Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Knocks Water Supply Scheme

Knocks Borehole(s)

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PROJECT DESCRIPTION

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

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

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

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1 Introduction

Groundwater Source Protection Zones are delineated for the Knocks Water Supply Scheme according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater Source Protection Zone Delineation.

The objectives of the report are as follows:

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

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

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

2 Methodology

Interviews were conducted on 8th and 14th July 2010 with the caretaker, supervisor and water services engineer as part of site visits. Site walk-overs, test pumping (20th July 2010) and field mapping (including a well survey, ordnance level survey, mapping of drainage indicators and logging of bedrock outcrops and subsoil exposures) of the study area were conducted during July and August 2010.

3 Location, site description and well head protection

Knocks Water Supply Scheme is located 10 km west of Portlaoise and 6 km north of Mountrath, in the townland of Knocks (Figure 1). The source comprises two adjacent boreholes located in a gated compound, approximately 40 m by 40 m, along a narrow access road just west of the R423.

The site was originally a surface water works and there are still five settlement tanks within the compound. The boreholes are located on the northwestern side of the compound, each in separate housing. An annotated aerial photograph in Figure 2 indicates the site configuration and a photograph of the compound is given in Photograph 1. The site is well protected along the access road with secure wall and gate. The original borehole was drilled *c*. 1977 (Daly, E.P., 1977) and served as a backup supply to the surface water intake, and currently serves as a supplementary borehole to keep the reservoir topped up. In mid-2003, a trial well was drilled and later in that year the current production well was drilled which took over from the surface water abstraction. The trial well was decommissioned thereafter.

The main borehole pumps twenty-four hours a day to a reservoir located in the compound, shown in Figure 2 (Photograph 1 is taken from the top of the reservoir). The reservoir is a concrete covered structure with a capacity of 30,000 gallons (approximately 6–8 hours storage). However, when the level in the reservoir drops to a below a certain point, the discharging water into the reservoir disturbs the sediment at the bottom of the reservoir. Therefore, to keep less turbid water going to the network, the level in the reservoir needs to kept close to the top. Before this occurs, the second (supplementary) borehole automatically starts to pump, thus supplementing the main borehole. Treated water is fed by gravity from the reservoir into the network which is located east of the compound. This means that houses west of the boreholes, i.e. uphill, are not fed by the scheme.

The main borehole shown in Photograph 2 is finished above ground level and is cement grouted. The housing is secured though vermin could probably get in at the back where there is a small gap. The top of the borehole is not capped. A dipping tube is inserted and extends, according to the council, as far as the pump. The original / supplementary borehole shown in Photograph 3 is finished above ground level. There is no outer casing, it is not sealed, the concrete plinth does not extend as to main casing and it is less well protected than the main borehole.

A stream runs alongside the opposite side of the access road, crosses underneath the road and continues adjacent to the southern side of the compound. It is known to flood the road and enter the site; the flooding waters do not enter the boreholes directly as they can fill one of the settlement tanks which remains empty.

4 Summary of borehole details

The main borehole was drilled in August 2003, with a sketch is given in Appendix 1 of the current understanding of the construction. The inner casing has a diameter is 254 mm (10 inches) and the depth is recorded at 48 m (157 feet). There is a cement grout seal in the annular space between the inner and outer casing. The average abstraction from the main borehole is 612 m^3/day, based on Laois County Council data and also the rate recorded during the pumping test.

The abstraction rate reduces over time because the pump draws in excessive sediment which wears down the pump and the flow meter. The supplementary borehole pumps intermittently at a rate of 327 m^3/day when it is called upon by the automatic level indicator in the reservoir. In general the main borehole pumps 24 hours a day and is usually sufficient to keep the reservoir full or nearly full. The log of the main borehole given in Appendix 1 represents the borehole construction based on interviews the driller and the caretaker. Appendix 2 provides a representative log of the trial well given by David Ball which based on interviews with Local Authority staff. The boreholes were drilled into sands and gravels, up to 36 m deep as seen in Appendix 1. It is assumed that the depth to bedrock of the trial well is approximately the same in the main borehole, as it is not known for certainty, however the last 10 m of blank casing suggest that it is. Table 3-1 provides the known details of all the boreholes.

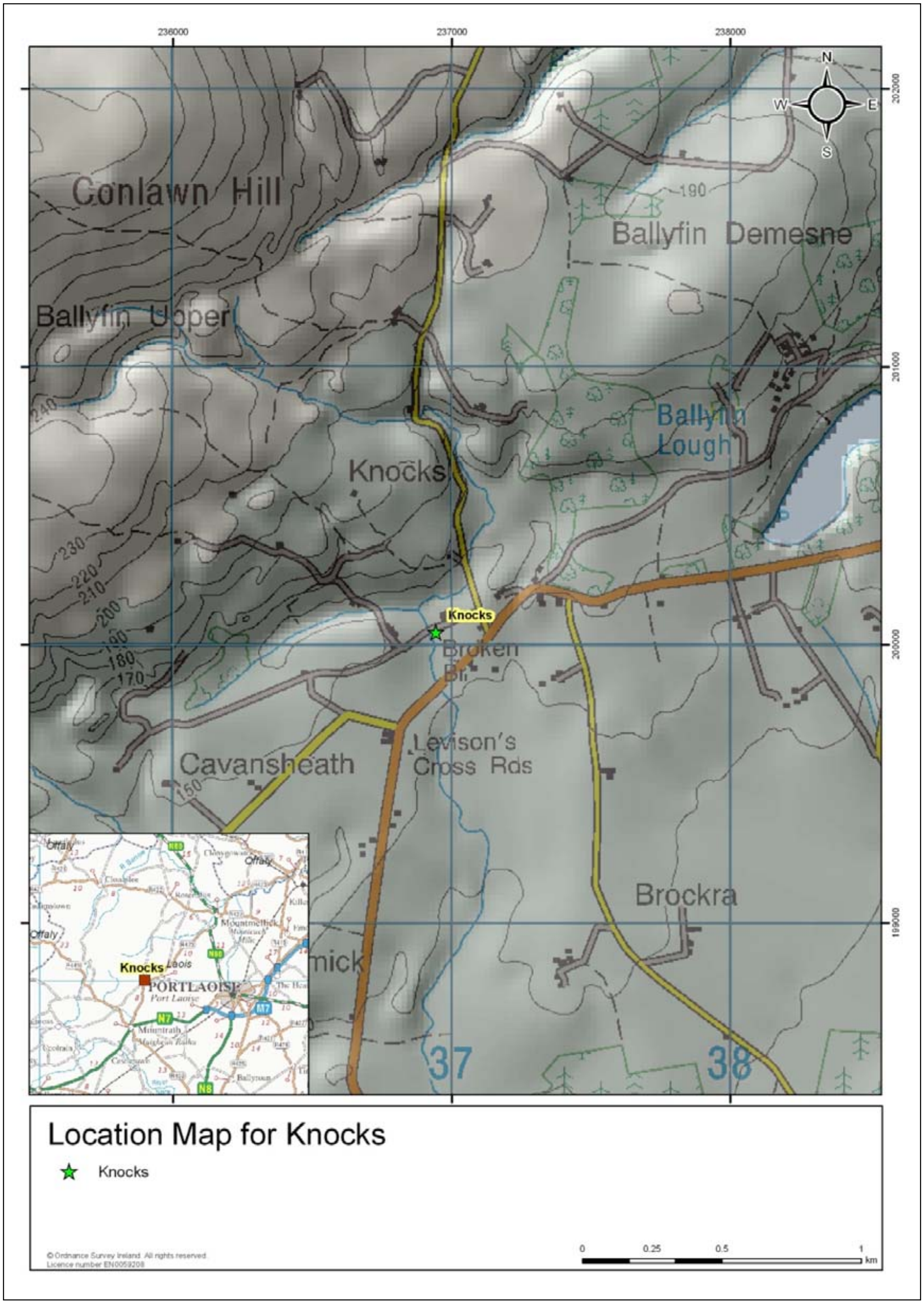


Figure 1 Location Map of Knocks Boreholes, in the footslopes of the Slieve Bloom Mountains

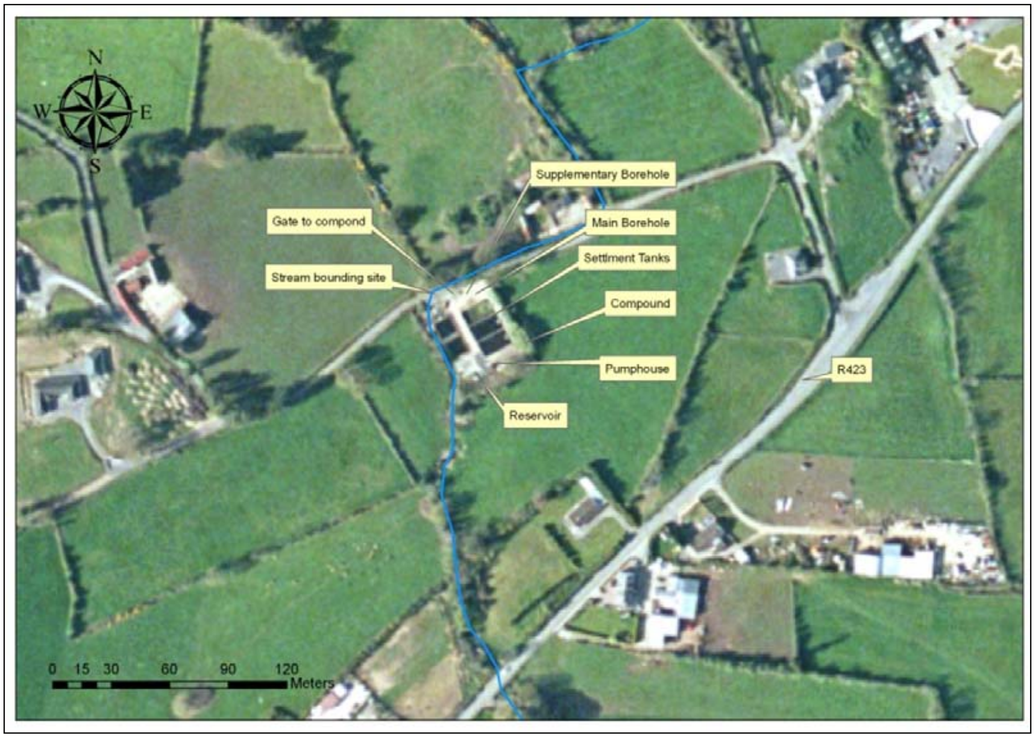


Figure 2 Aerial View of Site Compound

Photograph 1 Site Compound

Photograph 2 Main Borehole

Photograph 3 Supplementary Borehole

Table 4-1 Summary of Source Details

	Main Borehole	Original / Supplementary Borehole	Trial Well
EU Reporting Code	IE_SE_G_107_11_007	Not applicable	Decommissioned
Grid reference	E236939 N200048	E236337 N200050	Drilled north side of compound
Townland	Knocks		
Source type	Borehole		
Drilled	14–15 August 2003	1977 (EPDaly,1977)	July 2003
Driller	Briodys (P.)	Unknown	Briodys (P.)
Supervisors	Unknown	Unknown	Unknown
Owner	Laois County Council		
Elevation (Ground Level)	145.578 mOD	146 mOD	145.91 mOD
Depth	48 m	13 m (plumbed July 2010)	55 m
Depth of casing	See Appendix 1 Reconstructed Log	24 m (sediment infilling ?)	See Appendix 1 for Log
Casing Diameter	0.254 m (10”)	0.22 m (8”)	0.153 (6”)
Depth to rock	~ 36 m	~ 36 m	36 m
Static water level (14 July 2010)	4.26 bgl (141.3mOD)	4.26 bgl (141.6mOD)	N/A
Pumping water level (14 July 2010)	19.94 bgl (125.6mOD)	5.15 bgl (139.8mOD)	N/A
Average abstraction rate (Co Co records)	612 m^3/day, 24 hours a day	Intermittent, at a rate of 327 m^3/day	N/A
Specific Capacity	40 m^3/d/m	Unknown	N/A

Note: Dipping tube in main well is approximately 0.3 m above ground level. At the supplementary borehole, the casing is 0.44 m above ground level.

Note: The original borehole was probably drilled in 1977. A brief report by E.P. Daly 1977 refers to the drilling of a borehole at the Knocks Waterworks site.

5 Topography, surface hydrology and landuse

The boreholes are located in the footslopes of the eastern fringe of the Slieve Bloom mountains, with the general fall of the land to the southeast (Figure 1). The topography rises sharply west of the boreholes, from 150 mOD to 325 mOD at Conlawn Hill, whilst the slope is more gentle to the east. The topographic gradient west of the boreholes ranges from 0.078 to 0.09, and to the east it is 0.017.

The hydrology of the area is dominated by a stream that flows past the boreholes, shown in Figure 1 and Figure 2, originating in Ballyfin Upper at 250 m OD. According to the caretaker and the supervisor, the stream flows and levels are variable; from no flow or very low flow, to flooding and overtopping the banks. The stream banks alongside the compound are approximately 1.5 m deep and over 1 m wide. The invert levels of the stream in the vicinity of the compound were levelled in by TOBIN Consulting Engineers (August 2010). The stream path is shown in Figure 1 and Figure 2 and it can be seen that it is different on each in the vicinity of the access road to the boreholes. The path of the stream in Figure 2 is from the field mapping, and also corresponds to the path on the six inch sheets. Another smaller stream joins this stream from the southwest, originating from springs in Cavansheath, 900 m from the source. This stream reportedly dries up in prolonged, dry weather periods.

Landuse in the vicinity of the boreholes is dominated by dry grassland. On the slopes to the west, above 200 mOD, blanket peat dominates. There is a relatively low housing density in the area, with a house 60 m northeast, and several houses over 200 m distant (Figure 2). The houses north of the access road are served by private boreholes and on-site wastewater treatment systems. The closest house, 60 m away, has no borehole. Land use pressures are relatively low.

