Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Knocklong Water Supply Scheme

Church Road (Borehole BH-2)

December 2010

Prepared by:
OCM

With contributions from:
Dr. Robert Meehan, Ms. Jenny Deakin

And with assistance from:
Limerick County Council

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 300 m southwest of the village (no code). The Church Road Borehole, identified in this report as BH-2, is the older well in the scheme and was installed in 1959. BH-1 was installed in 1994 in response to an increased demand for water supply that could not be met by BH-2. Because of the distance between the two wells, separate Source Protection Reports have been compiled for each borehole. This report describes 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 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 undertaken on 28/06/10 and on 14/07/10. A short term recovery test was undertaken on the 29/09/2010 by OCM.

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-2 is located approximately 300 m southwest of the village of Knocklong, adjacent to the Knocklong to Mitchelstown North Road (Figure 1). BH-1 is located 500 m to the south of BH-2.

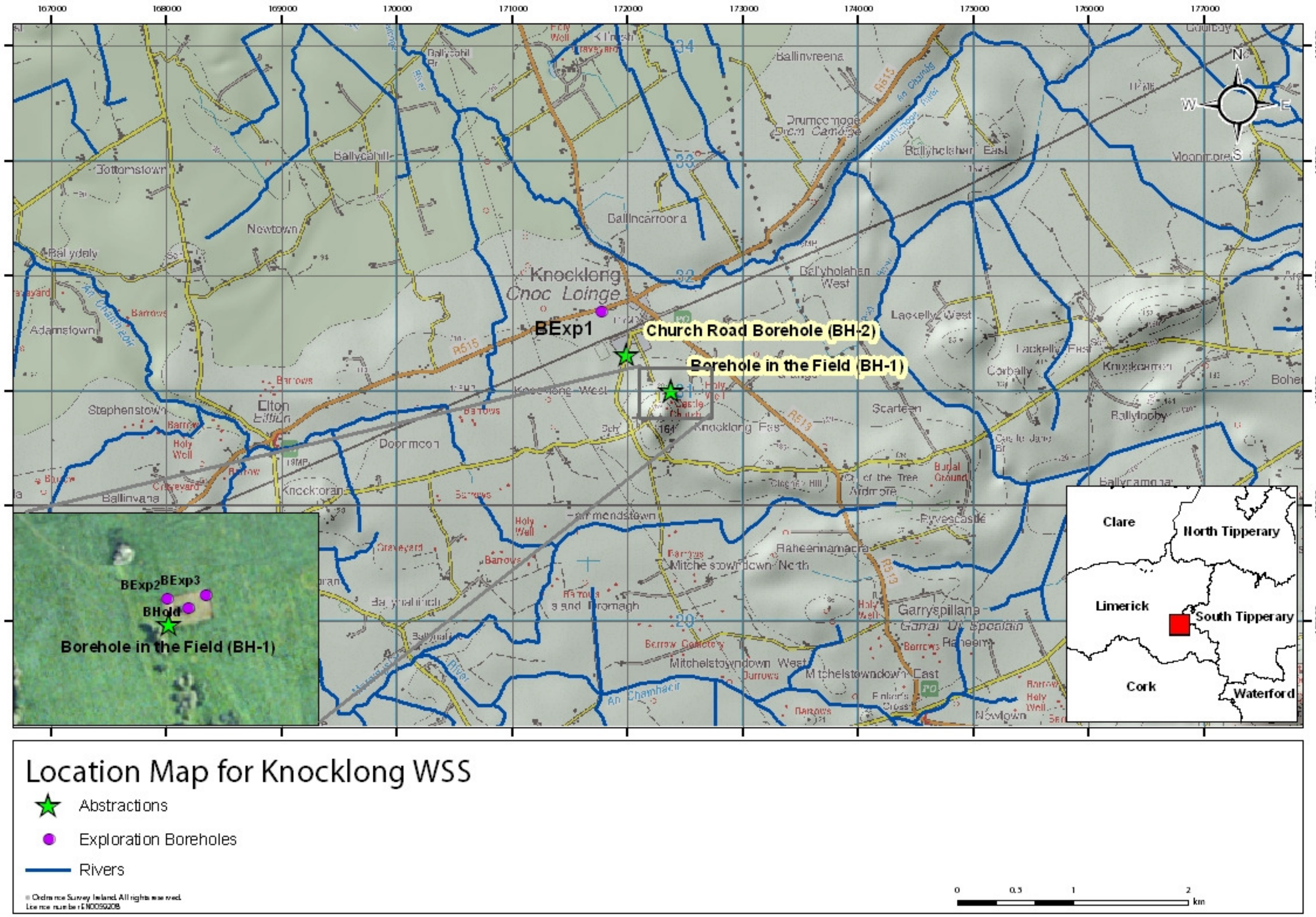


Figure 1: Location Map

BH-2 is inside a pump house which is situated in a compound surrounded by a c.1.0 m high concrete block wall and gate. The compound is adjacent to the public road that links the villages of Knocklong and Mitchelstown North. The ground surface in the compound comprises granular fill and grass (Photo 1). Water is treated in the pump house using a chlorination system (sodium hypochlorite). There is no cryptosporidium filter. After treatment the water is pumped directly to the distribution network.

Photo 1: Site Layout

The borehole is in a small concrete manhole chamber (c0.40 m by 0.70 m), which is set 0.2 m below ground level. The steel casing rises 0.40 m above the base of the chamber. The borehole is not capped (Photo 2). There is no information available (e.g. a borehole or well construction log) to establish whether or not the borehole is adequately sealed. However, given the age of the borehole it is likely that it is not grouted and the steel casing extends to the top of the bedrock. The borehole is artesian and is liable to overflow and flood the chamber. The overflow is piped to a road side drain which runs along the public road.

Photo 2: Well Head

4 Summary of Well Details

The information on well is limited and is derived primarily from interview with the caretaker, the GSI Well Database and on information provided by Mr. David Ball (Hydrogeologist), which is included in Appendix 1 and summarised in Table 3.1.

According to the caretaker, the borehole was installed around 1959. An operations log book in the pump house, which dates from 1959, indicates the starting date for operations for the scheme. The information provided by Mr. David Ball indicates the well was drilled to a depth of c.55.2 m deep. The site inspection observations established that the borehole is 140 mm in diameter. The pump is installed in the well at around 30 m.

The water is pumped continuously, directly to the scheme distribution main. The average abstraction for the well is recorded by the Council as 91 m^3/d. The caretaker stated that the yield is very reliable and the borehole has never suffered from a shortage of water. The caretaker also stated that the well becomes artesian when the pump is switched off and that this occurs throughout the year.

OCM completed a short term recovery test (170 minutes) in BH-2 on 29/09/2010. The recovery data are included in Appendix 2. A three-day pumping test had previously been undertaken in BH-1 by Limerick County Council in 1994. The pumping test data are included in Appendix 3.

Table 4-1: Well Details

	BH-2
EU Reporting Code	No Code
Grid ref. (GPS)	171997 131292
Townland	Knocklong East
Source type	Borehole
Drilled	1959
Owner	Limerick County Council
Elevation (Ground Level)	~110 m OD
Depth (m)	55.2 m
Depth of casing	Unknown
Diameter	140 mm
Depth to rock	21.6 m
Static water level	artesian
Pumping water level	7.3 m bgl for 91 m^3/d (29/09/2010)
Consumption (Co. Co. records)	3.8 m^3/h or 91 m^3/d
Recovery test summary: (i) Time of recovery	170 minutes (Short Recovery Test, 29/09/2010)
(ii) Specific capacity	-
(iii) Transmissivity	9 m^2/d

5 Topography, Surface Hydrology and Land Use

The borehole is located at an elevation of 110 m OD. The topography of the study area slopes gently from south to north, toward the Drumcomoge River, which is 700 m north of the borehole. The southern boundary of the catchment is defined by the high ground in Knocklong East, which at 650 m, is the highest point in the catchment. The topographical gradient at Knocklong east is approximately 0.15 and this decreases to 0.015 as the slope shallows in the vicinity of the well

Drainage density is generally low in the catchment, with much of the land comprising free draining agricultural grass land. There are no streams or rivers in the vicinity of the well. The land in the vicinity of the site drains toward the Dromcomoge River. The Drumcomoge River flows to the northwest joining the Camoge River 3 km to the northwest of the site.

The land use in the catchment is dominated by agriculture (grassland diary farming). There are six residential dwellings within 250 m of the compound.

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 that the source is located between the 1000 mm and 1200 mm average annual rainfall isohyet.

Annual evapotranspiration losses: 506 mm. 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 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 (Tobin Consulting Engineers on behalf of the Geological Survey of Ireland and Limerick County Council, 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)
- Source Protection Scheme Report for Hospital Public Supply (GSI, 1995)

7.2 Bedrock Geology

Sheet 18, the Geology of Tipperary published by the GSI indicates that the borehole is located in the Ballysteen Formation (Dark muddy limestone, shale) from the Lower Carboniferous period (Figure 2). The Waulsortian Limestones (fine pale-grey micrite with large sparry masses) from the Lower Carboniferous period are 500 m to the south. This formation was observed in the hill at Knocklong East which is the highest point of the catchment. The bedrock was pale, fractured, heavily weathered and consistent with the description of the Waulsortian Formation. Outcropping bedrock was also noted along the side and toward the top of the hill.

Sheet No. 18 indicates that the well is on the limb of an anticline, whose axis is situated approximately 2.1 km to the northwest. The bedding dips to the southeast. It is likely fracturing and faulting that accompanied the folding of the limestone has likely given rise to zones of enhanced permeability locally. 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.

