Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Enfield Water Supply Scheme

Enfield Borehole

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PROJECT DESCRIPTION

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

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

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

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1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Enfield 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 Enfield borehole is the main source for Enfield Public Water Supply. The borehole supplies approximately 100–110 m^3/day to Enfield.

The objectives of the report are as follows:

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

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

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The Enfield Borehole, operated by the Meath County Council since 2002, is located towards the southeast of Glen Abhain housing estate, Enfield. The site is surrounded by Enfield village to the north and the Enfield by-pass/ring road to the south (See Figure 2). The borehole intake brings the water to the pump house where the untreated water is chlorinated. The water is also treated to remove high concentrations of iron and manganese in the groundwater supply. The annulus around the borehole is grouted. The borehole cover and surrounding area is securely covered and the site is fenced off (Photo 1).

3 SUMMARY OF WELL DETAILS

A borehole (BH1) was drilled in the 1970s, and was the council well supply for Enfield prior to the drilling of PW1 in 2001. A production borehole PW1 was drilled (approximately 15 m from the BH1) and pump tested in 2001 to cater for the increase in pumping demands in Enfield. The borehole log is provided in Appendix I.

Table 3-1 provides a summary of details as currently known. The photograph below shows the site and location of production borehole.

Table 3-1 Summary Details

EU Reporting Code	IE_EA_G_002_17_004
Grid reference	E240682 N240682
Townland	Johnstown
Source type	Borehole
Drilled	2001
Owner	Meath County Council
Elevation (Ground Level)	c. 79 mOD
Depth	48.8 m
Depth of casing	Inner Casing 35.1 m Outer casing 21.3 m
Diameter	Inner casing 0.25 m, open hole at 0.2 to 48.8 m
Depth to rock	29 m
Static water level	Approximately 4 m bgl
Pumping water level	20 m bgl
Consumption (County Council records)	100-110 m^3/d
GSI Productivity Rating	Class IV
Specific capacity	6.5 m^3/day/m (Sept 2009)
Transmissivity	18 m^2/day (2001 pumping test)

Photograph 1 Borehole cover and adjacent treatment works

4 METHODOLOGY

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

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

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

Enfield Borehole is located 1 km north of the River Blackwater within the River Boyne catchment (Hydrometric Area 07). Refer to Figure 2 which shows the location of the well.

The topography in the vicinity of the well is relatively flat, with that surrounding Enfield comprising gently undulating and hummocky topography (approximately 74–82 mOD). Gradients in the study area are between 1:100 and 1:200. The land rises gently to the north of Enfield between the townlands of Posseckstown and Jordanstown, approximately 2 km to the north (90–110 m OD).

The Blackwater River has been channelized and locally deepened by approximately 3–4 m to the south of Enfield, as a flood preventive measure. The original watercourse formed the boundary between Meath and Kildare. The Ballycotton River and its tributaries are located 1 km to the north and east of the source and flow towards the River Blackwater. In general, the stream density is relatively low in the region between the Blackwater and Ballycotton rivers. However, according to the six inch maps, there is a relatively high density of drains north of the source in the vicinity of the Royal Canal, which is located 0.75 km to the northwest and north of the source.

Land use in the study area is a mixture of urban development and agricultural, with the latter lands set to pasture. Extensive building has been completed around the source within the last 5 years, and housing estates form the western and northern boundaries of the site, with agricultural land located to the east and south. A number of small farmyards have been noted in the area, though no farmyards were identified within 250 m of the borehole. While a number of industry/commercial areas including petrol stations and industrial estates were identified in the environs of Enfield Borehole, no IPPC licensed facilities are present. The M4 and the Enfield bypass are located to the south of Enfield borehole, with areas of cut and fill evident along the route.

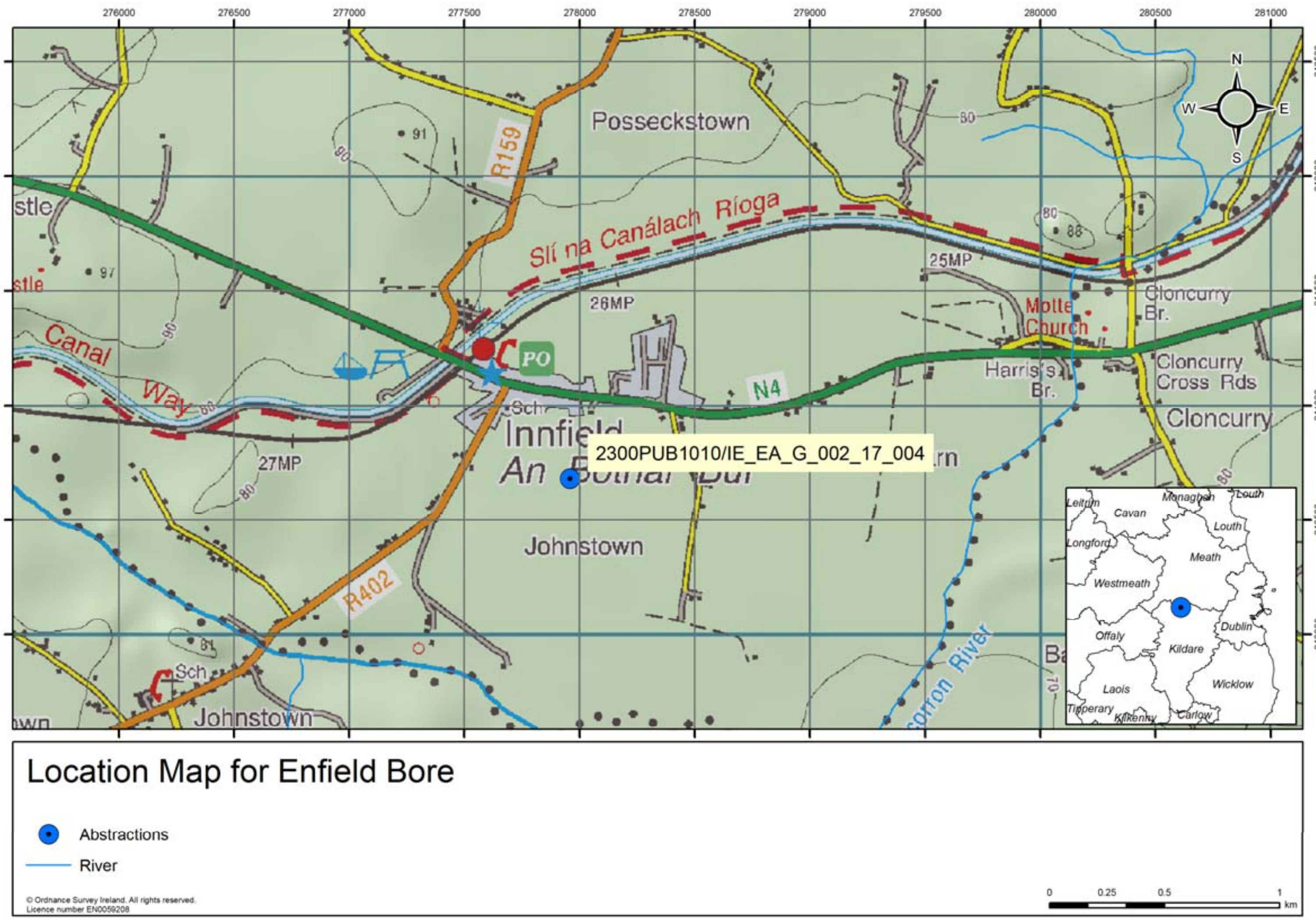


Figure 1 Location Map

6 GEOLOGY

6.1 BEDROCK GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Enfield source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based the Bedrock Geological Map of Meath Sheet 13, 1:100,000 Series (Archer et al, 1994) and the GSI Karst Database.