6 Hydro-meteorology

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

Annual rainfall: 1200 mm. The contoured data map of rainfall in Ireland (Met Éireann; 1961–1990 dataset) shows that the source is located along the 1,200 mm average annual rainfall isohyet. The closest historical meteorological station to the source is at 'The Cut', approximately 8 km west and at 430 mOD, where the average rainfall between 1961 and 1990 was 1635 mm/yr. At Portlaoise, 11 km east and at 100 m OD, the average rainfall during the same period was approximately 890 mm/yr (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: 428 mm. Potential evapotranspiration (P.E.) is estimated to be 450 mm/yr (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 428 mm.

Annual Effective Rainfall: 772 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore, 772 mm/year. See also Section 10 on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

7 Geology

This section briefly describes the relevant characteristics of the geological materials that underlie the Knocks source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based on the bedrock geological map of Galway and Offaly, Sheet 15, 1:100,000 Series (Geological Survey of Ireland (GSI), 2003) and accompanying memoir (Gatley *et al.,* 2003), the GSI Well, Borehole and Karst Databases and on bedrock outcrop and subsoil exposures encountered during site visits.

7.1 Bedrock geology

Thick flaggy sandstones and thin siltstones, termed by the GSI as Devonian Kiltorcan-type sandstones, underlie the Knocks Boreholes and are the principal rock type in the vicinity of the source. As the source is located at the edge of the Slieve Bloom mountains the bedrock over a wider area is shown on Figure 3 and described in Table 6.1; this bedrock consists of limestones, shales and sandstones. Shallow outcrops into the bedrock where the stream from Ballyfin Upper meets the road show flaggy highly fractured sandstones. Sandstone gravels and cobbles dominate the coarse grained fraction of the stream beds and exposures.

Table 6.1 Bedrock Geology of the Study Area

National Generalised Bedrock Map Name	Formation / member	GSI Code	Geological Description
Dinantian Lower Impure Limestones	Ballysteen Limestone	BA	Dark, muddy limestones and shale
Dinantian Early Sandstones, Shales and Limestones	Lower Limestone Shale	LLS	Sandstone, mudstone and thin limestone
Devonian Kiltorcan- type Sandstones	Clonaslee Member	CWcl	Thick Flaggy Sandstone, Thin Siltstone
Devonian Old Red Sandstones	Cadamstown Formation	CW	Pale and red sandstone and grit and claystone

7.2 Soils and subsoils

A wide variety of soils are mapped in the area and the pattern is quite complex. In general, the soils east of the boreholes are dominated by deep, poorly drained acidic ('wet') soils. These soils are also mapped on either side of stream channels. Northwest of the boreholes, above 200 mOD, the soils are mapped as poorly drained peaty acidic soils, and further upslope on Conlawn Hill, blanket peat predominates. Pockets of deep, well drained acidic ('dry') soils occupy areas in the vicinity of the boreholes, mainly on the lower slopes to the northwest. Intermingled with these dominant soils, there are shallow soils and shallow/rocky/peaty soils. Alluvium is mapped along the majority of the stream courses, particularly where the streams reach the lower slopes; however, along the stream adjacent to the site compound, as well as upstream for approximately 300 m, there is no alluvium mapped. A walkover along the stream sections in these areas indicates no alluvium (See Photograph 4-7) and shows that the bank is a cutting into till.

As mapped on the Teagasc subsoil map (2006), the subsoils at the surface are dominated by glacial till derived from Devonian sandstones and shales (TDSs). Sections into the glacial till, shown in Photograph 5, have been logged and classified as a gravelly sandy SILT with sub-rounded to sub-angular cobbles. Along the stream, particularly in the vicinity of the boreholes, the till is free draining and it comprises occasional sand and gravel lenses. Approximately 600 m and 1 km east of the source, small pockets of glaciofluvial sands and gravels derived from Devonian sandstones are mapped, which poke up through the glacial till as hummocks. It is known that the source boreholes are drawing water mainly from the sands and gravels and the reconstructed borehole logs show that sands and gravels are present to significant depths. As well as this, a local driller (Matt Lawlor, *pers. comm.*) suggests significant depths of sands and gravels in the area. It is considered that the sand and gravel comprises significant thin clay layers and it may be that the entire sequence comprises interbedded till and sand and gravel units. The possible extent and occurrence of the sand and gravel is considered to be constrained by the occurrence of the bedrock outcrop and subcrop areas and is shown on Figure 5.

Bedrock outcrops are primarily restricted along stream banks north of the source where the stream has eroded a relatively sharp incision into the lower flanks of the mountain.

The depth to bedrock at the source boreholes is at least 36 m, according to the log of the trial well shown in Appendix 2. The depth to bedrock across the area is variable as evidenced by variation in depths recorded in the source boreholes, the private boreholes and the GSI well database. From examining the borehole logs it seems that a glacial till 'cap' occurs, of varying depth, on top of the sands and gravels. This is absent where the sands and gravels occur at surface, such as at the borehole itself, but it should be noted that the 0.5–1.0 m depth of till in the adjacent stream illustrates the complexity of the stratigraphy.

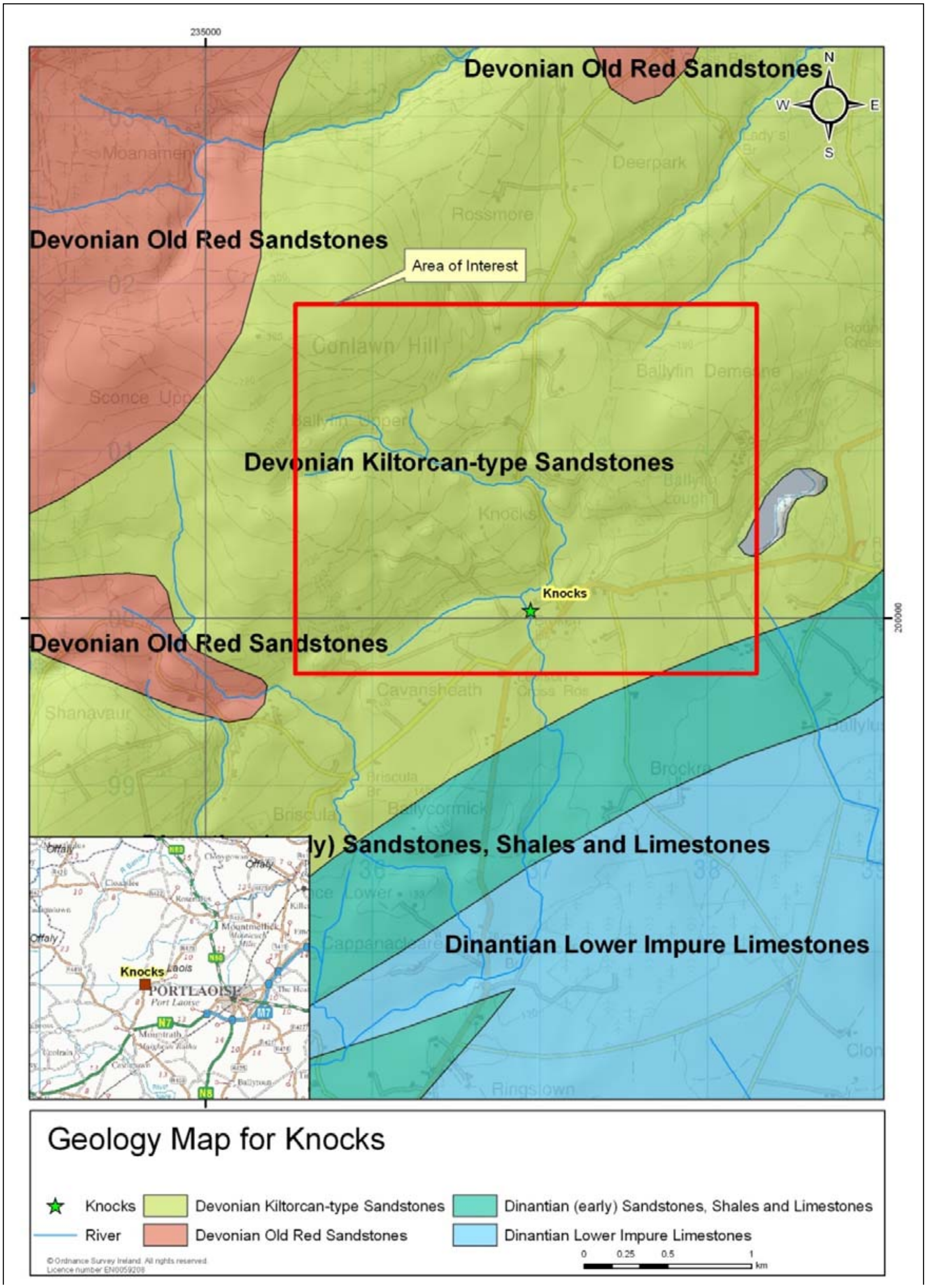


Figure 3 Geology in the vicinity of Knocks

Photograph 4 Section alongside compound Sandstone till, with no alluvium mapped along this stretch of stream

Photograph 5Stream Cutting adjacent to borehole – coarse grained gravels with sand lenses

Photograph 6 Stream cutting adjacent to borehole – coarse grained sediment

Photograph 7 Section into SILT with gravels 350 m north of source (sandstone till)

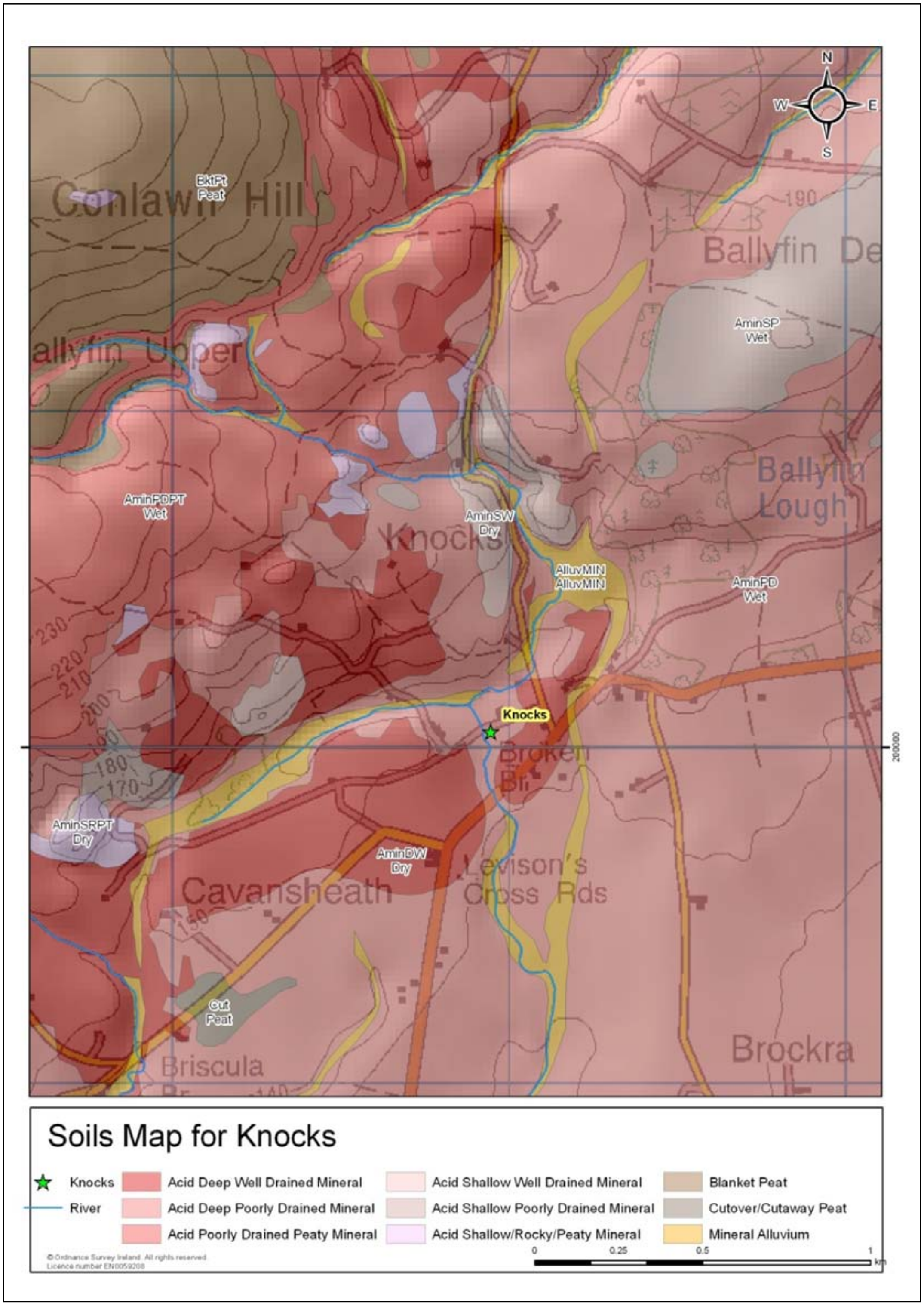


Figure 4 Soils in the vicinity of Knocks (Teagasc, 2006)