7.3 Soil and Subsoil Geology

The soil and subsoil distributions are illustrated in Figures 3 and 4, respectively. At BH-2, the soil is classified as Acid Mineral Poorly Drained (AminPD). This soil type extends from the area immediately around the compound to the southwest. To the north and west, toward the village of Knocklong, the soils are identified as Made Ground. Approximately 100 m south and east of BH-2 the soil is classified as Acid Mineral Deep Well Drained (AminDW). Toward the base of the hill at Knocklong East, 500 m to the south, the soils covering the hill are classified as Basic Mineral Deep Shallow Well Drained soil (BminSW).

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 ‘erratic’ 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 subsoil permeability of the Sandstone Tills is characterised as moderate. Based on BS5930 field assessment and field observations in the field to the south of the pump house, subsoils comprise glacial tills with sandstone gravels in a silt/clay matrix. The subsoil is more than 21 m deep at BH-2 and it is possible that the tills are less permeable at depth. The artesian conditions at the borehole support this assumption.

7.4 Depth to Bedrock

Information on the depth to bedrock was provided by Limerick County Council and Mr. David Ball. The data are included in Appendix 1. The data indicates that the depth to bedrock increases to the north and decreases to the south. Depth to bedrock at BH-2 is estimated at 21 m. An old exploration borehole, located 350 m to the north, indicates a depth to bedrock there at 30.5 m bgl. Depth to bedrock data for other exploration boreholes located 480 m to the south of BH-2, indicate a depth of bedrock of 9 m bgl. At BH-1 located 500 m to the south, the depth to bedrock is 1.8 m bgl. Rock outcrops along the hill at Knocklong East. The locations of all the boreholes are shown on in Figure 1.

