Establishment of Groundwater Source Protection Zones

Rockhill Public Water Supply

Rockhill Borehole

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1 Introduction

Groundwater Source Protection Zones (SPZs) are delineated for the Rockhill Public Water Supply (PWS) (Local Authority code: 1900PUB0056) 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 and in EPA Advice Note No. 7 (EPA, 2011).

Rockhill PWS is the main source for the rural area west of Bruree, Co Limerick, and comprises a borehole supply and treatment works.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Rockhill area, where the source is located.
- To delineate source protection zones for the Rockhill PWS.
- To assist the 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 consisted of data collection, desk studies, site visits, test pumping, and field mapping. Analysis of the information collected during the studies was used to delineate the SPZ.

The initial site visit and interview with the caretaker and Limerick County Council engineers took place on 12/04/2013. Site walk-overs, groundwater monitoring and field mapping of the study area (including measuring the electrical conductivity and temperature of streams in the area) were conducted on 30/04/2013, 02/05/2013 and 26/07/2012. Test pumping was carried out on 30/04/2013 (2 hour test) and 26/06/2013 to the 27/06/2013 (24 hour test).

The maps produced are based largely on the readily available information in the area, specific field work for this source protection mapping project, as well as 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. More details on protection zones are presented in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

3 Location, site description and well head protection

The source is located within a secure water treatment works at Ballyfookeen townland 2.2 km west of Bruree Village, shown in **Figure 1**. According to the council, the source has been in use since the 1960s, and was developed in1980 as the Rockhill Group Water Scheme (GWS), and was subsequently taken in hand by Limerick County Council in 2002. The original source comprised a shallow dug well, constructed using 2 foot diameter concrete rings to 3 m below ground level (bgl). A trial well was completed in 1991 by Linehan well drilling, and in 1992 a production well (PW1) was drilled by Dunnes Well drilling, Mallow. A submersible pump delivers the groundwater to the pump house where the untreated water is chlorinated and pumped to the Rockhill reservoir, 1 km to the south. From here the water supplies the rural areas to the west of Bruree. The source and water treatment works are protected by fencing accessed by a padlocked gate. Though the boreholes are covered (relatively recent), the annulus around the boreholes is not grouted in.

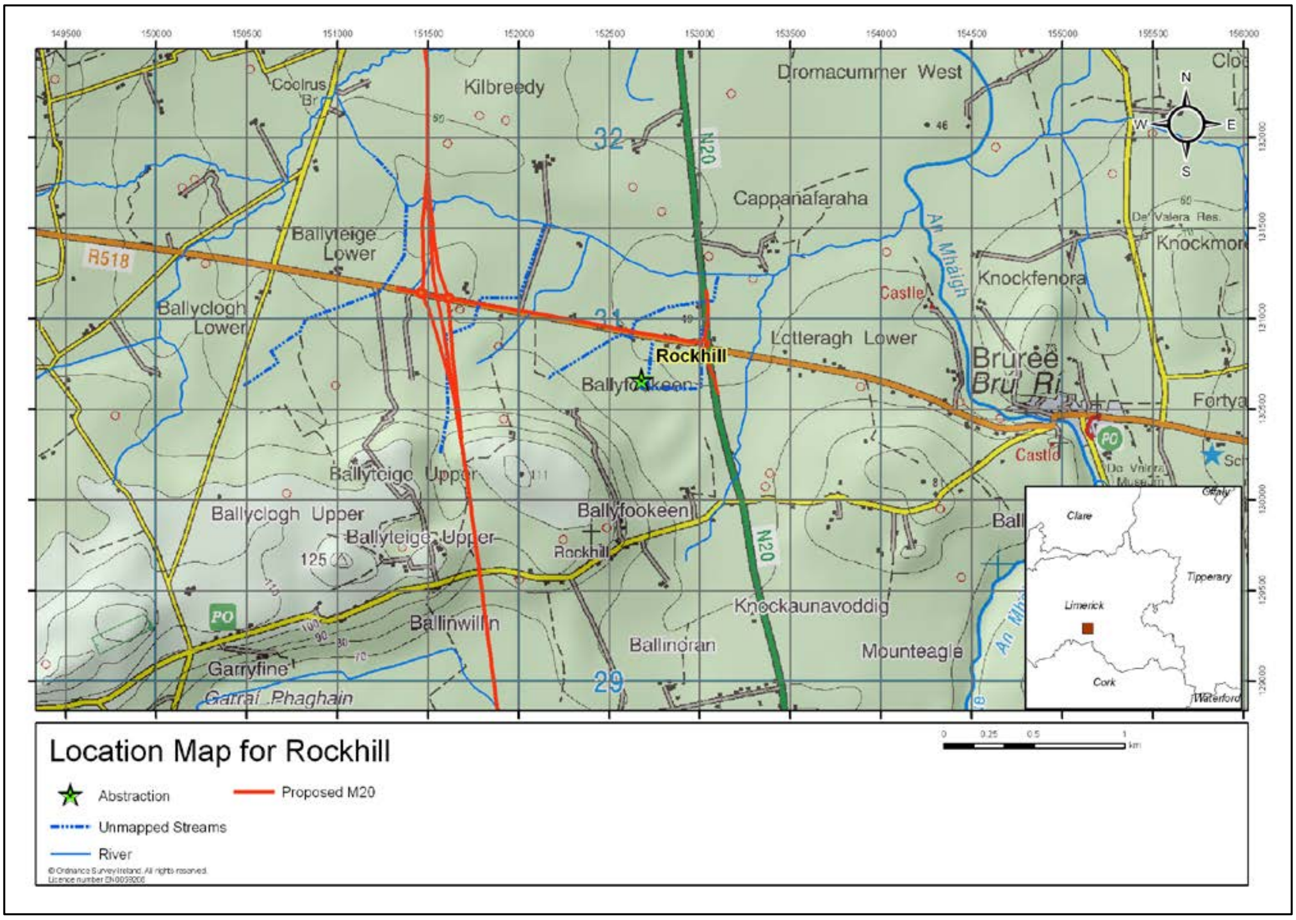

Figure 1 Location Map for Rockhill PWS

4 Summary of borehole details

There are no geological or borehole construction logs available and the details are based mainly on discussion with the well drillers. The trial well (TW1) was reportedly completed using 8” steel casing into bedrock (approximately 5 m) and left ‘open hole’ to 52 m bgl. The production borehole (PW1) was drilled approximately 15 m east of TW1, with a 12” steel outer casing completed towards the top of the bedrock, and left open hole through the bedrock to 50 m bgl. A free standing 8” Boode uPVC slotted casing was installed inside the 12” casing. The boreholes are not grout sealed.

During non pumping periods, a small upward flow of water up the outside of the casing was noted in the concrete chamber of PW1 between the outer casing and concrete plinth approximately 0.4 m above ground level – emphasising the lack of a seal around the annulus and suggesting confining conditions. Generally, PW1 pumps at around 41 m^3/hr for 3–5 hours per day based on 2012 data, giving an average of approximately 200 m^3/day. Occasionally, Bruree PWS requires augmentation from Rockhill, which means additional pumping; – up to 12 hours per day in total, which would be approximately 500 m^3/day. **Table 4-1** provides a summary of details as currently known. Photographs 1 and 2 show PW1 and TW1.

Table 4-1 Summary of Source Details

	Rockhill PW1	**Rockhill TW1**	**Rockhill DW1**
Code	1900PUB0056	NA	NA
Grid reference	E152685 N130665	E152670 N130663	E152675 N130677
Townland	Ballyfookeen		
Source type	Borehole	Borehole	Dug Well
Drilled	*c.*1992	*c.*1991	*c.*1980
Depth	50 m bgl	52 m bgl	3 m bgl
Owner	Limerick Co. Co.		
Elevation	Approximately 50 m OD		
Depth to rock	Approximately 5 m (17 feet, based on drillers estimate)		
Static water level	Approximately 0.4 m above ground level		
Pumping water level	7 m bgl during the normal pumping cycle 13.7 m below top of casing at the end of the 24 hour test – unsteady state		
Consumption (Co. Co. records)	Generally 41 m^3/hr for 3-5 hours /day, i.e., about 200 m^3/d.	NA	NA
Borehole Diameter	12 inch Outer Steel casing. 8 inch inner uPVC casing to 50 m bgl Not Grouted	8-inch to 52 m bgl Not Grouted	NA Not Grouted
Transmissivity	105 m^3/d/m (24hr test, unsteady state)		
Storativity	0.0015 to 0.002 (based on 24 test)		
Specific capacity	72 m^3/d/m 13.7 m drawdown at 984 m^3/day (24 hour test)	NA	NA
Hours Pumping	3-5 hrs/day @41 m^3/hr	NA	NA

Photograph 1 Pumping Well PW1

Photograph 2 Trial Well (not used)

5 Topography, surface hydrology and land use

The source is situated at approximately 50 m OD in a low lying area, shown in **Figure 1**. To the south of the source, the topography inclines to a relatively high ridge at Rockhill and Ballyteigue Upper. Typical topographic gradients range from between 1:10 (0.1) on the slopes to 1:100 (0.01) in the surrounding lower lying areas.

The source is located within the upper River Maigue watershed, in the River Shannon (HA24) catchment. The River Maigue is located 2.2 km east of Rockhill PWS and flows north, shown in **Figure 1**. The density of drainage ditches is low in the upland areas, but a relatively high density of streams occurs across the lowland areas surrounding Rockhill. Additional water courses were mapped during the course of the field work (**Figure 1**).

The source is located 0.4 km west of the N20 with access via the R518 located 0.15 km to the north. The proposed M20 will be constructed approximately 0.8 km to the west of Rockhill PWS, and includes a 7 m road cut through the upland area (**Figure 1**).

Land use in the area is primarily agricultural, with lands mainly set to pasture. The nearest farmyard is located approximately 400 m to the southwest of the source. No major industry was identified in the vicinity of the source. There is one-off housing located along the roads to the north, east and south, with the nearest along the R518 some 200 m to the north. **Figure 1** also indicates the proposed M20. In summary, land use pressures are considered to be moderate to high, principally due to farming.

6 Hydrometerology

Establishing groundwater source protection zones requires an understanding of general hydrometeorological patterns across the area of interest. This information was obtained from Met Éireann.

Annual rainfall: 1033 mm. Met Éireann rainfall data 1981-2010.

Annual evapotranspiration losses: 443 mm. Potential evapotranspiration (P.E.) is estimated to be 540 mm/yr. Actual evapotranspiration (A.E.) is then estimated as 82% of P.E., to allow for seasonal soil moisture deficits (Hunter Williams *et at.,* 2011, in press).

