Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Knocklong Water Supply Scheme

Borehole in the Field (Borehole BH-1)

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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).

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Knocklong Water Supply 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 Knocklong Scheme is provided by two boreholes located approximately 500 m apart. BH-1 (Borehole in the Field) is situated 600 m south of the village of Knocklong in a field (IE_SH_G_194_13_016), while BH-2 (Church Road Borehole) is located 300 m southwest of the village (no code). BH-2, the older well on the scheme, was installed in 1971 and provides 91 m^3/d, while BH-1, installed in 1994, provides 380 m^3/d.

As the two wells are located so far apart and have independent distinct zones of contribution, separate Source Protection Reports have been compiled for each borehole. This report relates to BH-1, which was installed in response to an increase in demand for water in the area that could not be met by BH-2.

The objectives of the study were:

- To outline the principal hydrogeological characteristics of the Knocklong area where the supply wells are located.
- To delineate source protection zones for the wells.
- To assist the Environmental Protection Agency (EPA) and Limerick County Council in protecting the water supply from contamination.

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

2 Methodology

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

An initial interview with the caretaker and a site and local area inspection was undertaken on 28/06/2010. A further interview with the caretaker took place on site on 14/07/2010. Field mapping of the study area was also carried out on 28/06/10 and on 14/07/10. A pumping test had been conducted in 1994 by Limerick County Council at BH-1 and OCM conducted a short term recovery test in 2010 at BH-2.

While specific fieldwork was carried out in the development of this report, the maps produced are based largely on the readily available information and mapping techniques using inferences and judgements from experience at other sites. As such, the maps may not be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

3 Location, Site Description and Well Head Protection

BH-1 is in a fenced compound in the middle of a field, approximately 600 m south of Knocklong, as shown in Figure 1. Access to the compound is via a 100 m long track through the field from a third class road linking the villages of Knocklong and Ardmore. The compound is protected by a chain link and concrete post fence, with a padlocked gate.

The ground surface inside the compound comprises granular fill and open grassed areas (Photos 1 and 2). The well is 10 m south of a pump house, which also houses a chlorination system (sodium hypochlorite). There is no cryptosporidium filter. After treatment, the water is pumped to a reservoir located on a hill 250 m to the southwest of the well.

Photo 1: Site Layout

Photo 2: Site Layout

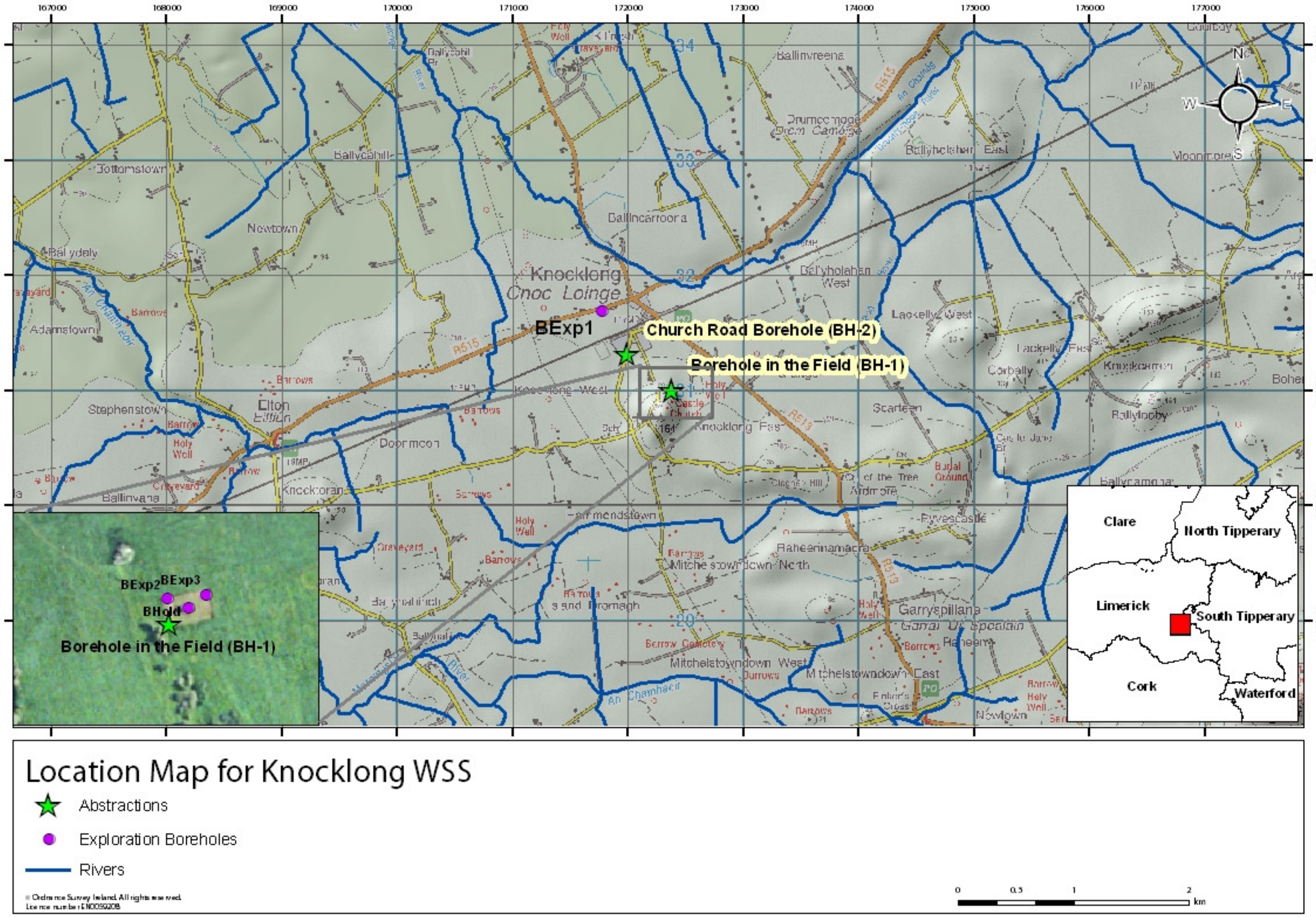


Figure 1: Location Map

The borehole is in a concrete manhole chamber (c3 m by 1 m), fitted with a concrete cover. The chamber is set c.0.20 m above the ground level which protects against the inflow of surface water run-off from the surrounding ground. The base of the chamber is 0.90 m below ground level (bgl). The steel casing rises 0.40 m above the bottom of the chamber. The borehole is capped and there is a concrete seal at the bottom of the chamber that provides protection against shallow subsurface water inflow (Photo 3). Based on the borehole log, it appears that the steel casing has been driven to the top of bedrock, but it is not known if borehole is grouted above the bedrock.

Photo 3 Well Head

4 Summary of Well Details

The well details are derived primarily from documents provided by Limerick County Council and Mr. David Ball (Hydrogeologist), which are included in Appendix 1 and summarised in Table 4.1.

In 1993, two exploration boreholes located 10 m apart were drilled 20 m to the north of the production borehole, in the northwest and north east corners of the compound. The wells were installed to a depth of 254 ft, or 77 m. There is no evidence of these wells and it is assumed that they were decommissioned. The log of one of the exploratory boreholes and the Production Well, compiled by Mr. James O’Callaghan of Limerick County Council is included in Appendix 1.

An old borehole, drilled before 1960 but no longer in use, is located inside the pump house. The depth of the well is unknown.

Following completion of exploratory testing, the production borehole was drilled in 1994 to a depth of 300 ft or 91.5 m. The drilling was supervised by Limerick County Council. The boring comprised a 305 mm outer steel liner from ground level to 1.8 m bgl, where the bedrock was encountered, then an unknown reduced diameter (probably 150 or 200 mm) open hole to the bottom of the borehole. It is not known if the borehole was grouted above the bedrock. OCM has compiled a borehole log for the well based on the handwritten field log notes made during the drilling and both the field notes and the interpreted log are presented in Appendix 1.

The water is pumped from the well at 33 m^3/h, operating around 13 hours per day, to a 103 m^3 capacity reservoir located on the top of a hill 250 m to the southwest of the borehole. The abstraction rate is controlled by the demand, which results in fluctuations in the rate. The average abstraction rate recorded by the Council is 430 m^3/d. The Caretaker stated that the yield is very reliable and that the borehole has never suffered from a shortage of water.

In 1994, Limerick County Council conducted a three-day pumping test in BH-1. The data from the pumping test have been compiled by OCM in table and are included in Appendix 2. OCM completed a short term recovery test (170 minutes) in BH-2, located 300 m to the northwest of BH-1, in September 2010. The recovery test data are included in Appendix 3.

Table 4-1: Well Details

	BH-1
EU Reporting Code	IE_SH_G_194_13_016
Grid ref. (GPS)	172396 131019
Townland	Knocklong East
Source type	Borehole
Drilled	1994
Owner	Limerick County Council
Elevation (Ground Level)	~120 m OD
Depth (m)	91.5 m
Depth of casing	11 m
Diameter	unknown
Depth to rock	1.8 m
Static water level	9.90 m bgl (19/09/1994) 6.70 m bgl (28/06/2010)
Pumping water level	70.15 mbgl for 26 m^3/h (21/09/1994)
Consumption (Co. Co. records)	33 m^3/h or 430 m^3/d
Pumping test summary: (i) abstraction rate	624 m^3/d
(ii) specific capacity	10.4 m^3/d/m
(iii) transmissivity	154 m^2/d

5 Topography, Surface Hydrology and Land Use

The borehole is located at an elevation of 120 m OD at the foot of a hill that rises to a high point of 164 m OD and is the highest point in the local catchment. The land slopes to the north from the hill toward the village of Knocklong. The topographical gradient on the hill at Knocklong east is approximately 0.15 and this decreases to 0.015 in the vicinity of the well compound. Further north and east the topography is very flat.

The well is in the catchment of Drumcomoge River which is 1 km to the north. The Drumcomoge River flows to the northwest joining the Camoge River, 3.3 km to the northwest of the site. To the south the catchment is defined by the top of knolls and ridges running between Knocklong east, Clogher Hill and Ardmore. Drainage density is generally low in the catchment, with much of the land comprising free draining agricultural grass land (dairy). The ordnance maps for the area (50,000 and 6 inch to 1 mile scale both indicate the presence of a holy well (St Patricks and St Pauls Well) to the east of the well compound. There is a small portion of less well draining land located approximately 150 m to the east of the compound where the drainage appears to be poor and rush growth is dominant and this may correspond to the location of the wells historically.

There is a greyhound training track located 155 m to the east of the compound. There are four residential dwellings within 250 m of the compound. It is possible that during the development of the greyhound track and/or residential dwellings that the well and associated drainage from the holy well was diverted or sealed off as there was no evidence of the holy well or spring discharges encountered in this area during the field inspections.

6 Hydrometeorology

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: 1100 mm. based on the contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961–1990), which shows the source is located between the 1000 mm and 1200 mm average annual rainfall isohyets.

Annual evapotranspiration losses: 506 mm. Average potential evapotranspiration (P.E.) is estimated to be 532 mm/yr based on the contoured data map of potential evapotranspiration in Ireland (Met Éireann website, data averaged from 1971–2000) which shows that the source is located between the 530 mm and 540 mm average annual evapotranspiration isohyets. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: *594* mm. The annual average effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 594 mm/year.

7 Geology

7.1 Introduction

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

The desk study data used comprised the following:

- Groundwater Vulnerability Map for County Limerick Digital Map, Geological Survey of Ireland (2010).
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2002)
- Boreholes logs of exploration wells and production wells from Limerick County Council (1994) and Mr. David Ball (2010).
- Geology of Tipperary. Bedrock Geology 1 : 100,000 Map series, Sheet 18, Geological Survey of Ireland (J.B. Archer, A.G. Sleeman and D. C. Smith, 1996)

7.2 Bedrock Geology

Sheet 18, the Geology of Tipperary published by the GSI indicates that the borehole is located close to the boundary between the Ballysteen Formation (Dark muddy limestone, shale) and the overlying Waulsortian

Limestones (fine pale-grey micrite with large sparry masses) from the Lower Carboniferous period (Figure 2). Further south of the Waulsortian, the bedrock comprises Dinantian Upper Impure Limestone.

The geological descriptions in the borehole logs are of limited value (Appendix 1), with the Production Well log providing details on only the depth to bedrock (6 ft c.1.8 m), total depth (300 ft c.91.4 m) and indicative water yields. The exploration borehole log indicates depth to bedrock (30 ft, 9.1 m), the presence of broken bedrock from 18 m (60 ft) to 27 m (90 ft) where first water strike encountered and the presence of limestone and sandstone between 27 m (90 ft) and 36 m (120 ft), with layers of limestone and sandstone (brown in color) from 36 m (120 ft) to 60 m (200 ft) and sandstone beneath this to 76 m (250 ft). It is possible that the brown sandstone and broken limestone description (which will have come from the drillers) would be typical of the dolomitised Waulsortian. Combined with hydrogeological data which is discussed in Section 9, it is more likely that the boundary between the Wausortian and Ballysteen Formations is actually further north and that the borehole is located in the Waulsotian bedrock formation.

During the field mapping, karstified bedrock outcrop was observed 10 m to the south of the borehole, in the footslope of the hill. The bedrock was pale fractured heavily weathered and consistent with the description of the Waulsortian Formation (Photo 5). Outcropping bedrock was also noted along the side and toward the top of the hill. It appears that the well is located very close to, if not on the boundary between the Waulsortian and the Ballysteen Limestone Formations.