The Bedrock Geological Map of Meath indicates that this area is principally occupied by Dinantian Upper Impure Limestones (Lucan Calp Formation). Refer to Figure 3 for Geology Map of the area. These rocks extend over a large area of south Meath/north Kildare.

The Dinantian Upper Impure Limestones (Lucan Limestone Formation) are comprised of dark grey argillaceous limestones, interbedded with thin shaly bands. Weathered limestone was encountered in the Enfield borehole in this unit, becoming highly fractured at 46 m bgl.

See Cross section in Figure 4 for a diagrammatic view across the study area.

6.1.1 Karst Geology

A brief karst mapping programme was undertaken in the study area by TOBIN Consulting Engineers in September 2009. No features had previously been identified from the GSI Karst Database. The mapping identified no karst features.

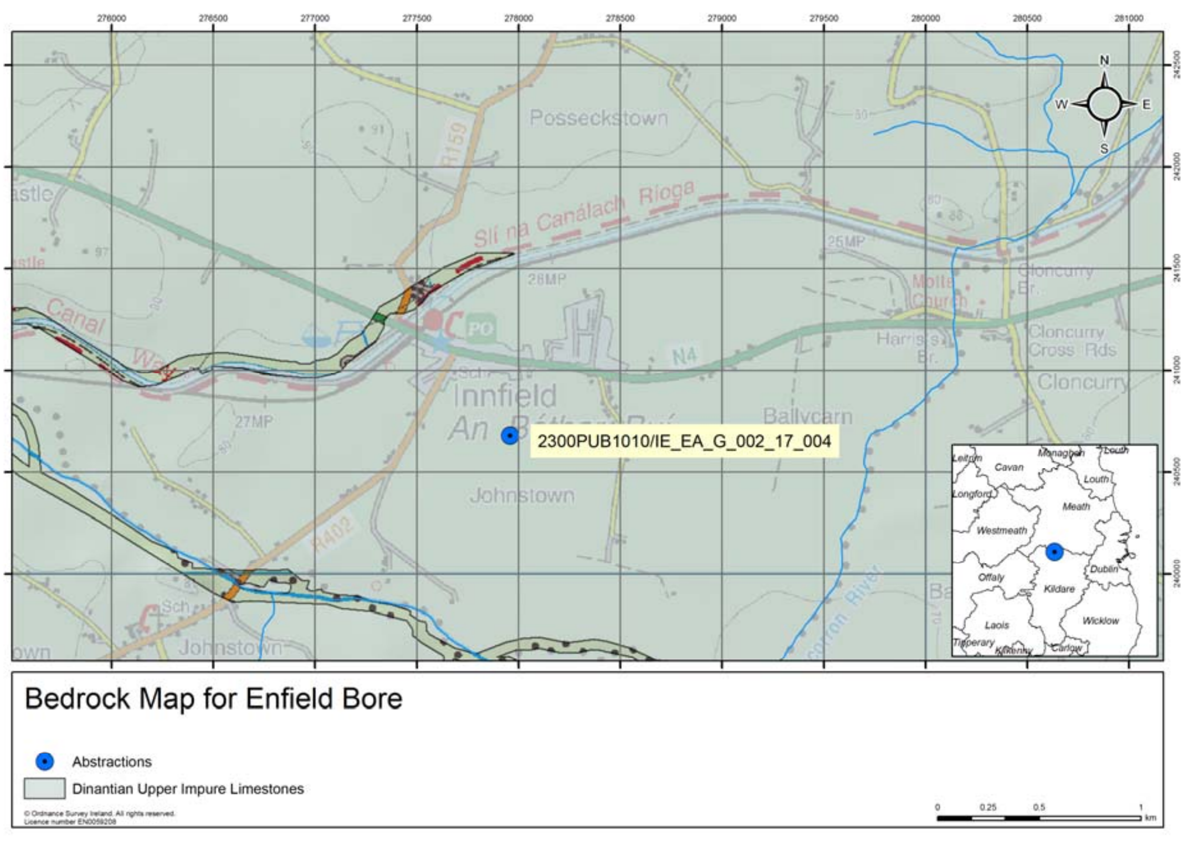


Figure 2 Geology Map

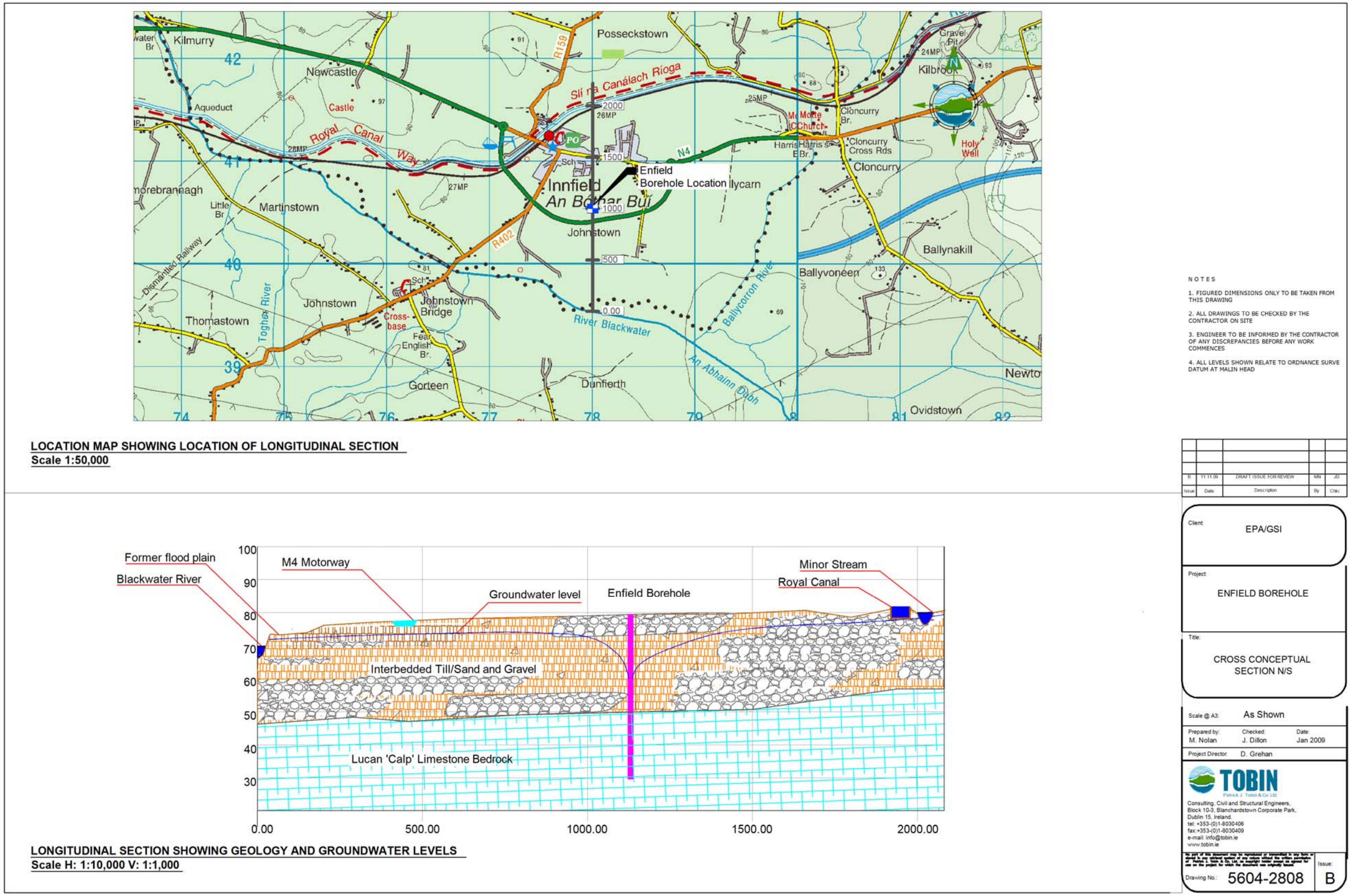


Figure 3 Cross Section

6.2 SUBSOILS GEOLOGY

According to GSI and EPA web mapping, the study area is dominated by till derived from limestone (TLs) and sand and gravel deposits derived from limestone (GLs). The Enfield area is underlain by a complex of interbedded deposits of till and sand and gravel with a large variation over short distances. This has been confirmed during the construction of the M4 Kinnegad to Kilcock road scheme. A diagrammatic east-west cross section of the M4 is included in Appendix 2.

