, the pumping must be preceded by a well interference test over several days or weeks to assess whether the operation of the new well could impact on the operations at the GWS.

Routine water level monitoring in one of the three boreholes in the GWS should ideally be carried out, and preferably on BH 2 (back-up well). Due to the frequent cycling of pumping, continuous measurements using a data logger are needed to obtain a true picture of water level trends. Council staff may wish to review the current pumping regime as it is considered to be inefficient with pumps cycling on and off several times each day.

The Drogheda region is experiencing an overall expansion in groundwater abstractions. At some point in the future, there will be a need to consider regional monitoring for potential seawater intrusion. Water level monitoring at the Ballymakenny GWS could be incorporated into a future regional monitoring programme. Such monitoring should include the installation of data loggers that can record changes in both groundwater levels and electrical conductivity, the latter being an indicator of salinity.

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APPENDIX 1

Borehole log for BH3

(Patrick Briody and Sons Ltd, 2005)

Patrick Briody & Sons Ltd.

DRILLING LOG

AQUADRILL SERVICES Well Drilling & Site Investigation Contractors

The Grove,
Rathangan,
Co. Kildare.
Tel (045) 524360
Fax (045) 524785
e-mail: info@briodydrilling.com

No 0281

Consultant/Engineer: C/o Tomas O'hEachaidh

Client: Ballymakenny GWS Drogheda

Borehole Reference No. .... Sheet 1 of 2

Borehole Location: Yellow batter GWS

Date of Drilling	Depth (from - to) mtrs/ft.	Actual Drilling Diametre	Drilling Conditions / Water Strike
2-8-05	Drilled test	Well with 8" steel casing initial	
	starting dig	0 - 120ft.	
3-8-05	0-40ft	14¾"	hard boulder clay
	40'-70'	"	tight clayee sand.
	70-120'	"	Very hard clay, soft rock
3-8-05	0-120ft		Supply + fit 12" mild steel casing
4-8-05	120'-155ft	12"	fractured bedrock
4-8-05	155ft-160ft	"	Very fractured with WATER
"	160ft-195ft	12"	Competent bedrock
5/8/05	195ft-205ft	12"	fractured with brown staining
5/8/05	205-245ft	12"	competent bedrock →

Total Depth of Well.........

Estimated Yield.........

Depth to Rock.........

Steel Casing Installed.........

P.V.C. Casing/Screen Installed.........

Other Remarks.........

Schematic View

Lead Driller......... Drilling Rig.........

Engineer Approval.........

Patrick Briody & Sons Ltd.

DRILLING LOG

AQUADRILL SERVICES — **Well Drilling & Site Investigation Contractors**

The Grove,
Rathangan,
Co. Kildare.
Tel (045) 524360
Fax (045) 524785
e-mail: info@briodydrilling.com

№ 0282

Consultant/Engineer: C/o Tomas O'hEochaidh

Client: Ballymakenny GNS, Drogheda.

Borehole Reference No.: .... Sheet 2 of 2

Borehole Location: Yellowbatter, Drogheda.

Date of Drilling	Depth (from - to) mtrs/ft.	Actual Drilling Diametre	Drilling Conditions / Water Strike
5/8/05	0 - 74.24m		Supply + fit 200mm O.D
			x 7.7mm wall thickness uPVC
			Screen/casing.
5/8/05	Pea Gravel		Install Pea Gravel
			at annulus to screen from
			74mr bgl - 24mt - (4 ton)
	Sand Layer		Sand layer 24m - 22.7mtr
	Cement Grout		Grout by tremie pipe
			injection 22.7mtr bgl to Outer
			total (2 ton cement)
	Airlift; Total	Hrs:	Airlift at various intervals
			test well, mid + completion of recovery
	Completion.		Hinged lockable lid
			+ site reinstatement

Total Depth of Well: 75mtr

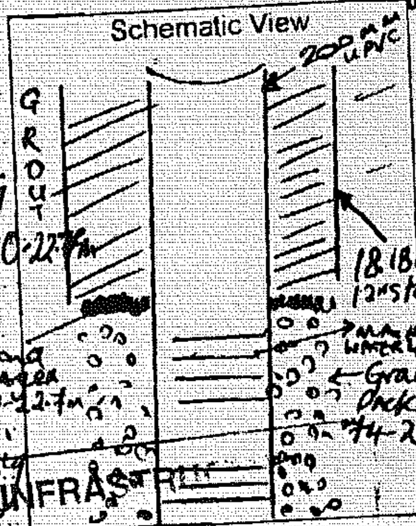
Estimated Yield: excess 3,000 gph 13m³/hr

Depth to Rock: 36.36

Steel Casing Installed: 18.18mtr x 12" steel casing

P.V.C. Casing/Screen Installed: ....

Other Remarks: ....



Lead Driller: Aidan Briody Drilling Rig: Knebel Rig

Engineer Approval: ....