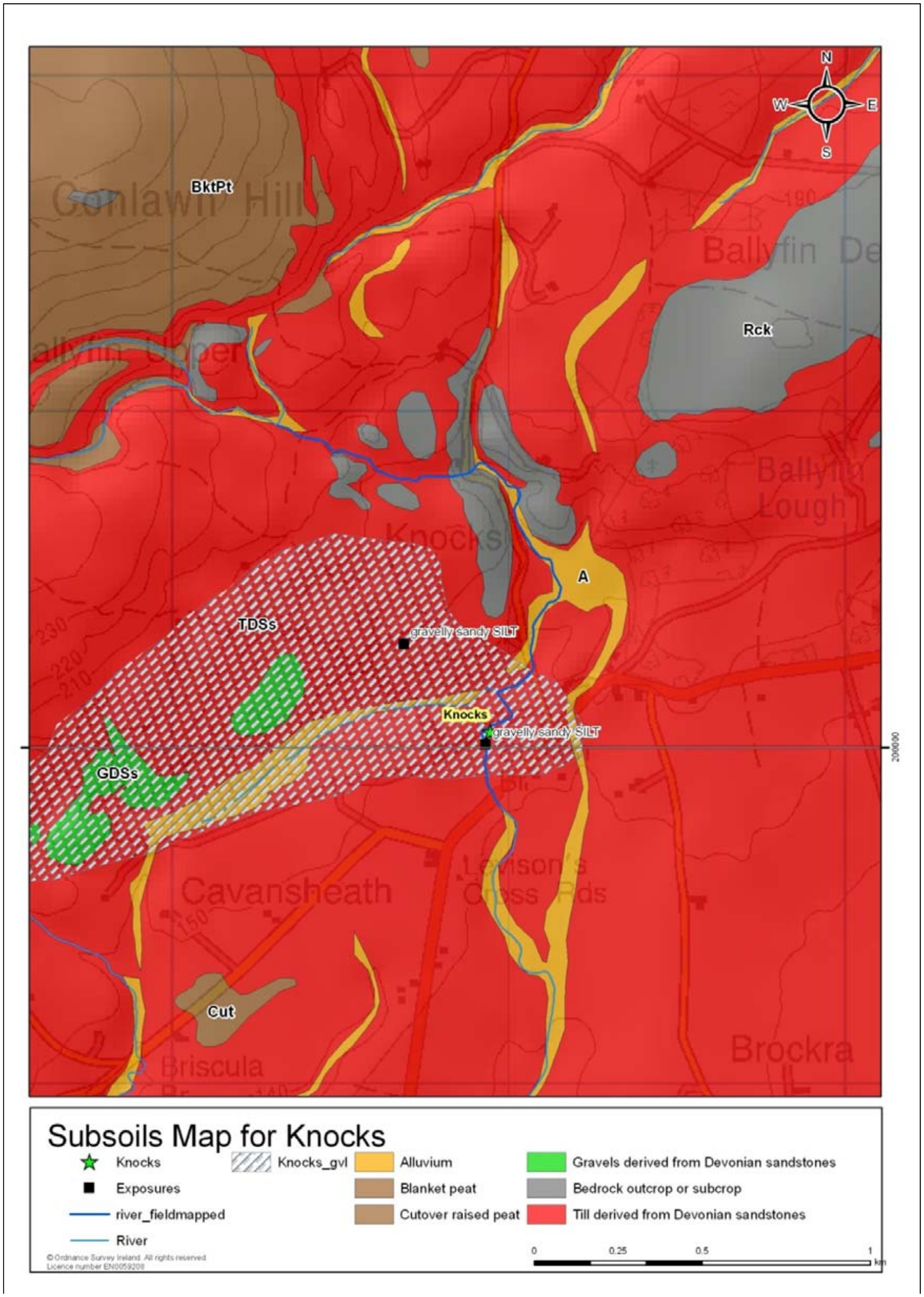


Figure 5 Subsoils in the vicinity of Knocks, proposed gravel outline included (Teagasc, 2006)

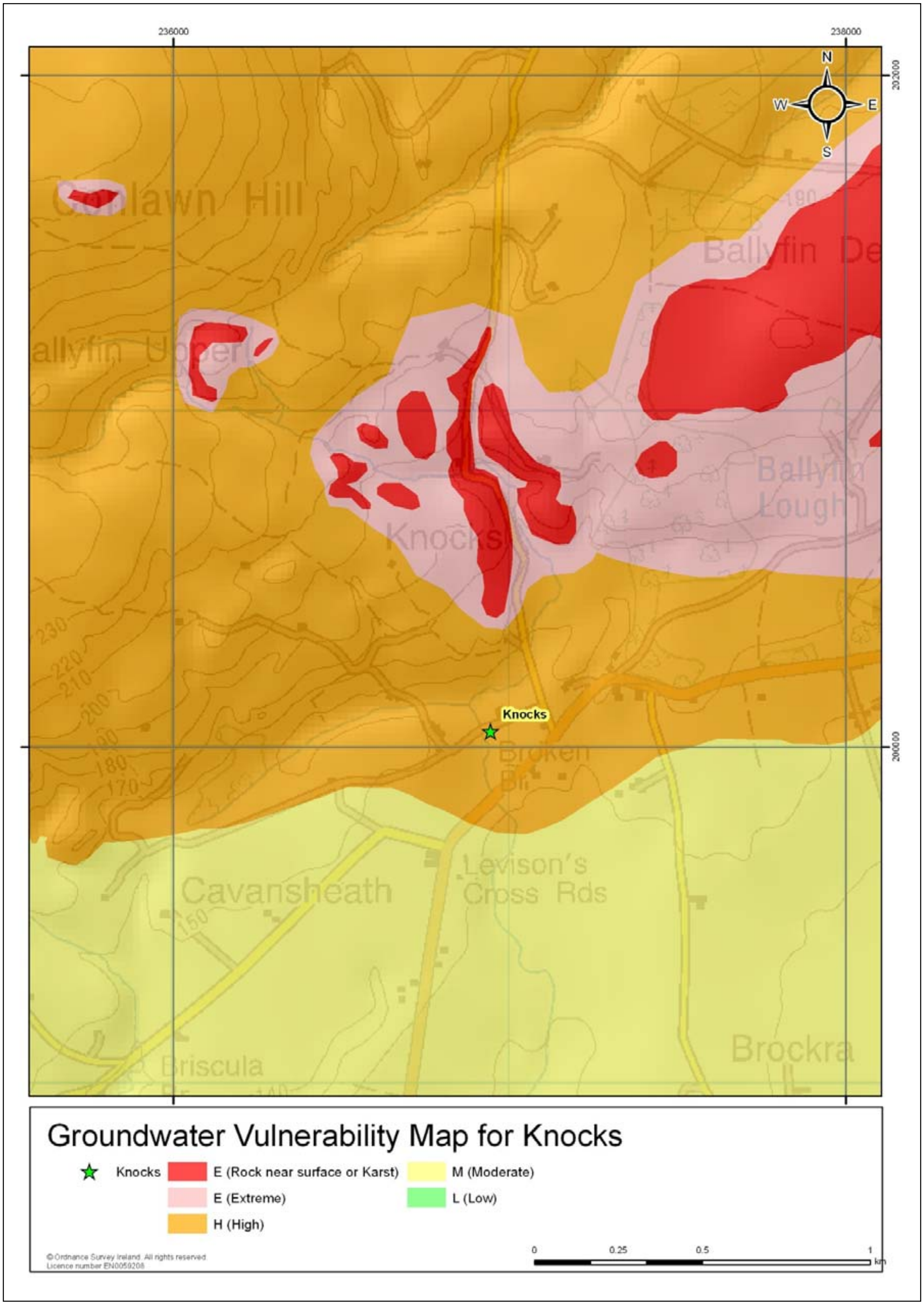


Figure 6 Groundwater Vulnerability in the vicinity of Knocks

8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target', which in this case is the sand and gravel aquifer. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al.*, 2003).

A groundwater vulnerability map for the area has been developed for County Laois by the GSI. The '**High'** vulnerability is based on the presence of '**High'** permeability sands and gravels in the vicinity of the source. The areas that are designated as rock at / or close to surface, are denoted as **'X'.** The remaining portion classified as '***Extreme***' is considered to comprise subsoils and soils with a depth of between 1 m and 3 m. The groundwater vulnerability is shown in Figure 6.

9 Hydrogeology

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

- GSI Website and Databases
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Laois Groundwater Protection Scheme (Deakin and Wright, 2000)
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan July 2010.
- GSI reports (Daly, EP., 1976, 1977, 1994)

9.1 Groundwater body and status

The source and the surrounding area are located within the Coolrain groundwater body (GWB) (GSI, 2004). The Coolrain GWB is classified as "at Good Status". The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the WFD website: www.wfdireland.ie.

9.2 Groundwater levels, flow directions and gradients

Groundwater levels were measured at the Knocks boreholes and in three private boreholes across the study area in July 2010, shown in Figure 7. Each of the boreholes and the stream adjacent to the compound was levelled in by TOBIN Consulting Engineers (August 2010). Static water levels are reported to be 4–5 mbgl for the source boreholes; this was confirmed during the recovery test from which the static water levels were 4.26 mbgl (141.3 mOD) in the main pumping borehole and 4.26 mbgl (141.6 mOD) in the supplementary borehole. In the main borehole, the pumping water level was measured at 19.94 mbgl (125.6 mOD) on 20/7/10 and at the same time, the water level in the supplementary borehole, was measured at 5.15 mbgl (139.8 mOD).

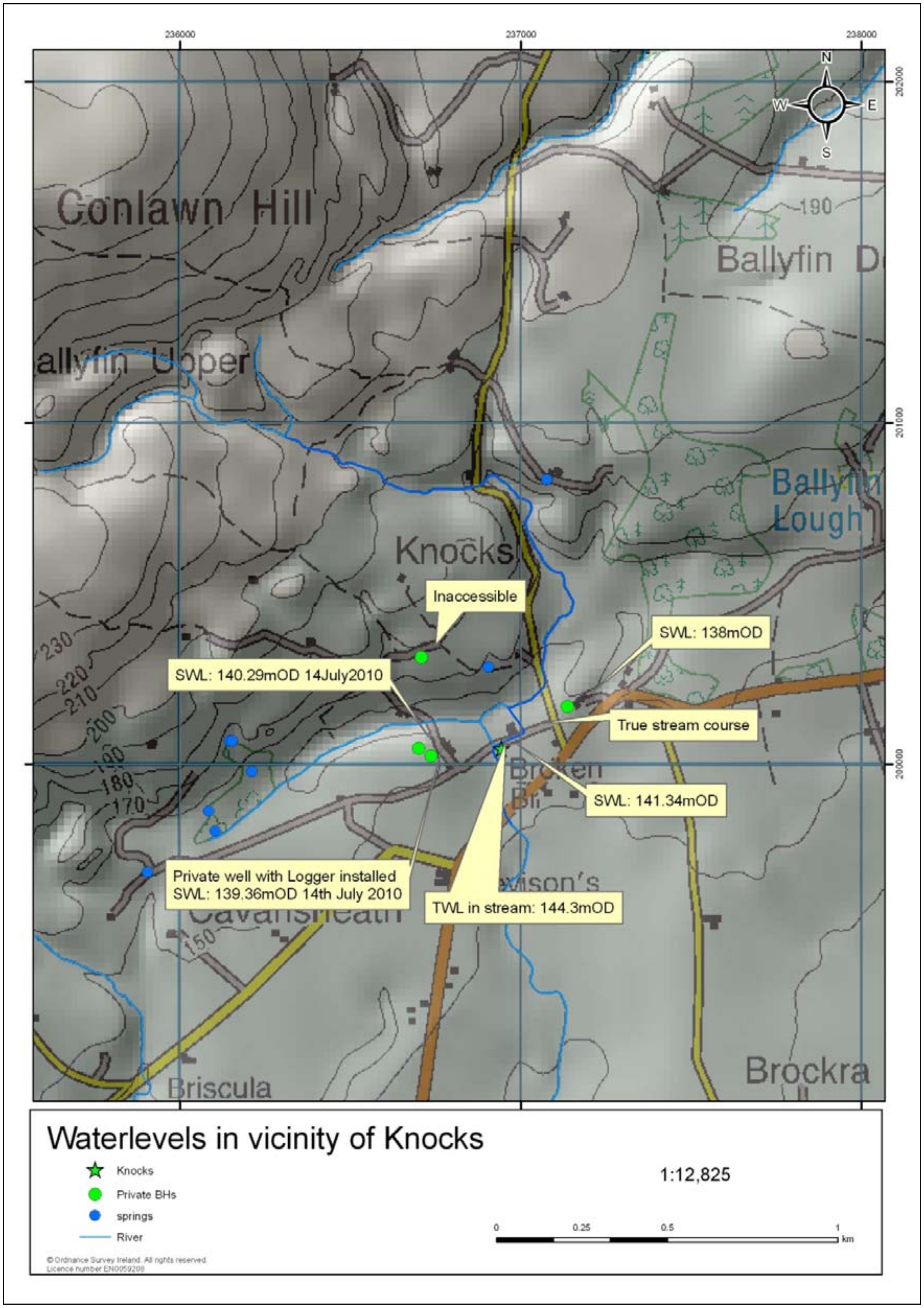


Figure 7 Water levels in boreholes in vicinity of Knocks

The private boreholes shown in Figure 7 are topographically higher than the source boreholes. Water levels in the private boreholes ranged from 11 m to 15 m below ground level (140 mOD); 1–2 m lower than the water level in the public supply boreholes. A data logger was placed into one of the private wells (See Figure 7 for location) to record the range of water level fluctuations in the borehole which are shown in Figure 8.

The data show that:

(1) the water level in the stream is 2–3 m above static water level in the vicinity of the source boreholes.

(2) the water levels in the private boreholes are slightly lower (1-2 m) than the static water level in the source boreholes and up to 7 m lower than the stream level. It is not clear what construction the private wells are – so the apparently slightly lower head may be due an upward gradient at the production borehole due to the scale of error.

(3) the water level fluctuations due to pumping in the private borehole are relatively small and that the static water fluctuations are relatively subdued; indicating that borehole is drawing from a relatively permeable aquifer – though it is not clear if it is the bedrock or sand and gravel.