Based on information from the borehole log of PW1, the underlying subsoil at the borehole is comprised of saturated gravel and very soft 'boulder clay' (till) to 29.1 m bgl. Subsoil exposures are limited within the Enfield area, and are typically <1 m in depth. At location S1, to the north of the Royal Canal, a 50 m long cutting exposed a complex subsoil sequence comprised of interbedded gravelly SILT/CLAY, sandy SILT and silty sandy GRAVEL. A small gravel pit was used until the 1960's, 150 m to the north, based on local information and the OSI 25" maps.

The soils on the till areas are predominately 'dry' soil types: typically well drained deep mineral soils (BminDW) and well drained shallow soils (BminSW) (EPA webmapping). Along the course of the Royal Canal and the River Blackwater, areas of poorly drained soils, lacustrine deposits and alluvial deposits are present. To the south of the source, a large area of alluvial deposits (c. 74 mOD) is located along the course of the River Blackwater. These deposits are thought to overlie the till and sand and gravels.

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

6.3 DEPTH TO BEDROCK

Based on the geological information acquired from the GSI Well Database, the depth to bedrock in the area is in general greater than 10 m, with no bedrock outcropping within 2.4 km of the source. Depth to bedrock at the production borehole PW1 is 29.1 m.

Additional information was also obtained from previous drilling data as part of the M4 motorway site investigation. Drilling near the M4/Johnstown Bridge encountered 29 m of overburden. Approximately 1 km to the south of the Blackwater River, subsoil depths appear to reduce to less than 10 m.

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. This means that vulnerability relates to the thickness of the unsaturated zone in the sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons et al, 2003). The vulnerability for the region, as mapped by GSI is dominated by 'moderate' vulnerability and is shown in Figure 5. Areas of '*High*' permeability sand and gravel deposits are located towards the north, south and west of the borehole.