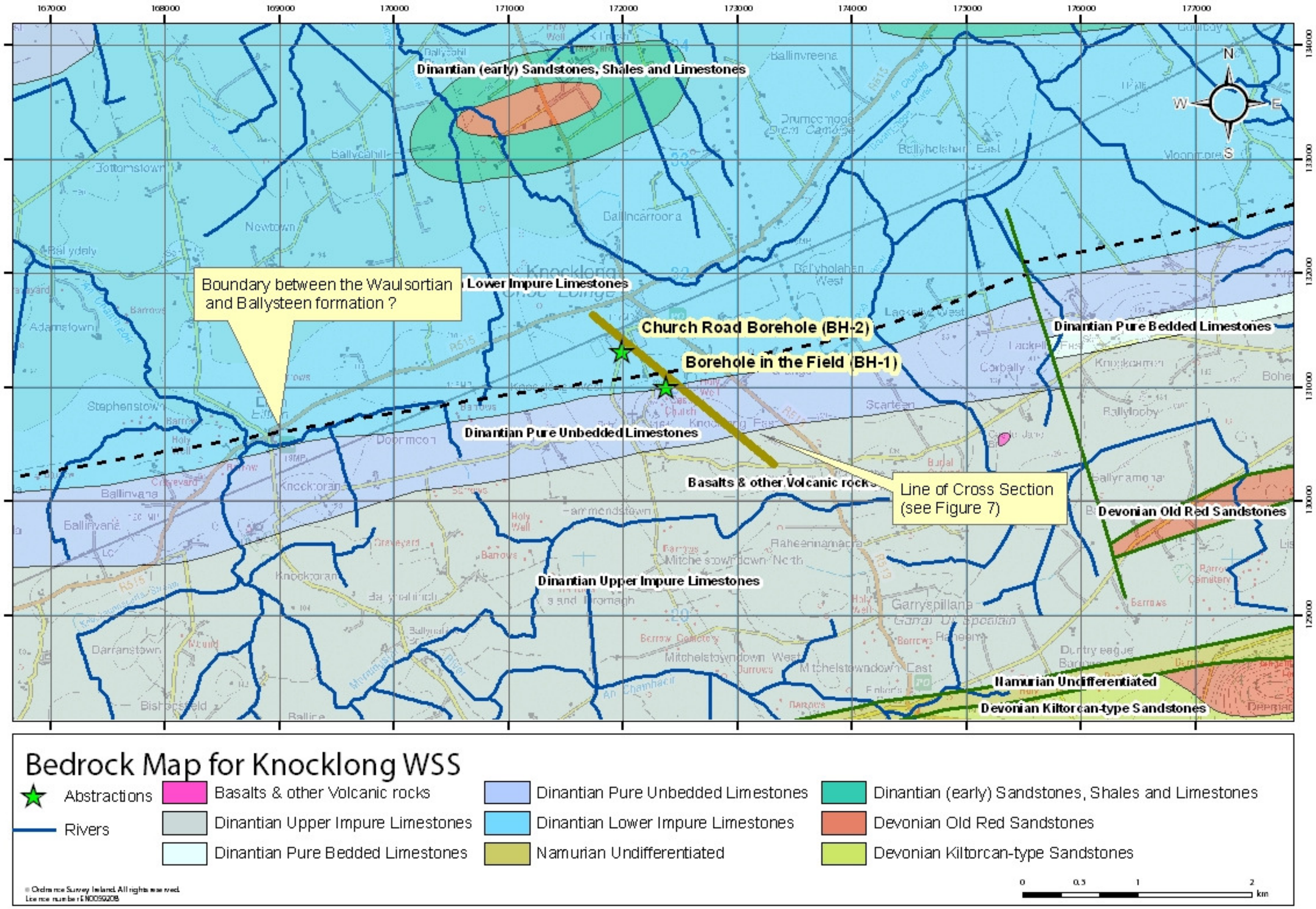


Figure 2: Bedrock/Rock Unit Map

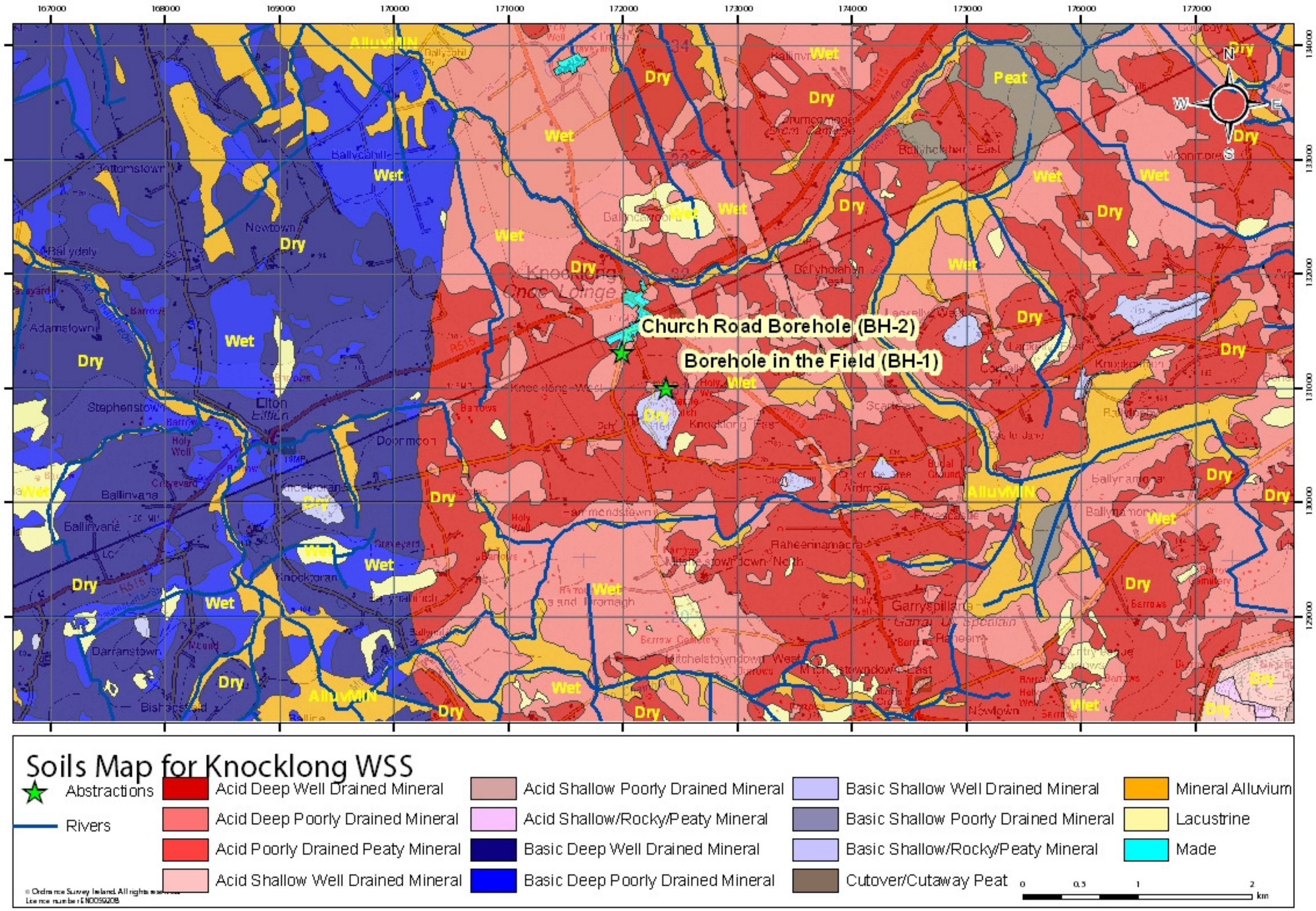


Figure 3: Soils Map

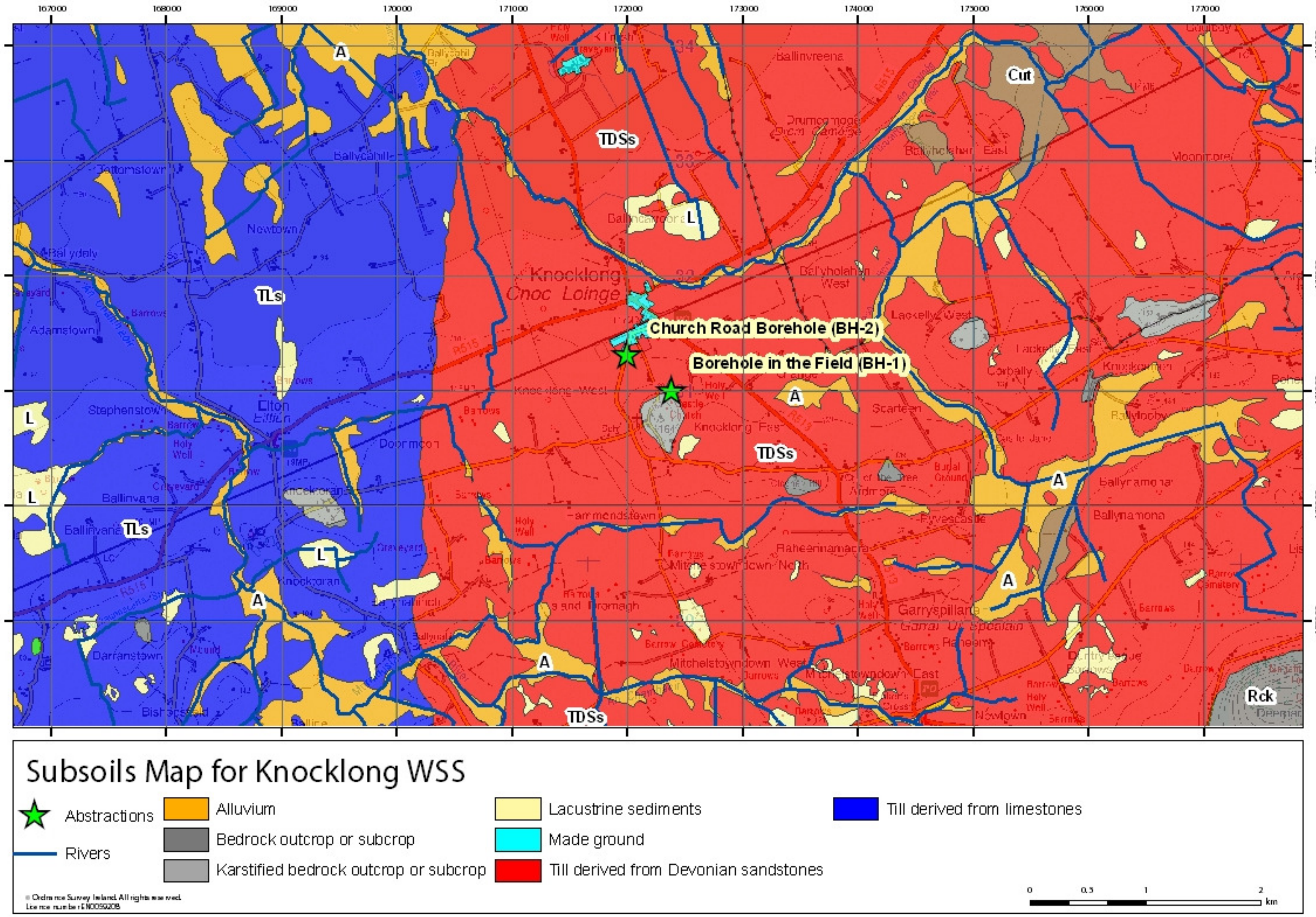


Figure 4: Suboils Map

8 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. 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. The vulnerability is primarily moderate. Approximately 500 m to the south in the footslopes of the hill in Knocklong East, the vulnerability reduces to Extreme with rock close to the surface or outcropping along the hill.

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
- Source Protection Scheme Report for Hospital Public Supply (GSI, 1995)

9.1 Groundwater Body and Status

The borehole is located within the Hospital 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

BH-2, is artesian and the caretaker indicated these conditions occur throughout the year. When the pump is switched off, groundwater flows out of the well after approximately 30 minutes. The old exploration borehole located 350 m to the northwest could not be accessed to monitor water levels during the field mapping. The static water level recorded in the main production borehole of the scheme, BH-1, located 500 m to the south, was 9.90 m bgl in September 1994 and 6.7 m bgl on 28/6/2010.

Based on the topography and local surface water drainage pattern, groundwater infiltrates the bedrock through the subsoils and flows to the northwest towards Drumcomogue River. It is anticipated that the groundwater gradient is shallow and likely to reflect the local topography. Therefore a value of 0.015 has been assumed.

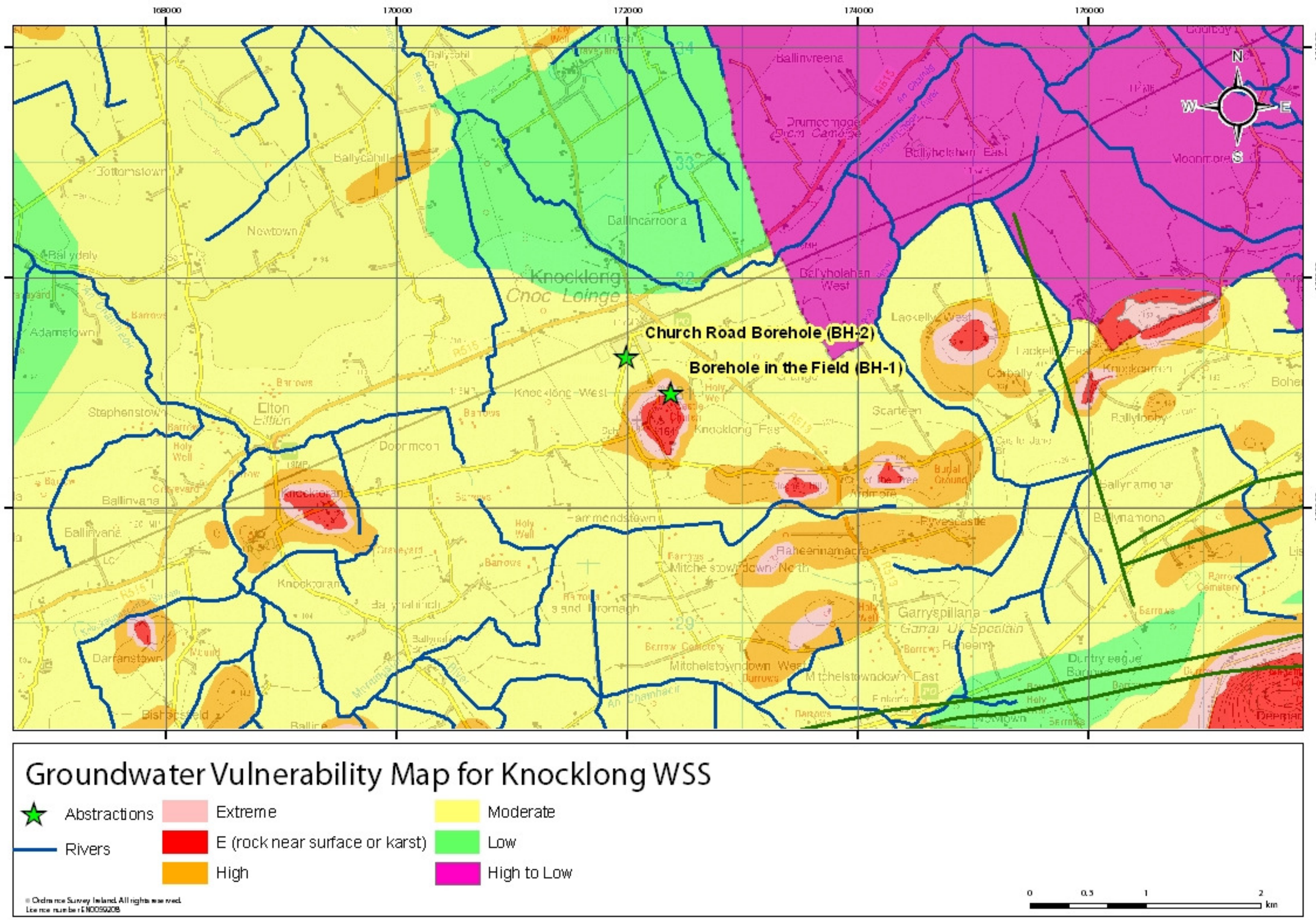


Figure 5: Vulnerability Map

9.3 Hydrochemistry and Water Quality

There is currently no pre-treatment monitoring of water quality at BH-2. Hydrochemical data have been obtained by EPA for BH-1 which is considered to be located in the Waulsortian Aquifer, therefore this hydrochemical assessment is limited.

At BH-1, analysis of hardness indicates a hard calcium bicarbonate hydrochemical signature (average 322 mg/l CaCO3). The average conductivity is 569 µS/cm and pH is around 7.2. 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 EU MAC of 50 mg/l or the threshold value of 37.5 mg/l has been exceeded over the measurement period. It is likely that similar or possibly lower nitrate levels are present at BH-2 due to the subsoil thickness in the vicinity of the well.

9.4 Aquifer Characteristics

Based on the GSI geology map, the borehole abstracts water from the Ballysteen Formation from the lower Carboniferous. 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 borehole provides an average of 91 m^3/d. The yield is sustainable and the scheme has never had problems meeting demand.

The artesian conditions at the borehole indicate that the aquifer is confined in the vicinity of BH-2 due to the presence of up to 21 m of glacial till overlying the aquifer. Given the artesian conditions, it is possible that the subsoil permeability reduces significantly with depth or that less permeable shaley limestone units overly and confine more productive units at depth. Artesian conditions may persist in the aquifer to the north given the subsoil thickness increases in the direction of Drumcomoge River. However, there are no data available (i.e. water levels) to confirm this assumption. The subsoil thins to the south approaching the boundary with the Waulsortian Aquifer and karst limestone bedrock outcrops around the hill at Knocklong East. The static water level in BH-1, which is in this area, is 9.9 m bgl.