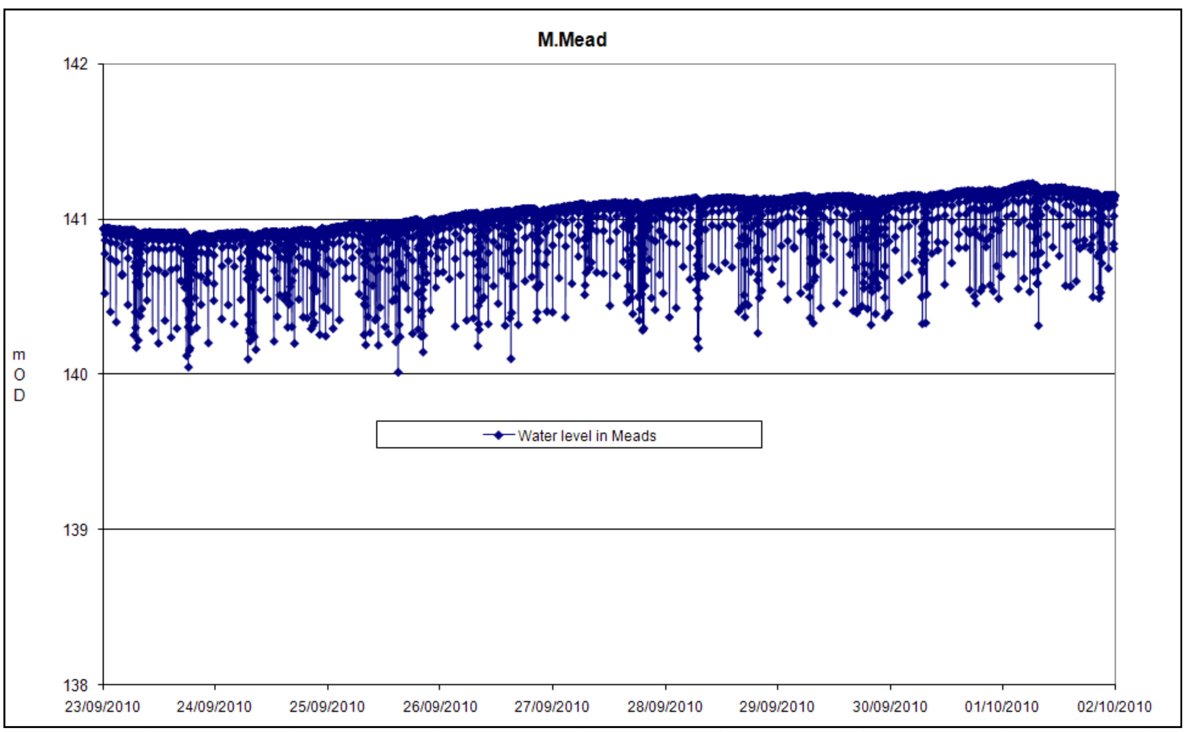


Figure 8 Water level fluctuations in private borehole near Knocks

It is reported that the stream goes dry, although it is not known if this is just across a specific section or if the entire stream goes dry. There is no alluvium in the vicinity of the borehole along the stream and the sediment is a coarse grained till with sand and gravel lenses. This evidence suggests that the stream probably contributes to the groundwater.

It is not known if the water levels in the private wells represent the water level in the bedrock and/or the sand and gravel aquifer. The electrical conductivity of the private wells is similar to that of the source borehole.

One borehole located 400 m directly uphill from the source borehole (shown in Figure 7) was capped. This may be accessible in the future as it is part of a house being built.

The topographic gradient north of the boreholes ranges from 0.078 to 0.09. The water levels in the private boreholes suggest a flattish gradient, but this is perhaps misleading as they are located off the main ridge close to the source. There are no data from north of the source to indicate the gradient. Due to the steep topography it is assumed to be approximately 0.02.

9.3 Hydrochemistry and water quality

There are hydrochemical analyses of 35 untreated samples from 1996 to 2009 (EPA data). The data up to mid-late 2003 must be from the original borehole which still serves as a supplementary borehole. Apart from temperature and ammonium, there appears to be no significant difference in the hydrochemistry post 2003. Using the entire EPA dataset, the water is moderately hard to very hard, with total hardness values of 176–494 mg/l (equivalent $CaCO_3$) and electrical conductivity (EC) values of 377–558 µS/cm, (average 416 µS/cm). The variability of the electrical conductivity suggests an input of less mineralised water. The groundwater has a calcium bicarbonate hydrochemical signature (EPA data), as shown in Figure 9. Alkalinity ranges from 131–250 mg/l $CaCO_3$, twice exceeding Total Hardness. The pH range is 6.6–8.2, with an average of 7.4, which is slightly alkaline. The temperature post 2003 ranges from 9–12^{o}C, with an average of 11^{o}C. In the data prior to 2003 the range is 7.6^{o}C to 14.2^{o}C, corresponding to the seasons. This may be due to the occasional pumping at that time or that as the borehole is closer to the stream that there is a greater influence from stream.

Samples regularly exceed acceptable levels for colour and turbidity and it is known that there is a high sediment load entering the borehole. This is exacerbated by any significant changes to the pumping regime. The sediment load has meant changes of the pump and of the flow meter have been necessary. Photograph 8 shows how much sediment is entrained in the water.

The mineralogy is not consistent in all the samples. Whilst the samples in the Durov plot are tagged with a similar signature, some samples are slightly different. There have been significant fluctuations in conductivity, total hardness, calcium, magnesium, potassium, sodium, strontium, all accompanied with persistently high Barium concentrations. From 22 samples, barium concentration ranges 138-877 µg/litre, with an average of 562 µg/litre. It may be related to undissolved sediment load or an influx of groundwater from another source, or possibly surface water. The main borehole intersects 10 m of bedrock thus there might be an upward component of groundwater affecting the chemical signature.

Figure 10 shows the data for the key indicators of contamination and the main points are as follows:

- Nitrate concentrations range from 8.7–20.4 mg/l with a mean of 12.5 mg/l. The mean is less than the groundwater Threshold Value (Groundwater regulations S.I. No. 9 of 2010) of 37.5 mg/l and less than standard (50 mg/l) set in the Drinking Water Regulations (S.I. No. 278 of 2007). There is a slight upward trend in the entire dataset, shown in Figure 7, but since 2009 there has been a reversal of that trend, which may be influenced be recent wet summers. There is no clear seasonal pattern present in the data.
- Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than 24 mg/l (Groundwater Threshold Value for Saline Intrusion Test, Groundwater Regulations S.I. No. 9 of 2010) may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from

8–20 mg/l with a mean of 12 mg/l, and there has been a slight decrease in recent data. Concentrations are slightly higher and more variable prior to 2003.

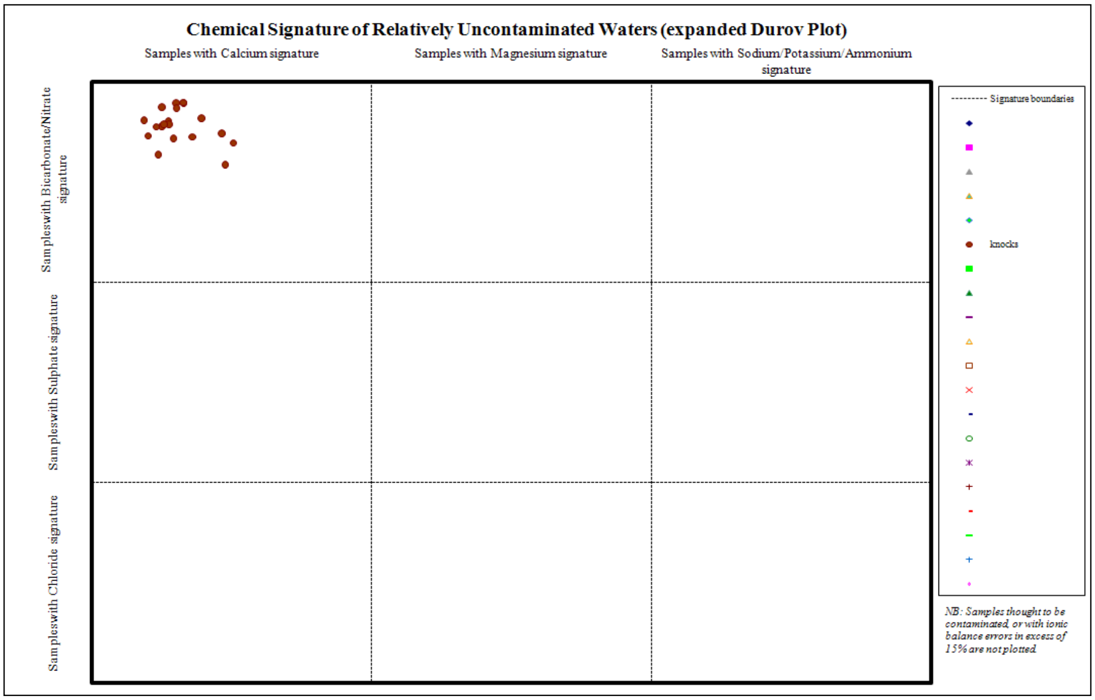


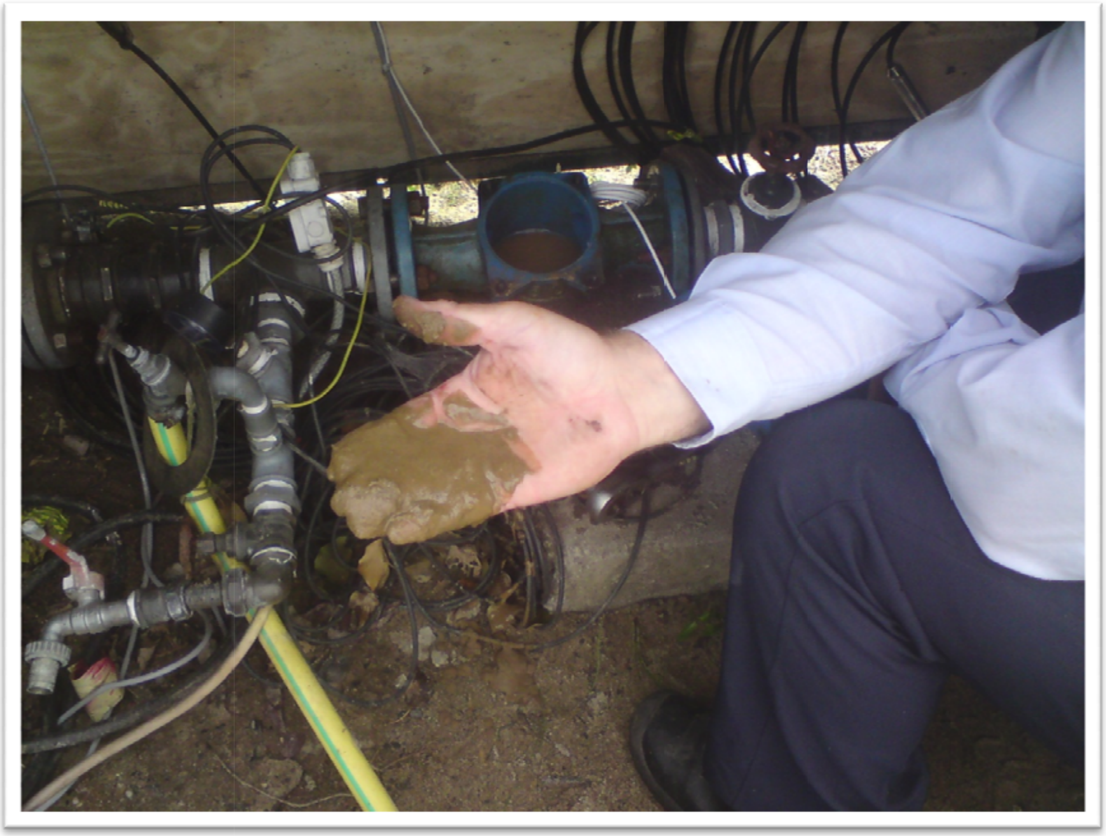
Figure 9 Durov Plot

- The average concentration of Molybdate Reactive Phosphorous (MRP) is 0.01 mg/L P, which is below the Groundwater Threshold Value (Groundwater Regulations S.I. No 9 of 2010) of 0.035 mg/L P; There was just one relatively high level of 0.051 mg/l P in August 2009. This may also support a surface water contribution to the groundwater in the vicinity of the production boreholes.

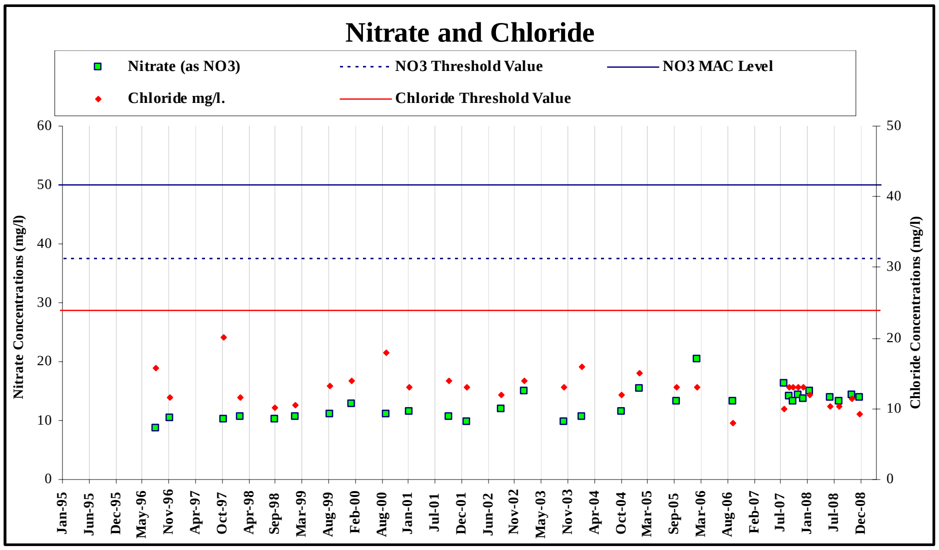
- The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated, along with other parameters, and may indicate contamination if the ratio is greater than 0.4. The ratio has exceeded 0.4 on five occasions due to elevated potassium (which is more prevalent prior to 2003). Sodium too is elevated on a number of occasions. The exceedances of K:Na are more frequent prior to 2003.

- Faecal coliform counts were exceeded once in December 2008 with a value of 4, which is relatively low – greater than 10 is considered gross contamination. Total coliform counts were exceeded on seven occasions and the counts are low.