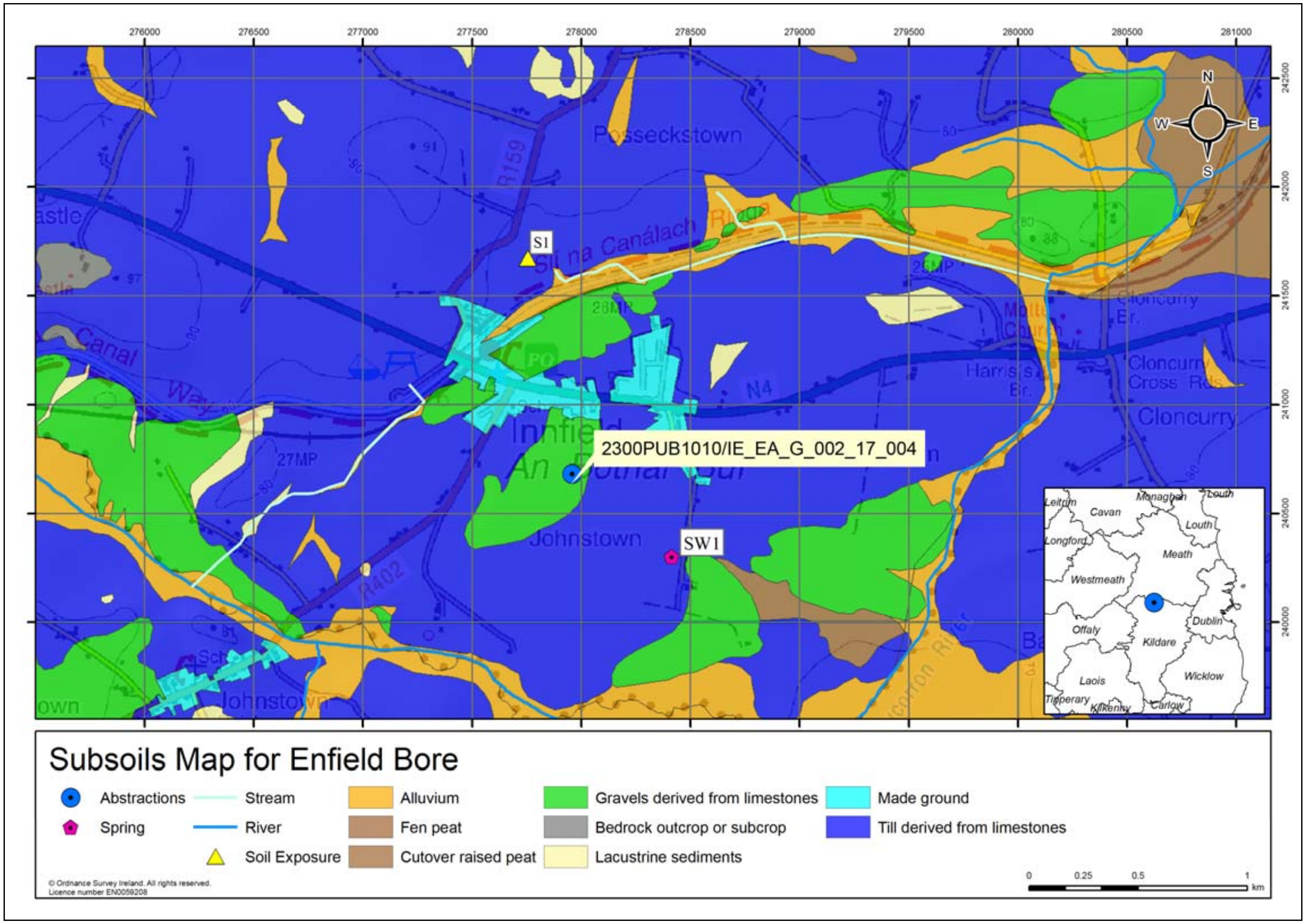


Figure 4 Subsoil Map

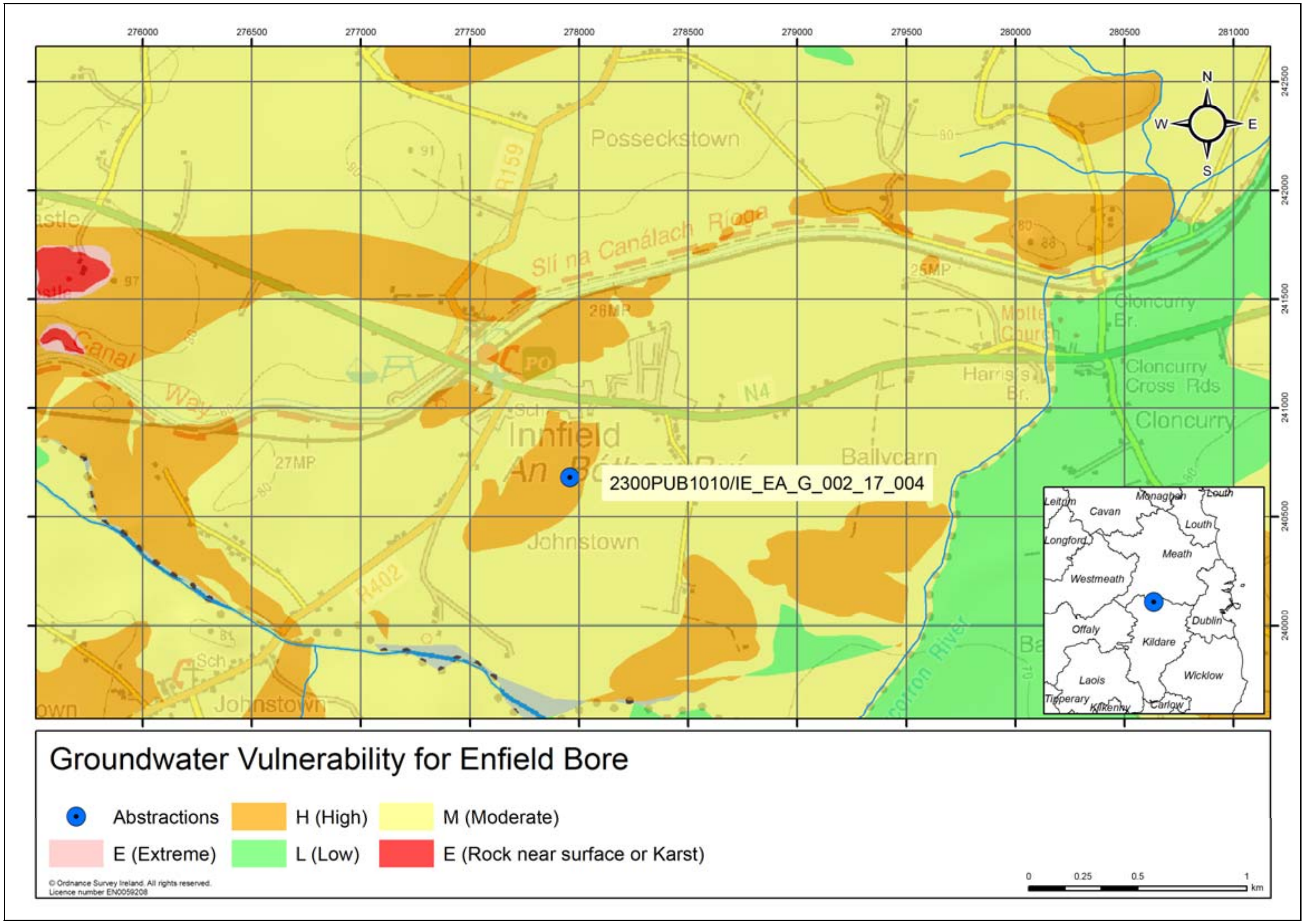


Figure 5 Groundwater Vulnerability in the area (GSI)

8 HYDROGEOLOGY

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

- GSI Website and Well Database
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan in September and November 2009.
- Woods et al (1998) *County Meath Groundwater Protection Scheme.*

8.1 GROUNDWATER BODY AND STATUS

The Enfield source is located within the Trim Groundwater Body which has been classified as being of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie .

8.2 METEOROLOGY

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

Annual rainfall: **796 mm.** The closest meteorological station to Enfield borehole is located at Kilcock Gauging station. Data records used (Kilcock) are based on Met Éireann data for annual average rainfall (Fitzgerald and Forrestal, 1996). Data from the Met Eireann website show that the source is located between the 800 mm and 1000 mm average annual rainfall isohyets.

Annual evapotranspiration losses: **450 mm.** Potential evapotranspiration (P.E.) is estimated to be 500 mm/yr (based on data from Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: **346 mm**. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 346 mm/year. See also Section 8.6 on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater in the subsoils in the area surrounding Enfield Borehole is close to the surface at less than 4 m bgl. The static water level in the bore is approximately 4 m bgl. Immediately south of the Enfield by-pass, a small spring discharges from the gravels (SW1). Some groundwater may also be intercepted by the M4 road cutting/drains. Local information suggests that the road cutting reduced groundwater discharge within the spring.

The regional groundwater flow direction is assumed to be in a predominately southerly direction towards the River Blackwater. The drains north of the borehole in the vicinity of the canal are likely to be intercepting overland flow and shallow groundwater flow. It is assumed that deeper groundwater flow north of the canal is flowing toward the Blackwater River. Local groundwater flow with the bedrock aquifer at PW1 maybe controlled by the pumping of the well as the drawdown is relatively large. In September 2009 following an extended period of dry weather, a pumping water level of 19.99 m bgl was measured in the borehole whilst pumping at 110 m^3/d.

The gradient is considered to be relatively flat, approximately 0.005, reflecting the gentle topographical gradients. There are no well data for the bedrock aquifer in the vicinity of the Enfield borehole. Data in this area could provide more conclusive information on flow directions and gradients.

8.4 HYDROCHEMISTRY AND WATER QUALITY

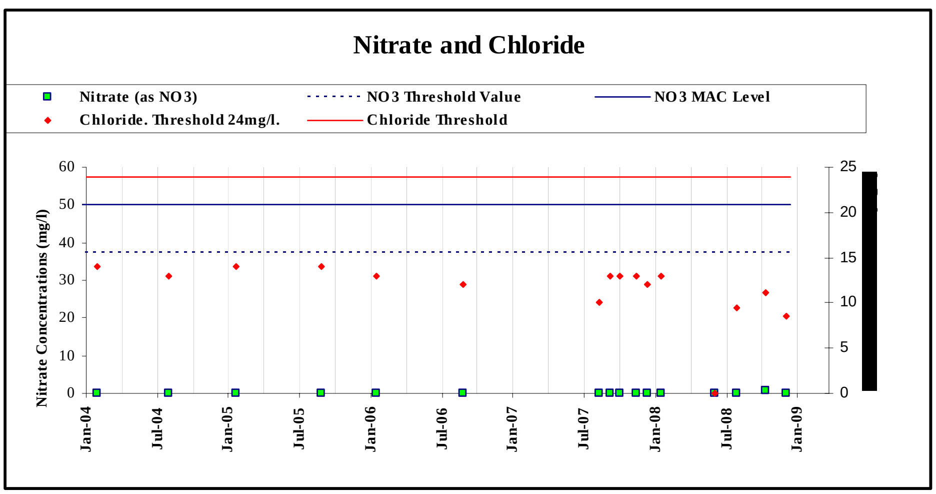
Seventeen samples were available from the EPA Groundwater Monitoring Network between 2007 and 2008. The water quality is hard (260 to 326 mg/l $CaCO_3$). Alkalinity ranges from 240 to 360 mg/l $CaCO_3$. The pH ranges between 7.2 and 7.6, which is alkaline. The field electrical conductivity ranges from 525 to 783 µS/cm @ 25°C. The hydrochemical signature of the groundwater is calcium bicarbonate.

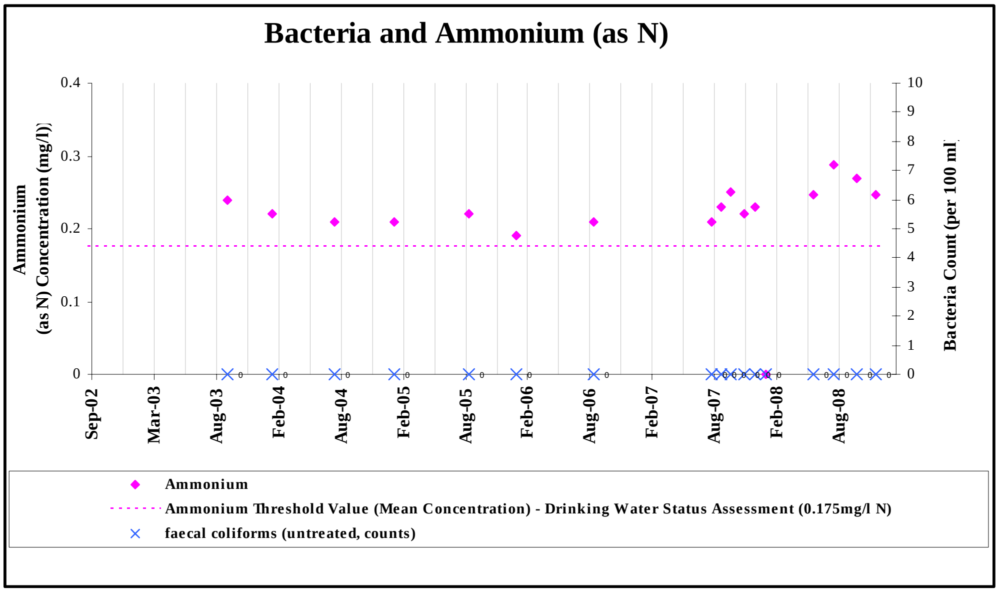
The concentration of nitrate is very low with all concentrations below 1 mg/l (as NO_3) and 15 samples below detection limits. Ammonical Nitrogen concentrations however were elevated in all samples with eight exceedances of its MAC. Nitrite was also elevated in seven samples but did not exceed it's MAC. This would suggest that reducing conditions are present within the aquifer and that denitrification may have occurred.