Annual Effective Rainfall: 590 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, 590 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 included the following:

- Geology of Shannon Estuary. Bedrock Geology 17: 100,000 Map series, Sheet 17, Geological Survey of Ireland (Sleeman, *et al.,* 1999);
- Forest Inventory and planning system – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Teagasc, 2004);
- M20 Cork Limerick Motorway Scheme EIS and borehole data (WYG/Arup 2011);
- Bruree Public Supply Groundwater Source Protection Zones (Deakin, 1995);
- Ballyagran Public Supply Groundwater Source Protection Zones (Deakin, 1995); and,
- Ballyagran Borehole data, D. Ball *per comm.*

7.2 Bedrock geology

This section briefly describes the relevant characteristics of the geological materials that underlie the Rockhill source. The geological information is based the bedrock geological map of Shannon Estuary Sheet 17, 1:100,000 Series (Sleeman *et al.,* 1999). Folding and faulting have affected the bedrock in this area of Limerick. As a consequence, gentle east-west trending anticlines dominate, with numerous cross faults, which consist of long straight vertical fractures (Deakin, 1995). Jointing is generally in a north-south direction and is steeply dipping, although there is also a subordinate set trending east-west.

The bedrock map (**Figure 2**) and the rock unit group map (**Figure 3**) indicate that the elevated area is the core of an anticline: the oldest rocks, consist principally of the Devonian Old Red Sandstones (Kiltorcan type sandstones) occur in the centre, and are flanked by shallow dipping (15°) undifferentiated Lower Limestone Shales (Dinantian Early Sandstones, Shales and Limestones). The Lower Limestone Shales are subsequently overlain by the Ballysteen Formation (Dinantian Impure Limestones), which underlie the ground to the north.

The source boreholes are mapped on the Lower Limestone Shale. While a borehole log is not available for the source, information provided by Linehan drillers indicate that fractured, competent to weak yellow sandstones are present. It is considered that the source boreholes intersect both the Lower Limestone Shales and the Kiltorcan type sandstones that underlie the shaley limestones. A cross section is shown in **Figure 14**.

Bedrock exposures at Rockhill church 2 km to the south of the source comprise moderately strong to strong, thinly to thickly bedded, fissile light grey/yellow sandstones (Photograph 3). The Lower Limestone Shales are described from outcrop information 5 km to the west as coarse grey and yellowish grits, with thin flaggy grey and rusty grits, and shales (Deakin, 1995).

Photograph 3 Competent thick bedded sandstones with 2mm near vertical fissure. Water seepage occurs at base of exposure, at the bed boundary

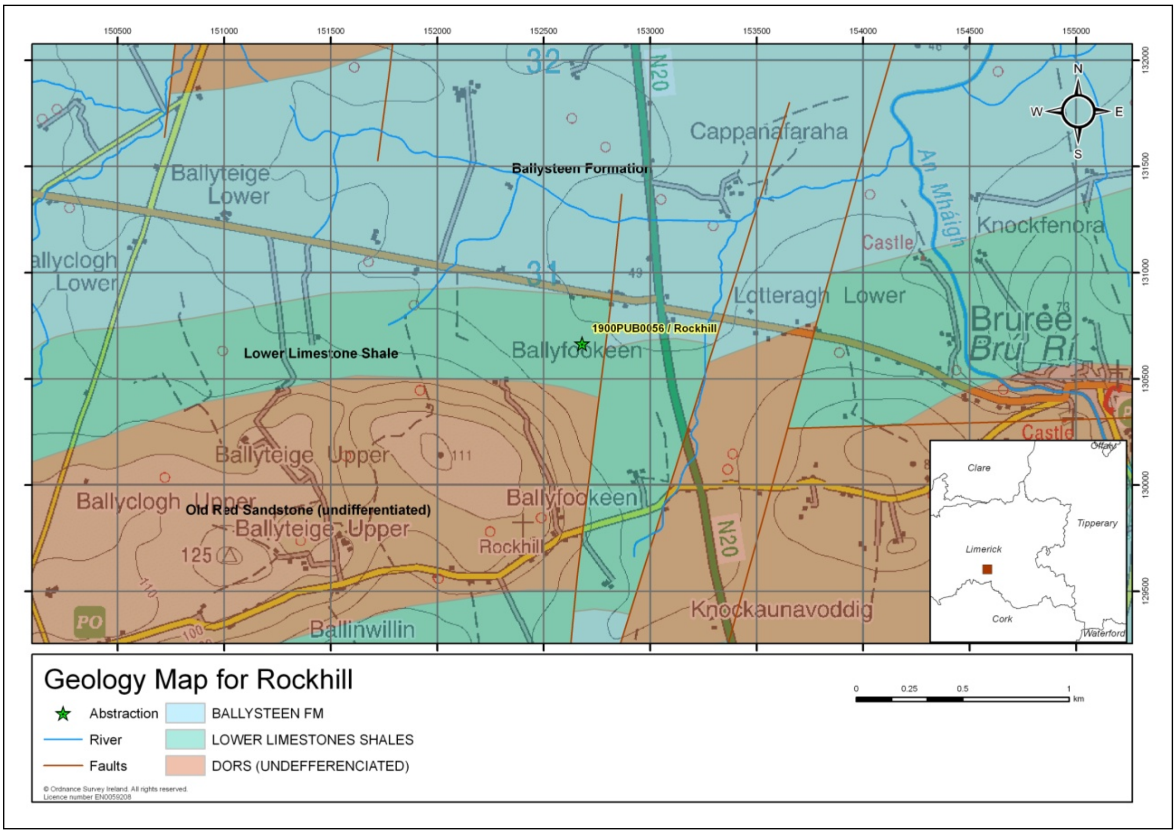

Figure 2 Bedrock geology map of the area around Rockhill PWS

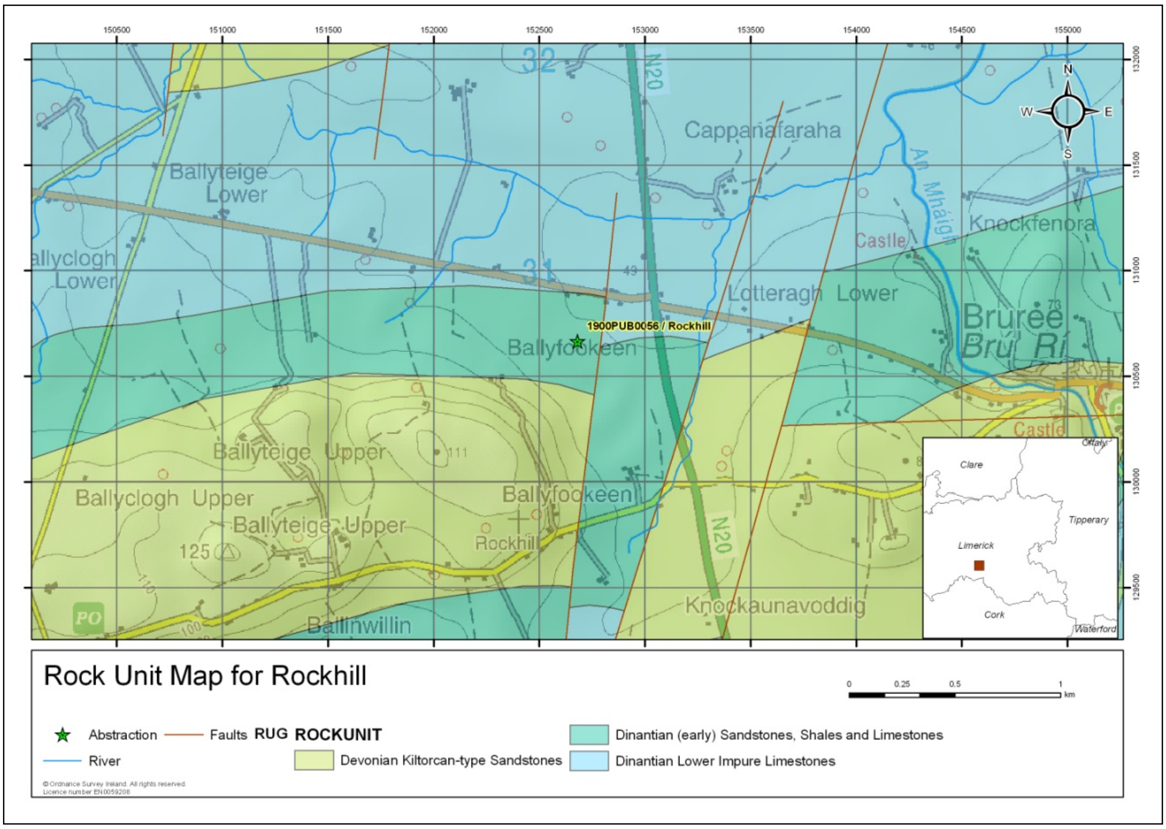

Figure 3 Rock Unit Group map of the area around Rockhill PWS

7.3 Soils and subsoils geology

Generally, the soils are dominated by acidic soil types: typically well drained shallow mineral soils (AminSW) and well drained deep soils (AminDW) (EPA website and An ForasTalúntais, 1980). To the east of Rockhill PWS substantial areas of basic well drained deep soils (BminDW) are present (**Figure 4**).

The subsoils are dominated by till derived from Devonian sandstone and shales (TDSs), till derived from limestones (TLs) and bedrock outcrop (Rck) (**Figure 5**). In the vicinity of the Rockhill PWS, lacustrine deposits are mapped which coincide with the low lying area around the boreholes.