In summary, the hydrochemistry is slightly anomalous due to the fluctuations in some parameters and barium concentrations are persistently elevated. The hydrochemistry suggests a surface water contribution and possibly a secondary groundwater contribution from the bedrock. The water quality is generally very good apart from turbidity, occasional but not gross bacterial contamination and occasionally elevated potassium:sodium ratio. The water quality is poorer prior to 2003; and it is considered that the original borehole being shallower obtains a higher contribution from the stream. Due to the heavy sediment load it may be that the undissolved constituent is particularly pronounced, possibly getting through the filtration process.



Photograph 8 Sediment taken out of the flow meter



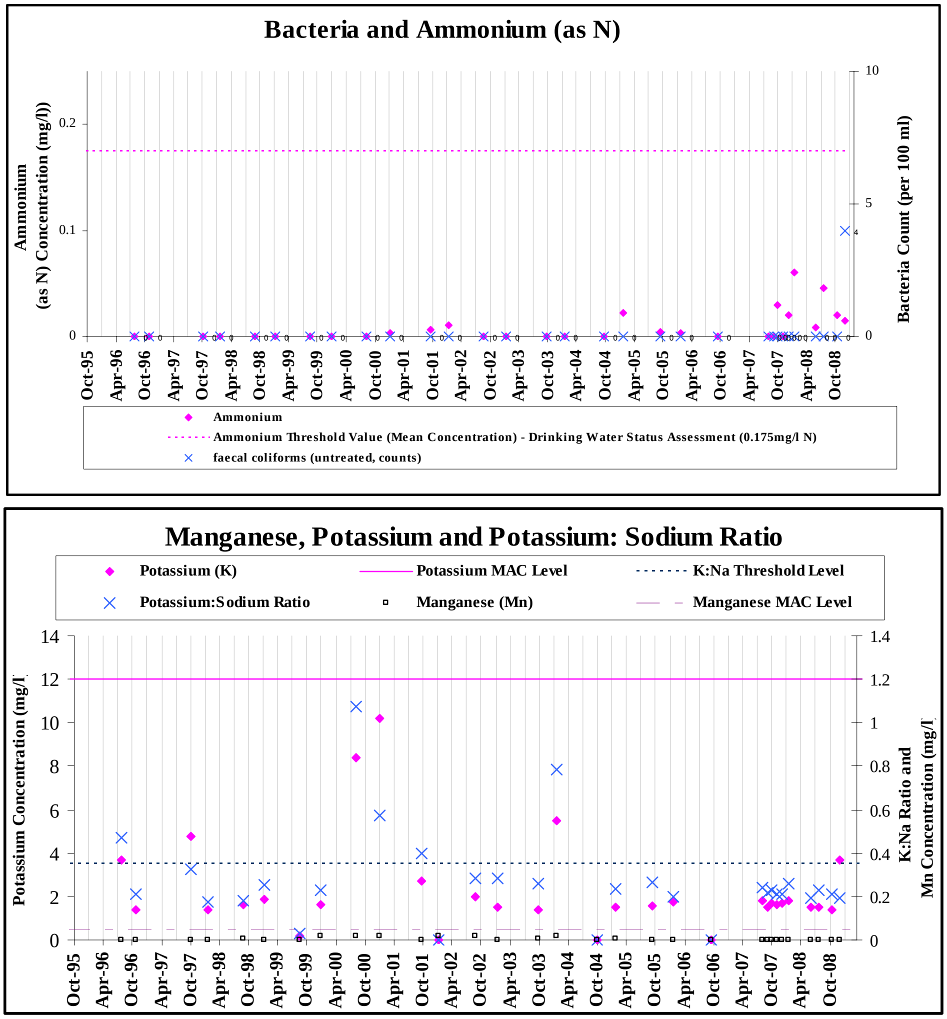


Figure 10 Key Indicators of Contamination at Knocks

9.4 Aquifer characteristics

Knocks borehole is an “Excellent” yielding borehole according to the GSI classification; greater than 500 m^3/day. Figure 11 is a “QSC” plot showing specific capacity (SC) against discharge (Q), which is a measure of ‘Productivity’, developed by GSI (Wright, 1997). It is a measure which takes account of drawdown – the greater the drawdown, the less productive the borehole is. The data for Knocks borehole plots in Class II, indicating a highly productive borehole.

Test pumping of the borehole was conducted in July 2010, at a rate of 612 m^3/d (425 l/min), with approximately 14 m of drawdown, giving a specific capacity of 40 m^3/d/m. The pumping test data are shown in Figure 12 and Figure 13 and given in Appendix 3.

The borehole is located principally in a sand and gravel deposit which is proposed as a Locally Important Sand and Gravel Aquifer (Lg), shown in Figure 14. The lowermost 10 m of the main production borehole comprises blank casing thought to be in the bedrock. There is likely to be a limited contribution from the outer hole up through the pea gravel around the outside of the inner blank casing.

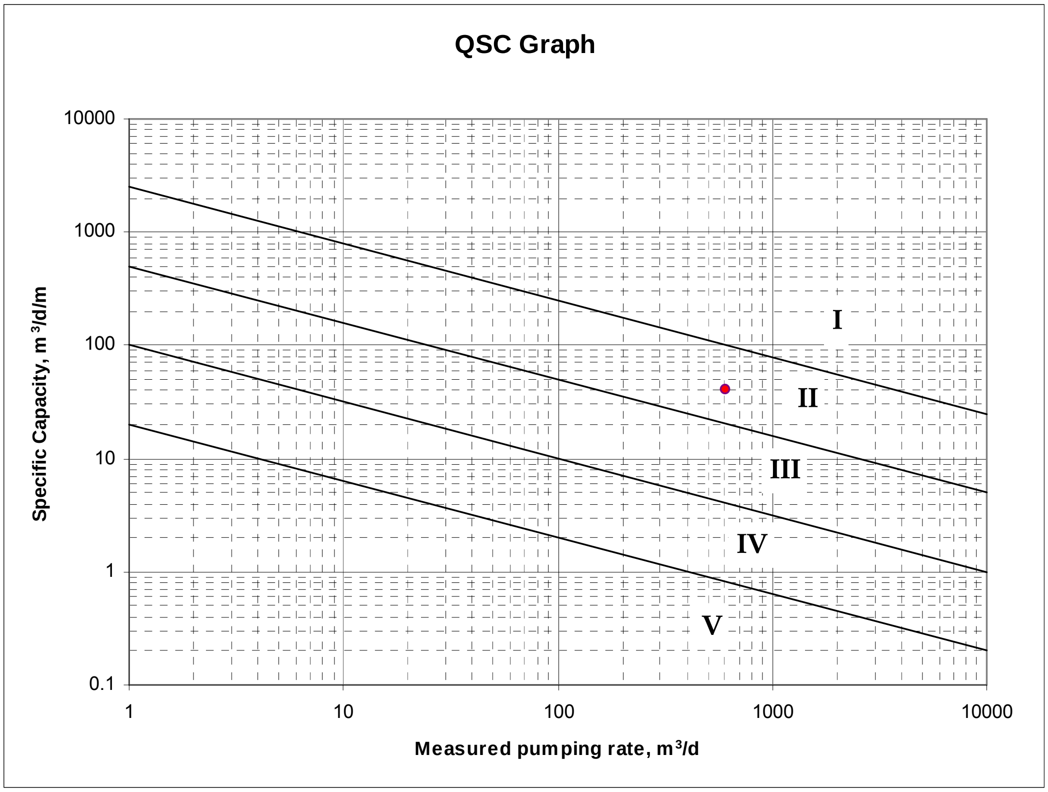


Figure 11 QSC Graph for Knocks

The apparent transmissivity (T) is estimated using the specific capacity data, the constant discharge-drawdown data for the production and observation boreholes, and the Aqtesolve software which allows for analysis using different solutions.

(1) Using the specific capacity data and the Logan approximation for unconfined aquifers (Misstear, 1998):

T = 2.43 Qb/(s(2b-s))

where b = aquifer thickness, taken to be approximately 35 m ((40 m depth to rock)– 4.5 m for static water level);

then T = 66 m^2/d

(2) Using the semi-log plot in Figure 10 and the Cooper-Jacob methodology (Misstear *et al*, 2006), then the apparent transmissivity ranges from 200 m^2/d (taking the flattest section of the curve) to 90 m^2/d for the mid part of the curve.

(3) Using the data for the observation well (original borehole which is 5 m west) the transmissivity is about 450 m^2/d.

(4) Analysis using Aqtesolve and the Theim equation resolved T to be in the order of 40 m^2/d.

The transmissivity values are taken to be in the order of 40–90 m^2/d and the value used for further analysis is 60 m^2/d.

The permeability (K, m/d) is estimated from the equation: T/b = 60/35 = 1.7 m/d.

This is a low value for a sand and gravel aquifer; normally higher permeability values in the order of 50 m/d would be expected. The transmissivity and permeability estimates indicate that the sediments comprising the sand and gravel aquifer are hydraulically restricted by either a relatively high clay percentage and / or that there are number of clay horizons / units present throughout the sequence. The persistent sediment load in the borehole suggests this to be the case. Further, water can be heard cascading into the borehole suggesting preferential flow zones. This is also evidenced by the log approximating the trial well drilled in advance of the current production borehole which indicates that there are thin clay horizons present.

The water level response in the observation borehole data, to pumping of the main borehole, appears to be relatively small, with a drawdown of just under one metre, even though it is only 6 m from the production well in 'sands and gravels'. It seems to support the view that there are clay layers present which would 'throttle' the response.

An estimate of the velocity (V, m/d) is based on the equation V =(K * gradient, i) / porosity, n

n is taken as 7%, a relatively low value based on GSI data for sands and gravels and also reflecting the higher clay content.

= (1.7 * 0.02) / (0.07) = 0.49 m/d.