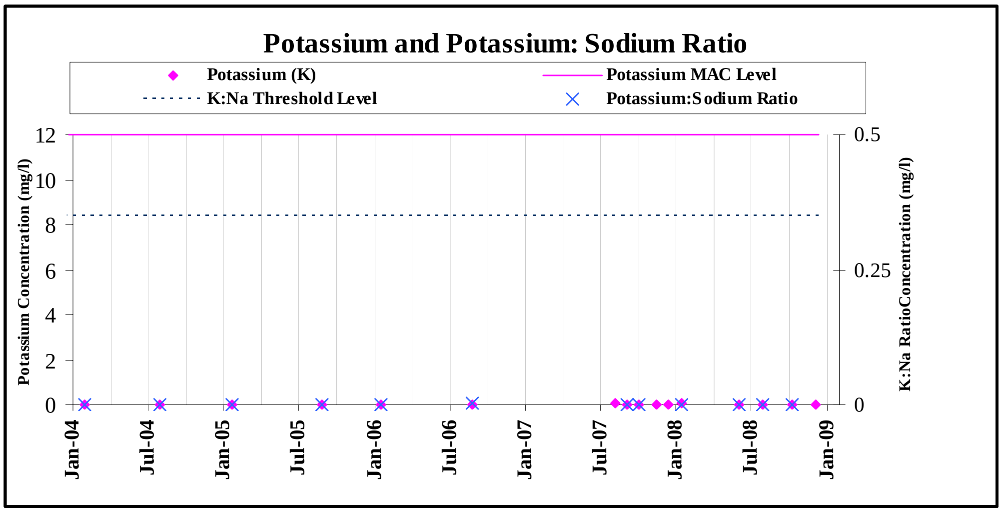
Chloride concentrations range from 8.6 to 14 mg/l, with a mean of 12.5 mg/l, which is considered to be below the mean natural background level of 18 mg/l (Groundwater newsletter 46, O'Callaghan Moran 2007) and the groundwater saline intrusion threshold value (S.I. No. 9 of 2010 Groundwater Regulations) of 24 mg/l. This is indicative of a low pollution loading at the source. Exceedance of the Manganese and Iron MACs are noted in the majority of samples. Naturally high iron and manganese concentrations are known to occur within the shaly limestone bedrock in Meath and also indicate that reducing conditions are prevalent.

Faecal and total coliforms were below detection limits in all water samples.

The concentration of Sulphate, Potassium, Sodium, Magnesium and Calcium are within normal ranges. The Potassium: Sodium (K:Na) ratio is low at less than 0.2.







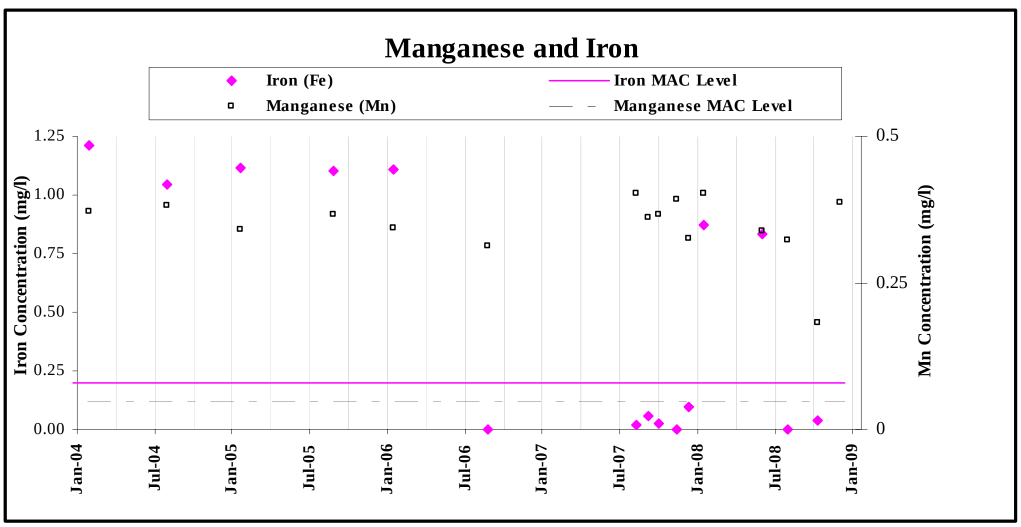


Figure 6 Water Quality Graphs

The concentrations of all other trace metals are generally low but appear to be slightly elevated compared to background groundwater levels. Elevated concentrations of strontium (> 1 mg/l) are present in the groundwater at Enfield. Strontium occurs in nature, in the form of the sulphate mineral, celestite ($SrSO_4$) or as Aragonite ($SrCO_4$). Strontium concentrations within the groundwater are generally low in Ireland, but appear to be slightly elevated within some groundwater samples from the Lucan Formation. Strontium behaves similar to calcium and magnesium in groundwater but has a much lower dissolution rate.

The concentration of all organic compounds is below the detection limit of the laboratory.

In summary, the groundwater quality monitoring from the source suggests that reducing conditions are present in the aquifer. Reducing conditions can either occur naturally in shaly limestones such as the Dinantian Upper Impure Limestones, or can be induced by organic pollution. However as the chloride and faecal coliforms are both low, it is considered that this is a natural phenomenon in this instance, rather than a pollution event. The source does however contain high ammonia, nitrite, iron and manganese which are common water quality issues in these reducing environments. Denitrification may be occurring.

8.5 AQUIFER CHARACTERISTICS

GSI bedrock aquifer map of the area indicates that the Dinantian Pure Unbedded Limestone (Lucan Limestones) is classified as a Locally Important Aquifer which is moderately productive (Lm). The aquifer is not considered to have any primary porosity with groundwater flow occurring predominantly through fractures, fissures and joints in the upper fractured and weathered zone. Aquifer storage is low based on the high drawdown and relatively modest yield, and groundwater flow paths can be dependent on faulting/fracturing.

The yield of Enfield borehole PW1 is 'good' according to GSI classification and the productivity is Class IV. Based on data from September 2009, the specific capacity of PW1 is approximately 6.5 m^3/day/m (17 m drawdown). This analysis is based on limited data and would require further monitoring to validate assumptions.

The bedrock is considered to provide the main groundwater contribution to PW1. However, the bedrock is thought to be hydraulically connected to the overlying subsoils. Groundwater slowly migrates through the subsoils towards the bedrock aquifer and while travel times are generally slow, they will be augmented by pumping from the underlying weathered limestones bedrock.

A pumping test was completed over a 72 hour period in November 2001 with records included in Appendix I. The borehole pumping rate was cut from 12.7 m^3/hr (305 m^3/day) to 11.8 m^3/hr (280 m^3/day) after 4 hours after a larger than expected drawdown within the well. The monitored recovery test data is also included in Appendix I. The estimated bedrock aquifer transmissivity is **18 m^2/day** based on the pumping test at PW1, using the Theis recovery method. Permeability is in the order of 0.9 m/day based on a minimum saturated thickness of 20 m, and effective porosity is assumed to be in the order of 1%. Therefore velocity, assuming a gradient of 0.005, is in the order of 0.45 m/day.