Photo 5: Outcrop of karstified Waulsortian limestone close to BH1

Sheet No. 18 indicates that the well is located on the limb of an anticline, whose axis is situated approximately 2.6 km to the northwest. The bedding dips to the southeast. It is likely therefore that the borehole is very close to the boundary between the Ballysteen and Waulsortian Limestone Formations. The presence of broken sandstone and limestone as described in the exploration borehole log suggest the potential for dolomitisation of the bedrock beneath the site. There are two large NNW to SSE and ENE to WSW trending faults mapped at 3 km to the east and the south of the borehole. However, it is likely fracturing and faulting that accompanied the folding of the limestone has likely given rise to zones of enhanced permeability locally.

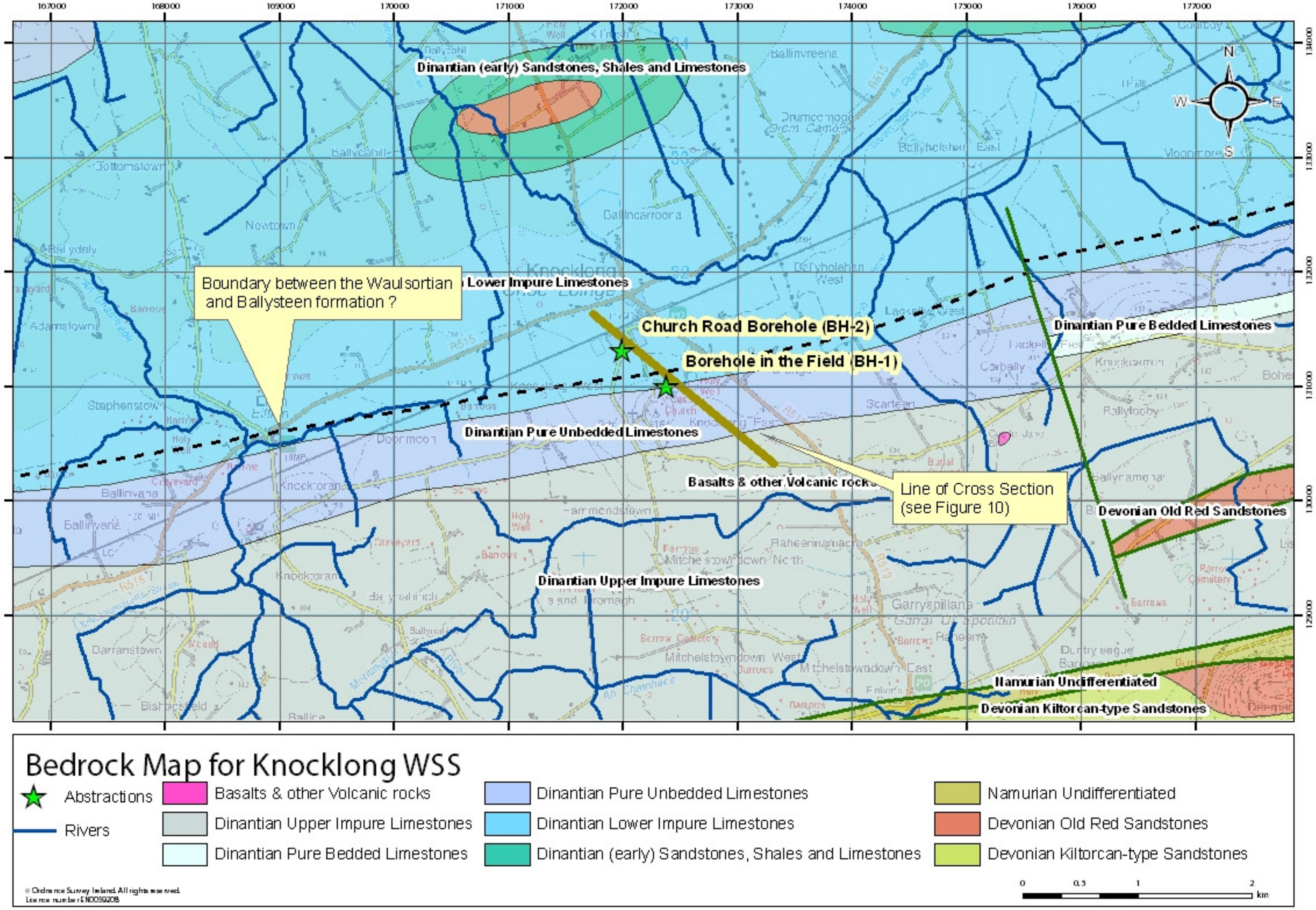


Figure 2: Bedrock/Rock Unit Map

7.3 Soil and Subsoil Geology

The soil and subsoil distributions are illustrated in Figures 3 and 4, respectively. The soils covering the hill to the south of the borehole are classified as Basic Mineral Shallow Well Drained soil (BminSW). There is a small area of the catchment to the east of the borehole close to the greyhound track where the soil is classified as Acid Mineral Poorly Drained (AminPD), while in the remainder of the catchment the soil is classified as Acid Mineral Deep Well Drained (AminDW).

The subsoils comprise mainly Devonian Sandstone Tills subsoils (TDSs). In this area, a unit of sandstone till has been carried out over the limestone bedrock by the ice during the last ice age as ‘carryover’ material. There is no subsoil on the hill to the south of the site, where Karstic bedrock (KarCK) is shown on the subsoil map.

The permeability of the Sandstone Tills is characterised as moderate based on BS5930 field assessment of samples collected approximately 50 m to the north and 35 m to the east of the pump house. Well drained lands were observed over most of the catchment. A small portion of poorly draining land was noted approximately 150 m to the south east of the borehole, where there is some rush growth close to the field boundary with an adjacent greyhound track.

7.4 Depth to Bedrock

Rock outcrops along the hill and on the footslope to the south of the compound. Depth to bedrock in the borehole is 1.8 m bgl. The depth to bedrock increases in all directions away from the hill, increasing to more than 9 m approximately 20 m north of the well (exploration borehole log) and to more than 10 m a further 50–60 m north toward Knocklong (GSI Vulnerability Map). Depth to bedrock data for BH-2, located 450 m to the northwest, is 21 m. Further to the north, the log of an old exploration borehole located 800 m to the northwest indicates a depth to bedrock at 30.5 m bgl. This degree of variation and the presence of the mounds are typical of karstified Waulsortian rocks. The depths are consistent with the Vulnerability mapping data for this area. The locations of all identified boreholes in the area are shown on Figure 1. The depth to bedrock data for the old exploration boreholes was provided by Mr. David Ball and is included Appendix 2.

8 Groundwater Vulnerability

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

The vulnerability map is illustrated in Figure 5. Rock outcrops or is close to the surface from the hill to the south of the well to an elevation of c130 m OD in all directions. The depth to bedrock at BH-1 is 1.8 m bgl. On the hill to the south, the vulnerability is Extreme with rock close to the surface or outcropping. Beyond the compound and the hill in all directions there is a band of high vulnerability for a distance of approximately 100 m. The high vulnerability zone extends a little further along the public road to the southwest of the hill approximately 200 m more than it does in other portions of the catchment. Outside the high vulnerability area, the vulnerability reduces to moderate.