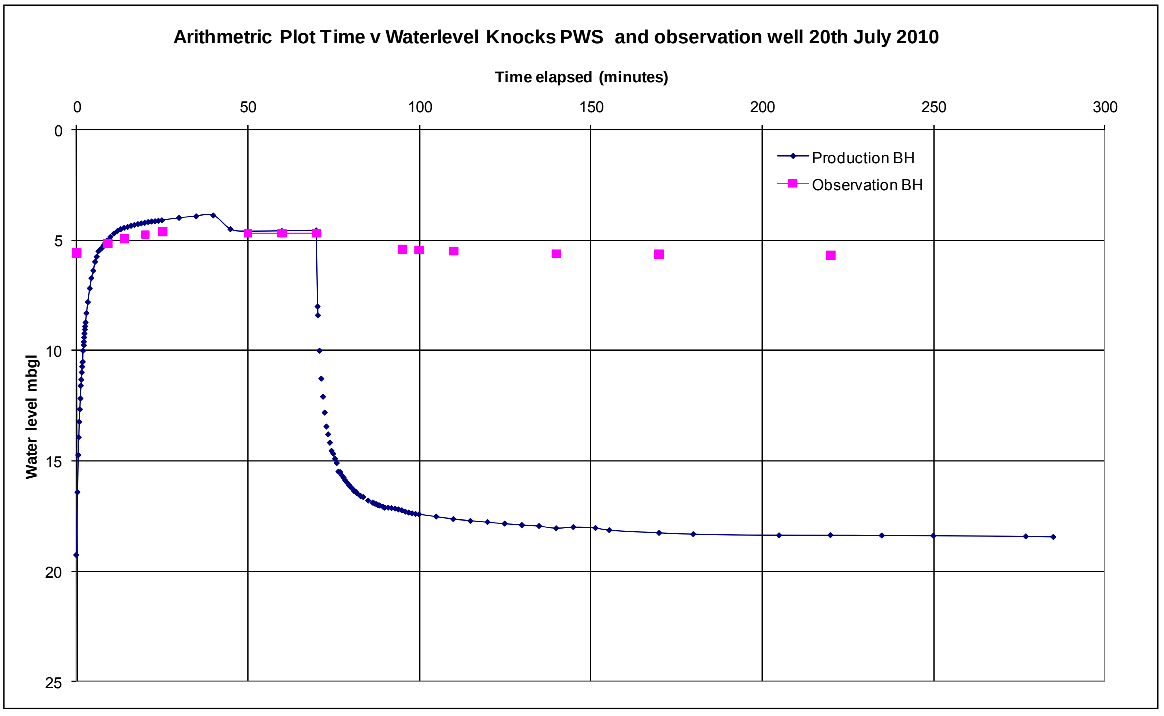


Figure 12 Water level response test pumping at Knocks

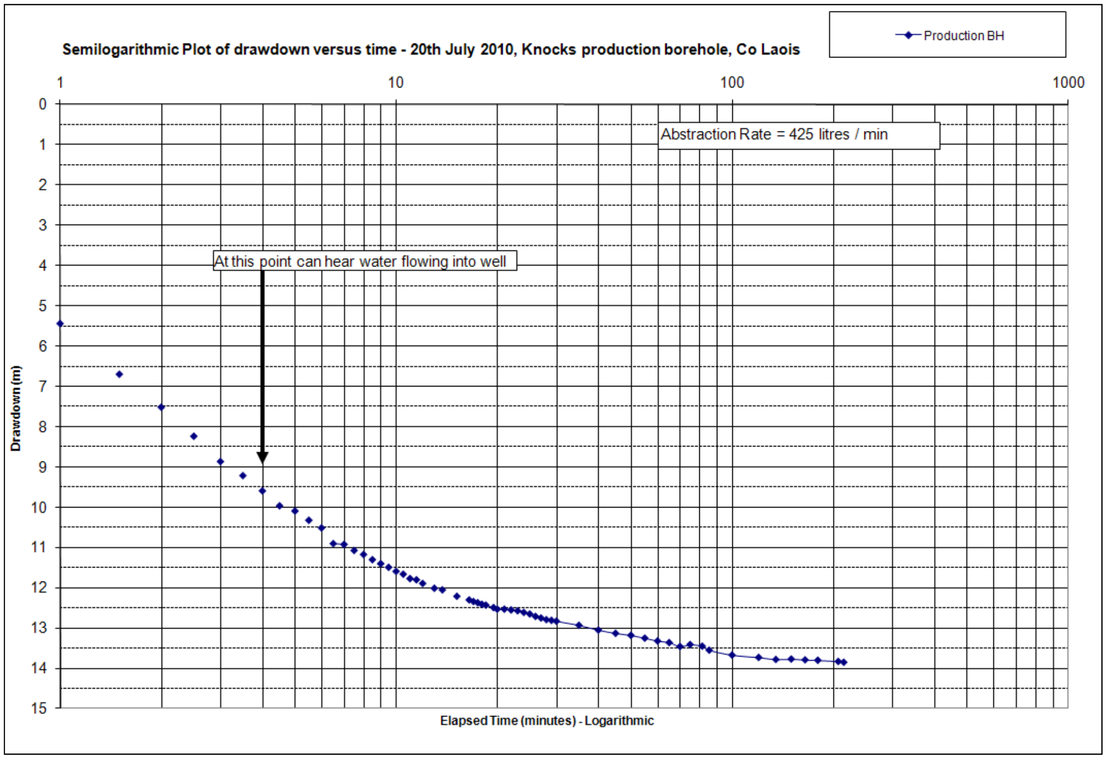


Figure 13 Semi-log plot of drawdown versus time for constant rate test at Knocks

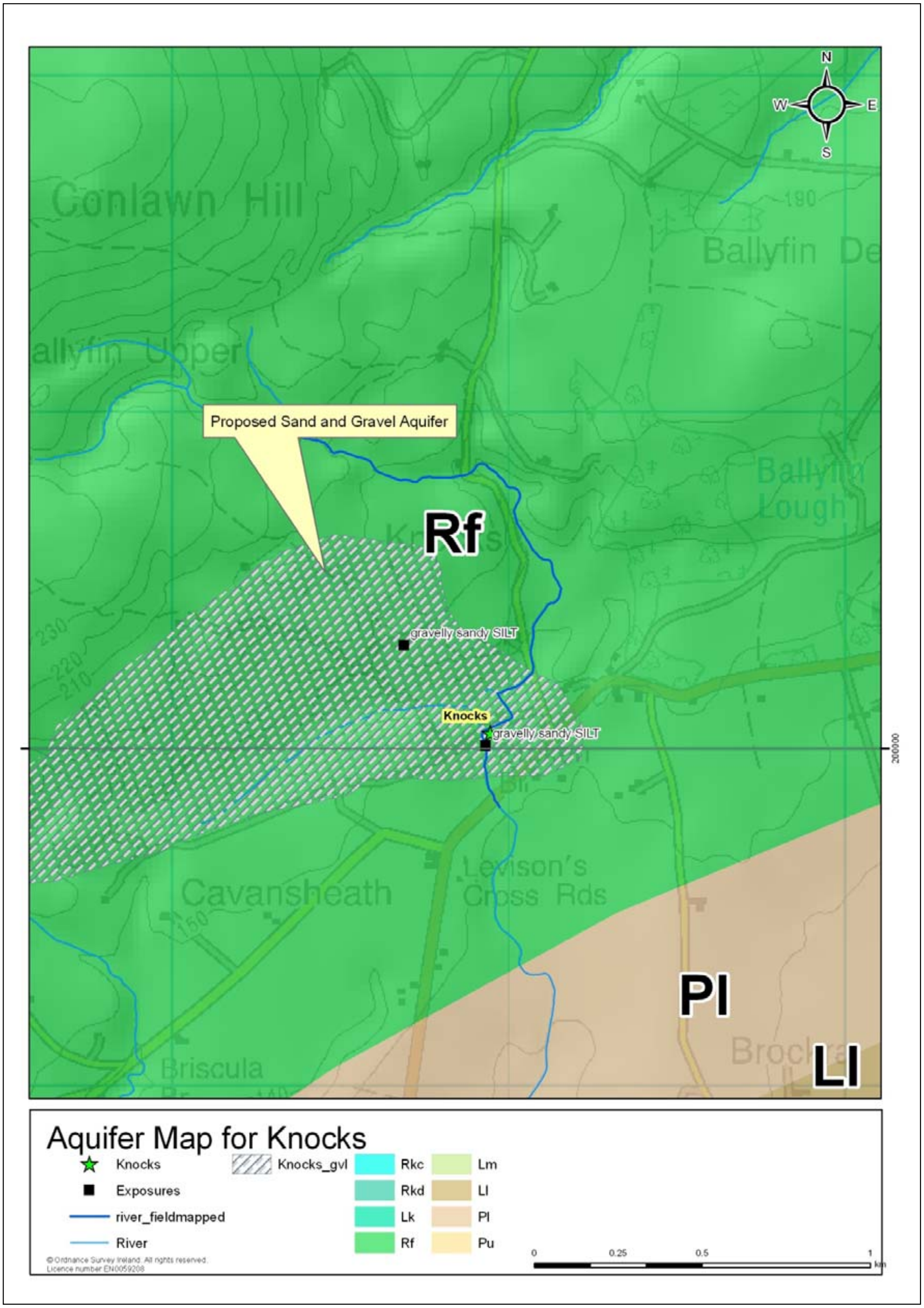


Figure 14 Knocks Aquifer Map

10 Zone of contribution

10.1 Conceptual model

The current understanding of the geological and hydrogeological setting is given as follows. The boreholes draw water from a sand and gravel deposit that is 'wedged' against the lower flanks of the Slieve Bloom mountains. The deposit is at least 30 m thick in the vicinity of the borehole and is capped by a thin and permeable glacial till. The sand and gravel deposit appears to include many thin clay horizons and may be an interbedded till and gravel sequence. Groundwater flow direction is predominantly N–S. The adjacent stream is considered to be partially losing in the vicinity of the borehole due to (1) it reportedly dries up in prolonged dry weather periods (although this may only be along a short losing section in the vicinity of the boreholes (2) the head in the stream is higher than the static water level in the boreholes (3) the stream bed comprises permeable sediments and there is no alluvium in the vicinity of the borehole (4) the groundwater signature of the boreholes points to mixing with less mineralized water.

The main production borehole may also be drawing water from the top of the bedrock, though this is expected to be limited due to the borehole construction. The bedrock aquifer and the sand and gravel aquifer are expected to be hydraulically connected though the clay content may be limiting the vertical hydraulic conductivity.

A schematic cross-section illustrating the conceptual model is shown in Figure 15 and Appendix 1 illustrates a schematic across the production borehole, supplementary borehole and stream.

10.2 Boundaries

The boundaries of the area contributing to the source are considered to be as follows (Figure 16):

The **Northern Boundary** is based on a combination of hydrogeological mapping and topography. The stream that flows past the borehole is believed to contribute to the groundwater in the vicinity of the source. It has a lower mineral concentration than the water in the borehole and flows along the bedrock between Ballyfin Upper and along the road before swinging west. Therefore it is assumed that the stream is fed by bedrock along the upper reaches. It is assumed that the northern boundary is a surface water and a groundwater divide. The northern ZOC boundary is extended beyond the northern limit of the proposed sand and gravel body as it is assumed that groundwater in the bedrock will discharge into the sand and gravel. It is reported that the stream dries up – but it is not known if there is a specific losing section along the stream floor adjacent to the source, or if it dries up entirely upgradient of the source.

The **Western and Northwestern Boundaries** are based on topography alone. It is considered that the groundwater flow direction is Northwest–Southeast, mirroring topography. There is uncertainty with the exact location of the apex of where the two boundaries meet and along the western boundary. The water levels in the private wells do not appear to be impacted upon by the production borehole.

The **Eastern boundary** is an extension of the northern boundary, meeting the southern boundary in the area where the access road meets the north-south road. The abstraction doesn't affect a private well located on the east of the road.

The **Southern Boundary** is estimated to be approximately 120 m based principally on the uniform flow equation (Todd, 1980) which is:

$$x_L = Q / (2\pi * T * i)$$

where
Q is the daily pumping rate (at 150% current rate: 900 m^3/d)
T is Transmissivity (taken from aquifer characteristics 60 m^2/d)
i is the background non-pumping gradient (0.02).

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 is assumed to consist of the rainfall input (i.e. annual rainfall) minus water loss prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as this dictates the size of the zone of contribution to the source (i.e. the outer Source Protection Area).

At Knocks, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient. The recharge coefficient is estimated using Guidance Document GW5 (Groundwater Working Group 2005), which is given in Appendix 4.

The recharge over the extreme and high vulnerability areas, comprising gravels and moderately permeable till and rock close to or at the surface, is mainly diffuse, and is in the order of 85%.

The recharge calculations are summarised as follows:

Average annual rainfall (R)	1200 mm
Estimated P.E.	450 mm
Estimated A.E. (95% of P.E.)	428 mm
Effective rainfall	772 mm
Recharge coefficient	85%
Recharge	656 mm

Water balance: The area described above and shown in Figure 15 is 0.71 km^2, and is more than sufficient for 150% of the current abstraction rate. The required size for 150% of the current abstraction rate (approximately 900-1000 m^3/day) is in the order of 0.5-0.6 km^2, which is smaller but cannot be isolated from the area delineated because of the hydrogeology.

11 Delineation of source protection zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an amalgamation of 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, shown in Figure 17.

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). This is based on the velocity estimate of 0.5 m/d given in the Aquifer Characteristics. Therefore the 100 day Time of Travel is estimated to be 50 m. Note it appears as a circle due to shallow gradients – it is not an arbitrary circle.

The **Outer Protection Area (SO)** encompasses the entire zone of contribution to the source, described in the previous section. It is based on hydrogeological mapping and is larger than the area required to supply 150% of the yield.

The Source Protection Zones are shown in Figure 18 and are listed in Table 11–1.

Table 11-1 Source Protection Zones

Source Protection Zone		% of total area (0.71km^2)
SI/H	Inner Source Protection area / High vulnerability	1% (0.0078km^2)
SO/X	Outer Source Protection area / ≤1 m subsoil	0.038% (0.0003km^2)
SO/E	Outer Source Protection area / <3 m subsoil	1.2% (0.009 km^2)
SO/H	Outer Source Protection area / High vulnerability	97.5% (0.69km^2)