Groundwater flow in the aquifer is through fractures, fissures and faults in the limestone. In general 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. Because there is no hydrogeological information available for BH-2, data typical of this Ll aquifer obtained from other sources have been used to establish the aquifer parameters. The data sources used are the Hospital Groundwater Body Report, Source Protection Scheme Report for Hospital Public Supply (GSI, 1995, 2002) and BH-1 borehole data.

OCM completed a short term recovery test in BH-2 in September 2010. The pump was switched off for 170 minutes. The recovery data are included in Appendix 2. The transmissivity calculated from the recovery is 9 m^2/d. Given the aquifer is confined, the CE Jacob Formula can be applied:

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

Where: Q = pumped discharge rate (m^3/d or m^3/s) and Δs = Change in drawdown per log cycle of t (m)

As part of the testing programme, BH-1 had been switched off for 130 minutes and the water level allowed to stabilize in the well. BH-1 was switched on for the last 40 minutes of the recovery in BH-2 in order to determine if there was any response detected in BH-2. No changes in the rate of water level recovery were observed when the pump in BH-1 was switched on. Given the low transmissivity of the Ballysteen Aquifer a response would not have been expected.

The bedrock permeability in this LI aquifer is expected to be low. The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer. In this aquifer type, the groundwater flow, in general, is concentrated in the upper 15 m of the aquifer. At this site, the borehole is thought to be 55.2 m deep. Given the sustainable well yield, an estimated saturated thickness of 55.2 meters has been assumed i.e. the full depth of the well. Permeability (k) is estimated as follows in Table 9.1

Table 9-1: Permeability for BH-2

	Local Assumption
Transmissivity (m^2/d)	9
Permeability (m/d)	0.16

The permeability for the aquifer is estimated to be 0.16 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:

Velocity (V) = (K x Groundwater Gradient(i)) / porosity

The natural gradient is estimated at 0.015 (Section 9.2). The effective fracture porosity in the Ballysteen Formation is estimated by GSI Source Protection Scheme Report for Hospital (1995) to be 0.015. That porosity value has been applied to the formation as part of the current assessment.

Table 9-2: Estimated Velocity for BH2

Velocity (m/d)	Local K Assumption (0.16 m/d)
Local Effective Porosity (1.5%)	0.16

The velocity of groundwater moving through the aquifer is estimated as 0.16 m/d.

The aquifer parameters are summarized in Table 9-3.

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

Parameters	Source of Data	BH1/BH2
Transmissivity (m^2/d)	Calculated (based on short recovery test)	9
Permeability (m/d)	Estimated from T value assuming saturated thickness is the full depth of the boreholes	0.16
Effective Porosity	Assumed (based on GSI (1995) Source Protection Scheme Report for Hospital)	1.5%
Groundwater gradient	Assumed based on topography and field observation	0.015
Velocity (m/d)	Calculated based on above	0.16

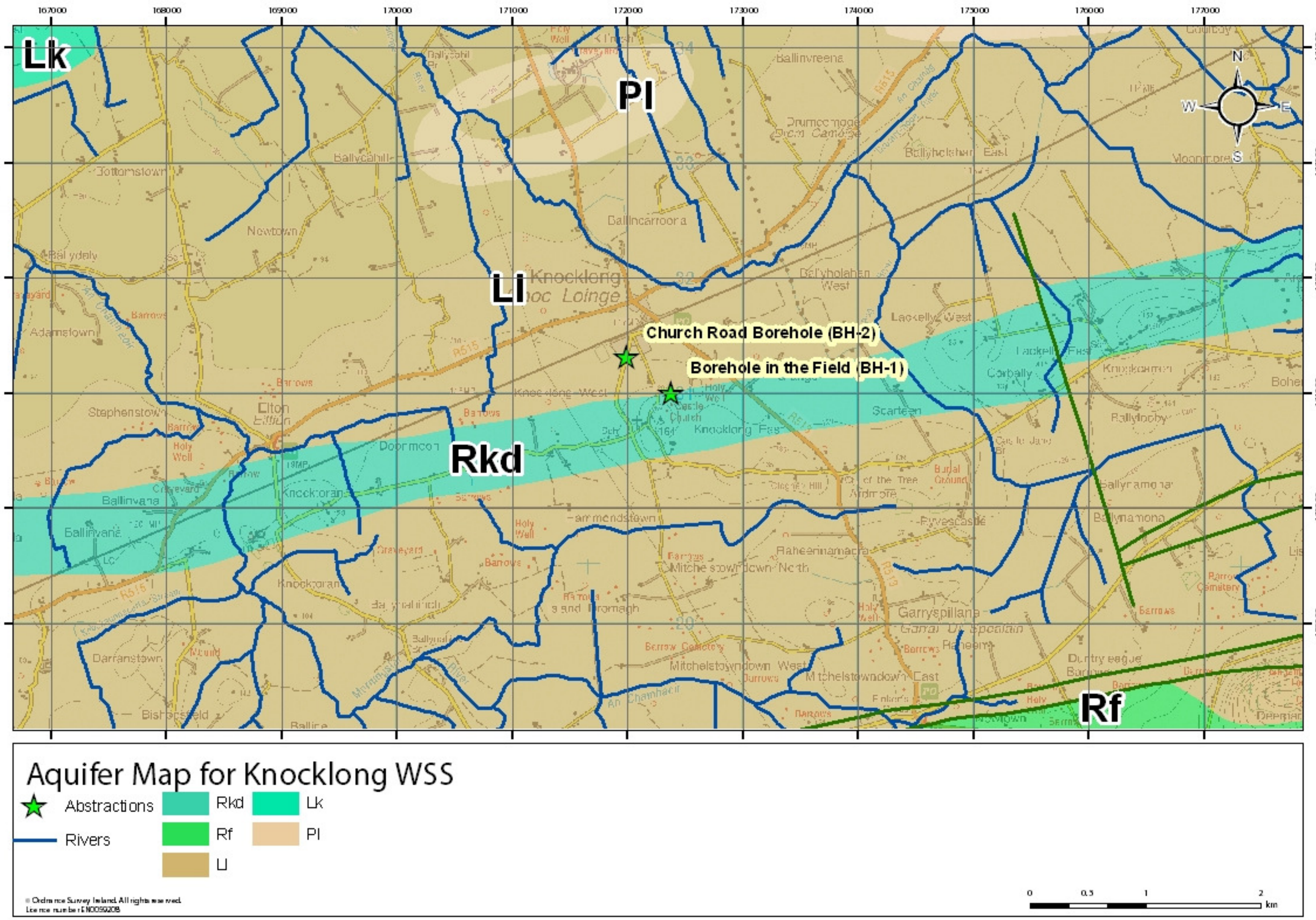


Figure 6: Aquifer map

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

BH-2 is located in the Ballysteen Formation which is mapped as a Locally Important aquifer; Moderately Productive only in Local Zones (LI). Groundwater flows from the direction of Knocklong East in the south to the north, toward BH-2. It is expected that because the subsoil cover thins and may be more permeable, much of the recharge occurs to the south and up hydraulic gradient of the borehole, closer to the boundary between the Waulsortian formation. The aquifer is confined in the area of BH-2 possibly due to the presence of up to 21 m of glacial till or as a result of shaley limestone units overlying and confining more productive limestone. Recharge in the vicinity of the borehole is likely to be reduced because of the presence of either shaley limestone and/or lower permeability of the till. Further south, as the subsoils thin approaching the boundary with the karst waulsortian limestone which outcrops in the high ground and Knocklong East (Figure 7). The yield and transmissivity calculated from the recovery test are consistent with LI aquifers.

10.2 Boundaries of the ZOC

The boundaries of the area contributing to the source are considered to be as follows (Figure 8):

The southern boundary is defined by the ZOC for BH-1. It is likely that the ZOC for BH-1 slightly overlaps that of BH-2 in this down gradient area. Given the higher yield in BH-1, it most likely captures most of the flow in the Waulsortian Aquifer and possibly a small portion of the flow from the Ballysteen Aquifer. It is unlikely therefore that the ZOC for BH-2 extends beyond the Waulsortian Aquifer boundary.

The eastern and western boundaries are difficult to delineate precisely because of the relatively gentle gradient across the area (0.015). The boundaries are primarily based on the topography, conceptualised groundwater flow-lines, which flow to the north in the direction of the Drumcomoge River, and the size of the estimated ZOC using the recharge and water balance equations (see next section).

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

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

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

Given the pumping rate is 91 m^3/d, the transmissivity is 9 m^2/d and the hydraulic gradient is 0.015, the approximate maximum downgradient distance is calculated at 110 m.