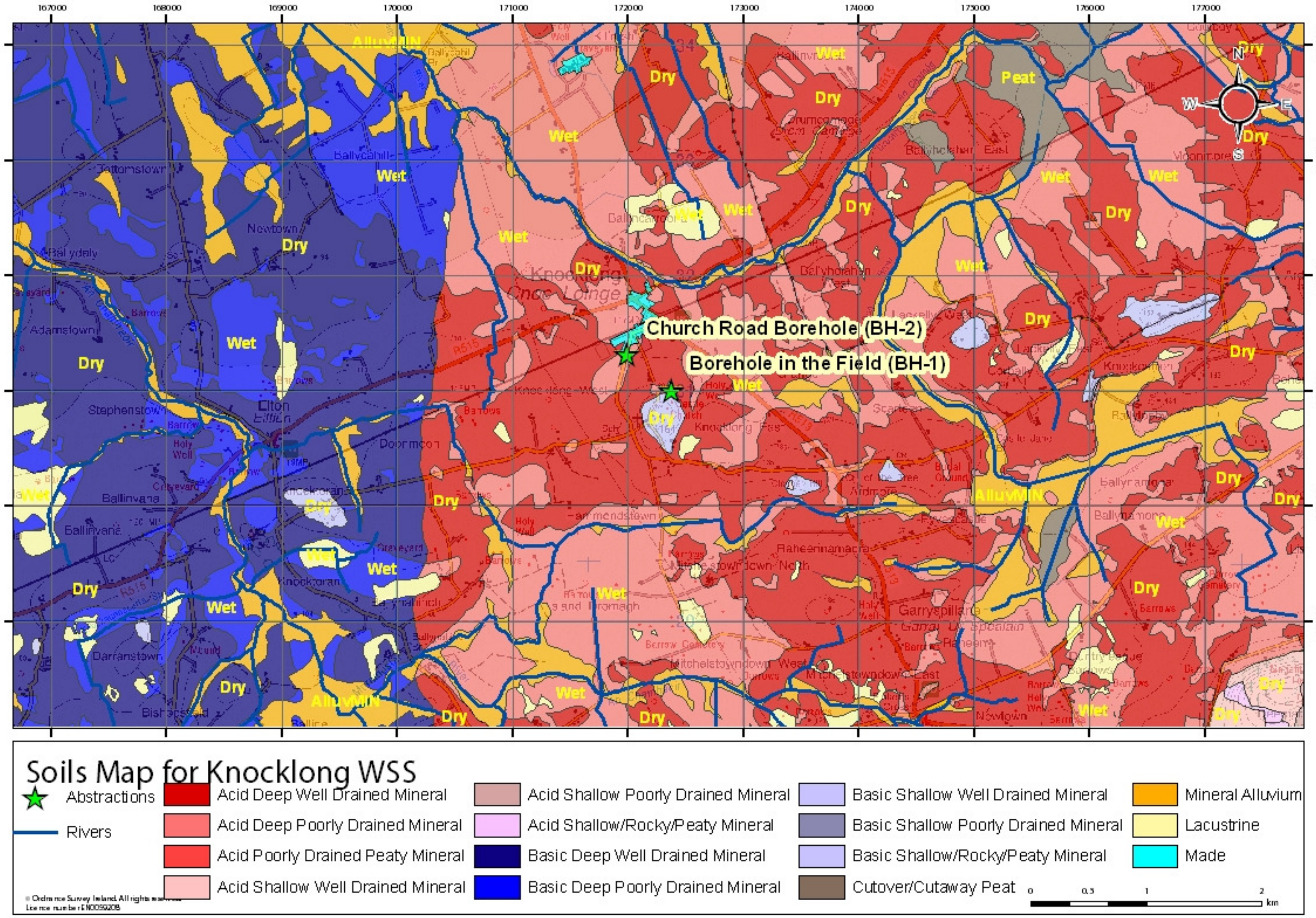


Figure 3: Soils Map

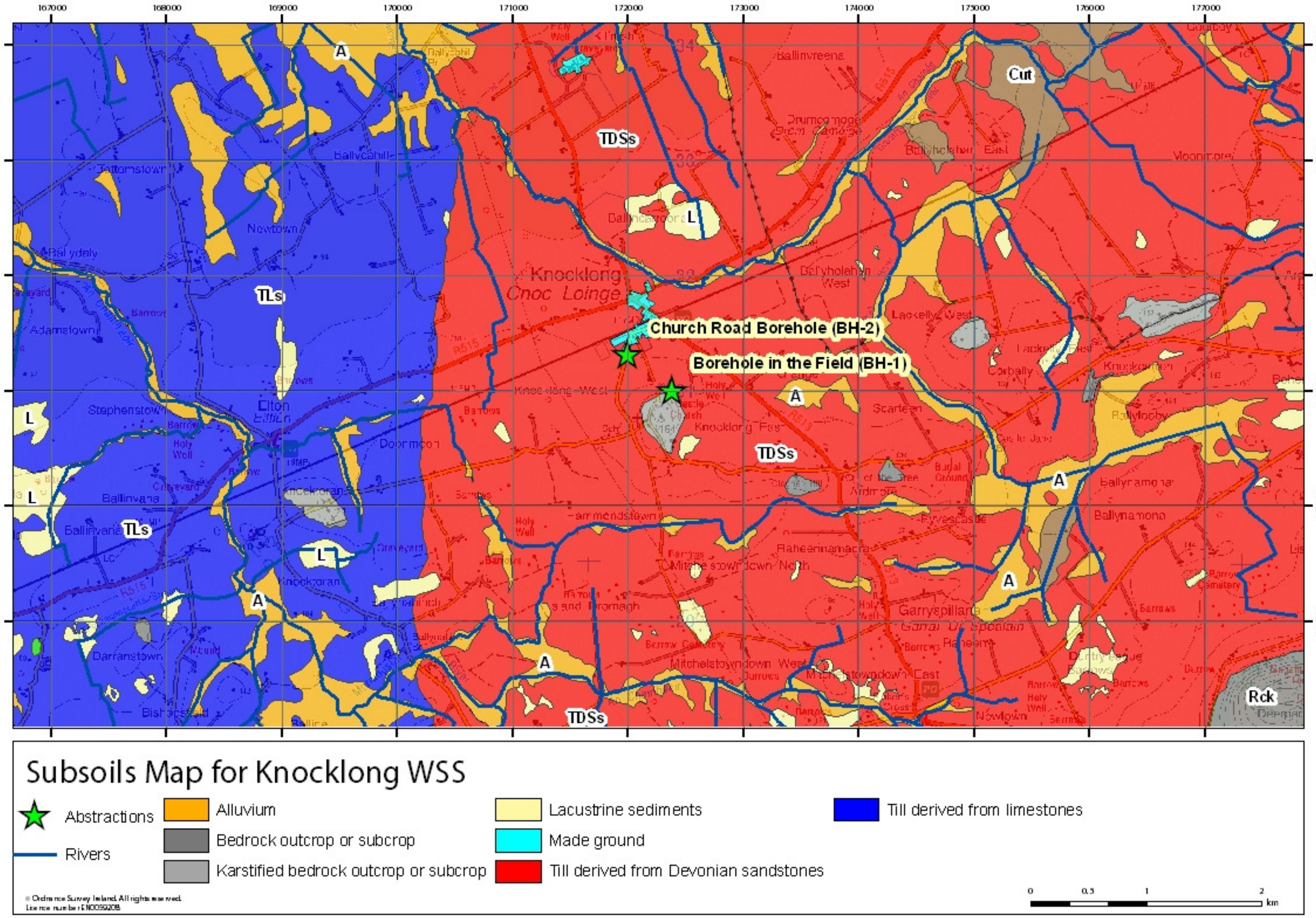


Figure 4: Suboils Map

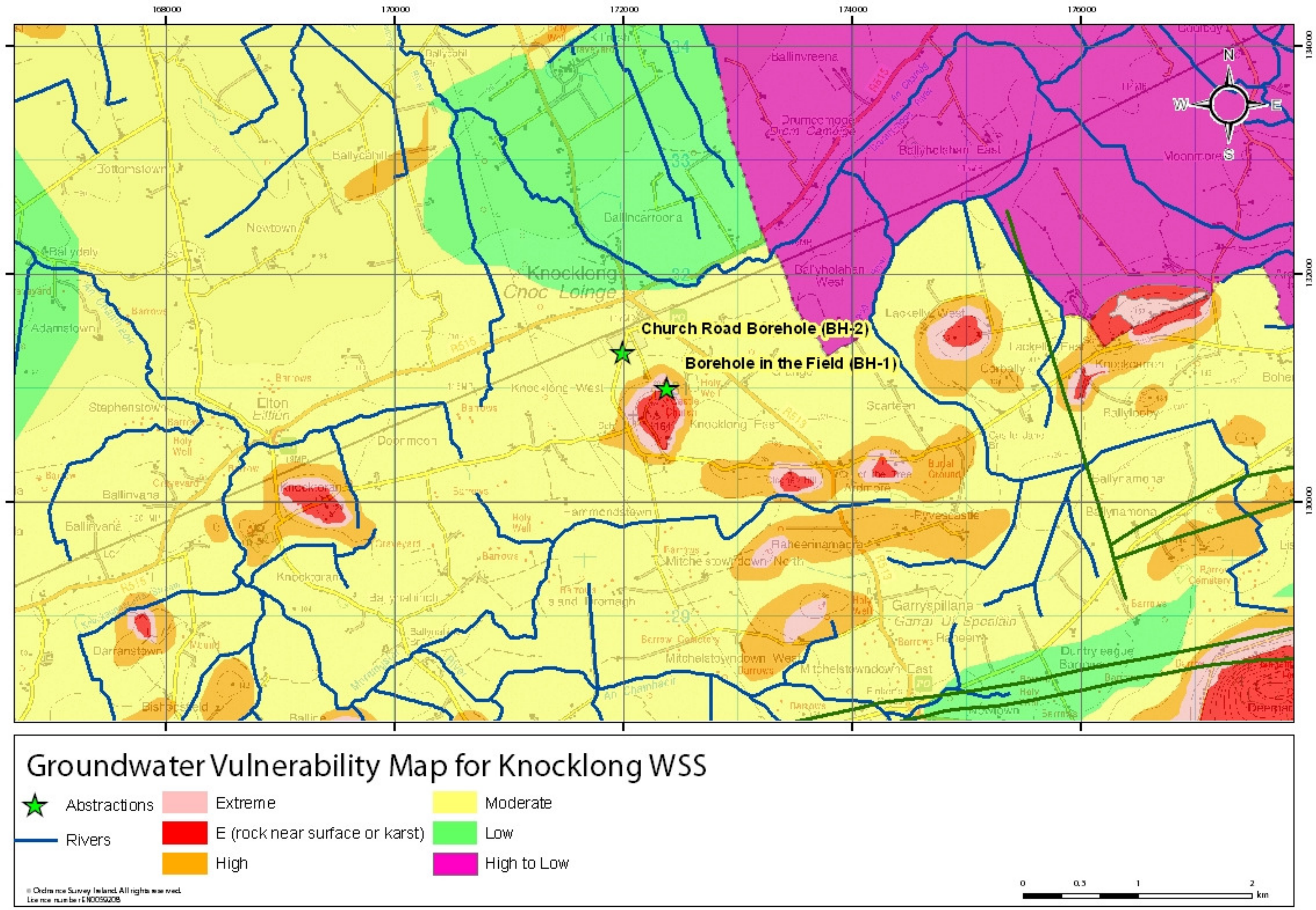


Figure 5: Vulnerability Map

9 Hydrogeology

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

- GSI Website and Database
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Pumping test data (1994) from Limerick County Council
- North Kilmallock GWB Report

9.1 Groundwater Body and Status

The borehole is located within the North Kilmallock Groundwater Body (IE_SH_G_194) 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/maps.html.

9.2 Groundwater Levels, Flow Directions and Gradients

The static water level in the production well prior to the September 1994 pumping test was 9.90 m bgl. On the 28th June 2010, the static water level was 6.7 m bgl. The higher level recorded in 2010 probably reflects the storage in the aquifer from the previous winter period. BH-2, located 450 m to the north-west in the same formation, is artesian. The borehole located in the pump house and the old exploration borehole located 800 m to the northwest could not be accessed to measure water levels during the field mapping programme.

Based on the topography and local surface water drainage patterns, groundwater infiltrates the upper impure limestone bedrock and further north the permeable subsoils and karst waulsortian bedrock beneath the well and flows to the northwest towards Drumcomogue River. The pumping gradient is steep based on the level of drawdown in the well during pumping (60 m bgl). but over much of the remaining portions of the catchment the groundwater gradient is expected to be shallow (0.01). An average value of 0.02 has been estimated for the catchment.

9.3 Hydrochemistry and Water Quality

The well has been included in the EPA operational chemical network since August 2007. The raw water sample point is a tap located outside the pump house close to the borehole. The laboratory results have been compared to the EU Drinking Water Council Directive 98/83/EC Maximum Admissible Concentrations (EUMAC) and, where relevant, mean values have been compared to the European Communities Environmental Objectives (Groundwater) Regulations (Threshold Values) 2010 recently adopted in Ireland under (S.I. No. 9/2010) as part of the implementation of the Water Framework Directive 2000. The EPA data are graphed in Figures 6 to 8 and summarised below.

- The water has a hard calcium bicarbonate hydrochemical signature (average 322 mg/l $CaCO_3$). The average conductivity is 569 µS/cm and the range is from 459 µS/cm to 685 µS/cm. The average pH is 7.2 while it ranges between 6.7 and 7.6.
- There is only one reported incident of Faecal Coliforms in 13 analyses. Ammonium has never exceeded the Threshold Value (0.175 mg/l).

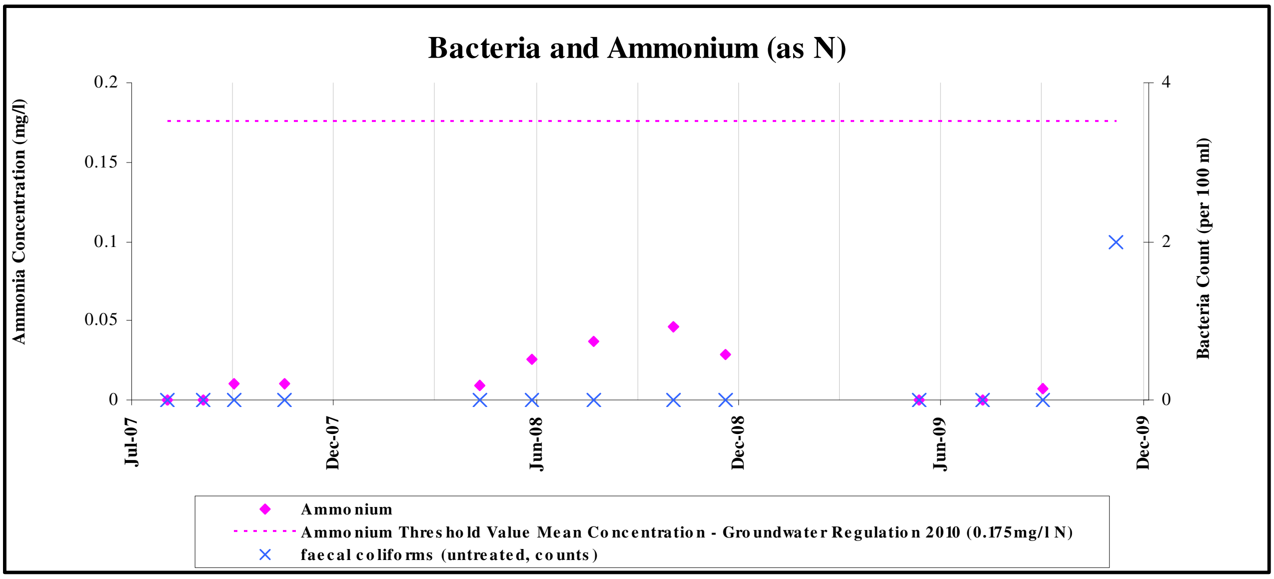


Figure 6: Key Indicators of Agricultural and Domestic Contamination: Bacteria and Ammonium

- The nitrate (as NO_3) level ranges from 1.7 mg/l to 24.1 mg/l, with a mean of 12.3 mg/l. Neither the MAC of 50 mg/l nor the Threshold Value of 37.5 mg/l have been exceeded.
- Chloride can be a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than the 24 mg/l Threshold Value may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 13.2 mg/l to 29 mg/l with a mean of 16.1 mg/l. Over the monitoring period both chloride and nitrate levels have been reducing.
- Turbidity exceeded the drinking water standard limit of 1 NTU on two occasions on the 30/10/2008 and the 16/12/2008, at 2.6 and 2.4 NTU, respectively. This is likely due to the presence of very fine clay particles entering the borehole.

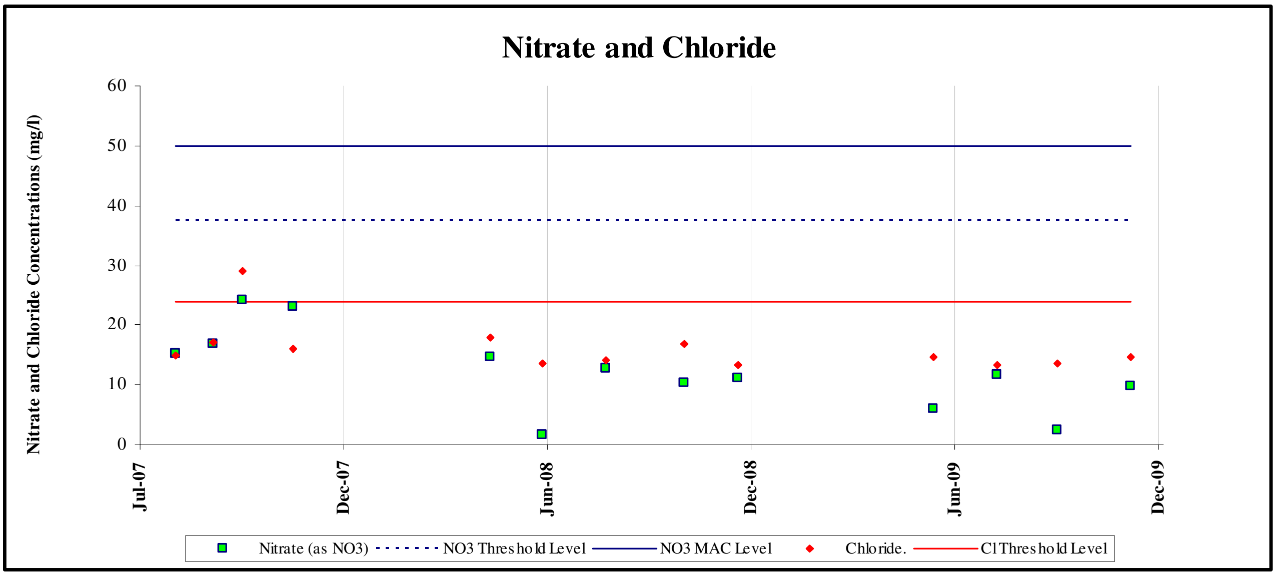


Figure 7: Key Indicators of Agricultural and Domestic Contamination: Nitrate and Chloride Graph

- The sulphate, potassium, sodium, magnesium and calcium levels are within normal ranges. The potassium:sodium ratio was above the threshold of 0.35, in nine of the 13 analyses.