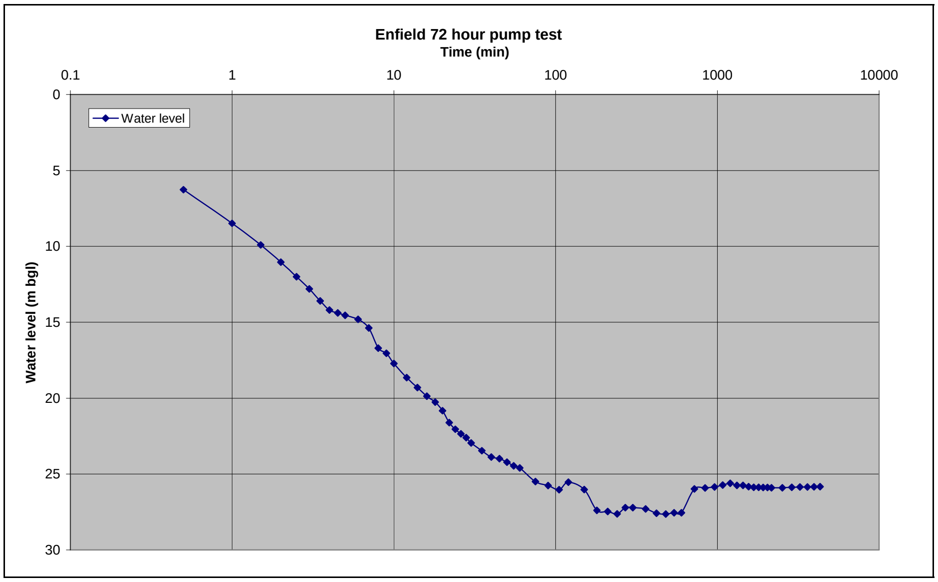


Figure 7 Test pumping PW1

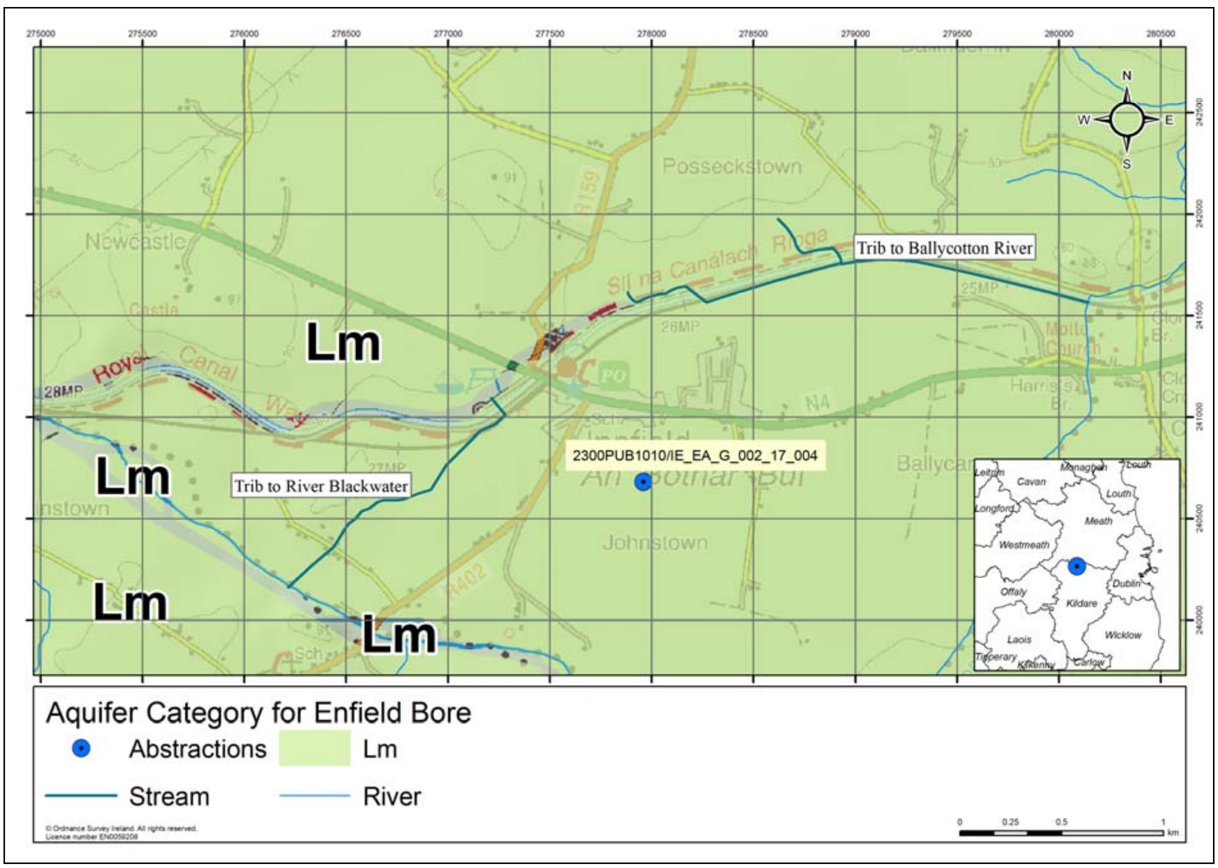


Figure 8 Aquifer Map in the vicinity of Enfield

8.6 RECHARGE

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

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

Runoff losses: 242 mm. Runoff losses are assumed to be 70% of potential recharge. This value is based on an assumption of *c*. 15% runoff for 5% of the area (high vulnerability, high permeability subsoils and soils), 65% runoff over 70% of the area due to moderate vulnerability, moderate vulnerability subsoil and 80% runoff for urban areas, approximately 25% of area (includes recent expansion outside the urban areas present on the subsoils map). (Guidance Document GW5, Groundwater Working Group 2005).

The bulk ***recharge coefficient*** for the area is estimated to be 30%.

These calculations are summarised as follows:

Average annual rainfall (R)	796 mm
estimated P.E.	450 mm
estimated A.E. (95% of P.E.)	427.5 mm
effective rainfall	346 mm
potential recharge	346 mm
runoff losses	70%
bulk recharge coefficient	30%
Recharge	**104 mm**

8.7 CONCEPTUAL MODEL

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

- The source comprises a borehole, drilled into a 29 m thick saturated till/sand and gravel deposit that overlies an Impure Bedded Limestone. The limestone is classified as a *Locally important aquifer which is moderately productive* (***Lm***). The borehole was completed in the weathered, fractured bedrock, sealing out any water inflows from the overburden. The borehole draws from the bedrock though the gravels and overburden provide additional storage.

- Abstraction rates from the borehole are 100–110 m^3/day. A large drawdown of approximately 20 m bgl was measured within the well during a site visit.

- In general, the depth to bedrock in the area is greater than 20 m, with no rock outcrops within 2.4 km of the source. The subsoils are comprised of a complex of interbedded till and sand and gravel. In general, the depth to bedrock is deep and the subsoils are classified as being of 'high' to 'moderate' permeability. The groundwater vulnerability is 'high' to 'moderate'.

- The regional natural groundwater gradient is towards the River Blackwater and is expected to be shallow at approximately 0.005.

- Groundwater recharge is likely to be from the land surrounding the borehole and from the upgradient area, to the north and northeast of the source. Groundwater recharges slowly through the till and gravel overburden, towards the bedrock and is assisted in the vicinity of the borehole by the large drawdown.

- Over the region, an average recharge rate of 104 mm/year is used, which is approximately 30% of the total potential recharge. The remaining 70% of potential recharge is rejected and discharge may be via overland flow during the winter months and/or intercepted via the urban storm water system. Recharge is diffuse.