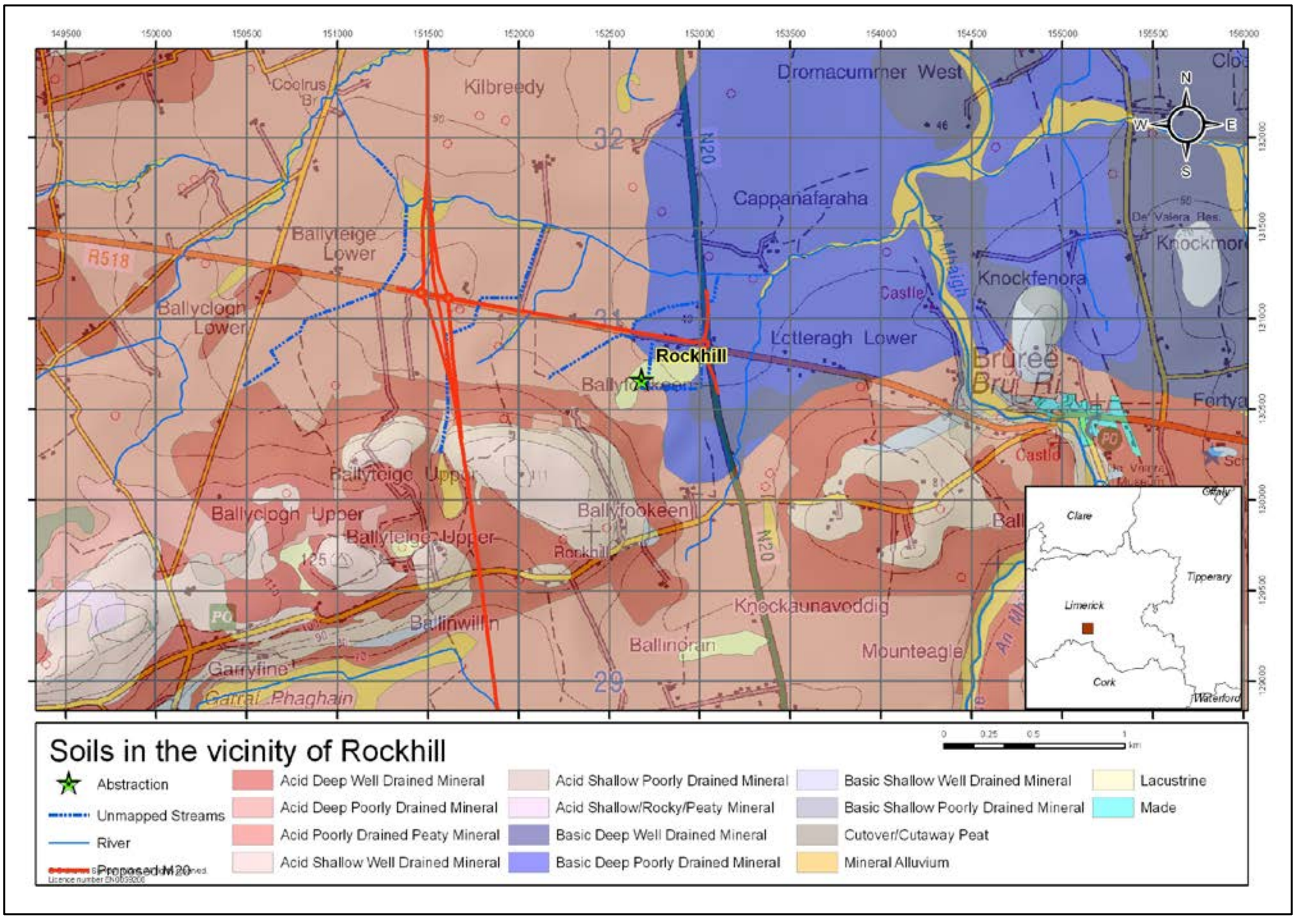

Figure 4 Soils map of the area around Rockhill PWS

7.4 Depth to bedrock

Information on the depth to bedrock was obtained from site investigation data completed as part of the M20 assessment report (WYG/Arup, 2011), GSI databases and Linehan Drillers. Summary information from the site investigation for the M20 is included in **Table 6-1** for the portion around Rockhill. Depth to bedrock at the source is reported to be in excess of 5 m *pers. comm. Linehan Drilling*.

The hydrogeological mapping and information obtained indicates that the depth of subsoil is generally less than 1 m on the ridges/elevated area, and in the order of 5 to 10 m across the lower slopes.

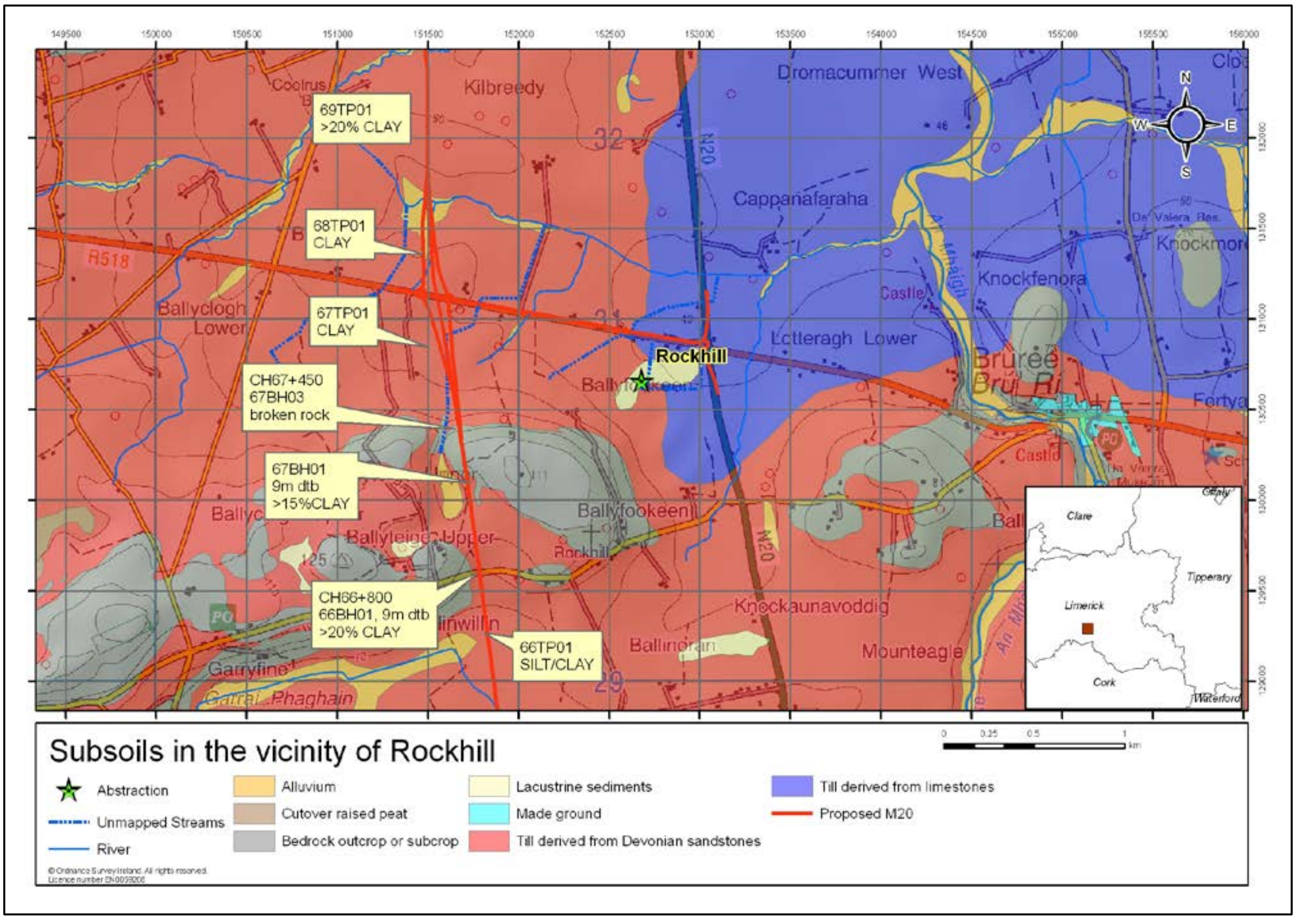

Figure 5 Subsoil map of the area around Rockhill PWS

Table 6-1 Summary information for selected BH's and Trial pits in the vicinity of Rockhill from SI for M20

Borehole I.D.	Depth to bedrock (m bgl)	Summary log
Rockhill TW1/PW1	5 – 10 m	
66BH01	9.8	3m CLAY, 0.7m SILT over 2.8m CLAY over 3.5 GRAVEL. PSD information: >20% CLAY, >50% fines
67BH01	9.0	9m CLAY PSD information: >12, 15% CLAY, >50% fines
67BH02	2.4	CLAY
67BH02A	7.1	CLAY PSD information: >12, 14% CLAY, >50% fines
67BH03	1.4	Broken Rock
69TP01	>3m	CLAY PSD information: >20% CLAY>50% fines
68TP01	>3m	CLAY
67TP01	>3m	CLAY
66TP01	>3m	SILT/CLAY

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).

A groundwater vulnerability map has been prepared by Tobin Consulting Engineers in 2011 as part of the National Groundwater Protection Scheme, on behalf of the Geological Survey of Ireland, and a portion of the Rockhill area is shown in **Figure 6**.

Across the crests and upper flanks of the Rockhill, the vulnerability is mapped as 'Extreme', which is dominated by rock at or close to surface. Soil depths increase rapidly on the downslopes with a halo of extreme, high and moderate vulnerability surrounding the rock close areas. Areas of low vulnerability predominate the lowland areas including the area around source.

Site investigation date summarised in **Table 6-1** indicates that the subsoils are dominated by CLAY, with clay percentages generally greater than 12%, 15%, and with fines percentages greater than 50%. The presence of permanent surface water features and secondary indicators of low subsoil permeability support the site investigation data and that the subsoils are dominated by '*Low Permeability*' subsoil, in keeping with the regional maps.

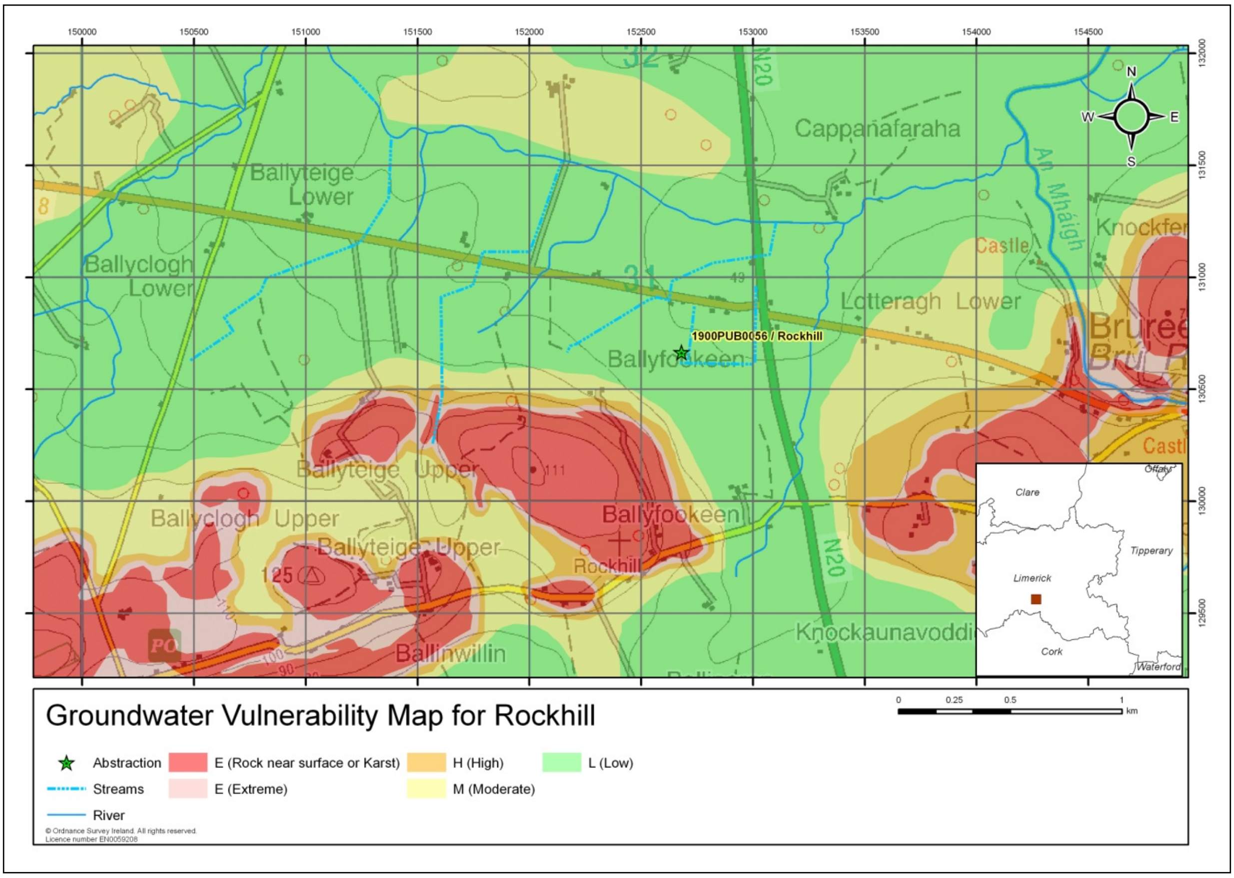

Figure 6 Groundwater Vulnerability in the area around Rockhill PWS

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 Well Database;
- Limerick County Council Staff;
- EPA website and Groundwater Monitoring database;
- Local Authority Drinking Water returns;
- Hydrogeological mapping carried out by TOBIN Consulting Engineers in June 2013;
- Bruree Public Supply Groundwater Source Protection Zones (Deakin, 1995); and,
- Ballyagran Public Supply Groundwater Source Protection Zones (Deakin, 1995).