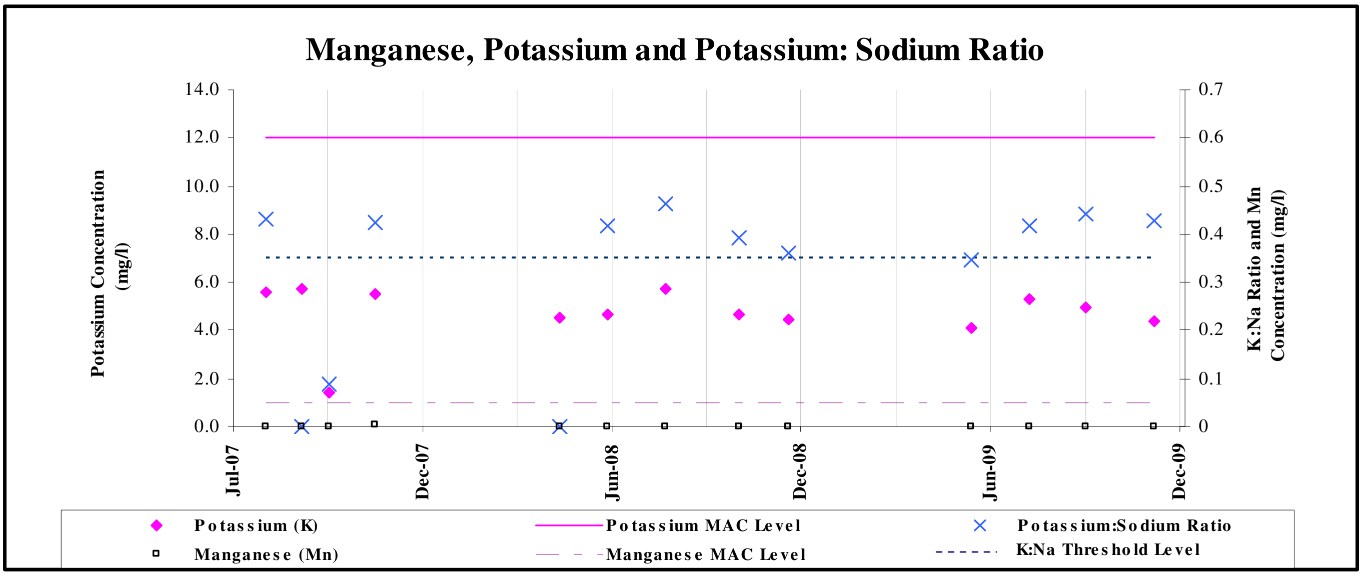


Figure 8: Key Indicators of Agricultural and Domestic Contamination: Manganese, Potassium and K/Na ratio

- The concentrations of iron and manganese are below the normal ranges.
- Other trace metals were either within the normal range for good quality drinking water or were not detected. Organic compounds and herbicides have not been detected.

In summary, faecal coliforms have been detected only once in the untreated water and at low levels. It is possible that the source of contamination is the presence of cattle grazing in the field surrounding the compound. The nitrate levels average 12.3 mg/l and reflect the low agricultural pressures and thick subsoil beyond the compound and hill side to the south. The exceedance of the potassium:sodium ratio in nine of 13 analyses is due to the high potassium levels. While this could indicate contamination by animal manures and sewage, the other associated contaminant indicators are low i.e. faecal coliforms and ammonium. It is possible that the potassium levels are naturally occurring associated with the local geology.

9.4 Aquifer characteristics

According to the geological map the borehole is situated in the Ballysteen Limestone Formation. However, the presence of karst bedrock within 10 m of the well indicates that it may be close to the interface between the Waulsortian and the Ballysteen Formations or more likely in the Waulsortian Formation. The Ballysteen Aquifer is classified by the GSI as a *Locally Important aquifer which is moderately productive only in Local Zones (Ll),* as indicated in Figure 9. The Waulsortian Aquifer is classified as a Regionally Important Karst Aquifer with diffuse flow (Rk_d). Further to the south of the Waulsortian Aquifer is the Upper Impure Dinantian Limestone which is also an Ll aquifer. BH-1 provides an average yield of 380 m^3/d. The yield is sustainable and the scheme has never had problems meeting demand. A sustainable yield this high is unusual for an Ll aquifer and indicates that it is more likely to be situated in the Rk_d aquifer.

Both the Wausortian and the Ballysteen Aquifers are unconfined in the vicinity of the borehole, with a static water level between 9.9 and 6.7 m bgl (Section 9.2). The other borehole in the Scheme (BH-2), located 450 m to the north, is in the Ballysteen Formation. Here the aquifer is overlain by up to 21 m of moderate permeability glacial till and the borehole is artesian.

Groundwater flow in the aquifer is through fractures, fissures and faults in the limestone. Generally in Ll aquifers, the groundwater flow is concentrated in the upper 15 m, although deeper inflows along fault zones or connected fractures can be encountered. The exploration and production boreholes logs show that the main water strikes at Knocklong were encountered in fractured bedrock zones at depths of approximately 45 m and 76 m bgl. These types of water bearing zones are more indicative of the Waulsortian karst aquifer. Groundwater flow in karst aquifers is along solution enhanced fractures and fissures. Where the limestone has been subjected to dolomitisation this can further enhance the permeability characteristics of these aquifers.

The pumping test undertaken in BH-1 by Limerick County Council in 1994 ran from September 19th to 21st. The recovery was measured for 2 hours and 45 minutes after completion of the pumping test. At an abstraction of 624 m^3/d, the drawdown was 60 m bgl, indicating a low specific capacity of 10.4 m^3/d/m. This steep drawdown probably occurred because the pumping rate was initially too high. However, after 5 hours of pumping, the water stabilized at 70.15 m bgl until the end of the pumping test (i.e for 65 hours) indicating the yield of 624 m^3/d is potentially sustainable. The recovery to the initial static level was relatively quick in only 33 minutes.

The transmissivity calculated based on the results of the pumping test carried out in 1994 is 1100 m^2/d using the pumping section of the test. This value is not consistent with the observed steep drawdown observed under pumping in the well. In the Groundwater Body Description for the Kilmallock GWB which is located to the west of Knocklong, the GSI indicate that transmissivity in diffusely karstified aquifers is in the range 20–2000 m2/d. however in this area of the country, the median value will be towards the lower end of the range. Using the recovery portion of the pumping test from 1000- 10000 seconds a transmissivity value of 154 m^2/d was calculated. While the transmissivity could potentially be in the range indicated under the pumping section of the test, as a result of dolomitisation, the transmissivity value of 154 m^2/d, calculated using the recovery data, has been applied in this study based on the GSI experience in this part of the country.

The drawdown, for this part of the test is <30% of the thickness of the aquifer, the CE Jacob Formula can be applied for unconfined condition:

$$\text{Transmissivity (T)} = 0.183Q / \Delta s$$

Where Q=discharge and ΔS= change in the drawdown over 1 log cycle.

OCM completed a short term (170 minutes) recovery test in September 2010 in BH-2 located 300 m to the northwest. One objective was to establish if there was a connection between BH-1 and BH-2, i.e. are they located in the same aquifer. BH-1 was switched off for 130 minutes prior to the start of the test. Then BH-2 was switched off and allowed to recover. BH-1 was then switched back on but there was no water level response in BH-2. This is probably due to the distance apart and BH-2 being located in the Ballysteen aquifer. However, given the distance apart, a much longer test period is required to confirm this observation. The calculated transmissivity for BH-2 of 9 m^2/d is much lower than for BH-1 and indicates that the boreholes are most likely located in different aquifer units.

The bedrock permeability for an Rkd aquifer is expected to be high due to the presence of solution enhanced fractures and fissures and possibly dolimitisation. The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer.

Based on the available information, the saturated thickness of the aquifer is assumed to be c.89.5 m. (the full depth of BH-1 minus the depth of overlying subsoil thickness of 2 m). Therefore the bulk permeability (K) is estimated as follows:

Table 9-1: Permeability for BH1

	Local Assumption
Transmissivity (m^2/d)	154
Permeability (m/d)	1.70

The permeability for the aquifer is estimated to be 1.70 m/d. This is calculated by dividing the calculated transmissivity by the assumed aquifer thickness.

The velocity of water moving through this aquifer to the borehole has been estimated using Darcy's Law:

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

The natural gradient is estimated at 0.02. The effective fracture porosity assuming an a RKd Formation is estimated at 0.02. Aquifer porosity for Rkd aquifers in Ireland typically ranges from 0.01 – 0.25 based on values stated by GSI in groundwater body descriptions incorporating RKd aquifers. That porosity value has been applied to the formation as part of the current assessment.

Table 9-2: Estimated Velocity for BH1

	Velocity (m/d)
Local Effective Porosity (2.0%) **Local K Assumption (1.70 m/d)**	1.7

The velocity of groundwater moving through the aquifer is estimated as 1.7 m/d.

The aquifer parameters are summarized in Table 9-3.

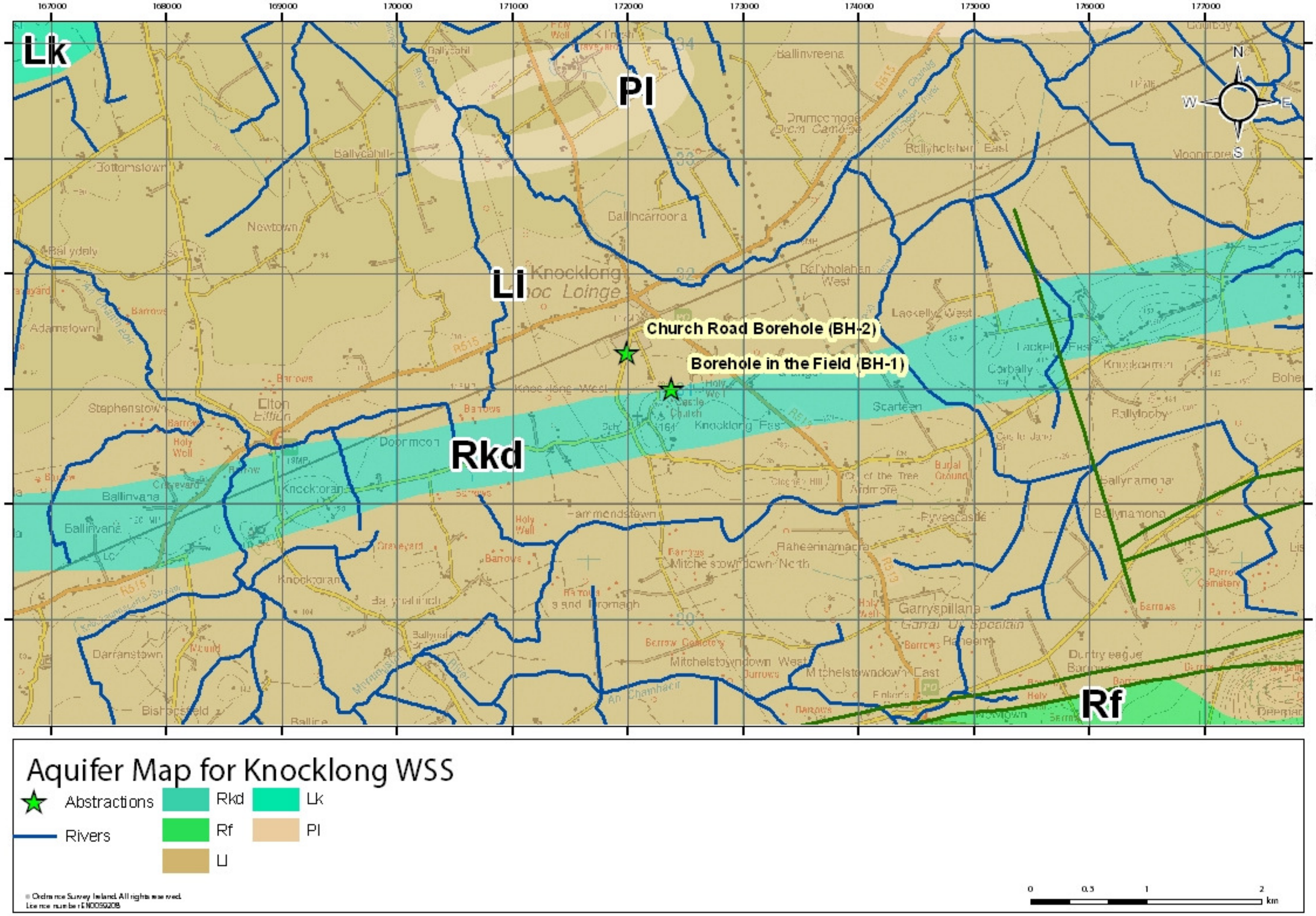


Figure 9: Aquifer map

Table 9-3: Indicative Parameters for the Waulsortian Formation from the Lower Carboniferous in Knocklong

Parameters	Source of Data	BH1/BH2
Transmissivity (m^2/d)	Calculated (based on exploration borehole pumping test data in 1994)	154 m^2/d
Permeability (m/d)	Estimated from T value assuming saturated thickness is the full depth of the boreholes	1.70
Effective Porosity	Assumed (based on values stated by GSi in groundwater body descriptions)	2.0%
Groundwater gradient	Assumed based on topography	0.02
Velocity (m/d)	calculated based on above	1.7

10 Zone of Contribution

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

10.1 Conceptual model

The groundwater in the local catchment flows from the high ground along the ridges running between Knocklong east, Clogher Hill and Ardmore to the south and flows to the northwest towards the Drumcomogue River. The rainfall infiltrates the soil and subsoil and recharges the Dinantian Upper Impure Limestones in the high ground and lower down the Waulsortian bedrock, flowing north toward the borehole. Immediately beneath the site and to the south, recharge also occurs through the thin subsoil into the underlying bedrock.