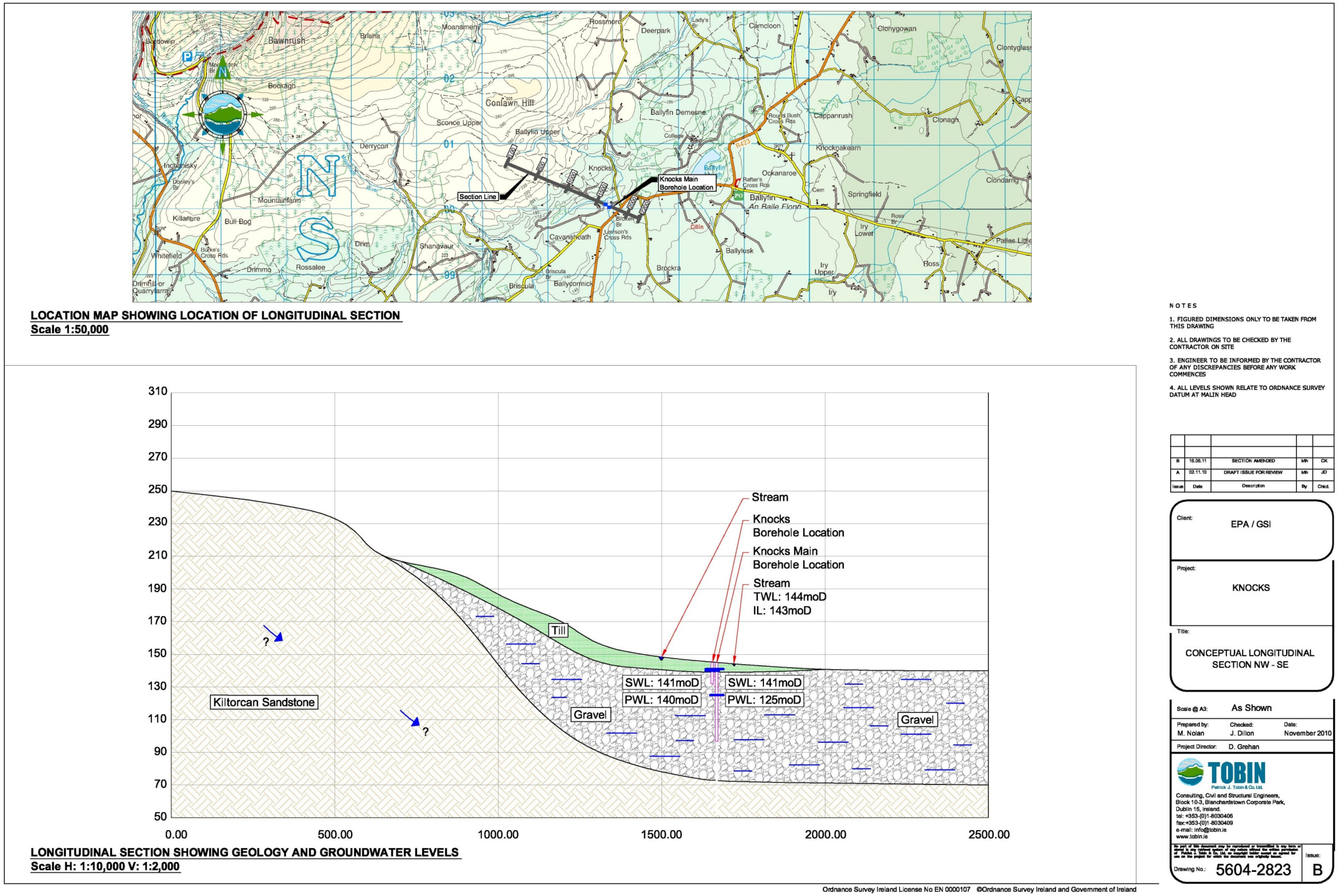


Figure 15 Cross Section

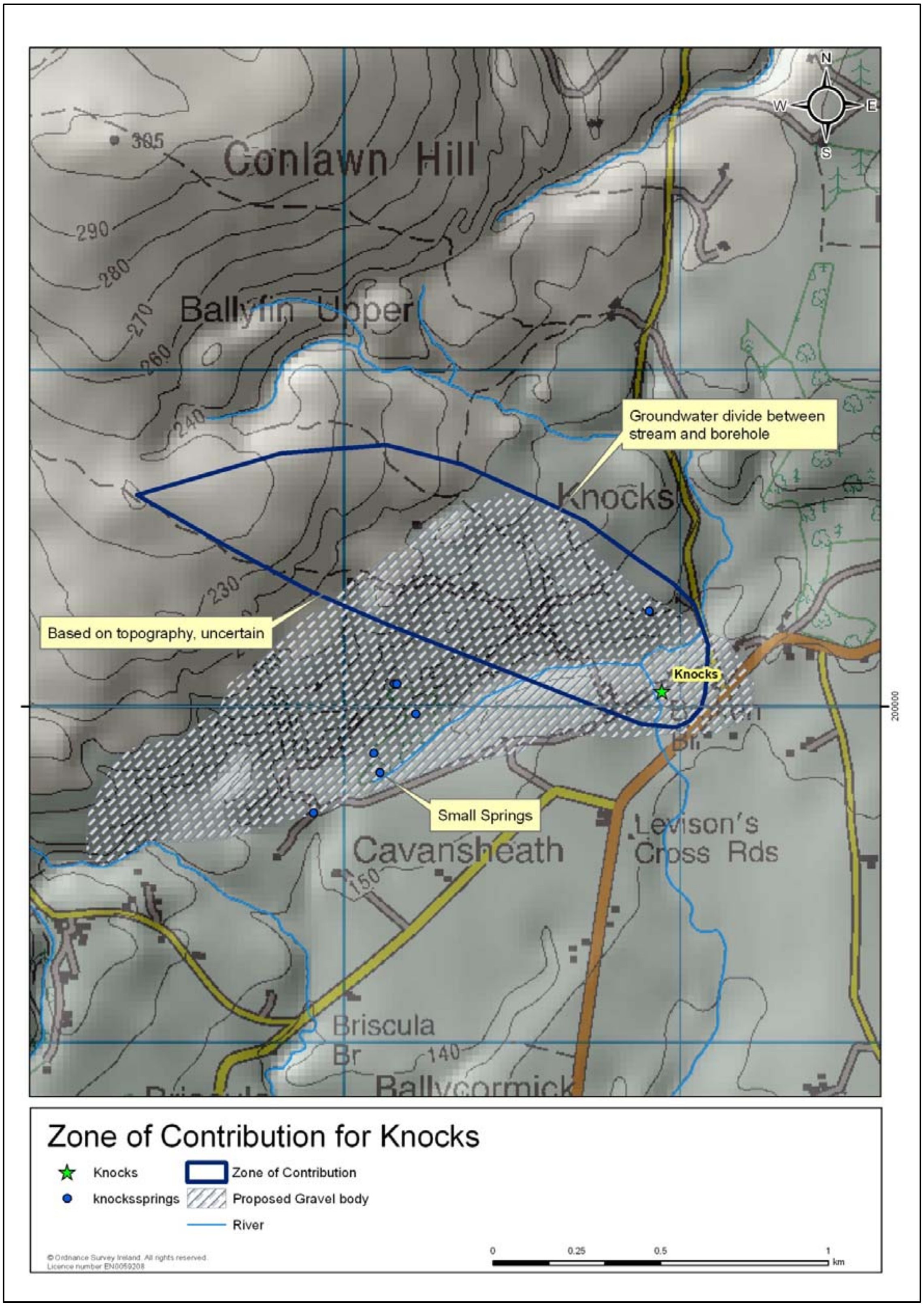


Figure 16 Zone of Contribution to Knocks

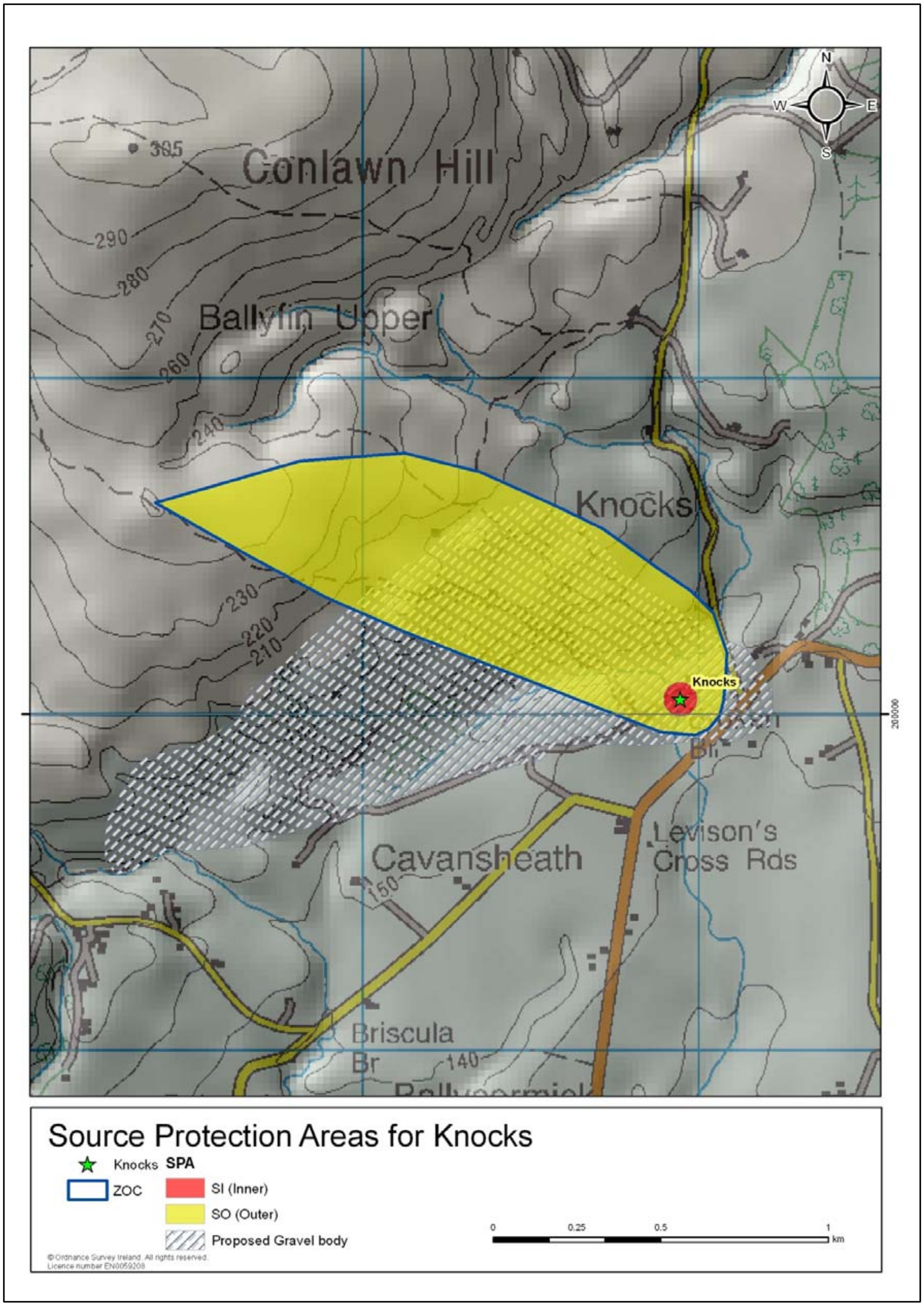


Figure 17 Source Protection Areas to Knocks

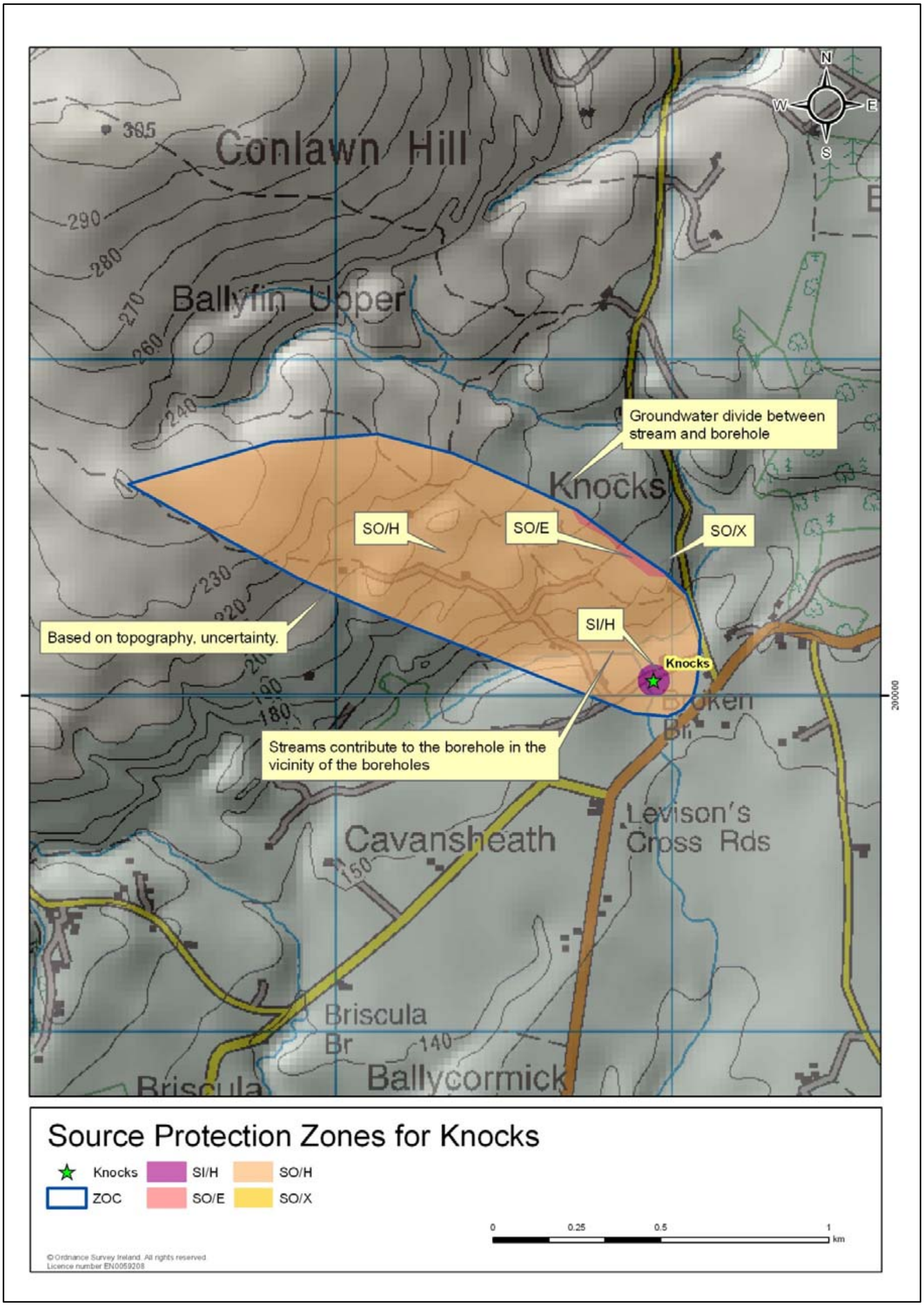


Figure 18 Source Protection Zones to Knocks (SO/X area occupies very small area)

12 Potential pollution sources

The main borehole shown in Photograph 2 is finished above ground level and is cement grouted but is not capped. The housing is secured though vermin could probably get in at the back where there is a small gap. The original / supplementary borehole shown in Photograph 3 is not capped, has no outer casing and it is not grouted. The boreholes have never been flooded by the stream however, there is a risk of contamination down the boreholes, particularly the supplementary borehole. This is possibly reflected in the water quality – only one incident of faecal coliforms with a low count.

The Inner Protection Area (SI) encompasses a 50 m buffer around the boreholes, all of which is '**highly**' vulnerable to contamination. Land use in this area is mainly set to grazing cattle.

Across the rest of the Outer Protection Area (SO), the groundwater vulnerability is '***extreme'*** (both '**E'** and '**X'**) or '**high'**. There are number of houses and farms and farm yards upgradient of the boreholes which pose a risk to the source.

There is potential for contamination to occur from the stream as it is considered to be contributing to the aquifer in the vicinity of the source, thus a 10 m buffer extends along the stream network. The risk is relatively low because pressures are low, there is likely to be dilution and the contributing component has to infiltrate through sands and gravels before getting into the borehole.

Finally, there is only a small length of road present in the ZOC and the traffic density is low, so the risk of contamination is low from this source.

13 Conclusions

The Knocks Water Supply Scheme comprises two adjacent boreholes drawing water mainly from sands and gravels. There is a significant sediment load getting into the boreholes which is affecting the pumps and flow meters, and the operation of the distribution. Any small change to the system can cause an influx of greater amounts of sediment.

The hydrochemistry is slightly anomalous due to the fluctuations in some parameters and persistently elevated barium concentrations. The water quality is generally very good apart from turbidity, occasional but not gross bacterial contamination, and the frequently elevated potassium:sodium ratio. Due to the heavy sediment load, it may be that the undissolved constituent is particularly pronounced, possibly getting through the filtration process.

The groundwater vulnerability is mainly '***high***'. Land use pressures are relatively low.

The ZOC encompasses an area of 0.7 km^2. 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

Further investigations might usefully include.

- Obtain a water level of the private borehole north of the source once it goes into use.
- Complete grouting on the supplementary well and cap both wells.