9.1 Groundwater body and status

The upland area around Rockhill PWS is within the Bruree Groundwater body (IE_SH_G_135), close to the boundary between it and the Hospital Groundwater Body located to the north. Both groundwater bodies are of Good Status (www.wfdireland.ie/maps.html). The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the EPA website: www.epa.ie.

9.2 Groundwater levels, flow directions and gradients

The groundwater levels under the crest of Rockhill typically varied between 10 m and 20 m bgl during the M20 investigation period (2008 to 2012). The groundwater elevation in PW1 and TW1 in April 2013 is 0.4 m above ground level (approx 50 m OD). Groundwater gradients range from 0.02 to 0.03, depending upon the topography and seasonal variation. Groundwater in the area surrounding the Rockhill PWS rises at a number of locations along the lowland area. Groundwater discharges to the local drainage network within the surrounding lacustrine area. Flow directions radiate broadly from the upland area mirroring topography. Hydrogeological field mapping carried out in June and July 2013 included obtaining field measurements of electrical conductivity and temperature of water courses, summarised in **Table 8-1.**

Table 8-1 Field measurements of electrical conductivity and temperature at Rockhill

ID	Conductivity (µS/cm @ 25^{o}C)	pH	Dissolved Oxygen (%)	Temperature (^{o}C)	Notes
Production Well 1	630	7.1	71	11.1	
River Maigue	560	7.2	104	14	
SW1	630	7.1	59	11.7	Flow approximately 1 l/s
SW 2	650	7.2	51	10.8	Flow approximately 1l/s

9.3 Hydrochemistry and water quality

Available records included limited historical group scheme data, and Local Authority Drinking Water Returns. The majority of samples have a limited number of analytes. The water is hard to very hard (262 to 300 mg/l

$CaCO_3$). Alkalinity ranges from 260 to 276 mg/l as $CaCO_3$. The pH ranges between 6.6 and 7.4, which is neutral. The electrical conductivity ranges from 456 to 667 µS/cm. The hydrochemical signature is calcium bicarbonate and compares favourably with the signature and data given in the Bruree Groundwater Body description. The borehole intersects both sandstones and limestones.

Figure 7 shows the faecal coliform counts and ammonium concentrations. There is no evidence of gross contamination (greater than 100 faecal coliforms per 100 ml). The relatively high count on 18th August 2008, occurred before improvements to well head protection were made (covers), and recorded counts are 0 since. There are small numbers of total coliforms present occasionally, which may be related to the lack of a grout seal. Ammonium concentrations are below the Groundwater Threshold Values, though have occasionally been elevated above the normal concentrations reported, which may indicate an organic source close by.

Nitrate concentrations range from 9 to 54 mg/l, with an average of 34 mg/l (**Figure 8**). From 2007 to early 2013 the concentrations are consistently elevated between 30 and 40 mg/l with an average of 36 mg/l over that period, with one exceedance of the standard (50 mg/l) set in the Drinking Water Regulations (S.I. No. 278 of 2007) and several occurrences above 37.5 mg/l (Groundwater Threshold Value, Groundwater regulations S.I. No. 9 of 2010). It is difficult to do a trend analysis: across the entire dataset it is a rising trend but the most recent data shows a decline, though still clearly elevated. The source may be inorganic fertiliser or an organic waste source.

Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and levels higher than 24 mg/l (Groundwater Threshold Value, 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 25.1 to 35.1 mg/l, with a mean of 26.8 mg/l (**Figure 8**), which is considered to be above the mean natural background level of 18 mg/l (Baker *et al.*, 2007), and the Groundwater Threshold Value (24 mg/l). This may be as a result of contamination from organic sources.

Manganese concentrations whilst generally low exceeded the Drinking Water Standards in 2001 and 2008 with concentrations in the order of 0.1 mg/l. There are few potassium:sodium ratios, and recent data suggests low ratios. However historical data suggest ratios in the order of 0.3 to 0.33, due to elevated potassium concentrations in the order of 4 to 5 mg/l (**Figure 9**). These elevations accord with elevated ammonia and manganese on those dates and suggest an organic waste source.

Available phosphate concentrations indicate a mean concentration of 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.

In summary, persistently elevated nitrate and chloride concentrations, occasional though apparently historical elevated and exceedences of manganese, potassium, ammonia suggest contamination from an organic waste source and/or from agricultural pressures within the catchment. The bacteriological exceedances appear to be related to poor well head completion.

Information from Limerick County Council reports a cryptosporidium risk assessment score of 71 which is classed as Moderate Risk; the categories being - low, moderate, high and very high.