BH-1 appears to be is installed close to the interface between the Waulsortian and the Ballysteen Formations. However, based on the data obtained as part of this study it is considered to be located in the Waulsortian Formation which is fractured and possibly dolomitised/karstified bedrock. The main water strikes were encountered at depths of approximately 45 m and 76 m bgl. The groundwater table is close to the surface reflecting the topography in the Drumcomoge River catchment. Near the borehole, the aquifer is unconfined and is extremely vulnerable. However, within 100 m to the north and northwest, the aquifer is overlain by thick glacial till subsoil.

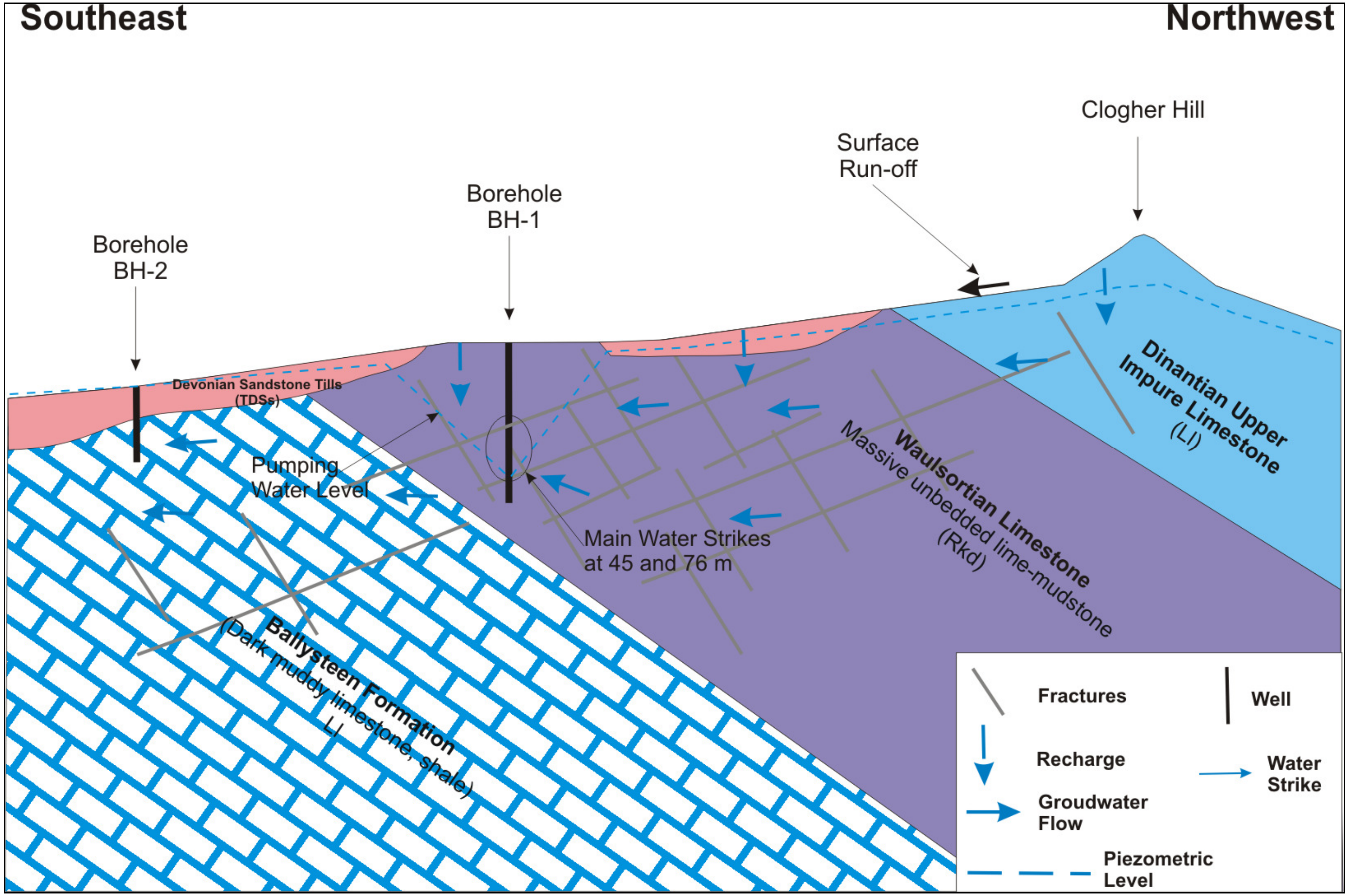


Figure 10: Conceptual Model

10.2 Boundaries of the ZOC

The boundaries of the area contributing to the source are considered to be as follows (Figure 11):

The Southern boundary is defined by the topographic divide along the top of ridges running between Knocklong east, Clogher Hill and Ardmore, which are assumed to coincide with the groundwater divide.

The Eastern and Western boundaries are based on topography and also the presence of karst waulsortian limestone extending to the east and west of the well and the associated higher recharge expected in this formation to provide groundwater flow to the well.

The Northern boundary – the Downgradient boundary is the maximum downgradient distance that groundwater can be drawn to the borehole and is based on the uniform flow equation (Todd, 1980).

$$x_L = Q / (2\pi * T * i) \text{ where}$$

Q is the daily pumping rate +/- X%
T is Transmissivity (taken from aquifer characteristics)
i is gradient.

Given the pumping rate is 430 m^3/d, the transmissivity is 154 m^2/d and the hydraulic gradient is 0.02, the approximate maximum downgradient distance is around 22 m. In this case the down gradient boundary has been extended to the north to include for the extremely vulnerable aquifer area which extends approximately 120 m to the north of the borehole.

10.3 Recharge and water balance

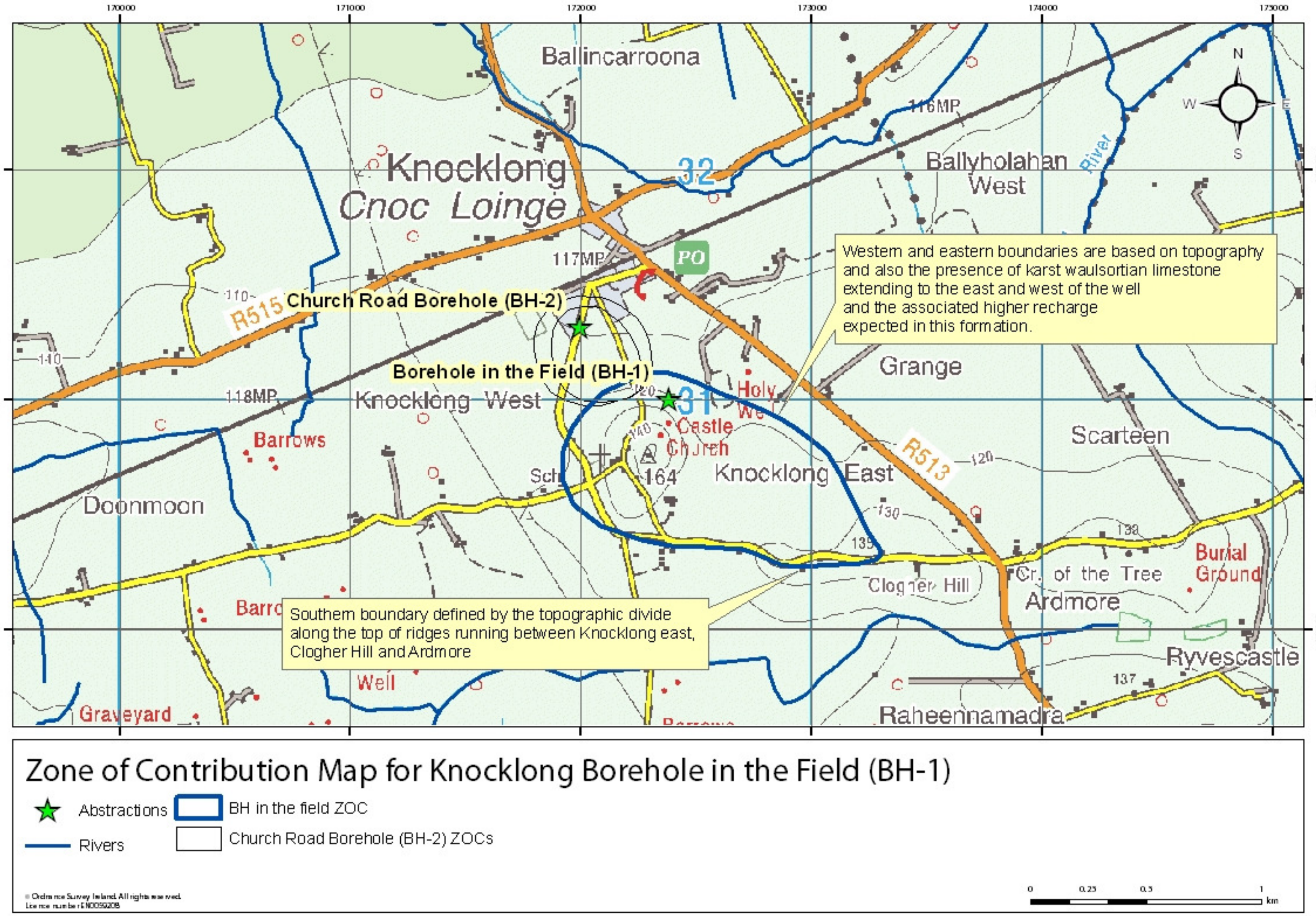
The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (i.e. annual rainfall) less water loss prior to entry into the groundwater system (i.e. annual evapotranspiration and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

Given the high permeability and presence of a Regionally Important Karst Aquifer no recharge cap has been applied, At Knocklong therefore, the main parameters involved in recharge rate estimation are: annual rainfall, annual evapotranspiration and a recharge coefficient. The recharge is estimated as follows.

Potential recharge is equivalent to 594 mm/yr i.e. (Annual Effective Rainfall as outlined in Section 6).

Actual recharge has been estimated to be 416 mm/yr; this value is based on the following observations:

32% of the ZOC is occupied by the extreme vulnerability and outcropping rock. The top of the hills immediately to the south and further to the southeast and their slopes are classified as Extreme Vulnerability, with the bedrock either outcropping and/or close to the surface, while the base of the hills is overlain by thin well drained soils and are classified as High Vulnerability (26%). Two separate recharge coefficients (Guidance Document GW5) have been assigned to these areas: 0.85 where rock is close to or at the surface, i.e no subsoil and 0.60 where thin well draining subsoil overlies the bedrock. The remainder of the ZOC (42%) is mapped as Moderate Vulnerability, as the bedrock is overlain by more than 10 m of moderate permeability subsoil and well drained soil. GW5 recommends a recharge coefficient in the range of 0.25 to 0.60 be applied for these conditions, with an inner range of 0.30–0.40 (IWWG, 2005). The low drainage density indicates that recharge occurs readily. The shallow slope of the sub-catchment containing the



Western and eastern boundaries are based on topography and also the presence of karst waulsortian limestone extending to the east and west of the well and the associated higher recharge expected in this formation.

Southern boundary defined by the topographic divide along the top of ridges running between Knocklong east, Clogher Hill and Ardmore

Zone of Contribution Map for Knocklong Borehole in the Field (BH-1)

Figure 11: Zone of Contribution

source where BH-1 is located is likely to promote a small degree of runoff. Given subsoils are more than 10 m thick, it is considered that the highest inner range coefficient of 0.40 can be applied in this case.

Runoff losses in the total catchment are assumed to be 40% of the potential recharge (effective rainfall). This value is based on an assumption of c.26% runoff for 58% of the area (extreme vulnerability – rock close to surface- High Vulnearbility) and c.60% runoff for 42% of the area (Moderate vulnerability). The bulk recharge coefficient for the area is therefore estimated to be 60%.

Runoff losses: 178 mm/yr. Runoff losses are assumed to be 30% of potential recharge.

These calculations are summarised as follows:

Average annual rainfall (R)	1100 mm
Estimated P.E.	532 mm
Estimated A.E. (95% of P.E.)	506 mm
Effective rainfall	594 mm
Potential recharge	594 mm
Recharge coefficient	32% of the area at 0.85 26% of the area at 0.60 42% of the area at 0.40
Bulk recharge coefficient	60%
Runoff losses	40%
Assumed Recharge	356 mm*

The water balance calculation requires that the recharge over the area contributing to the source, should equal the discharge at the source. At a recharge of 356 mm/yr, an average yield of 430 m^3/day would require a recharge area of 0.31 km^2.

The ZOC described above is 0.77 km^2 which is 150 % larger than a ZOC required to sustain the current pumping rate. The larger ZOC area delineated is primarily based on the topography and conceptualized groundwater flow-lines while also considering the recharge and water balance equations. To allow for daily variations in abstraction, a possible increase in demand, and for the expansion of the ZOC during dry weather periods, the GSI recommends increasing the abstraction rate by 50% for the purposes of delineating the ZOC. The ZOC delineated is greater than that required to support the abstraction and increasing the size of the ZOC in this case would be unrealistic in terms of the hydrogeological limitations of the boreholes and the topography of the catchment. The boundaries of the ZOC are shown in Figure 11.