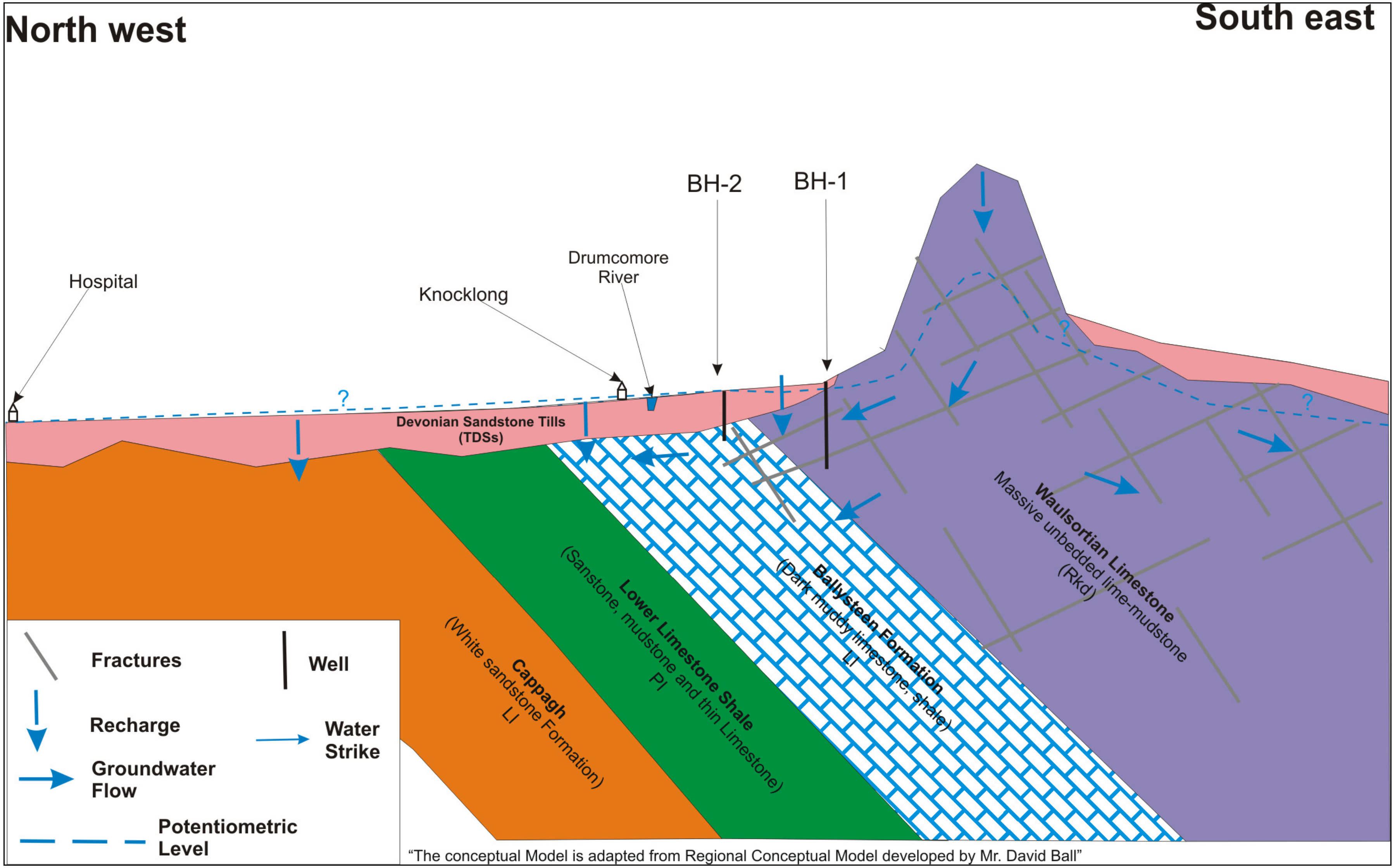


Figure 7: Conceptual Model

To allow for daily variations in abstraction and to the expansion of the ZOC during dry weather periods, the GSI usually increase the source abstraction rate by a factor of safety of 50%. The ZOC has been extended accordingly to the east, west and north. The ZOC was not extended to the south due the presence of the ZOC from BH-1 and the aquifer boundary with the Waulsortian Limestone. The boundaries of both ZOC options (100% and 150%) are shown in Figure 8.

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 of this aquifer locally and the overlying pockets of deep well drained subsoil, the recharge aquifer cap of 200 mm normally applied to an LI aquifer has not been applied here. 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 256 mm/yr; this value is based on the following observations:

The majority of the ZOC (85%) is mapped as Moderate Vulnerability, as the bedrock is overlain by more than 10 m of moderate permeability subsoils and well drained soils. Guidance document 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 in the study area indicates that recharge occurs readily. The shallow slope of the sub-catchment containing the source is likely to promote a small degree of runoff. Given the subsoils are more than 10 m thick, it is considered that the highest inner range recharge coefficient of 0.40 can be applied in this case.

The reminder of the ZOC (15%) is defined by the northern slopes of the knoll located to the south of the compound. The slopes are overlain by thin well drained soils and are classified as High Vulnerability. From Guidance Document GW5 a recharge coefficient of 0.6 has been assigned to this area.

Runoff losses in the total catchment are assumed to be 57% of the potential recharge (effective rainfall). This value is based on an assumption of c.40% runoff for 15% of the area (High Vulnerability) and c.60% runoff for 85% of the area (Moderate vulnerability). The bulk recharge coefficient for the area is therefore estimated to be 43%.

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	85 % of the area at 0.40
	15 % of the area at 0.60
Bulk recharge coefficient	43%
Runoff losses	57%
Assumed Recharge	256 mm

The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. At a recharge of 256 mm/yr, an average yield of 91 m^3/day would require a recharge area of 0.13 km^2. This is the area of the ZOC described above, and shown in Figure 8.

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. Therefore, assuming an abstraction of 136 m^3/d, the size of required recharge area would be increased to 0.19 km^2. The boundaries of both ZOC options are shown in Figure 8.

11 Source Protection Zones

The Source Protection Zones are a land use 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 have been 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 9.4, the groundwater velocity is 0.16 m/d, and hence the 100-day time of travel distance is 16 m. The Inner Protection Area is illustrated in Figure 9.

The Outer Protection Area (SO) encompasses the entire zone of contribution to the source. In order to take the more conservative approach, the ZOC based on the 50% increased yield is adopted, i.e. 0.19 km^2.