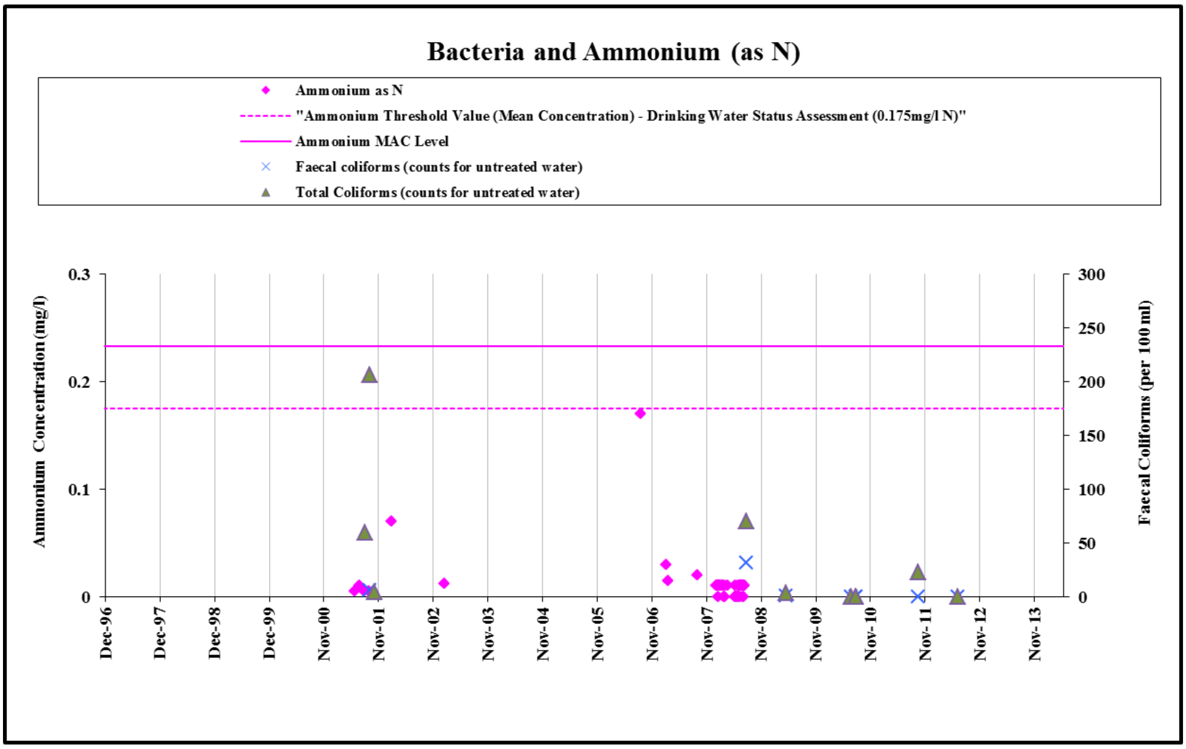

Figure 7 Ammonium and Faecal Coliform data for Rockhill PWS

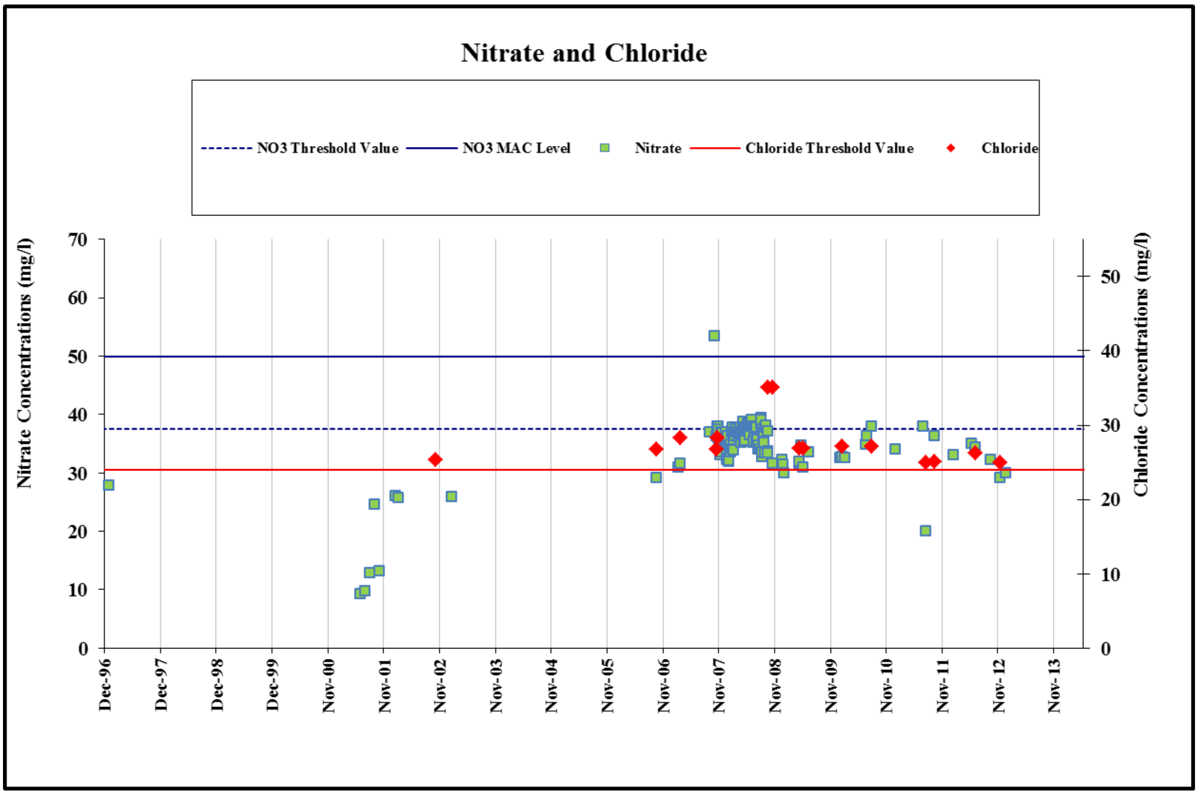

Figure 8 Nitrate and Chloride concentrations for Rockhill PWS

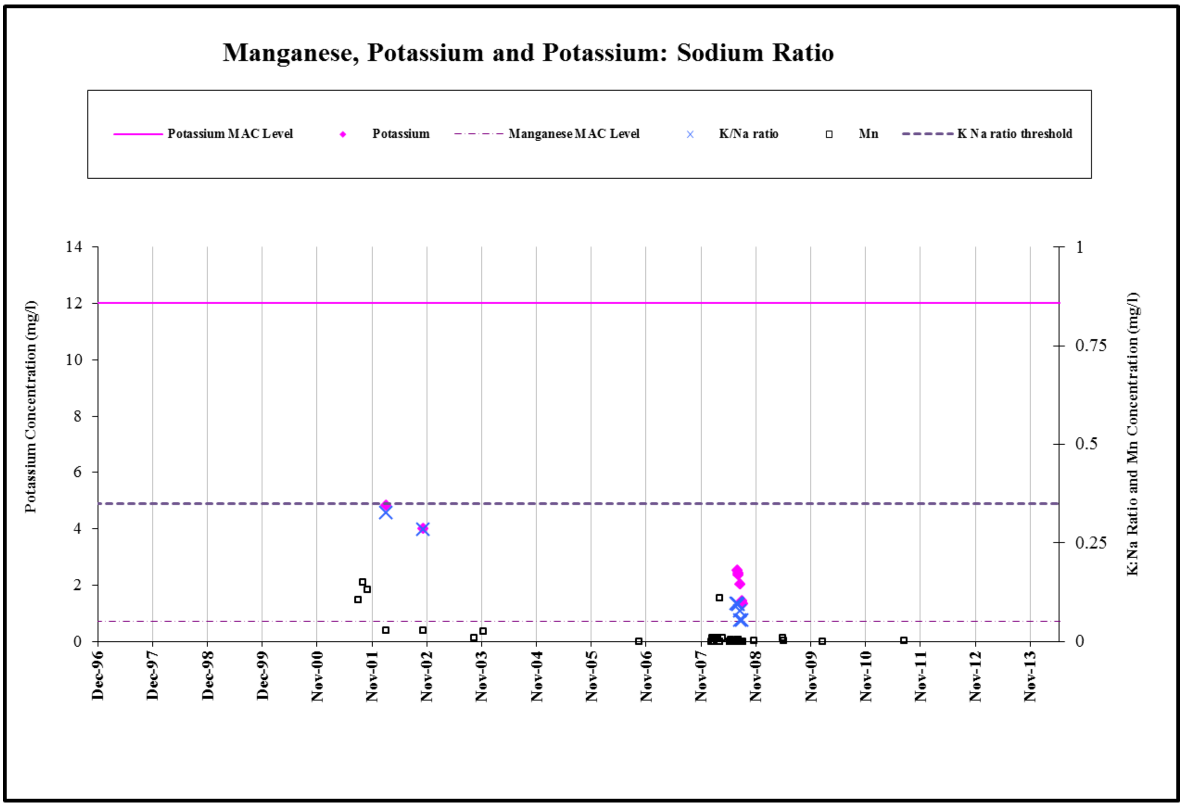

Figure 9 Manganese and Potassium concentrations and Potassium:Sodium ratio

9.4 Aquifer characteristics

The groundwater source is located in the Bruree Groundwater Body. The GSI bedrock aquifer map of the area show the Old Red Sandstones and Lower Limestone Shales classified as a *Regionally Important Fissured Aquifer (Rf)* (**Figure 9**). Increased permeability is recorded in the Lower Limestones Shales due to the presence poorly cemented, highly weathered sandstones. It is assumed that both units are in hydraulic connection and that the source boreholes intersect both. Flow in the aquifer is assumed to follow topography and occur through the more permeable, interconnected fault/fracture zones and within the weathered sandstone bedrock. Faults, and additional fracturing associated with these faults, are likely to increase the permeability of the aquifer. The faults and fractures are likely to have resulted in a higher transmissivity zone running NW-SE.

The effective porosity is expected to be approximately 2% (Bruree GWB). Groundwater gradients are approximately 0.025 based on the groundwater level data and reflect the steep topography of the area.

PW1 plots as a category II well according to the GSI Productivity Chart (QSC graph) (**Figure 10**), indicating that it is a productive well.

A 24 hour pumping test at a rate of 41 m^3/hr (984 m^3/day) was undertaken on 26th and 27th June 2013 with monitoring undertaken in PW1 and TW1. A maximum drawdown of 13.7 m was achieved by the end of the pumping test but was unsteady – still declining at a rate of about 3 cm per hour.