11 Source Protection Zones

The Source Protection Zones (SPZ) 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 overlay of the source protection areas and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. Two source protection areas are usually delineated, the Inner Protection Area and the Outer Protection Area.The Inner Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999). Based on the indicative aquifer parameters presented in section 8.5, the groundwater velocity is 1.7 m/d, and hence the 100-day time of travel distance is 170 m. However, because the Waulsortian Formation is karstified and/or dolomitised the Inner Source Protection (SI) will encompass the whole formation and the Outer Protection Area (SO) will be located only in the Dinantian Upper Impure Limestone. The Inner Protection Area is illustrated in Figure 12

The groundwater Source Protection Zones are shown in Figure 13 and are listed in Table 11-1. They include SI/X, SI/E and SI/H, although the majority of the ZOC is designated as SO/H and SO/M.

Table 11-1 Source Protection Zones

Source Protection Zone		**% of total area (km^2)**
SI/X	Inner Source Protection area / ≤1 m subsoil	16.88 % (0.130 km^2)
SI/E	Inner Source Protection area / <3 m subsoil	15.58 % (0.120 km^2)
SI/H	Inner Source Protection area / High vulnerability	16.88 % (0.130 km^2)
SI/M	Inner Source Protection area / Moderate vulnerability	25.97 % (0.200 km^2)
SO/H	Outer Source Protection area / High vulnerability	9.09 % (0.070 km^2)
SO/M	Outer Source Protection area / Moderate vulnerability	15.58 % (0.120 km^2)

12 Potential Pollution Sources

The borehole is in a securely fenced and locked compound and is sealed to protect against the inflow of contaminated surface or shallow subsurface water. The ground surface in the compound comprises granular fill and grassed areas. Given the high level of wellhead protection and the location of the borehole, the potential risk for contamination as a result of surface spills in the immediate vicinity of the well head is low.

The land use within the SI is primarily pastureland for farm animals. The main potential microbial pollution source is cattle grazing in the lands surrounding and particularly up hydraulic gradient in the high ground to the south of the compound. Faecal coliforms have been detected only once in the untreated water and at low level. Given the predominantly Extreme vulnerability of the karstic Waulsortian Limestone Formation which outcrops or is close to surface within the Inner Source Protection Area, the potential risk from cryptosporidium and viruses is high.

The majority of land within the SO is agricultural grassland and the dominant farm activity is dairy farming. There is 1 farm and 10 dwellings within the ZOC. The main potential pollution sources associated with farming activities are animal slurry storage areas, farmyard washings, grazing animals and landspreading of agricultural waste. The possible impacts to the water quality of the public supply associated with these activities within the Outer Source Protection Area are elevated levels of ammonia, nitrate, phosphate, chloride, potassium, BOD, COD, TOC and pesticides. These parameters are not elevated in the untreated water supply.

In summary, given the land use and the Extreme vulnerability rating within the SI, there is a need for a cryptosporidium filter to be provided

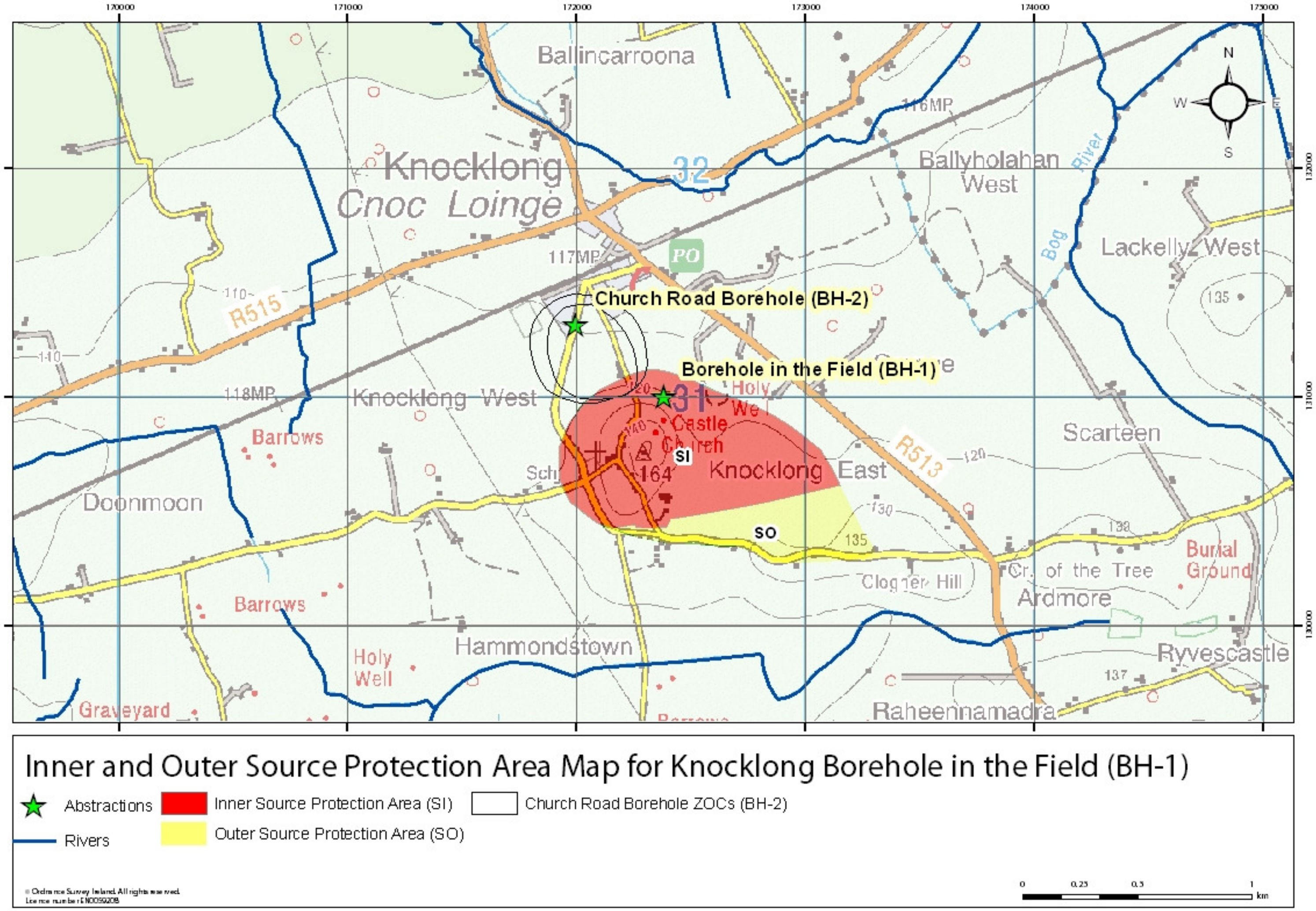


Figure 12: Inner and Outer Protection Areas

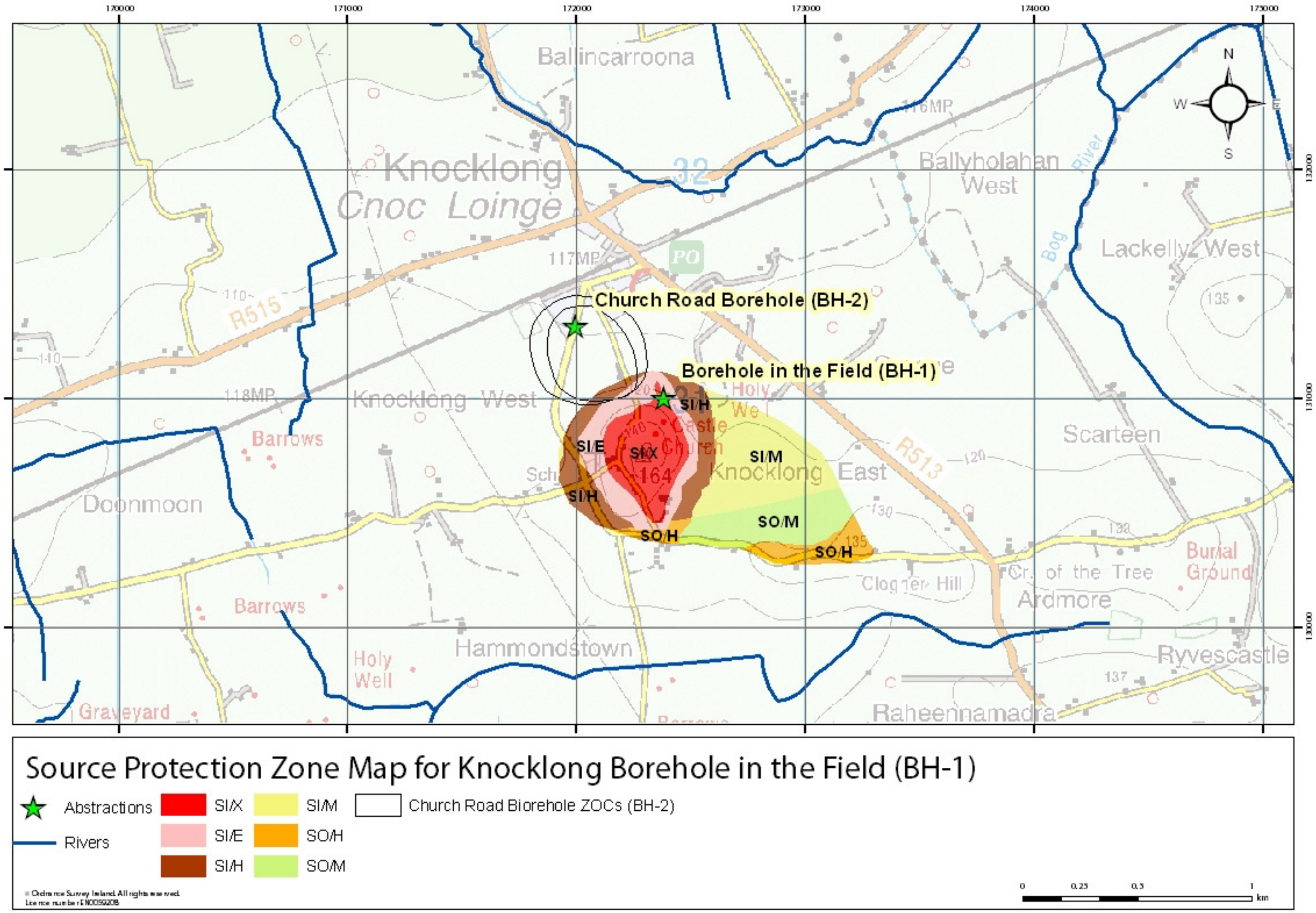


Figure 13: Source Protection Zones

13 Conclusions

BH-1 abstracts water from the Waulsortian and Ballysteen Limestone Formations. The Waulsortian Formation is classified as a Regionally Important Karstified Aquifer (Rk_d) while the Ballysteen Formation is classified as a Locally Important Aquifer that is Moderately Productive only in Local Zones (LI). The well has provided a sustainable yield 430 m^3/d since 1994.

Waulsortian Limestone bedrock outcrops within 10 m of the well compound. The groundwater vulnerability in the SI is classified as Extreme with rock close to the surface or outcropping. Over the remainder of the area to the north, the aquifer is confined by up to 21 m of glacial till and the vulnerability is classified as Moderate. Water quality indicators are generally good.

The ZOC encompasses an area of 0.77 km^2 which incorporates a 150 % increase in the current pumping rate. .The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries.

14 Recommendations

A cryptosporidium barrier should be provided to mitigate risk of microbial contamination.

15 References

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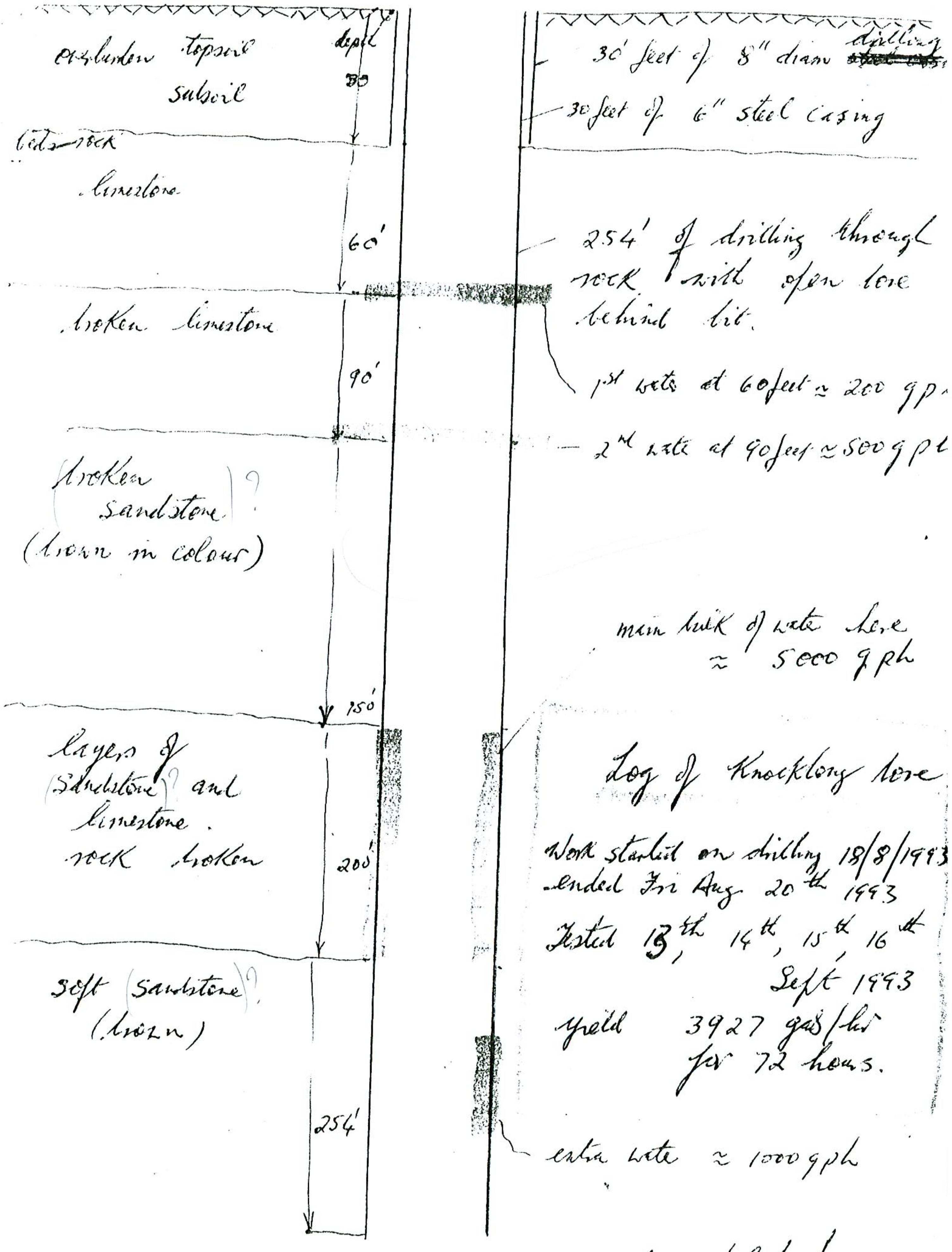
APPENDIX 1

Borehole in the Field Log: Original hand writing description and OCM interpretative log

Borehole Exploration Log

David Ball Documentation about the boreholes

1993 Expl. Bh.



Log of Knocklong bore

Work started on drilling 18/8/1993
ended Fri Aug. 20th 1993
Tested 13th, 14th, 15th, 16th
Sept 1993
yield 3927 gals/hr
for 72 hours.