- The groundwater is of calcium bicarbonate signature and hard. Nitrate concentrations are low and below detection limits in most cases but concentrations of ammonium and nitrite have been elevated on a number of occasions. This would suggest denitrification is taking place within the bedrock, and that there may be a relatively long time of travel to the well. Further evidence for a long time of travel is the elevated levels of strontium and the complete absence of faecal coliforms within the groundwater samples. Iron and manganese concentrations are also elevated which is a natural phenomenon in these rocks. Chloride concentrations are low in all groundwater samples.

9 DELINEATION OF SOURCE PROTECTION AREAS

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater pattern, as described in Section 8.7 Conceptual Model and presented in Figure 4.

Two source areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution.

- Outer Protection Area (SO), encompassing the zone of contribution to the source.

9.1 OUTER PROTECTION AREA

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

The **Southern Boundary** is based on a combination of hydrogeological mapping and the uniform flow equation (Todd, 1980).

The uniform flow equation (Todd, 1980) is:

$xL = Q / (2\pi * T * I)$ where

Q is the daily pumping rate

T is Transmissivity (taken from aquifer characteristics)

I is the background non-pumping gradient.

The uniform flow equation suggests the wells could pump from 200 m downgradient (based on an approximate transmissivity of 18 m^2/day, a natural groundwater gradient of 0.005).

The **Northern Boundary** is difficult to delineate as it is uncertain as to interaction of groundwater and surface water in the vicinity of the canal where there are a few drains flowing toward the Ballycotton River. To account for a regional head and deeper groundwater flow and groundwater flow direction to toward the Blackwater it is assumed that groundwater can flow from the area around Posseckstown toward the source. It is unlikely that the ZOC would extend past this stream or the Royal Canal. There is some uncertainty regarding the tributary as it has been modified.

The **Western Boundary** is based on assumed groundwater flow directions and the presence of a stream to the west of Enfield. Gravel deposits are located adjacent to the stream and extend towards Enfield village centre (See Figure 4 and Figure 8). Given the proximity of the permeable sand and gravel deposit to the stream, groundwater within the gravels is assumed to discharge to this stream.

The **Eastern Boundary** is based on the presence of a tributary of the Ballycotton River and a water balancing exercise. Groundwater towards the east of Enfield and the ZOC is thought to discharge to this stream.

Water balance: Based on an abstraction of 110 m^3/day on average and the estimated recharge of 104 mm/year, a zone of contribution of 0.4 km^2 in area is calculated. Current GSI guidance states that ZOC delineation should conservatively account for 150% of the abstraction volume if the hydrogeological conditions allow. Thus 0.6 km^2 is required for 165 m^3/day. The ZOC described above is 1.4 km^2 and is conservative and allows uncertainties in the current understanding of the hydrogeology and flow directions .

9.2 INNER PROTECTION AREA

This area is designed to protect against the effects of human activities that might have an impact on the quality of the groundwater source. The Inner Source Protection Area is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source. The 100-day time of travel is chosen in Ireland as a conservative limit to allow for the heterogeneous nature of Irish aquifers. The 100-day horizontal time of travel to the abstraction boreholes is calculated from the velocity of groundwater flow in the bedrock. This velocity is determined using Darcy's law, $v = K(dh/dl)/n_e$.

K is the Hydraulic Conductivity = 0.9 m/day (Transmissivity of 18 m^2/d/saturated thickness of 20 m)

dh/dl is the gradient = 0.005

n_e is the effective porosity = 0.01

The velocity of groundwater flow in the bedrock is estimated to be approximately 0.45 m/day.

Therefore the 100-day horizontal time of travel is calculated to extend 45 m around the source.

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in 9, and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/H, SO/M and SO/H. The majority of the area is designated SO/M.

Table 10-1 Source Protection Zones

Source Protection Zone	% of total area (1.4 km^2)
SI/High	<0.1%
SO/High	27 %
SO/Moderate	72%

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- The area surrounding the source is highly urbanized with many businesses and suburban dwellings within the ZOC. These businesses and residential areas are served by a main sewer network. The main potential contaminants from sewerage leaks are ammonia, nitrates, phosphates, chloride, potassium, faecal bacteria, viruses and cryptosporidium.

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

- A number of businesses are located within the ZOC. These businesses include petrol stations and launderettes. The main potential contaminants from these sources are hydrocarbons and chlorinated solvents including perchloroethylene, petroleum solvents or trichlorotrifluoroethane.

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

12 CONCLUSIONS

The borehole is a moderately yielding borehole that abstracts from a weathered, fractured, impure bedded limestone. The bedrock is overlain by approximately 29 m of interbedded till/sand and gravels. Groundwater is thought to infiltrate slowly through the subsoils towards the bedrock.

The untreated groundwater is currently of good microbial quality, but there are some water quality issues with high iron, manganese and ammonia. Nitrite is also elevated. These problems are related to the reducing conditions naturally prevalent in these shaly rocks. The Outer Source Protection Area or the Zone of Contribution is calculated to extend to 1.4 km^2.

The Inner Source Protection Area or the 100-day horizontal travel time is calculated to extend 45 m from the abstraction source.