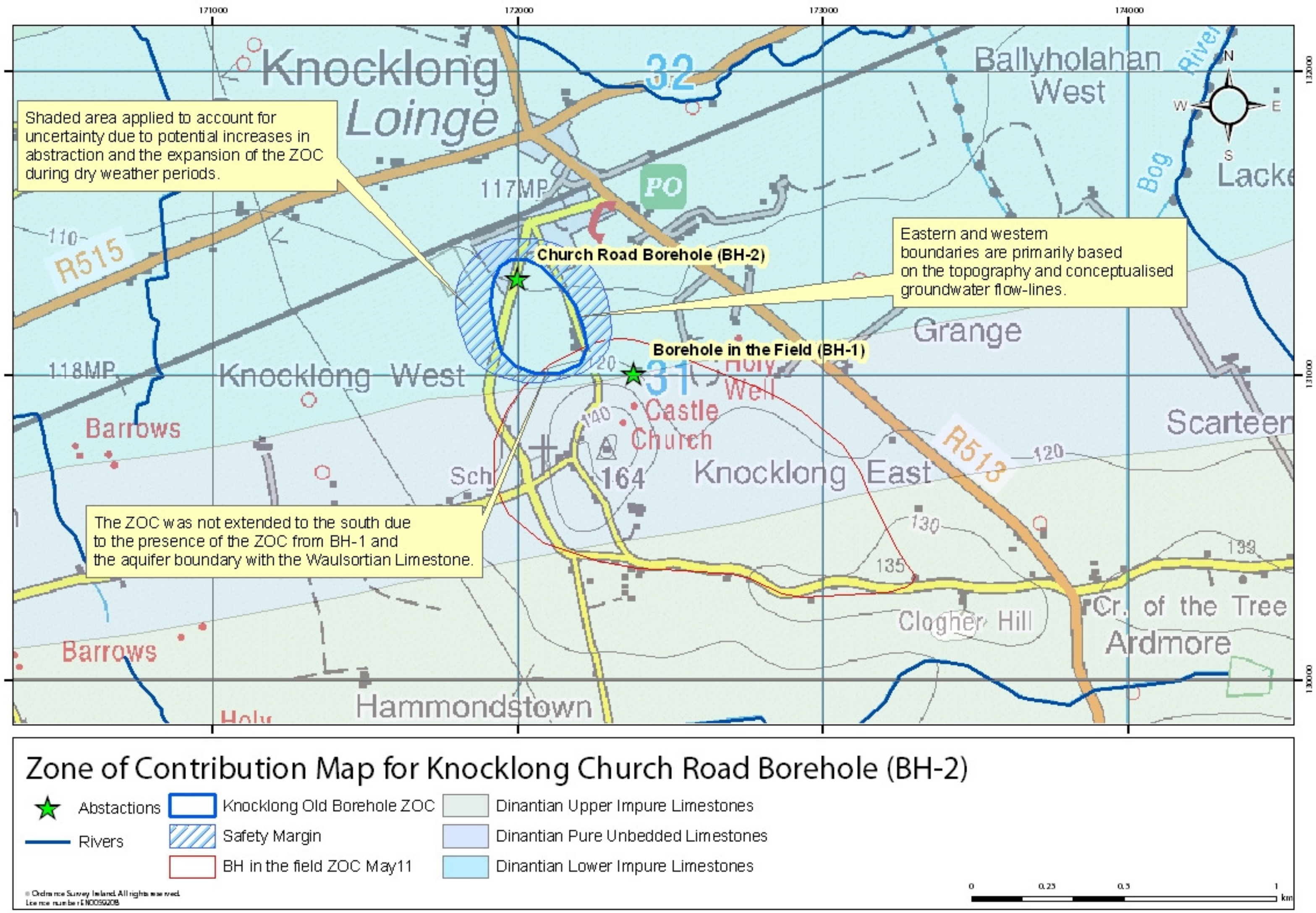


Figure 8: Zone of Contribution

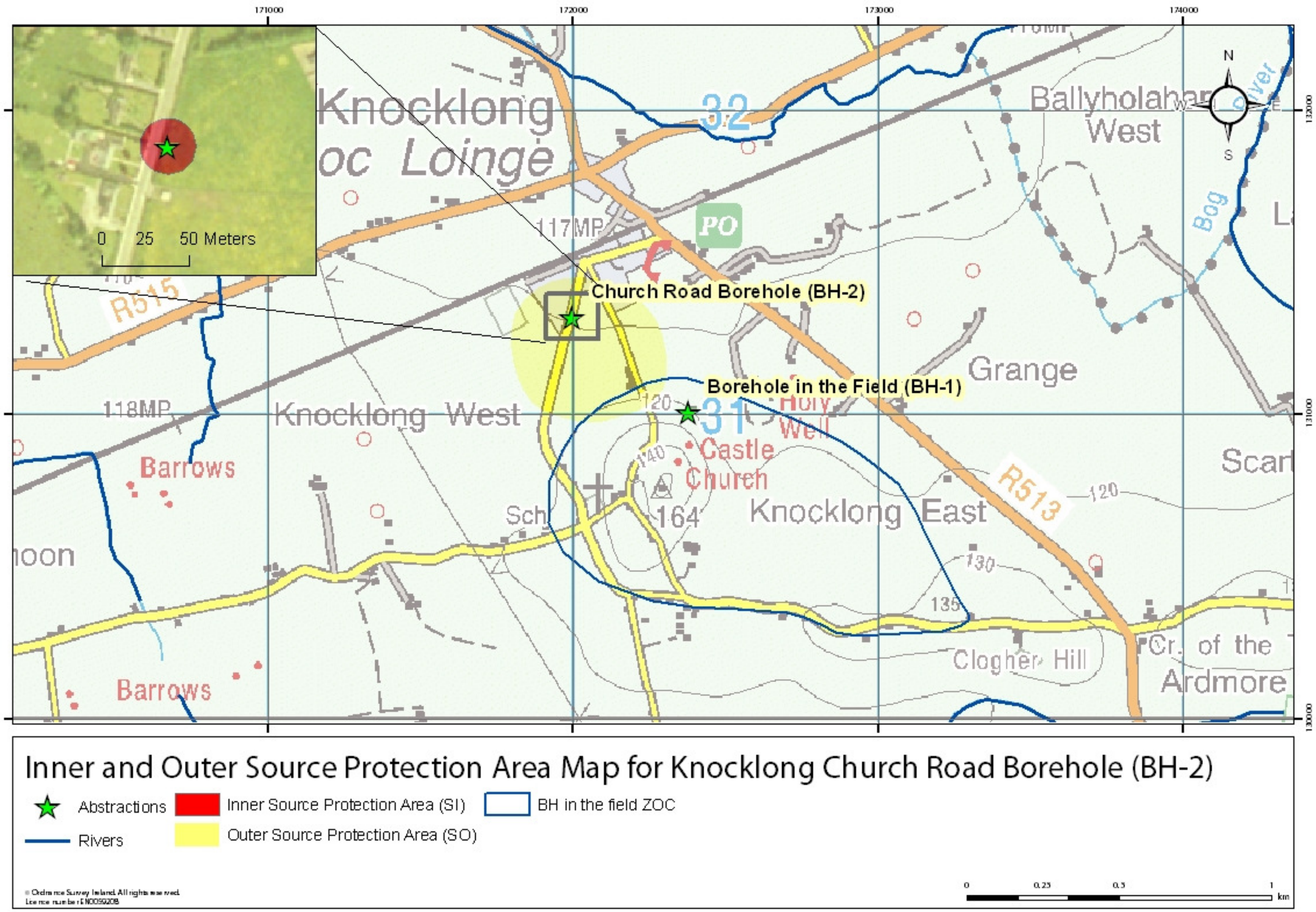


Figure 9: Inner and Outer Protection Areas

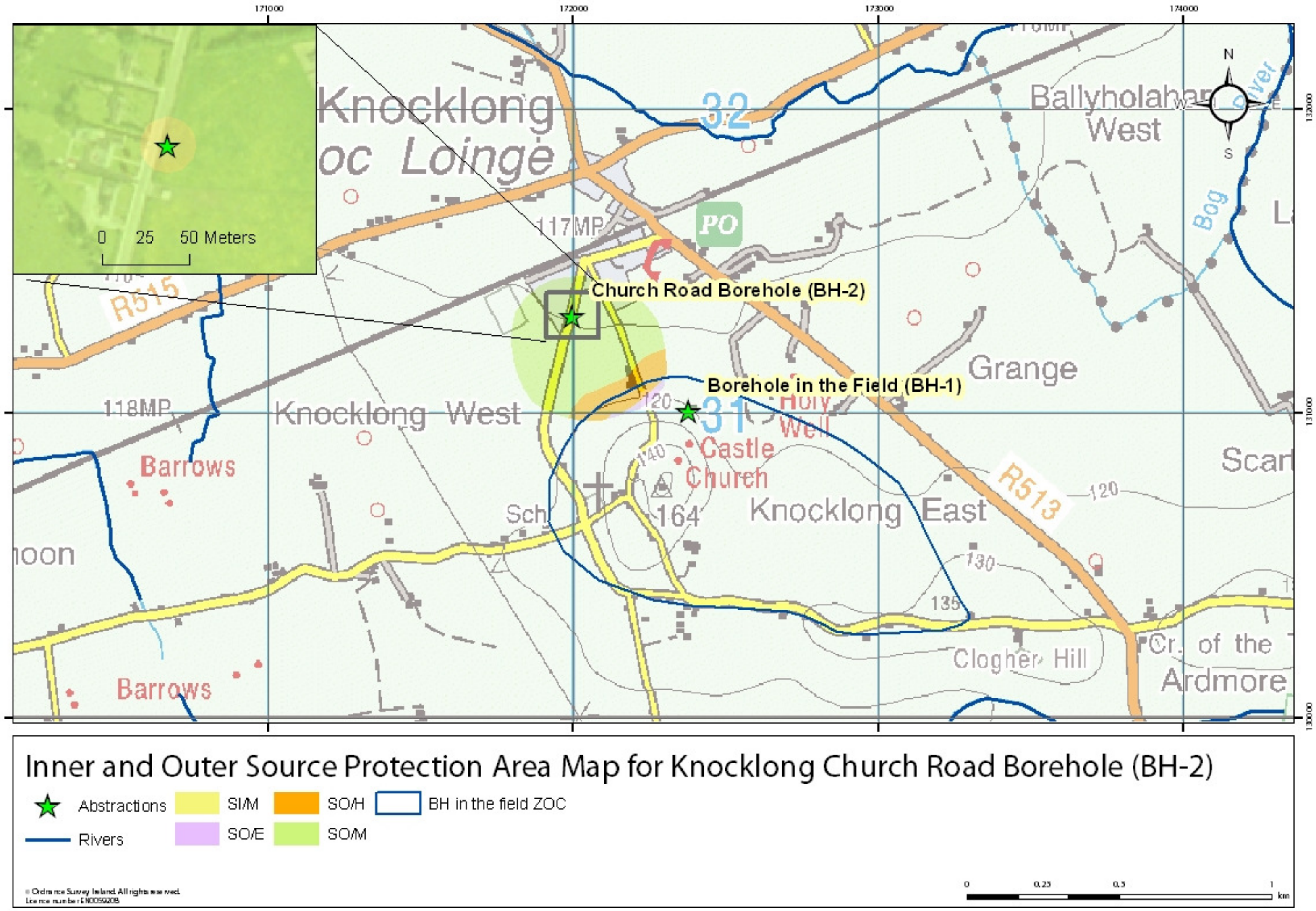


Figure 10: Source Protection Zones

The groundwater Source Protection Zones are shown in Figure 10 and are listed in Table 11-1. They are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/M, SO/E, SO/H and SO/M. The majority of the area is designated SO/M.

Table 11-1 Source Protection Zones

Source Protection Zone		**% of total area (km^2)**
SI/M	Inner Source Protection area / Moderate vulnerability	0.41% (0.0008 km^2)
SO/E	Outer Source Protection area / <3 m subsoil	2.05% (0.004 km^2)
SO/H	Outer Source Protection area / High vulnerability	16.43% (0.032 km^2)
SO/M	Outer Source Protection area / Moderate vulnerability	81.11% (0.158 km^2)

12 Potential Pollution Sources

The borehole is located in a pump house approximately 10 m from the public road. The risk of a surface spill along the public road reaching the well is low given there is a step at the entrance door preventing the ingress of water to the pump house.

The land use within the Inner Source Protection Area is primarily pastureland for grazing animals. The main potential microbial pollution sources are considered to be the presence of cattle and horses in the fields surrounding the compound. There are no untreated water quality data available. However, given the predominantly Moderate vulnerability of the Ballysteen Formation within the Inner Source Protection Area, the potential risk from cryptosporidium and viruses should be low.

The majority of land within the Outer Source Protection Area is agricultural grassland and the dominant farm activity is dairy farming. The main potential pollution sources associated with farming activities are grazing animals and landspreading of agricultural waste.

In summary, given the land use, and the Moderate vulnerability rating within the SI, the risk posed by cryptosporidium is likely to be low.

13 Conclusions

BH-2 abstracts water from the Ballysteen Limestone Formation. The aquifer is classified as a Locally Important Aquifer that is Moderately Productive only in Local Zones (Ll). The well, which is artesian when not being pumped, provides 91 m^3/d. This pumping rate has been sustainable since the well was commissioned in 1959.

There are no water quality data available, but given the Moderate groundwater vulnerability within the Inner Source Protection Area, the water quality is expected to be good. Monitoring is required to confirm this assumption.

The ZOC encompasses an area of 0.19 km^2, which incorporates a 50% increase in the pumping rate as recommended by the GSI. 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

Given that BH-2 in constant use for public supply purposes it is recommended that pre-treatment sampling be undertaken at the same frequency and range of parameters as that for BH-1.

15 References

Archer, J.B., Sleeman, A.G. and Smith, D.C. (1996) Geology of Tipperary. Bedrock Geology 1:100,000 Map series, Sheet 18, Geological Survey of Ireland.

Environmental Protection Agency (2003). Towards Setting Guideline Values for the Protection of Groundwater in Ireland. Environmental Protection Agency.

European Communities (2000) (Drinking Water) Regulations. S.I. No. 439 of 2000.

European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9/2010).

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

Geological Survey of Ireland (2004) 1st Draft Hospital GWB Description.

GSI (1995) Source Protection Scheme Report for Hospital Public Supply

Meehan, R. (2002) Forest Inventory and planning system – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc.