James O'Callaghan
22 Jul 1993

1994 Prod. Bh

Well boring in Knocklong
August 1994.
Production borehole

John Lynch started work Thursday Aug 11th 9
boring through 6' of overburden
in 15" dia.

Lined into rock in 12" steel casing

12/8/94. Hassle and obstruction
from John Molony

16/8/94 J Lynch bored to 170 feet

17/8/94 Slow progress in 12"

19/8/94. New compressor going:
down to 250 feet.
yield guessed at 8000 gph

22/8/94. Backwashing at final depth
of 300 feet.

No lining in rock.

Ready for ESB and testing.

22/8/94

O'Callaghan Moran & Associates
Phone: 021-4321521 Fax: 021-4321522

Borehole I.D. BH in the field

Project: 10-164-01

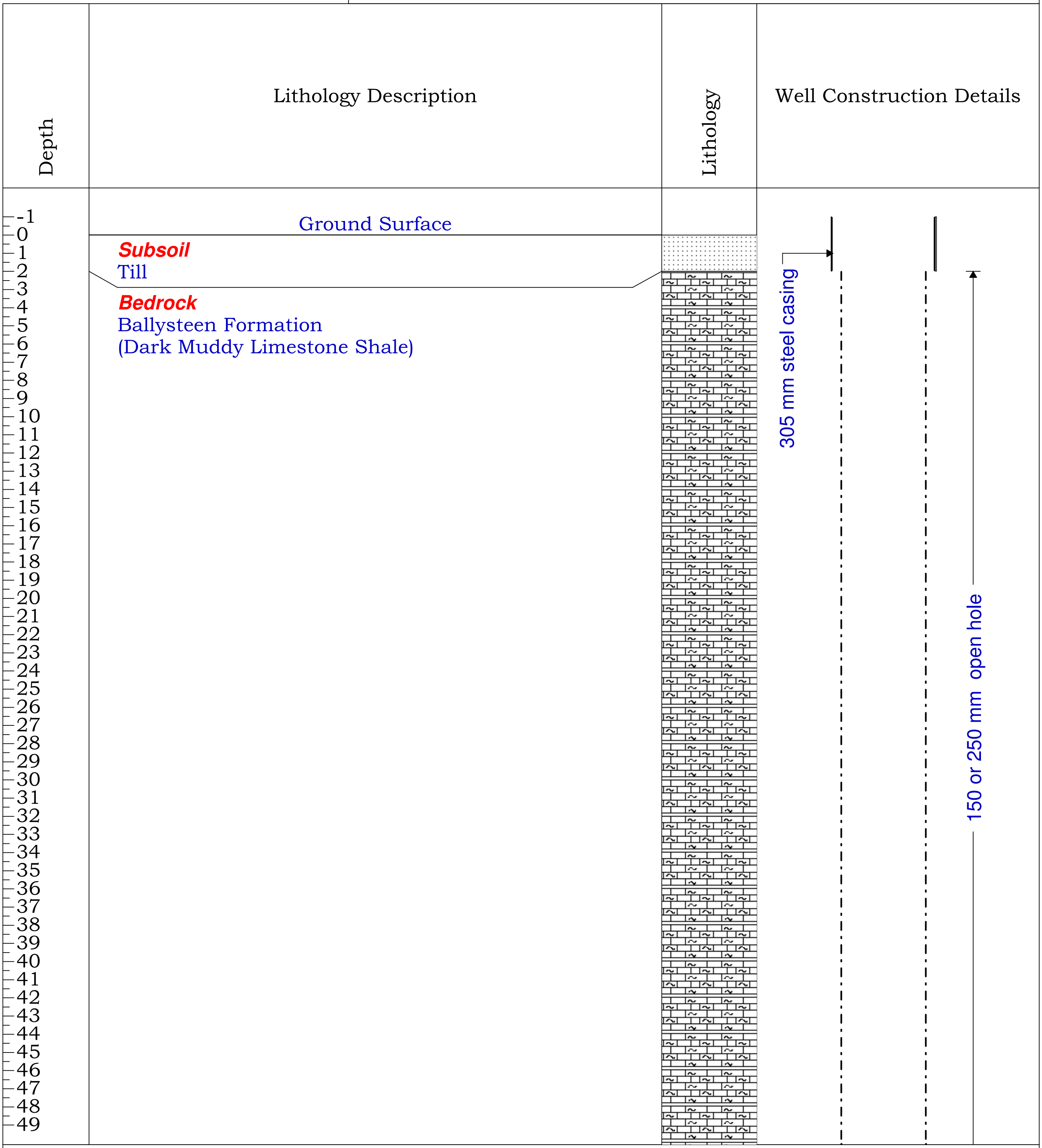
Client: Co. Limerick

Location: Knocklong

Borehole Depth: 91.5 meters

SWL (m): 6.70 m bgl (28/06/10)

Borehole Type: Water Well



Drilling Contractor:

Drill Method:

Drill Date: 1994

Hole Size: 250 mm ?

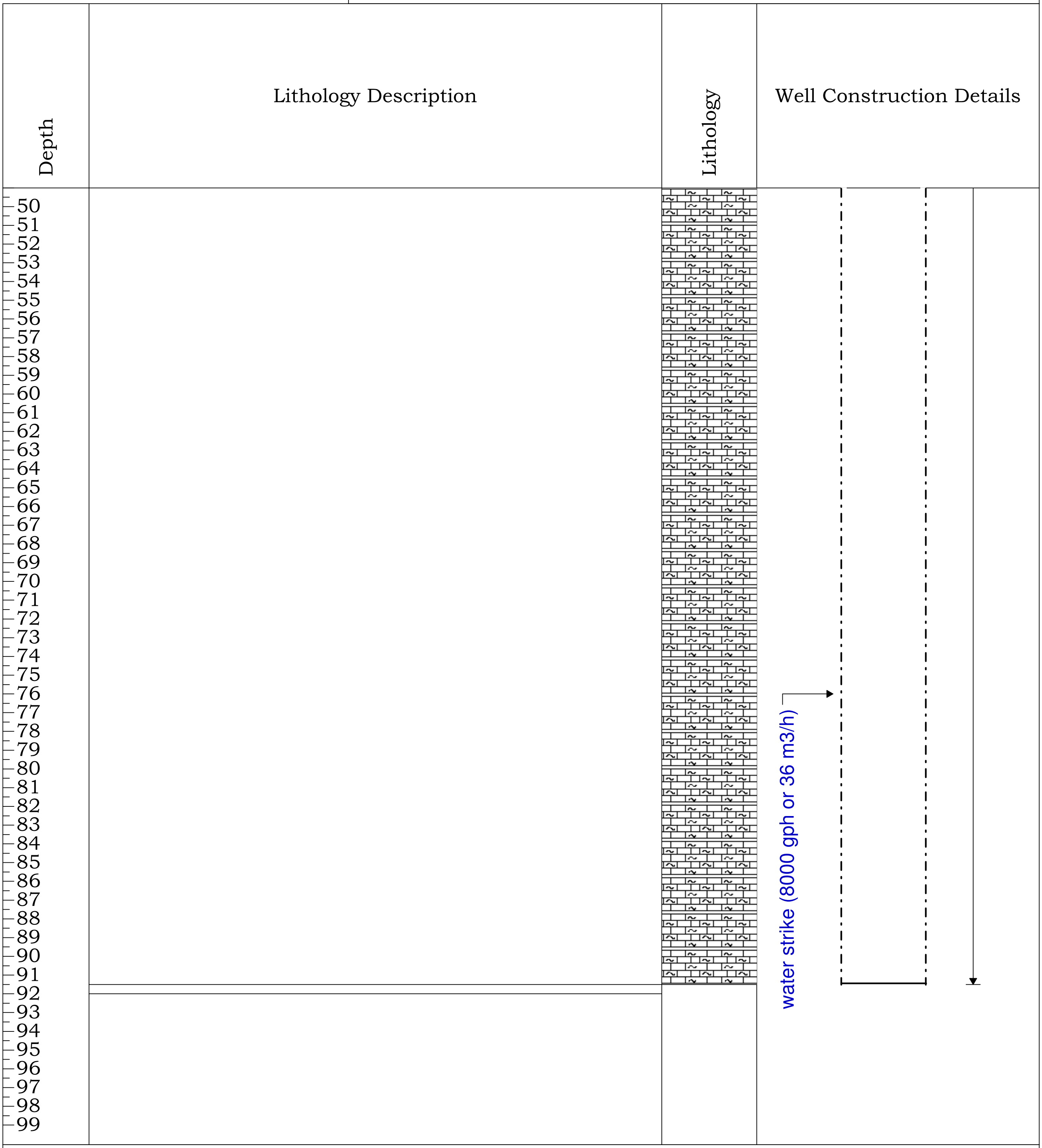
Geologist:

Sheet: 1 of 2

O'Callaghan Moran & Associates
Phone: 021-4321521 Fax: 021-4321522

Borehole I.D. BH in the field

Project: 10-164-01	Borehole Depth: 91.5 meters
Client: Co. Limerick	SWL (m): 6.70 m bgl (28/06/10)
Location: Knocklong	Borehole Type: Water Well



Drilling Contractor:	Hole Size: 250 mm ?
Drill Method:	Geologist:
Drill Date: 1994	Sheet: 2 of 2