- Conduct a down hole camera survey to investigate the borehole construction, in particular the location, sizing and orientation of slots.
- Investigate methods of reducing velocities around the pump to reduce sediment intake.
- Investigate further the contribution of the surface water stream to groundwater

15 References

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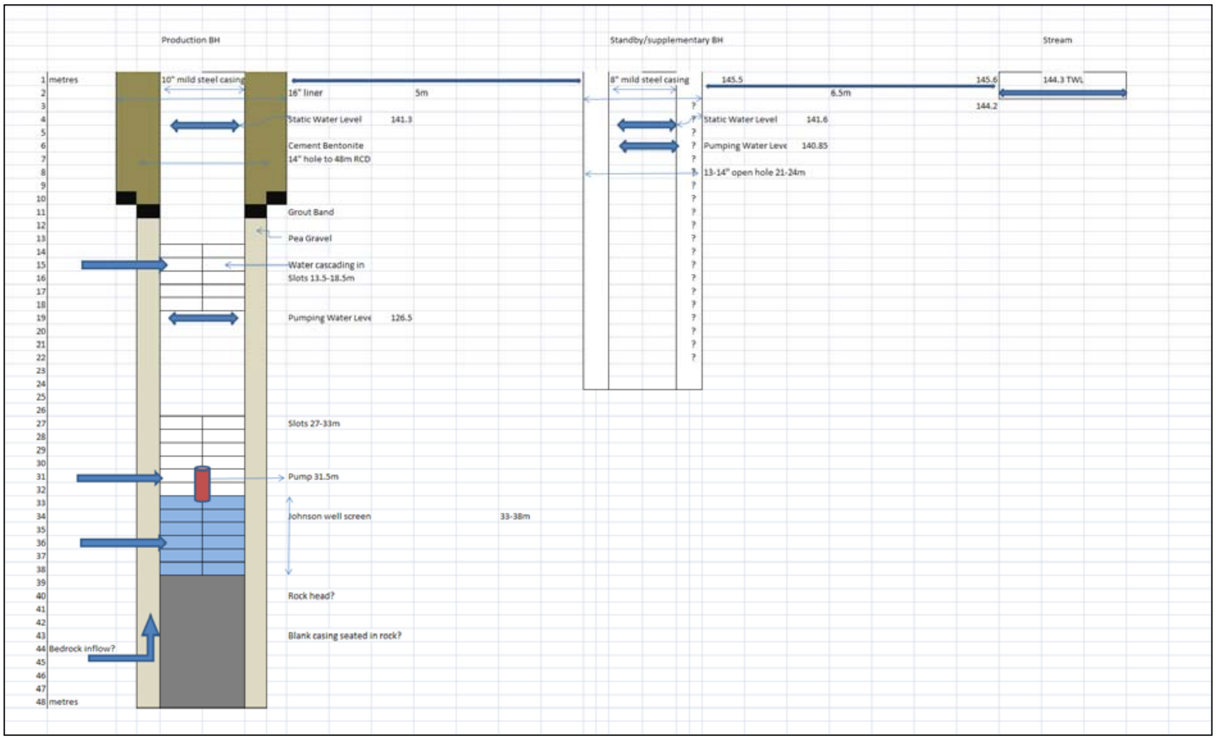
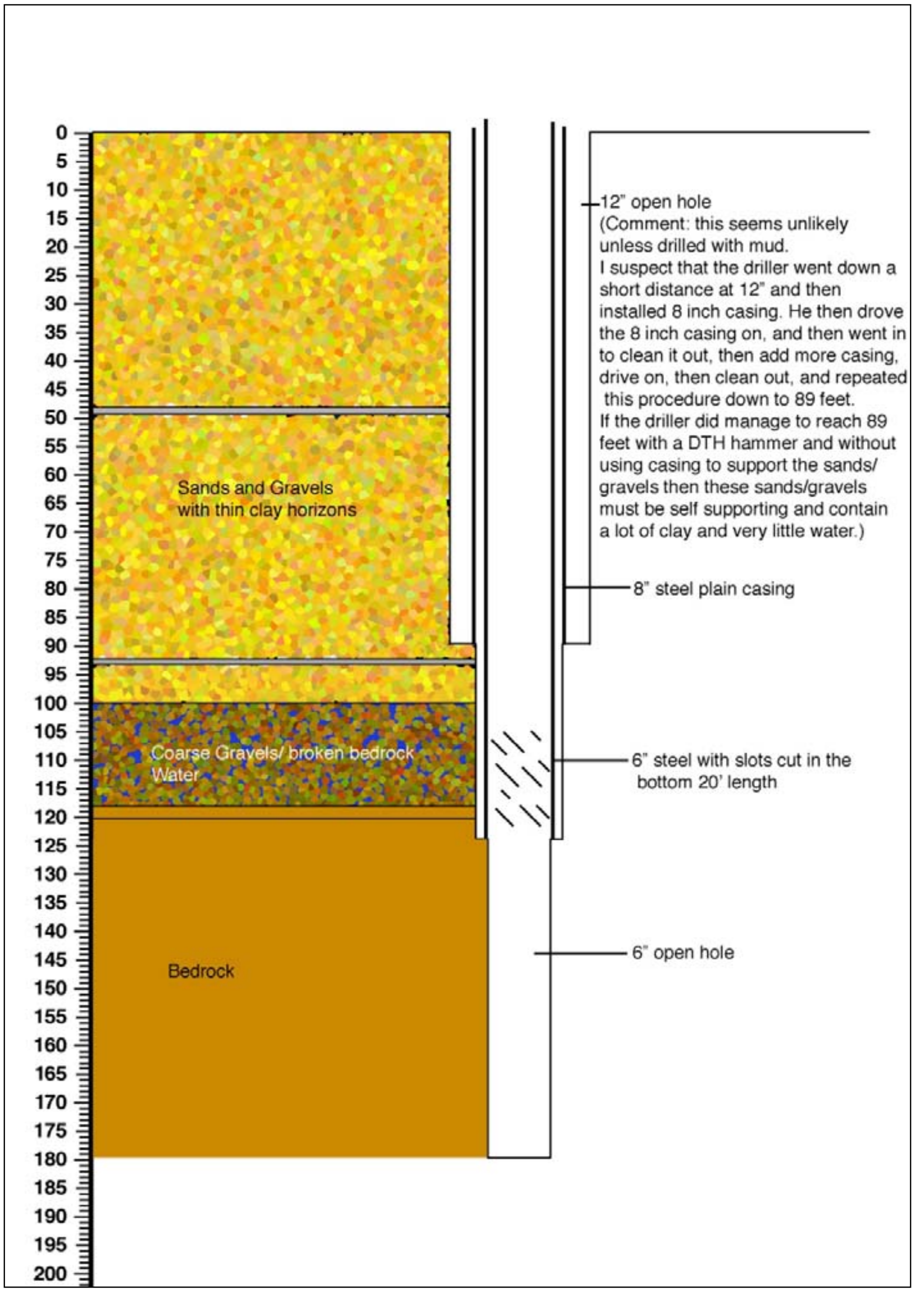
APPENDIX 1 Sketch of boreholes and stream



APPENDIX 2 Log of trial well

Trial Well log drawn by David Ball based on his understanding of what was encountered when trial well was drilled.



APPENDIX 3 Test data

Date	Comments	Elapsed time	water level in PW	mins	water level in ob bh
20-Jul-10			**19.24**	0.00	**5.59**

			16.40	0.36	
			14.72	0.63	
			13.91	0.75	
			13.22	0.90	
			12.65	1.08	
			12.16	1.25	
			11.58	1.33	
			11.31	1.50	
			10.98	1.63	
			10.72	1.75	
			10.52	1.83	
			10.50	1.90	
			10.00	2.00	
			9.75	2.22	
			9.60	2.26	
			9.40	2.33	
			9.22	2.41	
			9.04	2.55	
			8.90	2.63	
			8.72	2.75	
			8.30	3.00	
			7.80	3.40	
			7.18	3.96	
			6.72	4.42	
			6.38	5.00	
			5.98	5.50	
			5.75	6.00	
			5.50	6.50	
			5.42	7.00	
			5.35	7.50	
			5.24	8.00	
			5.12	8.50	
			5.01	9.00	**5.17**
			4.85	10.00	
			4.70	11.00	
			4.59	12.00	
			4.50	13.00	
			4.44	14.00	**4.95**
			4.40	15.00	
			4.35	16.00	
			4.31	17.00	
			4.27	18.00	
			4.24	19.00	
			4.21	20.00	**4.76**
			4.18	21.00	
			4.16	22.00	

			4.14	23.00	
			4.12	24.00	
			4.10	25.00	**4.62**
			3.99	30.00	
			3.92	35.00	
			3.88	40.00	
			4.50	45.00	
			4.60	50.00	**4.70**
			4.58	60.00	**4.70**
			4.56	70.00	**4.70**
20-Jul-10	**11:37:00**	00.00.00	4.56	70.00	
		00.00.25	8.00		
		00.00.31	8.40	0.51	
		00.00.37	8.87		
		00.00.46	9.31		
		00.00.49	9.49		
		00.00.51	9.60		
		00.00.58	9.83		
		00.01.00	10.00	1.00	
		00.01.03	10.12		
		00.01.08	10.43		
		00.01.13	10.62		
		00.01.19	10.87		
		00.01.24	11.00		
		00.01.28	11.15		
		00.01.30	11.26	1.50	
		00.01.34	11.37		
		00.01.37	11.50		
		00.01.41	11.58		
		00.01.46	11.73		
		00.01.49	11.83		
		00.01.54	11.98		
		00.01.59	12.08	2.00	
		00.02.02	12.17		
		00.02.05	12.23		
		00.02.09	12.30		
		00.02.13	12.41		
		00.02.18	12.53		
		00.02.23	12.65		
		00.02.26	12.72		
		00.02.30	12.80	2.50	
		00.02.32	12.84		
		00.02.36	12.95		
		00.02.40	13.00		
		00.02.57	13.33		
		00.03.01	13.43	3.00	
		00.03.07	13.47		
		00.03.11	13.49		
		00.03.15	13.56		
		00.03.18	13.63		
		00.03.22	13.65		

		00.03.26	13.70		
		00.03.28	13.72		
		00.03.30	13.78	3.50	
		00.03.35	13.83		
		00.03.40	13.89		
		00.03.44	13.92		
		00.03.46	13.96		
		00.03.51	14.03		
		00.03.58	14.07		
	Hear Water inflow	00.04.03	14.16	4.00	
		00.04.07	14.23		
		00.04.20	14.30		
		00.04.27	14.53	4.50	
		00.04.41	14.48		
		00.04.47	14.56		
		00.04.58	14.66	5.00	
		00.05.06	14.68		
		00.05.15	14.76		
		00.05.22	14.85		
		00.05.30	14.89	5.50	
		00.05.34	14.93		
		00.05.44	15.00		
		00.05.50	15.04		
		00.05.56	15.08	6.00	
		00.06.03	15.13		
		00.06.08	15.17		
		00.06.13	15.19		
		00.06.22	15.26		
		00.06.25	15.29		
		00.06.39	15.40		
		00.06.54	15.47	6.50	
		00.07.05	15.49	7.00	
		00.07.12	15.52		
		00.07.24	15.59		
		00.07.36	15.64	7.50	
		00.07.52	15.70		
		00.07.59	15.74	8.00	
		00.08.14	15.80		
	9 m^3 pumped	00.08.28	15.87	8.50	
		00.08.38	15.90		
		00.08.57	15.97	9.00	
		00.09.09	16.00		
		00.09.25	16.06	9.50	
		00.09.35	16.09		
		00.09.45	16.13		
		00.09.54	16.16	10.00	
		00.10.11	16.19		
		00.10.26	16.23	10.50	
		00.10.39	16.26		
		00.10.52	16.30		

		00.11.11	16.34	11.00	
			16.37	11.50	
			16.40		
			16.44		
			16.46	12.00	
			16.55		
			16.58	13.00	
	11 m^3 pumped		16.59		
			16.62	13.73	
			16.68		
			16.72		
			16.78	15.17	
			16.82		
			16.87	16.50	
			16.91	17.00	
			16.94	17.50	
			16.98	18.00	
			17.00	18.50	
	one reading missed		17.06	19.50	
			17.10	20.00	
			17.10	21.00	
			17.12	22.00	
			17.14	23.00	
			17.18	24.00	
			17.22	25.00	5.41
			17.28	26.00	
			17.32	27.00	
			17.36	28.00	
			17.38	29.00	
			17.40	30.00	5.45
			17.50	35.00	
			17.62	40.00	5.5
			17.70	45.00	
			17.75	50.00	
			17.82	55.00	
			17.89	60.00	
			17.93	65.00	
			18.03	70.00	5.61
			17.98	75.00	
	40 m^3 pumped		18.02	81.50	
			18.12	85.50	
			18.24	100.00	5.65
			18.30	120.00	
	63 m^3 pumped		18.35	135.00	
			18.34	150.00	5.68
			18.36	165.00	
			18.37	180.00	
			18.40	207.00	

			18.42	215.00	
	116 m^3 pumped		18.44	220.00	

APPENDIX 4 Recharge coefficient table

Table 1: Recharge coefficients for different hydrogeological settings.

'ulnerability category		Hydrogeological setting	Recharge coefficient (rc)		
			Min (%)	Inner Range	Max (%)*
Extreme	1.i	Areas where rock is at ground surface	60	80-90	100
	1.ii	Sand/gravel overlain by 'well drained' soil	60	80-90	100
		Sand/gravel overlain by 'poorly drained' (gley) soil			
	1.iii	Till overlain by 'well drained' soil	45	50-70	80
	1.iv	Till overlain by 'poorly drained' (gley) soil	15	25-40	50
	1.v	Sand/ gravel aquifer where the water table is = 3 m below surface	70	80-90	100
	1.vi	Peat	15	25-40	50
High	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	60	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by 'well drained' soil	60	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil			
	2.iv	Moderate permeability subsoil overlain by 'well drained' soil	35	50-70	80
	2.v	Moderate permeability subsoil overlain by 'poorly drained' (gley) soil	15	25-40	50
	2.vi	Low permeability subsoil	10	23-30	40
	2.vii	Peat	0	5-15	20
Moderate	3.i	Moderate permeability subsoil and overlain by 'well drained'soil	25	30-40	60
	3.ii	Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil	10	20-40	50
	3.iii	Low permeability subsoil	5	10-20	30
	3. iv	Basin peat	0	3-5	10
Low	4.i	Low permeability subsoil	2	5-15	20
	4.ii	Basin peat	0	3-5	10
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

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