Tobin Consulting Engineers on behalf of the Geological Survey of Ireland and Limerick County Council (2010). Groundwater Vulnerability Map for County Limerick Digital Map.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edition New York: John Wiley & Sons

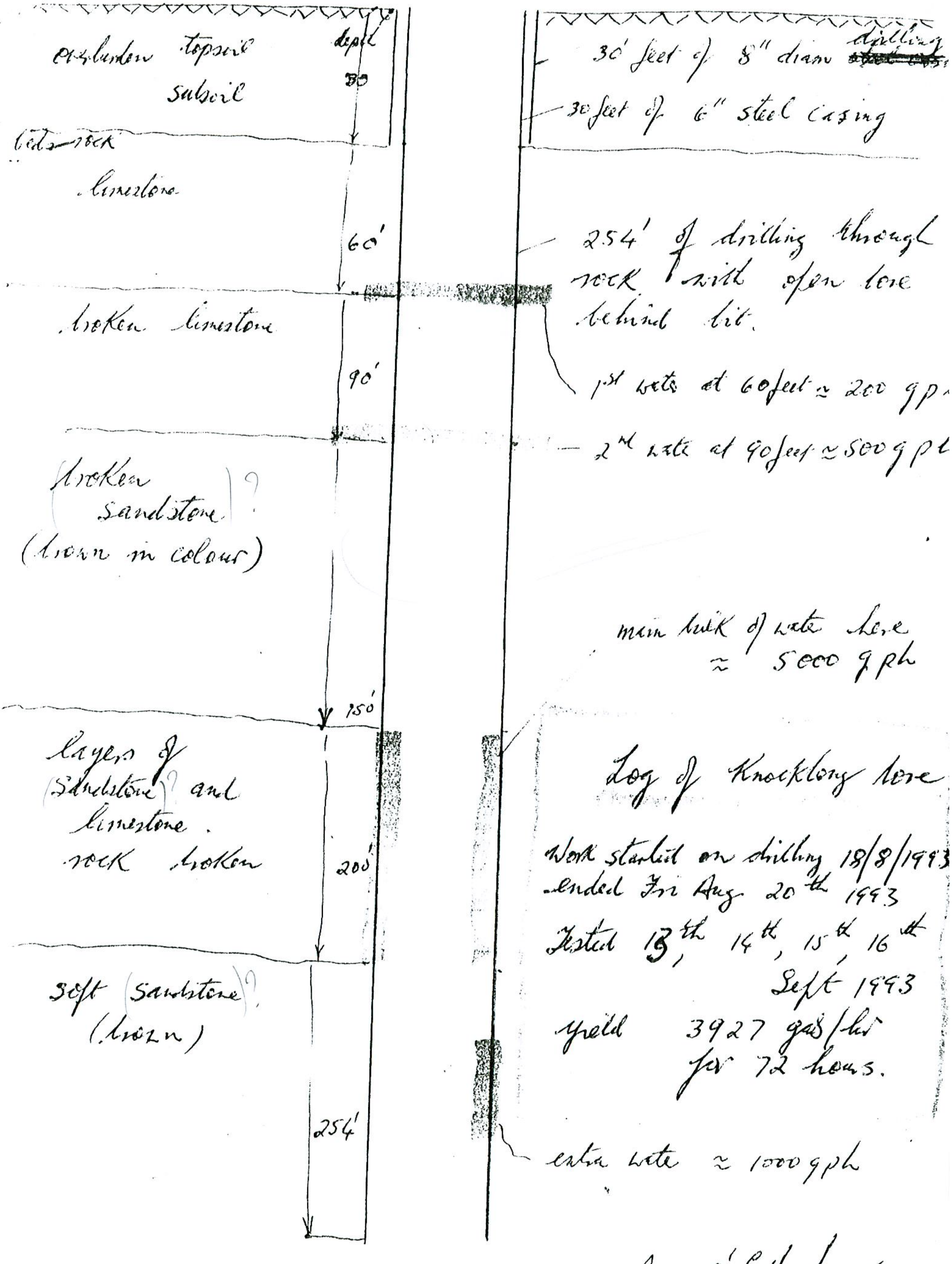
APPENDIX 1

Borehole Exploration Log

Borehole in the Field Log: Original hand writing description and OCM interpretative 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/Oct/1993

1994 Prod. Bh

Well boring in Knocklong
August 1994.
Production borehole

John Lynch started work Thursday Aug 11th '94
boring through 6' of overburden
in 15" dia.

Lined into rock in 12" steel casing

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

16/8/94 J Lynch bored to 170 feet
in 12"

17/8/94 Slow progress

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.

[signature]
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

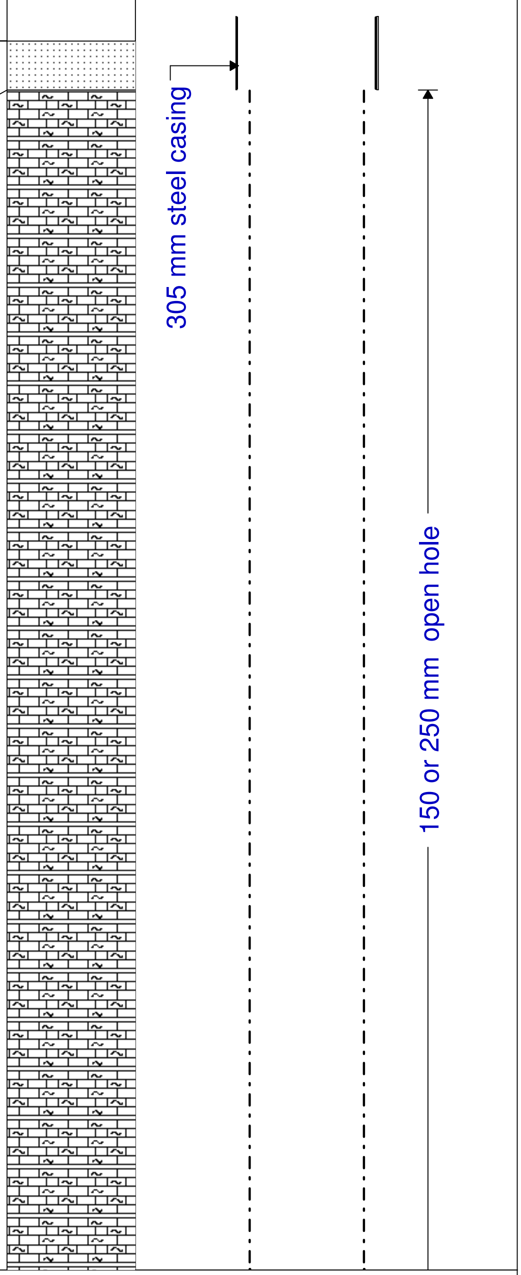
Borehole Depth: 91.5 meters

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

Borehole Type: Water Well

Depth	Lithology Description	Lithology	Well Construction Details
-1 to 49	Ground Surface		
0 – 3	**Subsoil** Till		
3 – 49	**Bedrock** Ballysteen Formation (Dark Muddy Limestone Shale)		

Depth: -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49



Drilling Contractor:

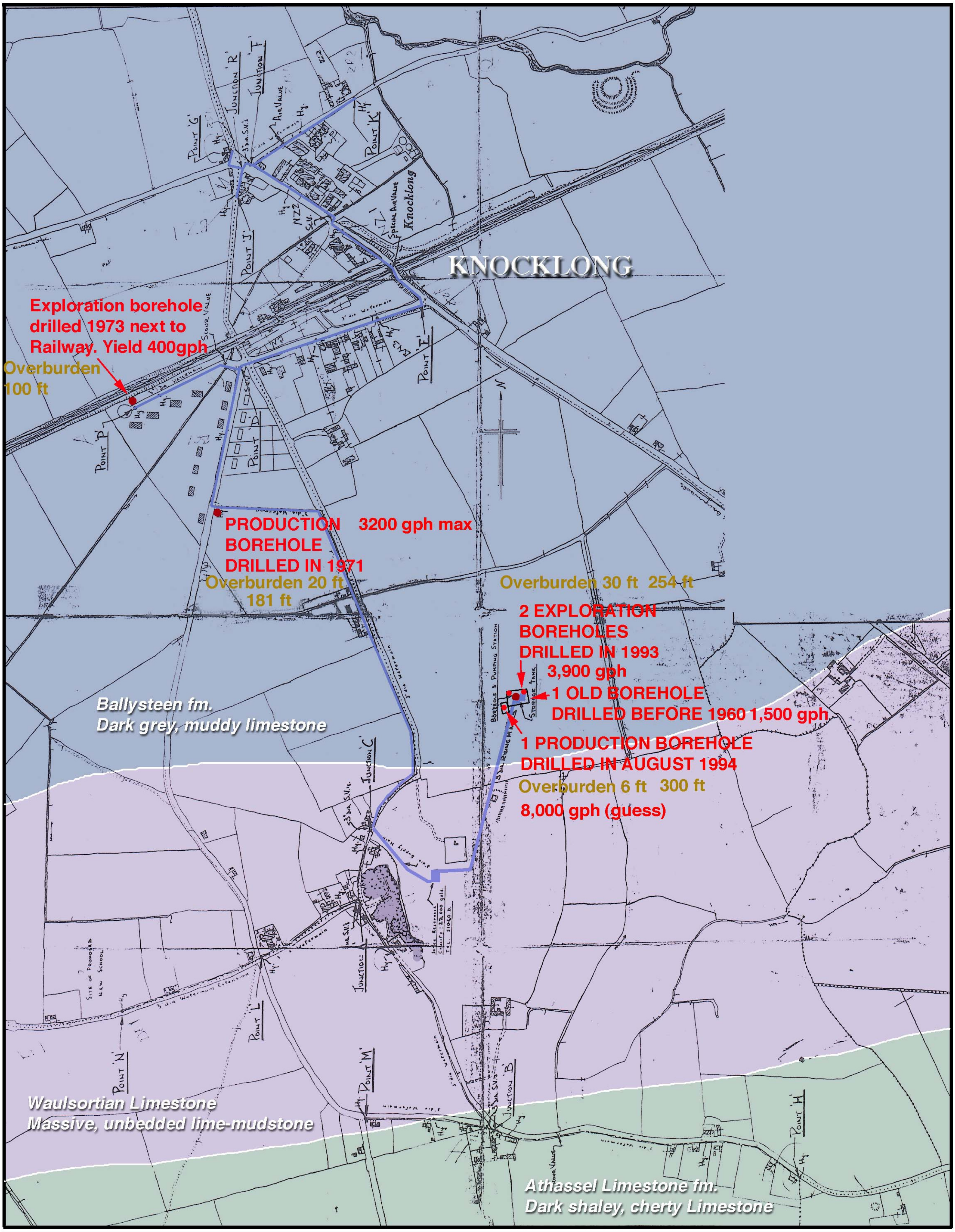
Drill Method:

Drill Date: 1994

Hole Size: 250 mm ?