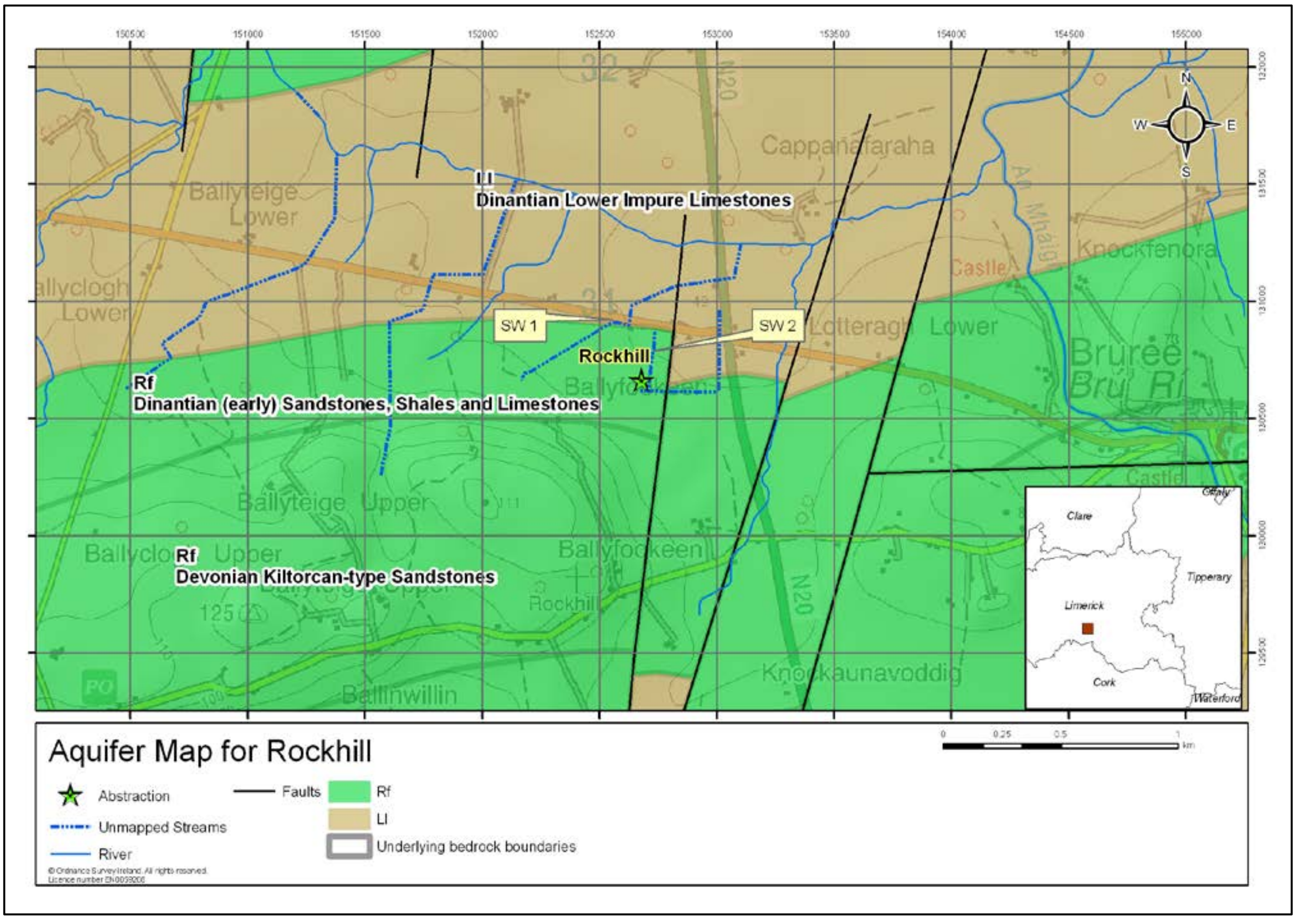

Figure 10 Aquifer map in the vicinity of Rockhill PWS

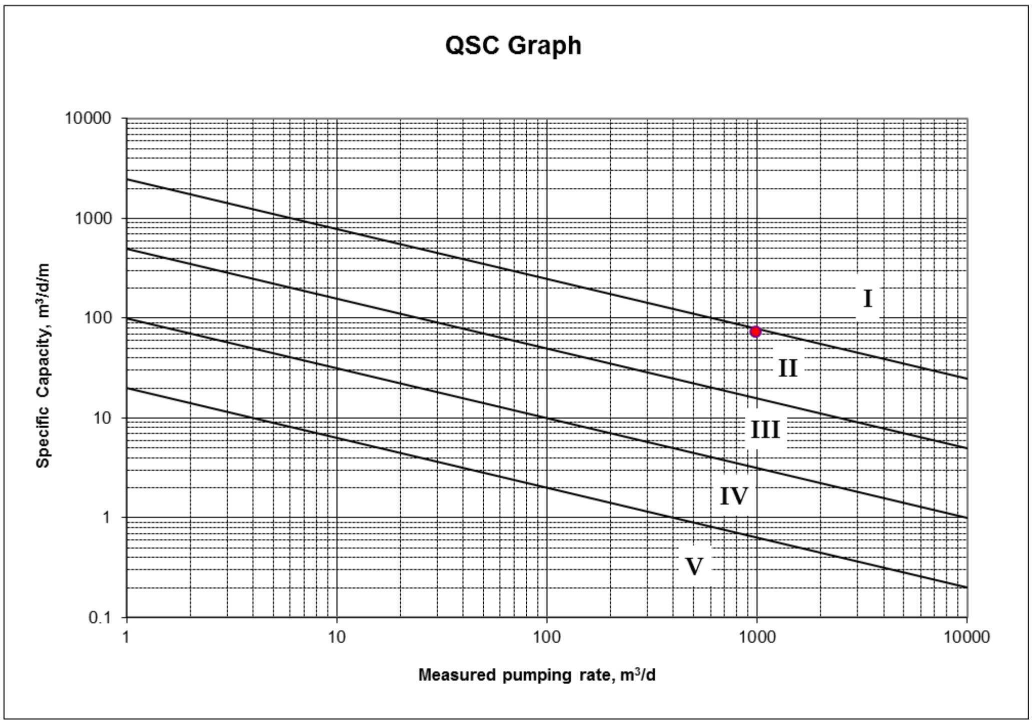

Figure 11 GSI Well Productivity Values – Rockhill PWS plots as index II

Plots of drawdown against time for the pumping well and the observation well (TW1) are given in **Figure 11**, and **Figure 12**, and a diagnostic plot of drawdown and the derivative of drawdown against time is given in **Figure 13**. The data shows that drawdown has not stabilized after 24 hours. The plots suggest that the pumping test could have been continued for longer, and that a number of analytical solutions may be viable for assessing and interpreting the data, though it appears that a double porosity model may be most applicable. There

A transmissivity value of 105 m^2/day is calculated based on the data from the observation well (TW1) test data from PW1 using a Cooper-Jacob or either a Moench solution. A cross check using the specific capacity and Logans equilibrium estimate of transmissivity suggests a transmissivity in the order of 80 m^2/d. Full details of the 2013 pumping test are provided in Appendix 1. Storativity is calculated at between 0.0015 and 0.002 based on the observation well (TW1) data from the pumping test. The source may be fully or partially confined. The well is artesian under non pumping conditions at the source, and the vulnerability map suggests that in the lower part of the area around the source that 10 m of low permeability subsoil is present. The Lower Limestone Shales, though considered in connection with the underlying Kiltorcan sandstones, may have shale layers that restrict and confine flow. The cone of depression around PW1 may induce unconfined conditions during pumping but the water level in the observation well during pumping is likely to be above the top of the rock.

Transmissivity values throughout the aquifer are likely to vary depending on the degree of fractures/fissures present. The estimated transmissivity corresponds favourably with the Bruree groundwater body data, which indicates high transmissivity (50-190 m^2/day). The thickness of the aquifer is assumed to be 50 m based on borehole data.

Based on the estimated bedrock aquifer transmissivity and the aquifer hydraulic gradients, the average linear groundwater flow velocity can be estimated based on the equation:

$$v = \frac{T \cdot i}{b \cdot n_e}$$

where: v = average groundwater velocity (m/day);

T = aquifer transmissivity (m^2/day) = 105

n_e = effective porosity (dimensionless) = 0.02

i = hydraulic gradient = 0.025; and,

b = aquifer thickness =50 m.

Therefore velocity is in the order of 2.5 m/day.

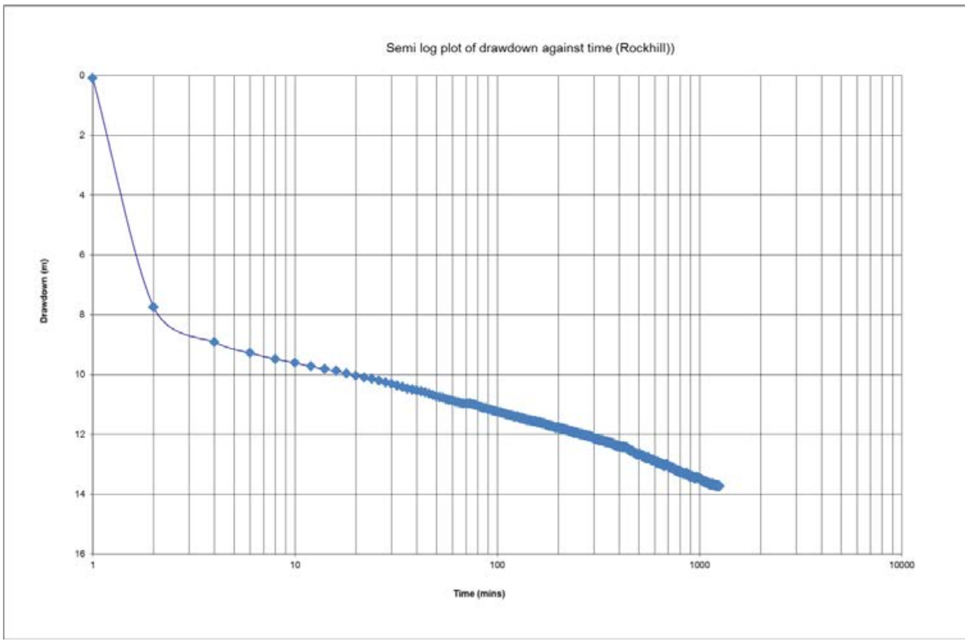

Figure 12Semi-log plot of s versus time, rate at 41m^3/hr in PW1

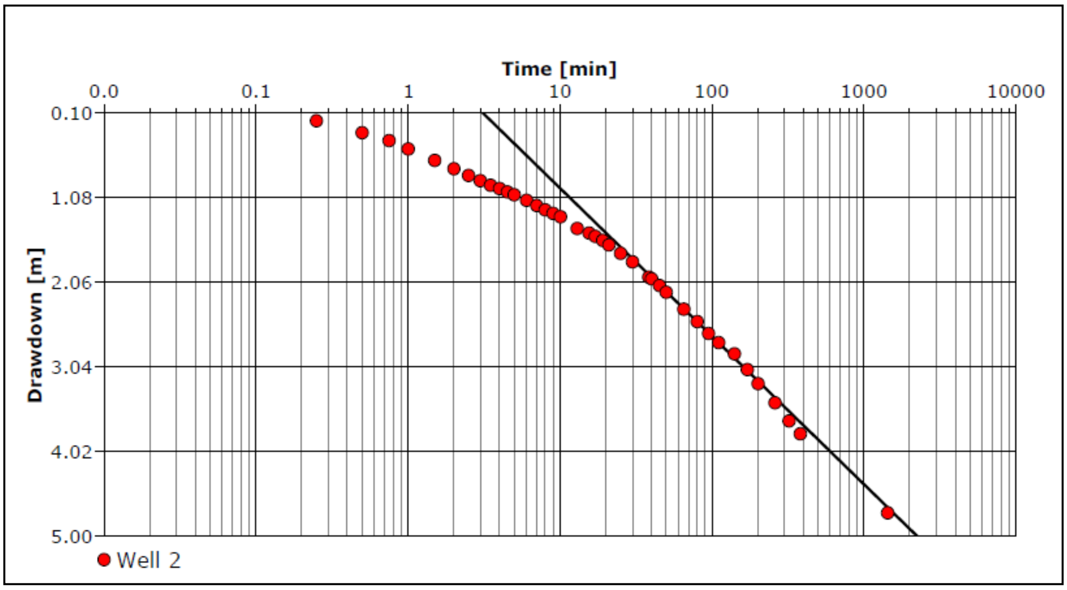

Figure 13 Semi-log plot of s versus time, for the observation well (TW1), 15m from PW1

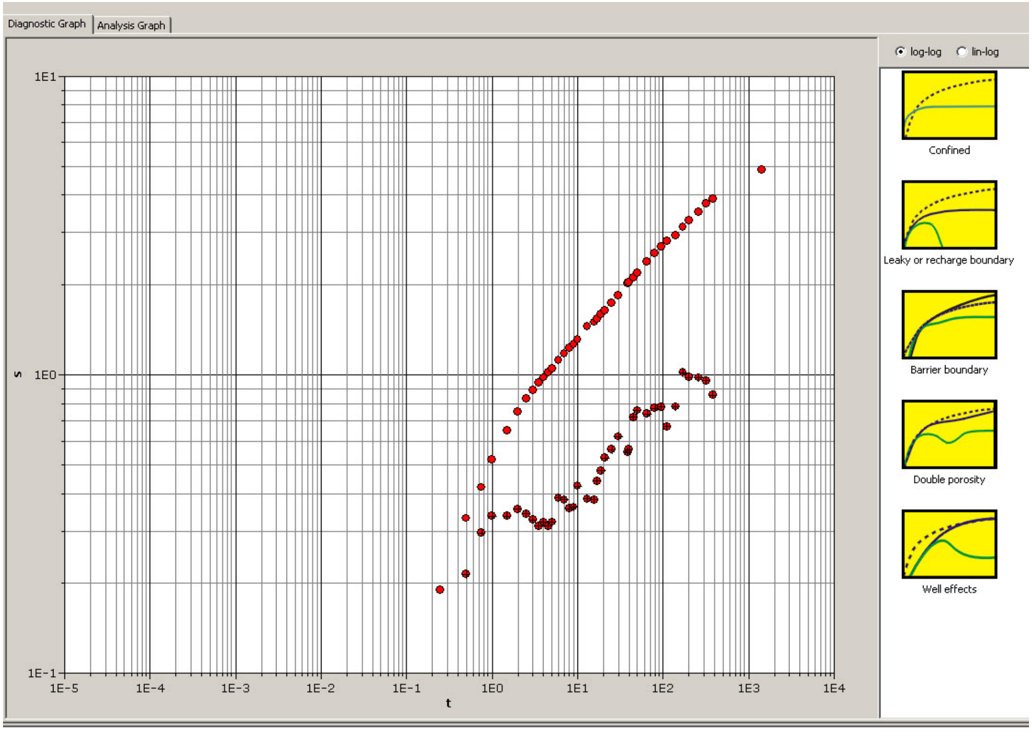

Figure 14 Log-log plot of drawdown and derivative of drawdown against time.

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

Groundwater flow to the boreholes is from the surrounding up-gradient area and is controlled by topography. Average groundwater abstraction from PW1 is approximately 200 m^3/day. Groundwater flow within the catchment is structurally controlled with enhanced flow and transmissivity along the fissures and faults. The north-south faulting of the sandstones is a particularly important factor for flow through the sandstone units. The less permeable units, such as Lower Limestone Shales, may inhibit groundwater flow across these inclined units. However, the ‘open hole’ borehole intersects both units and the water is hard – which is considered to suggest contribution from the shaley limestones.