APPENDIX 2

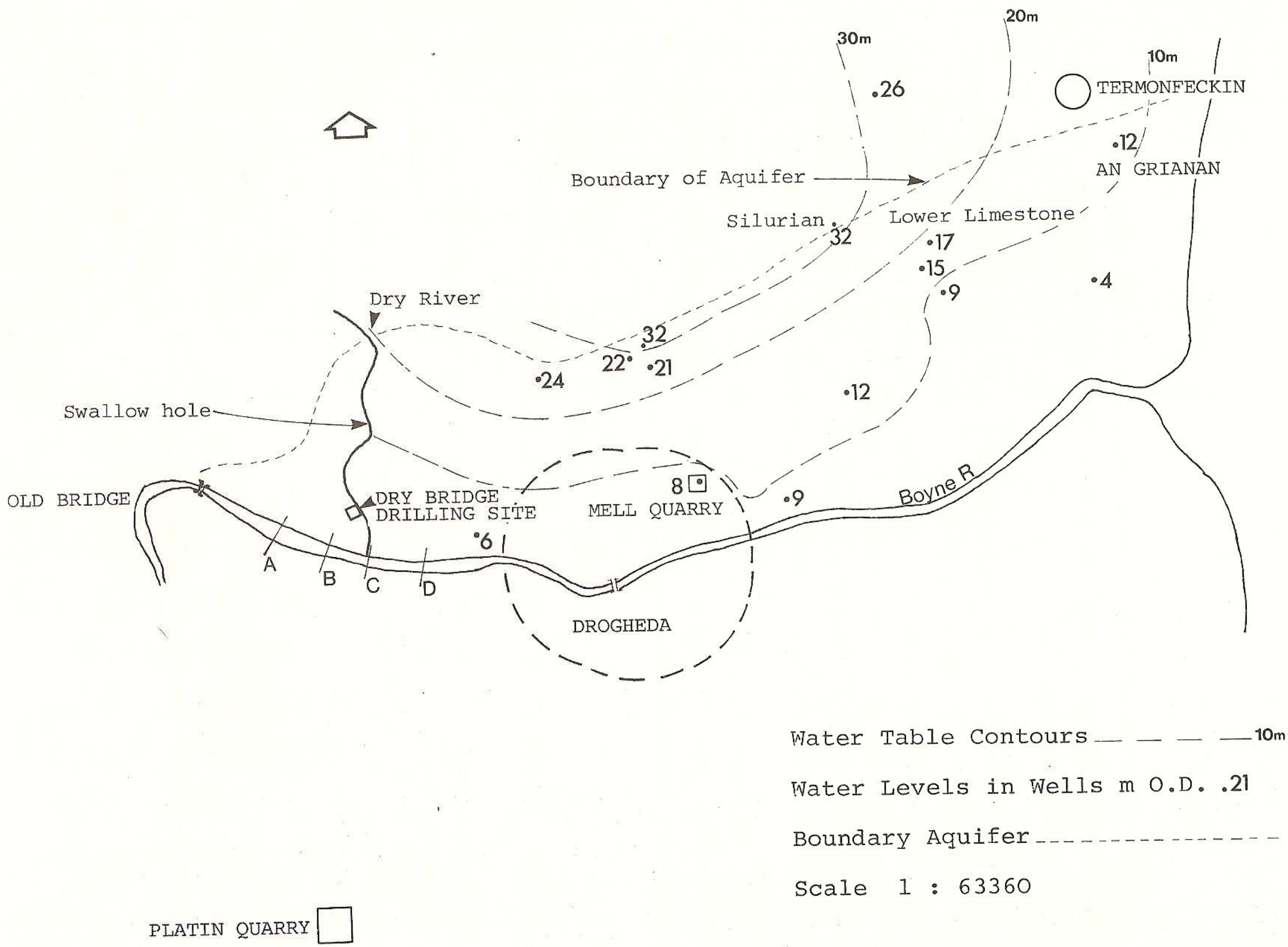
Water Level Contour Map

NERDO 1981

won Drift.

Sth Louth Lwr Lst
b, Ne, T, Rch
Drybridge Swallow hole
Boyne tidal effect e BA

Raised (Balt



APPENDIX 3

Pump Test Results BH3 (Kearney and Sons Ltd, 2005)

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Thursday, 13 October 2005

Patrick Briody & Sons Ltd.
The Grove,
Rathangan
Co Kildare

Tel:045/524360 Fax:045/524785
e-mail: Info@briodydrilling.com

Ref: Ballymakenny Group Water Scheme Well Test

Well Test commenced @ 12 noon on Thursday 29th September and finished @ 12 noon Sunday 2nd October, at 30 minute intervals. Static water level and yield was measured for the 1st 2 Hours. Water was discoloured and the water level dropped down until it levelled off and water ran clear, pumping at 6000 g.p.h with a static water level of 43.6 mtrs from there onwards for the next 70 hours.

Two existing wells on site were monitored at all times for duration of well test. Water levels remained the same at all times .

M. Kearney

Michael Kearney & Sons Ltd.