Geologist:

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



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

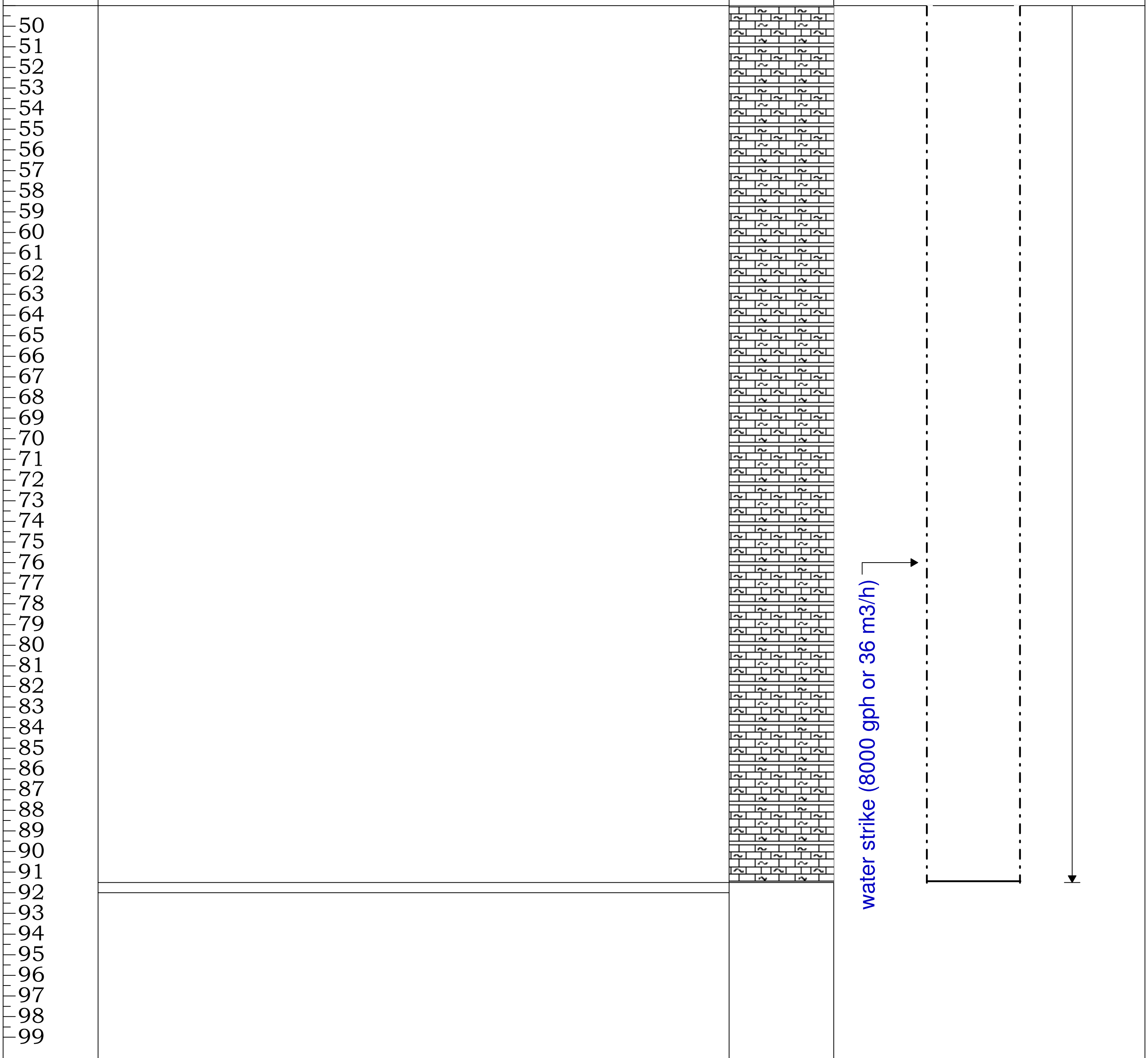
Client: Co. Limerick

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

Location: Knocklong

Borehole Type: Water Well

Depth	Lithology Description	Lithology	Well Construction Details



Drilling Contractor:

Hole Size: 250 mm ?

Drill Method:

Geologist:

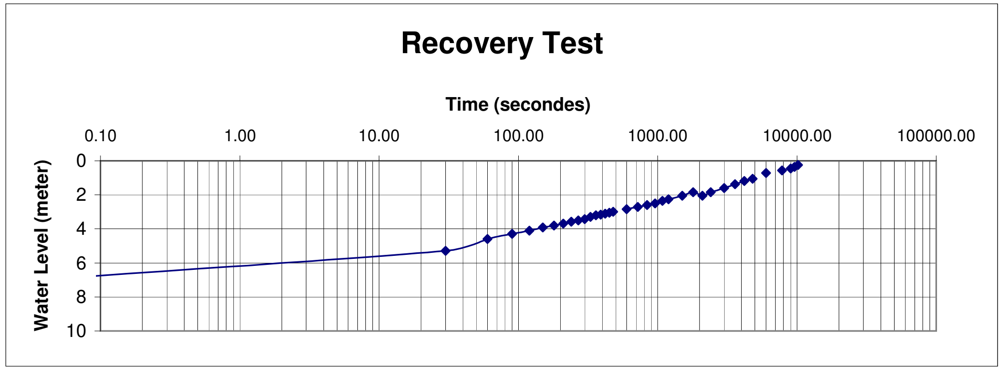
Drill Date: 1994

Sheet: 2 of 2

APPENDIX 2

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

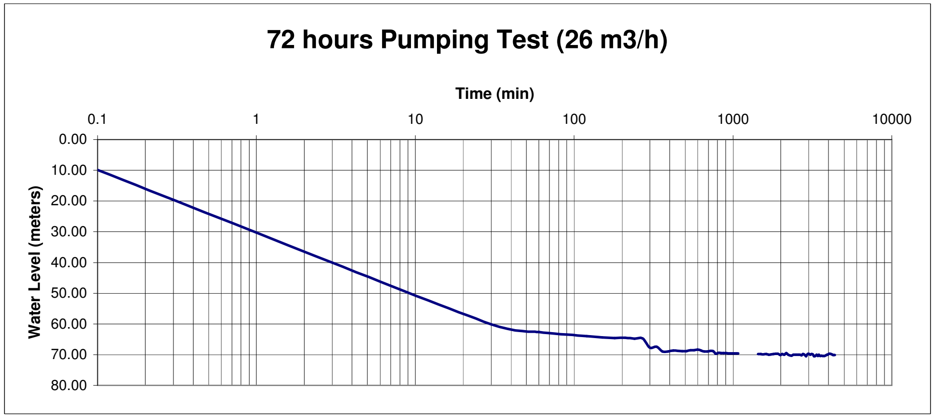
	t1-10	t10-100	t100-1000	t1000-10000	Average
T - Transmissivity (m2/d)		**7.56**	**10.03**	**8.74**	**8.78**
Q - Final Discharge (m3/d)	100.8	100.8	100.8	100.8	
t1 - point in time					
S1 - Drawdown at t1		6.64	4.2	2.36	
S2 - Drawdwon at t1*10		4.2	2.36	0.25	
dS - Change in drawdown over 1 log cycle	0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

APPENDIX 3

Pumping Test Data (1994) 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/h	m3/d
26	624

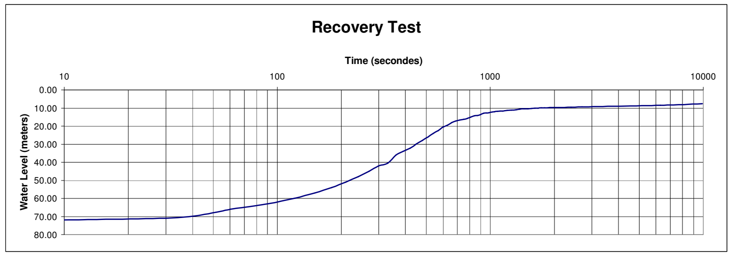
Transmissivity Estimation
T = 0.183Q / dS

	t1-10	t10-100	t100-1000	
T - Transmissivity (m2/d)	**5.7096**	**8.396471**	**19.032**	7.053035
Q - Final Discharge (m3/d)	624	624	624	
t1 - point in time				
S1 - Drawdown at t1	30	50	63.6	
S2 - Drawdwon at t1*10	50	63.6	69.6	
dS - Change in drawdown over 1 log cycle	20	13.6	6	

	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/h	m3/d
26	624

Transmissivity Estimation
T = 0.183Q / dS

	t10-100	t100-1000	t1000-10000	
T - Transmissivity (m2/d)	**8.784**	**2.330449**	**26.25103448**	5.557224
Q - Final Discharge (m3/d)	624	624	624	
t1 - point in time				
S1 - Drawdown at t1	74	61	12	
S2 - Drawdwon at t1*10	61	12	7.65	
dS - Change in drawdown over 1 log cycle	13	49	4.35	