The aquifer is considered to be unconfined over the elevated hillside where there is extreme and high vulnerability, though is probably confined at the source, where there is low vulnerability and artesian conditions during non-pumping periods. The boreholes are recharged across the elevated area, through the relatively thin subsoils. The natural hydraulic gradients in the aquifer are estimated to be approximately 0.02 to 0.03. High groundwater velocities are expected through a network of faults, fractures and fissures. The limited water quality data accord with interpretation of much of the recharge area being of extreme to moderate vulnerability, with relatively high agricultural pressures.

The conceptual model of flow to the boreholes is illustrated in **Figure 14**. Uncertainties to the model are mainly connected to a lack of information on geology and detailed aquifer properties, such as porosity.

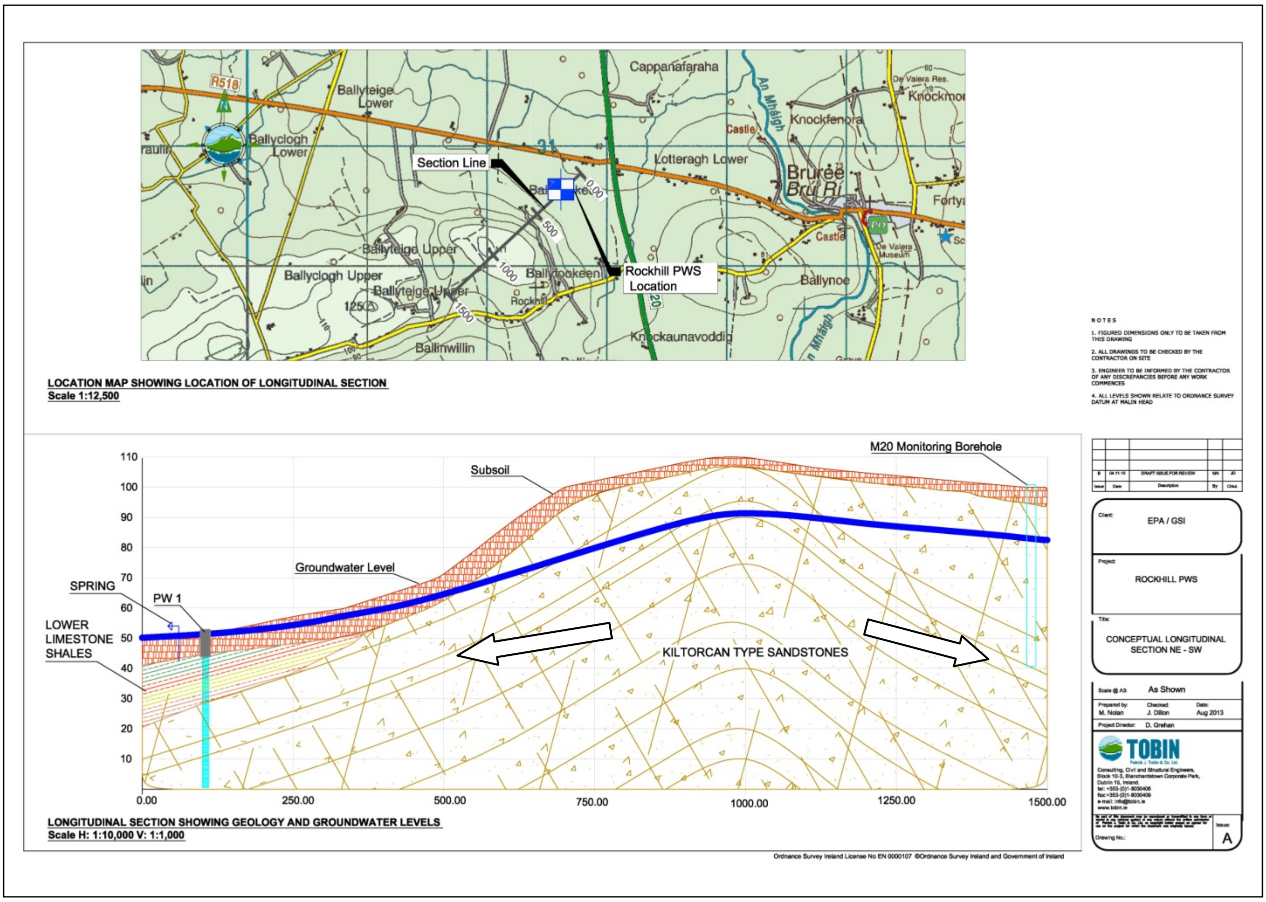

Figure 15 Cross section through Rockhill PWS

10.2 Boundaries of the ZOC

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

The northeastern boundary is estimated to be approximately 50 m from the borehole and is 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 900 m^3/d for 24 hour pumping test)
T is Transmissivity (taken from aquifer characteristics 105 m^2/d)
i is the background non-pumping gradient (0.025).

The Southern and southwestern boundary: The southern and southwestern boundary is based on the topographic and groundwater divide. It is assumed that groundwater at an elevation higher than the boreholes, from the hills surrounding them, flows toward the boreholes.

The Western boundary is based on assumed groundwater flow directions and the presence of a stream to the west of Rockhill. Given the proximity of the permeable bedrock to the stream, groundwater within the sandstones is assumed to discharge to this stream. The groundwater divide is assumed to mirror the surface topography divide.

The **Eastern boundary** is based on a topographical divide and constrained by the water balance. The eastern boundary is based on the topographic divide. It is assumed that groundwater at an elevation higher than the boreholes, from the hills surrounding them, flows toward the boreholes.

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 critical in source protection delineation, as it will dictate the size of the zone of contribution to the source (*i.e*., the outer Source Protection Area).

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Groundwater Working Group 2005; Hunter Williams *et al.,* 2011, & in press). The Geological Survey of Ireland have prepared a recharge coefficient map and a portion for the Rockhill area is depicted in **Figure 15**.

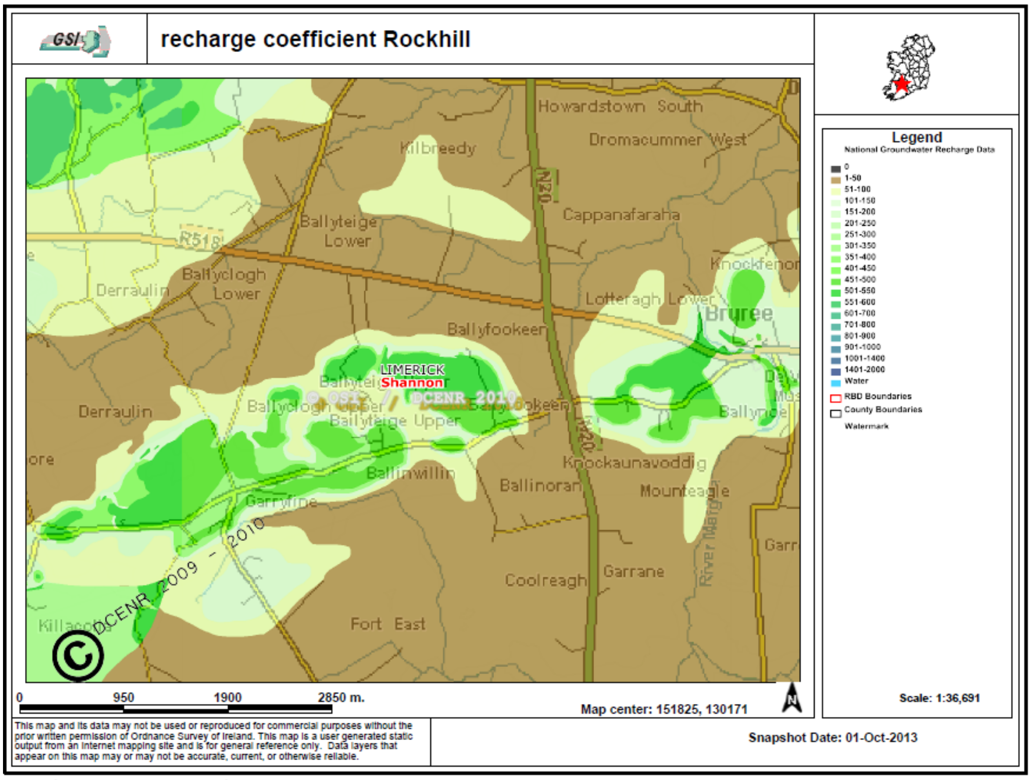

Figure 16 Recharge Coefficient Map for Rockhill (GSI)

Runoff losses are assumed to be 42% of potential recharge (effective rainfall). This value is based on an assumption of *c*. 15% runoff for 60% of the area (high and extreme vulnerability - moderate permeability subsoils and soils, few drains or surface streams and moderate to steep slopes (Groundwater Working Group 2005; Hunter Williams *et al.,* 2011, & in press); *c*. 45% runoff for 8% of the area (moderate vulnerability) and c.82.5% runoff from low vulnerability areas.

The bulk ***recharge coefficient*** for the area is therefore estimated to be 58%.

These calculations are summarised as follows:

Average annual rainfall (R)	1033mm
Estimated P.E.	540 mm
Estimated A.E. (82% of P.E.)	443mm
Effective rainfall (Potential recharge)	590mm
Bulk recharge coefficient	58 %
Recharge	**342mm**

The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. Based on an abstraction of 200 m^3/day on average and the estimated recharge of 342 mm/year, a zone of contribution of 0.21 km^2 in area is calculated. Current GSI guidance states that ZOC delineation should conservatively account for 150% of the abstraction volume if the hydrogeological conditions allow. Thus 0.32 km^2 is required for 300 m^3/day. The ZOC described above is 0.35 km^2 and allows for uncertainties in the current understanding of the hydrogeology and flow directions. Given the current abstraction from Rockhill PWS, there is a potential to modestly increase the abstraction at the existing borehole. An extended pumping test during low flow conditions is required to assess the sustainable abstraction rate.

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 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 areas are generally delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution.
- Outer Protection Area (SO), encompassing the zone of contribution to the source.

The Inner Source Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the abstraction boreholes is calculated from the velocity of groundwater flow in the bedrock. This velocity is determined using Darcy's law, $v = K.i/n_e$.

The velocity of groundwater flow in the bedrock is estimated to be approximately 2.5 m/day (see Section 9.4, page 13). Therefore the 100-day horizontal time of travel is estimated to extend approximately 250 m upgradient of the source.

The Outer Source Protection (SO) is the remainder of the ZOC, bounded by the complete catchment area to the source. Groundwater protection zones are shown in **Figure 17** and are based on an overlay of the groundwater vulnerability on the source protection areas. Therefore the groundwater protection zones, shown in **Table 10-1**, are SI/L, SO/X, SO/E and SO/H, SO/M and SO/L. The majority of the area is designated SO/X.