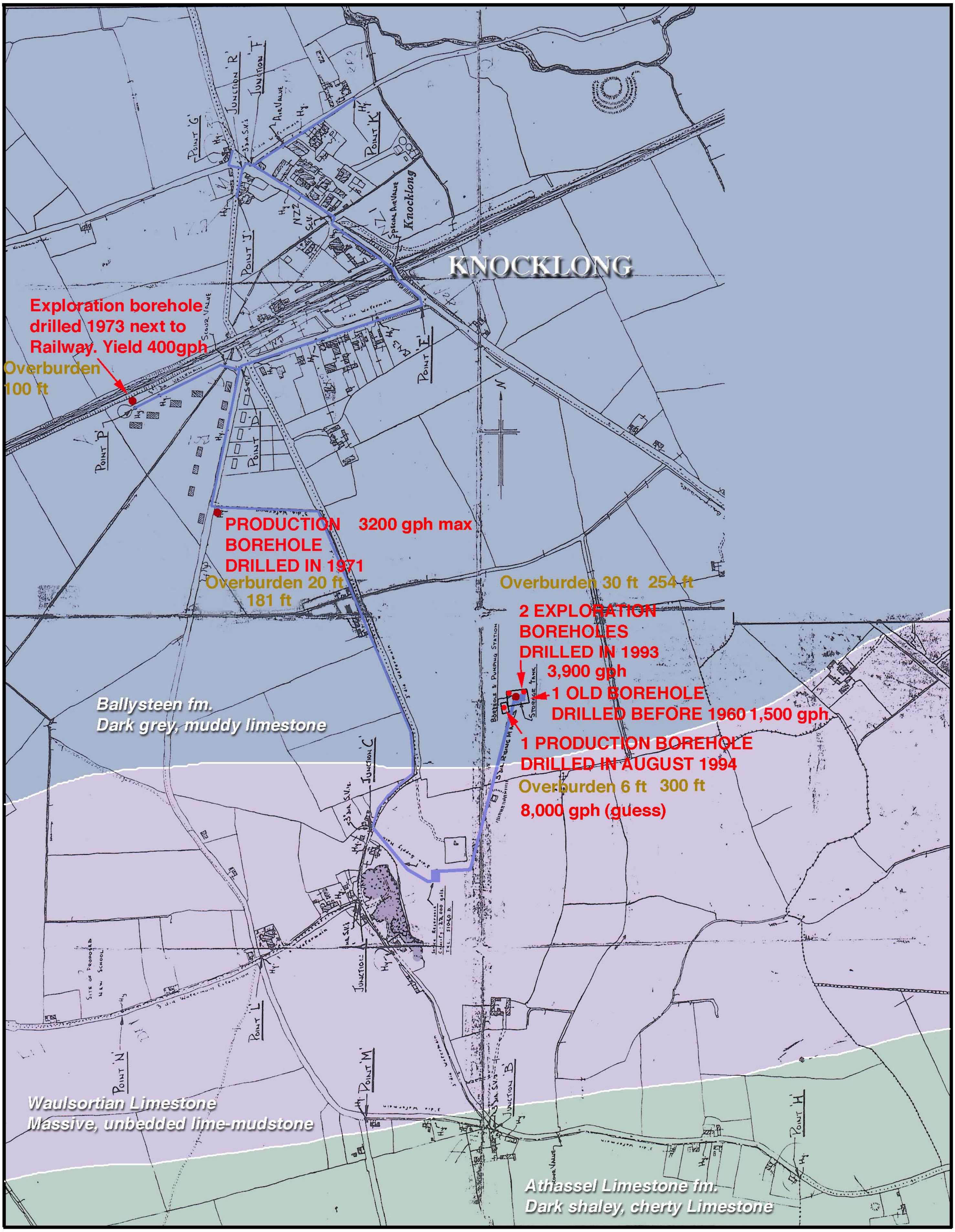


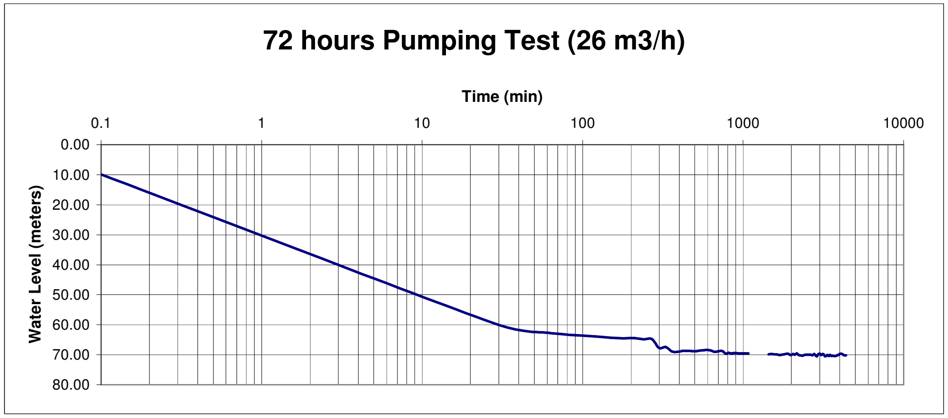
Figure 2 Knocklong - Munster Packaging Site - Existing Water Supply Boreholes

APPENDIX 2

Pumping Test Data (1994) on BH-1 and Interpretation (2010)

Depth of water in well when test started = 9.90 meters
Depth of water in well when test ended = 76 meters

Date	Time	50 Gallon Tank Test	Yield (L/min)	Yield (m3/h)	Depth of water (m)
19/09/1994	0.1	24	567.5	34	9.90
	30	28	486.4286	29	60.10
	60	29	469.6552	28	62.60
	90	30	454	27	63.50
	120	30	454	27	63.95
	150	31	439.3548	26	64.36
	180	31	439.3548	26	64.59
	210	31	439.3548	26	64.50
	240	31	439.3548	26	64.85
	270	31	439.3548	26	64.72
	300	31	439.3548	26	67.70
	330	31	439.3548	26	67.40
	360	31	439.3548	26	68.95
	390	31	439.3548	26	69.00
	420	31	439.3548	26	68.70
	450	31	439.3548	26	68.75
	480	31	439.3548	26	68.86
	510	31	439.3548	26	68.86
	540	31	439.3548	26	68.60
	570	31	439.3548	26	68.54
	600	31	439.3548	26	68.40
	630	31	439.3548	26	68.65
	660	31	439.3548	26	68.98
	690	31	439.3548	26	68.93
	720	31	439.3548	26	68.76
	750	31	439.3548	26	68.90
	780	31	439.3548	26	69.68
	810	31	439.3548	26	69.35
	840	31	439.3548	26	69.54
	870	31	439.3548	26	69.50
	900	31	439.3548	26	69.50
	930	31	439.3548	26	69.60
	960	31	439.3548	26	69.60
	990	31	439.3548	26	69.60
	1020	31	439.3548	26	69.60
	1050	31	439.3548	26	69.60
	1080	31	439.3548	26	69.60
	1110	31	439.3548	26	
	1140	31	439.3548	26	69.20
	1170	31	439.3548	26	
	1200	31	439.3548	26	69.30
	1230	31	439.3548	26	
	1260	31	439.3548	26	69.20
	1290	31	439.3548	26	
	1320	31	439.3548	26	69.10
	1350	31	439.3548	26	
	1380	31	439.3548	26	69.25
	1410	31	439.3548	26	
	1440	31	439.3548	26	69.85
20/09/1994	1500	31	439.3548	26	69.81
	1560	31	439.3548	26	69.87



	m3/d
Logan Approximation	**624**

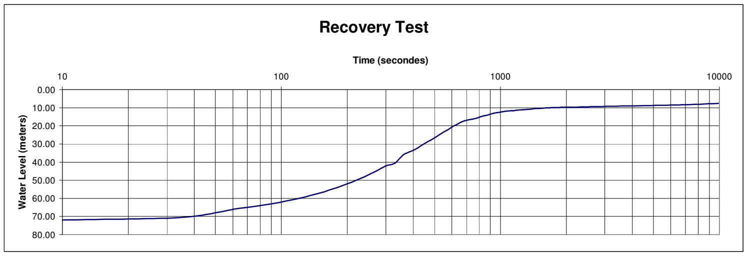
Transmissibility Estimation
T = 1.22 (Q / dS)

	m2/d					
T - Transmissivity (m2/d)		**14.08**	**100.33**	**121.81**	**134.74**	**1087.54**
Q - Final Discharge (m3/d)		624	625	625	624	624
dS - Change in drawdown over 1 log cycle		54.05	7.60	6.26	5.65	0.70
		T10-T100	T30-T300	T50-T500	T120-T1020	t400-t4000

	1620	31	439.3548	26	69.85
	1680	31	439.3548	26	70.05
	1740	31	439.3548	26	69.95
	1800	31	439.3548	26	69.83
	1860	31	439.3548	26	69.65
	1920	31	439.3548	26	69.75
	1980	31	439.3548	26	70.09
	2040	31	439.3548	26	69.78
	2100	31	439.3548	26	69.98
	2160	31	439.3548	26	69.53
	2220	31	439.3548	26	70.05
	2280	31	439.3548	26	70.20
	2340	31	439.3548	26	70.30
	2400	31	439.3548	26	70.05
	2460	31	439.3548	26	70.00
	2520	31	439.3548	26	70.00
	2580	31	439.3548	26	70.00
	2640	31	439.3548	26	70.00
	2700	31	439.3548	26	70.20
	2760	31	439.3548	26	69.81
	2820	31	439.3548	26	70.05
	2880	31	439.3548	26	70.54
21/09/1994	2940	31	439.3548	26	69.90
	3000	31	439.3548	26	69.70
	3060	31	439.3548	26	70.05
	3120	31	439.3548	26	69.79
	3180	31	439.3548	26	69.88
	3240	31	439.3548	26	70.53
	3300	31	439.3548	26	70.42
	3360	31	439.3548	26	70.05
	3420	31	439.3548	26	70.45
	3480	31	439.3548	26	70.05
	3540	31	439.3548	26	70.42
	3600	31	439.3548	26	70.34
	3660	31	439.3548	26	70.38
	3720	31	439.3548	26	70.40
	3780	31	439.3548	26	70.40
	3840	31	439.3548	26	70.20
	3900	31	439.3548	26	70.05
	3960	31	439.3548	26	70.00
	4020	31	439.3548	26	69.70
	4080	31	439.3548	26	69.70
	4140	31	439.3548	26	69.80
	4200	31	439.3548	26	69.95
	4260	31	439.3548	26	70.15
	4320	31	439.3548	26	70.15
22/09/1994	4380	31	439.3548	26	70.15

Total recovery rate time = 2hours-45min

Time (min)	Time (sec)	depth of water in the well	Remarks
0	0.01	76.00	
0.5	30	71.00	
1	60	66.00	
1.5	90	63.00	
2	120	60.00	
2.5	150	57.00	
3	180	54.00	
3.5	210	51.00	
4	240	48.00	
4.5	270	45.00	
5	300	42.00	
5.5	330	40.60	
6	360	36.10	
6.5	390	34.00	
7	420	32.20	
7.5	450	29.90	
8	480	27.90	
8.5	510	26.00	
9	540	24.00	
9.5	570	22.40	
10	600	20.60	
10.5	630	19.40	
11	660	18.10	
11.5	690	17.10	
12	720	16.60	
12.5	750	16.20	
13	780	15.70	
13.5	810	15.00	
14	840	14.40	
14.5	870	14.10	
15	900	13.60	
15.5	930	13.00	
16	960	12.80	
16.5	990	12.60	
17	1020	12.25	
17.5	1050	12.00	
18	1080	11.80	
18.5	1110	11.70	
19	1140	11.70	
20	1200	11.35	change from 30sec to 1min
21	1260	11.10	
22	1320	10.90	
23	1380	10.70	
24	1440	10.50	
25	1500	10.40	
26	1560	10.25	
27	1620	10.15	
28	1680	10.00	
29	1740	9.97	
30	1800	9.90	
31	1860	9.85	
32	1920	9.80	
33	1980	9.75	
34	2040	9.65	
39	2100	9.65	change from 1min to 5min
44	2400	9.50	
49	2700	9.40	
109	6300	8.45	change from 5min to 1hour
169	9900	7.65	



m3/d

Logan Approximation **624**

Transmissivity Estimation

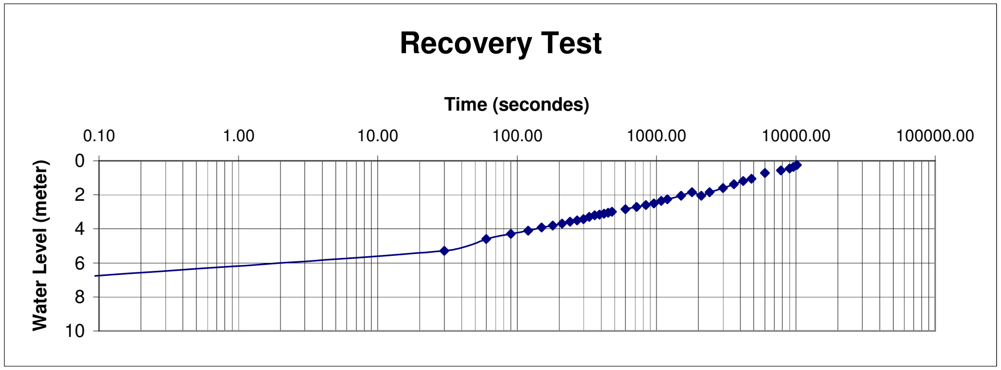
T = 1.22 (Q / dS)

	m2/d		
T - Transmissivity (m2/d)	**69.2072727**	**15.9430366**	**154.040404**
Q - Final Discharge (m3/d)	624	624	625
dS - Change in drawdown over 1 log cycle	11.00	47.75	4.95
	T10-T-100	T100-T1000	T1000-T10000

APPENDIX 3

Recovery Test Data and Interpretation Of Borehole BH-2

29/09/2010	Time (min)	Time (sec)	Level (m)
	0.00	0.01	7.3
	0.50	30.00	5.3
	1.00	60.00	4.6
	1.50	90.00	4.3
	2.00	120.00	4.1
	2.50	150.00	3.91
	3.00	180.00	3.8
	3.50	210.00	3.7
	4.00	240.00	3.58
	4.50	270.00	3.5
	5.00	300.00	3.43
	5.50	330.00	3.3
	6.00	360.00	3.2
	6.50	390.00	3.16
	7.00	420.00	3.1
	7.50	450.00	3.05
	8.00	480.00	3
	8.50	510.00	
	10.00	600.00	2.85
	12.00	720.00	2.72
	14.00	840.00	2.6
	16.00	960.00	2.5
	18.00	1080.00	2.36
	20.00	1200.00	2.26
	25.00	1500.00	2.05
	30.00	1800.00	1.85
	35.00	2100.00	2.05
	40.00	2400.00	1.85
	50.00	3000.00	1.6
	60.00	3600.00	1.38
	70.00	4200.00	1.18
	80.00	4800.00	1.05
	90.00	5400.00	
	100.00	6000.00	0.72
	110.00	6600.00	
	120.00	7200.00	
	130.00	7800.00	0.56
	140.00	8400.00	
	150.00	9000.00	0.45
	160.00	9600.00	0.35
	170.00	10200.00	0.25



m3/h m3/d

4.2 100.8

Transmissivity Estimation

T = 0.183Q / dS

	t1-10	t10-100	t100-1000	t1000-10000	Average
T - Transmissivity (m2/d)		**7.56**	**10.03**	**8.74**	**8.78**
Q - Final Discharge (m3/d)	100.8	100.8	100.8	100.8	
t1 - point in time					
S1 - Drawdown at t1		6.64	4.2	2.36	
S2 - Drawdwon at t1*10		4.2	2.36	0.25	
dS - Change in drawdown over 1 log cycle	0	2.44	1.84	2.11	