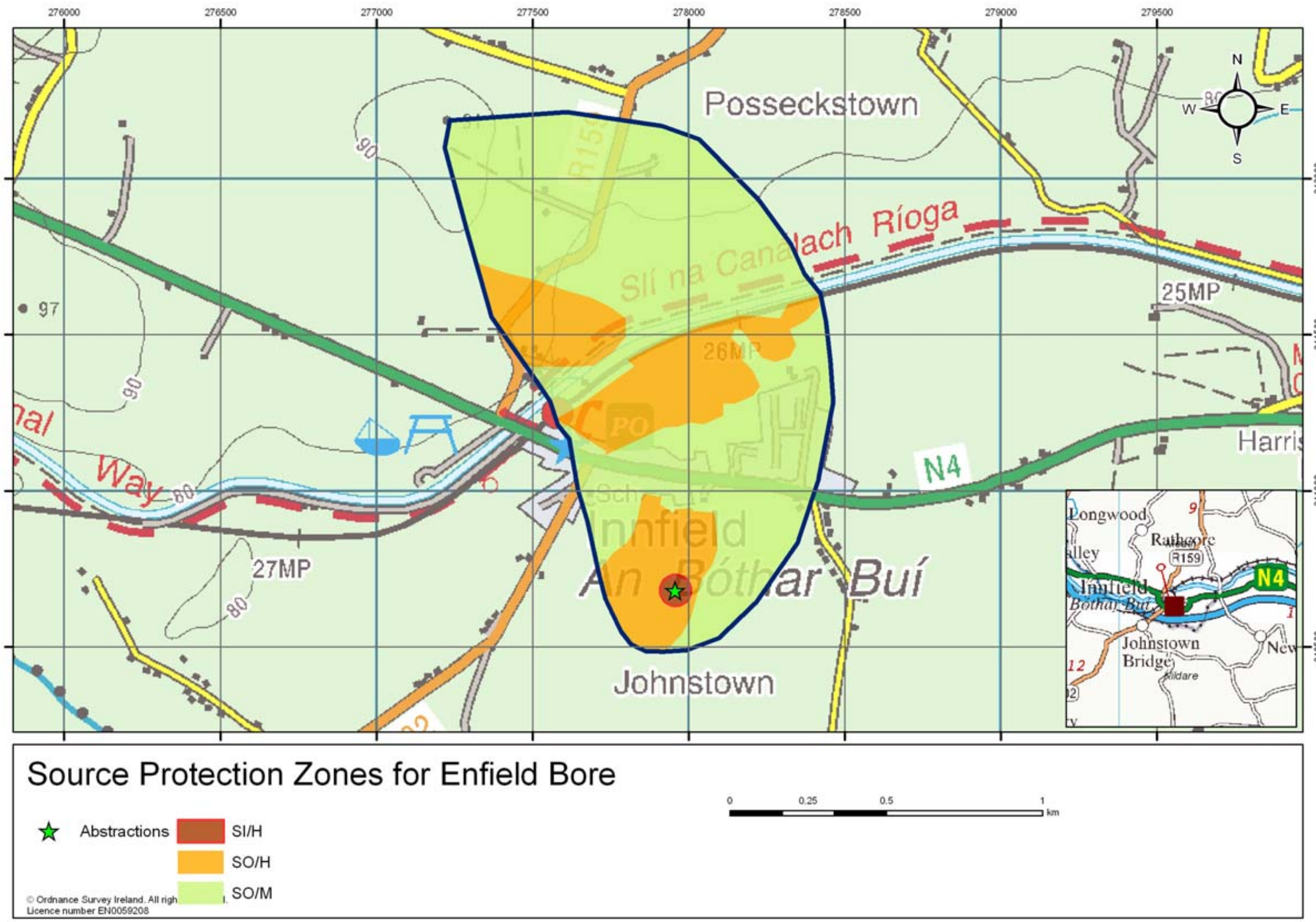


Figure 9 Source Protection Zones around Enfield Borehole

13 RECOMMENDATIONS

Monitoring water levels during the operation of the scheme should be continued to develop a real-time database of hydrogeological information.

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

A cordon around the source is recommended in order to ensure that potentially polluting materials are not stored or deposited in the immediate vicinity of the source. Secure, anti-intrusion fencing is currently erected around the source site, which acts to protect the integrity of the borehole headwork's and ancillary infrastructure.

14 REFERENCES

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

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

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

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

Jennings, P, (2005) IGI conference Engineering Geology of M4 Motorway Kilcock - Kinnegad

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

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

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

Trim GWB: Summary of Initial Characterisation. www.wfdireland.ie CDM

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

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

APPENDIX 1

Borehole Log & Pumping test

WELL LOG

Customer Name: Meath County Council,
Address: County Hall,
Navan,
~~Co.~~ Meath.

16 inch
Dry initially.

Site No. 6: Enfield

200mm DIAMETER WELL

TOTAL DEPTH OF WELL: 48.8 mts

DESCRIPTION	DIAMETER	DEPTH
Drill	300mm	21.3 mts
Supply & Install Steel Casing	250mm	21.3 mts
Drill	250mm	21.3 mts – 35.1 mts
Supply & Install Steel Casing	200mm	35.1 mts
Drill	200mm	35.1 mts – 48.8 mts
Well Grouted		Yes
Chlorinate Well		Yes

Type of Subsoil: 0 mts - 29.0 mts Gravel & Very Soft Boulder Clay

Depth to Bedrock: 29.0 mts

Type of Bedrock: Weathered Limestone. Very bad from 46.0 mts on

Supply at time of testing with drilling rig:	Depth	Gallons Per Hour
	48.8 mts	3,600

Remarks:
Supply & Install Lockable Cap.
Airlift well for 4 hours.
Important. Don't put pump down any further than 34 mts.

TOM BRIODY & SON LTD.

Artesian Well Drilling Engineers,Pump Installation,

Water Filtration and 72 Hour Pump Testing

Telephone: 046 924 3614 Fax: 046 924 3610 Mobile: 087 237 5511

RECOVERY ON TEST WELL

Well at: Enfield | Date: 05.11.04

Client: Meath Co Council | Recovery: Yes

Site: Enfield

Test & Measurements conducted by: Tom Briody & Son Ltd.

Height of casing below g.l. 0.9 mts | Diameter of well: 200 mm

Height of measuring point above g.l: 1.08 mts | Distance from pumping well to outfall: 58 mts

Pump intake at 33.45 mts below measuring point | Pump Type: Subteck PMG 300

Date	**Day**	**Time**	**Elapsed time HRS**	**MINS**	**Water level m**	**Meter Reading in Gallons**	**Discharge Remarks**
05.11.04	Friday	12.30		0	25.83		
				0.5	21.37		
				1	19.61		
				1.5	18.39		
				2	16.82		
				2.5	15.79		
				3	15.11		
				3.5	14.34		
				4	13.74		
				4.5	13.30		
				5	12.93		
				6	12.35		
				7	12.04		
				8	11.81		
				9	11.66		
				10	11.52		
				12	11.26		
				14	11.09		
				16	10.90		
				18	10.77		
				20	10.63		
				22	10.54		
				24	10.41		
				26	10.34		
				28	10.24		
				30	10.17		
				35	9.93		
				40	9.82		
				45	9.64		
				50	9.50		
				55	9.37		
			1	0	9.23		
				15	8.90		
		14.00		30	8.63		

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72 HOUR TEST WELL DATA SHEET DURING PUMPING

Well at: Enfield

Date started: 02.11.04

Date finished: 05.11.04

Client: Meath Co Council

Pumping: Yes

Site: Enfield

Test & Measurements conducted by: Tom Briody & Son Ltd.

Height of casing below g.l. 0.9 mts

Diameter of well: 200 mm

Height of measuring point above g.l: 1.08 mts

Distance from pumping well to outfall: 58 mts

Pump intake at 33.45 mts below measuring point

Pump Type: Subteck PMG 300

Date	**Day**	**Time**	**Elapsed time HRS**	**MINS**	**Water level m**	**Meter Reading in gallons**	**Discharge Remarks**
02.11.04	Tuesday	12.30		0	4.11	10216160	
				0.5	6.27		
				1	8.48		
				1.5	9.91		
				2	11.04		
				2.5	12.00		
				3	12.80		
				3.5	13.60		
				4	14.20		
				4.5	14.39		
				5	14.54		
				6	14.81		
				7	15.38		
				8	16.70		
				9	17.05		
				10	17.72		
				12	18.65		
				14	19.30		
				16	19.87		
				18	20.26		
				20	20.83	10217090	
				22	21.61		
				24	22.05		
				26	22.35		
				28	22.60		
				30	22.95	10217520	
				35	23.46		
				40	23.88	10218006	
				45	23.98	10218240	
				50	24.21		
				55	24.46	10218720	
		13.30	1	0	24.60	10218960	

	72 HOUR TEST WELL DATA SHEET DURING PUMPING						**Page 2 of 2**
Well at: Enfield							
Client:	Meath County Council					Date started:	02.11.04
Site:	Enfield					Date finished:	05.11.04
Date	**Day**	**Time**	**Elapsed time HRS**	**MINS**	**Water level m**	**Meter Reading in gallons**	**Discharge Remarks**
02.11.04	Tuesday	13.45	1	15	25.50	10219710	
				30	25.76	10220450	
				45	26.03	10221180	
		14.30	2	0	25.54	10221920	
				30	26.02	10223400	
			3	0	27.39	10224870	
				30	27.46	10226320	
			4	0	27.62	10227760	*
		17.30	5		27.21	10230570	
			6		27.29	10233340	
			7		27.58	10236110	
		20.30	8		27.63	10238880	
			9		27.55	10241650	
			10		27.55	10244420	*
03.11.04	Wednesday	00.30	12		25.98	10249650	
			14		25.92	10254850	
			16		25.85	10260050	
			18		25.73	10265230	
		08.30	20		25.61	10270440	
			22		25.75	10275620	
			24		25.75	10280790	
		14.30	26		25.83	10285990	
			28		25.87	10291180	
			30		25.87	10296390	
		20.30	32		25.88	10301580	
			34		25.88	10306790	
04.11.04	Thursday	00.30	36		25.91	10312000	
			42		25.91	10327610	
		12.30	48		25.87	10343240	
			54		25.85	10358890	
05.11.04	Friday	00.30	60		25.85	10374540	
			66		25.84	10390170	2,600 GPH.
		12.30	72		25.83	10405840	

* Slowed down flow rate on pump.

APPENDIX 2

M4 Geological Cross Section

Exaggerated Vertical Alignment Showing Geology