Table 10-1 Source Protection Zones

Source Protection Zone	% of total area (0.35 km^2)
SI/Low	22.3%
SO/X – <1 m subsoil	44.6%
SO/Extreme	4.5%
SO/High	7.2%
SO/Moderate	13.1%
SO/Low	8.2%

12 Potential pollution sources

PW1 is covered and secured and fenced, however the main stand is not capped. Vermin could probably get in at the back of the housing where there are small gaps.

The majority of land within the ZOC is agricultural land, primarily grassland and there are a number of farming operations present. The main potential contaminants from these sources are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium.

The dwellings in the area are serviced by domestic waste water treatment systems. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium. As well as this, there are some private home heating fuel tanks. The main potential contaminants from this source are hydrocarbons. There is currently no evidence of any contamination from hydrocarbons at the source.

Finally, there is limited public road access within the ZOC and consequently traffic density and the associated risk of contamination from this source is low.

The inner protection area has ‘low’ vulnerability to contamination. However, further up the catchment, groundwater vulnerability ranges from ‘extreme’ to ‘moderate’. Any potentially polluting activities in these areas will be likely to cause chemical contamination at the source.

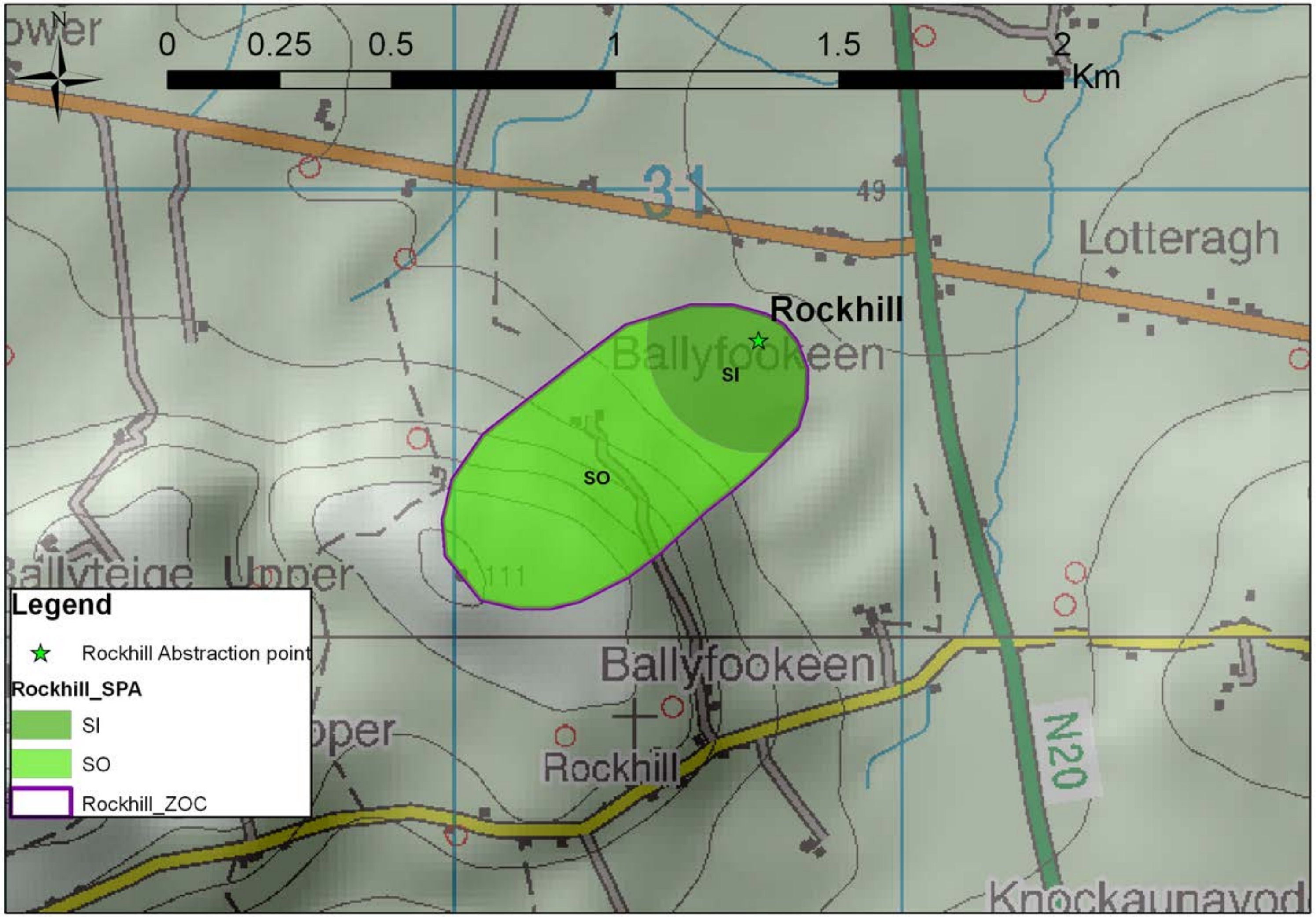

Figure 17Source Protection Areas for Rockhill PWS

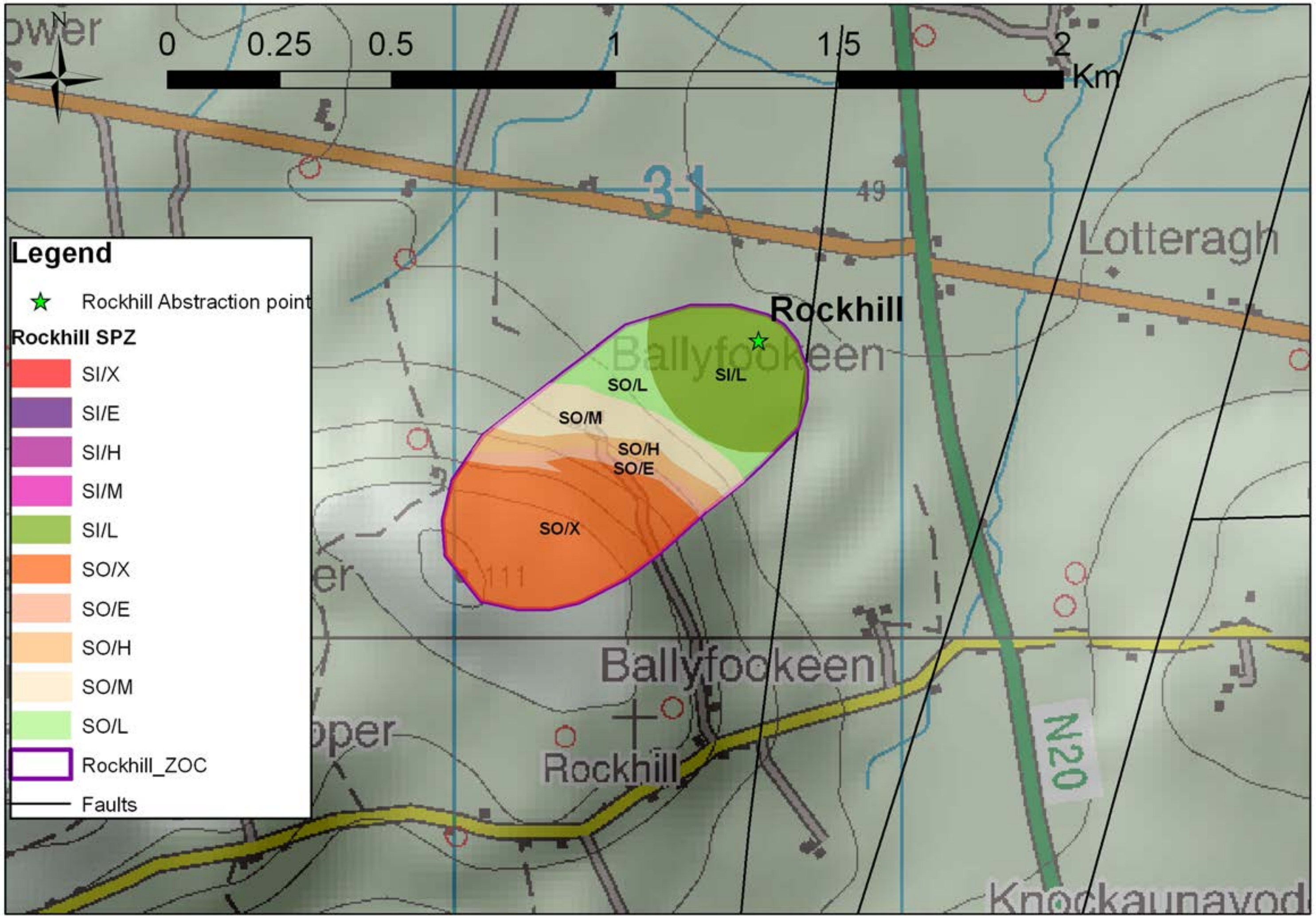

Figure 18 Source Protection Zones around Rockhill PWS

13 Conclusions

A high yielding borehole abstracts from a regionally important bedrock aquifer. The groundwater shows evidence of consistently elevated concentrations of nitrate and chloride. The available data suggest contamination from an organic source and/or agricultural pressures in the catchment.

Occasionally total coliforms and faecal coliforms are present in the untreated water but the counts are relatively low and probably relate to the lack of a grout seal, and both the pumping well and the trial well are uncapped.

Given the current abstraction from Rockhill PWS, there is a potential to modestly increase the abstraction at the existing borehole. An extended pumping test during low flow conditions is required to assess the sustainable abstraction rate.

The SPZ delineated is based on the current understanding of groundwater conditions and bedrock geology; and on the available data. The conclusions should not be used as the sole basis for site-specific decisions.

14 Recommendations

It would be beneficial to grout seal with cement and cap the boreholes if possible. Any grouting works on the well will require an understanding of the well construction and geology. EPA has published an advice note on borehole construction and well head protection (EPA, 2013).

Continued monitoring of the water levels and flow data during the operation of the scheme could be carried out to further develop the real-time database of hydrogeological information. A longer term monitored pump test using existing infrastructure would improve the interpretation of the hydraulic parameters, the overall conceptual model and the boundaries of the Zone of Contribution, and also the long-term sustainable yield of the supply.

Further and more detailed monitoring could be undertaken for additional parameters such as sodium, manganese, iron and potassium – preferably on the untreated water. On-going assessment of nitrate concentrations should be maintained, particularly any indications of upwards trends in concentration. Nutrient loadings from grazing, fertilisers and farmyard activities should be assessed in the ZOC.

The ZOC of the source includes an extensive area of **Extreme** Vulnerability with a significant proportion of it comprising shallow rock. A hazard survey is recommended across the entire ZOC, and an assessment of setback distances in accordance with EPA Advice Note No. 11 (EPA, 2011) is recommended.

At the time of the M20 Cork-Limerick Motorway Scheme Environmental Impact Statement (2010), no source protection areas were defined for Rockhill. Consideration should be given to the findings of this report in the development of the M20 Cork-Limerick Motorway scheme and in particular the 7 m road cutting in close proximity to the source.

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