Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Ardfert Water Supply Scheme

Ardfert South Borehole

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PROJECT DESCRIPTION

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

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

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

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1 Introduction

Groundwater Source Protection Zones are delineated for the Ardfert South Boreholes, 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 sources.
- To delineate source protection zones for the boreholes.
- To assist the Environmental Protection Agency and Kerry 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

The methodology comprised data collection, desk studies, site visits, field mapping of karst features and exposures, hydrogeological mapping, well audits and water level recording. Analysis of the information collected during the studies was used to delineate the SPZ. Site visits (including an interview with the caretaker), site walkovers and field mapping were conducted during November 2011 and February 2012. Gathering of additional information, including consultation of previous reports provided by Kerry County Council, provided background information on the boreholes.

3 Location, site description and well head protection

The Ardfert South source currently comprises two boreholes, PW1 and PW2, which are located 0.7 km northwest of Ardfert village along the R551 regional road, shown in Figure 1 and Figure 2, and deliver water to Ardfert and Fenit.

The scheme has undergone several changes; historically, there were other boreholes on the site which are now backfilled or abandoned, further detailed in Section 4. Photograph 1 shows PW 1 and PW 2; and Photograph 2 shows locations of the decommissioned though still accessible, boreholes, contained within a ‘Cofferdam’ and ‘BH2’ in relation to the current abstraction boreholes.

The production boreholes PW1 and PW2, are located 5 m apart within a fenced and gated Local Authority compound. The photographs for PW1 and PW2 show the well heads and metal housing. The boreholes are pumped alternatively on a 24 hr basis to the adjacent treatment plant and subsequently distributed through the network, approximately 9 km of pipework (RPS, 2011). In order to prevent excess pressure and stress on the water main distribution network, the borehole is pumped at a variable speed to meet demand. The abstraction ranges from 1200 to 1900 m^3/day.

The boreholes (PW1 & PW2), which are grouted, are finished approximately 1 m below ground level, in a concrete chamber covered with a metal lid. PW1 is not properly sealed, as can be seen in Photograph 4, as groundwater is issuing up outside the casing.

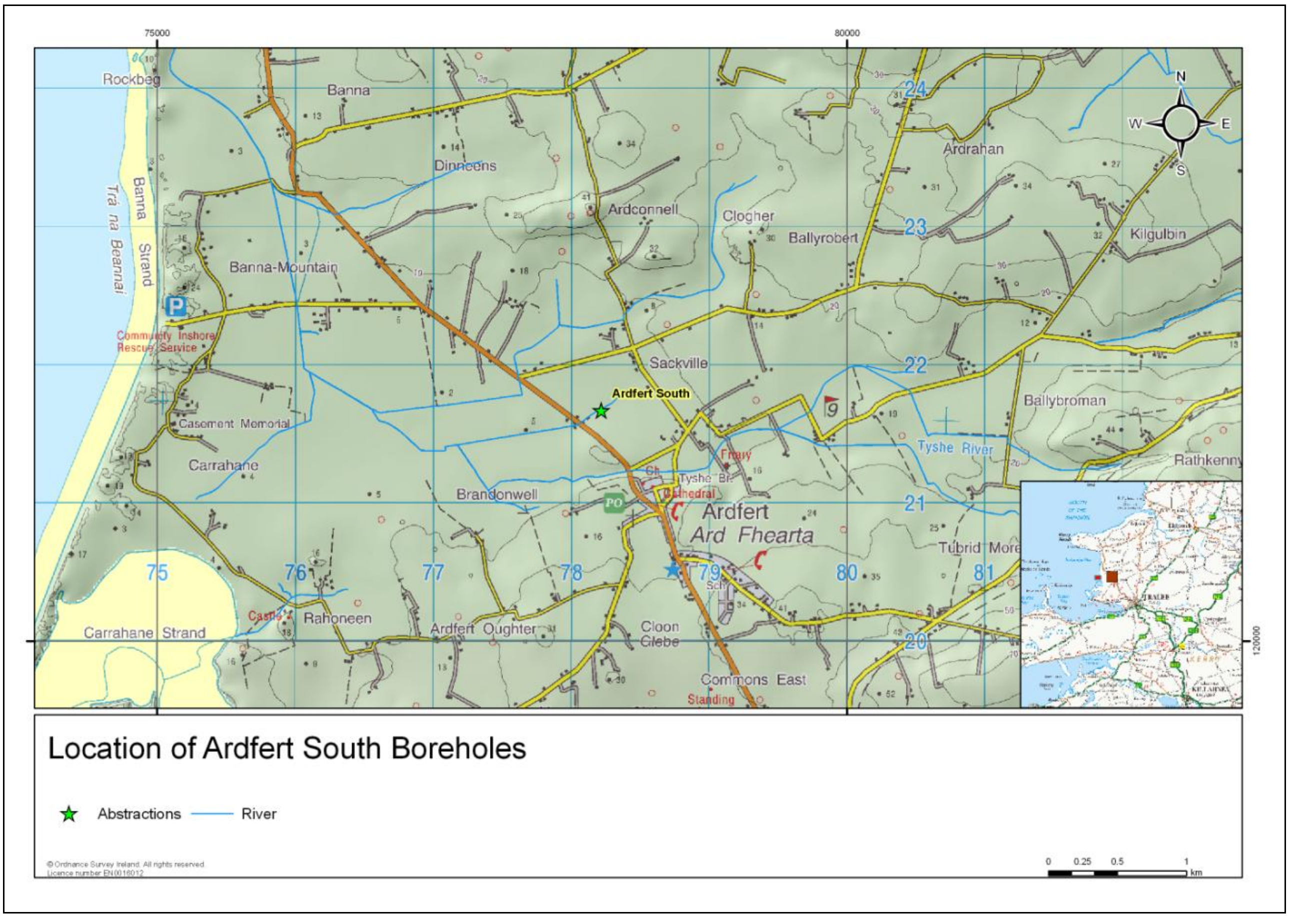
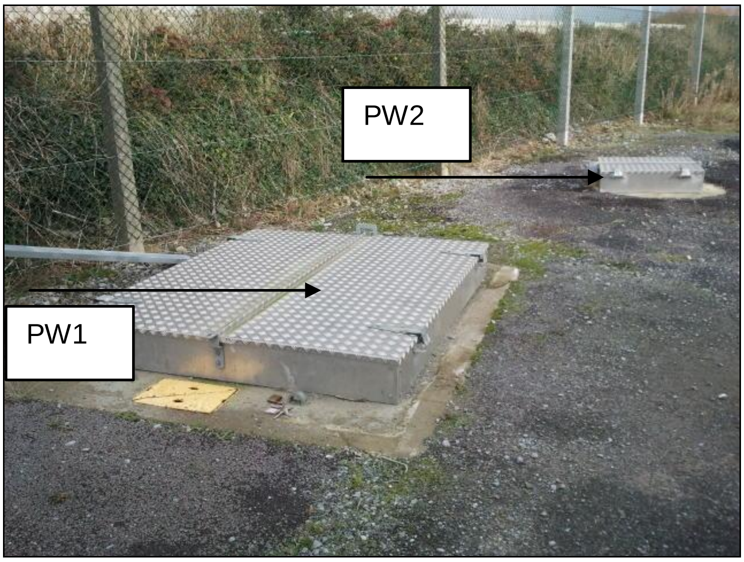


Figure 1 Location Map for Ardfert South Boreholes



Photograph 1 PW1 and PW2 in Site compound

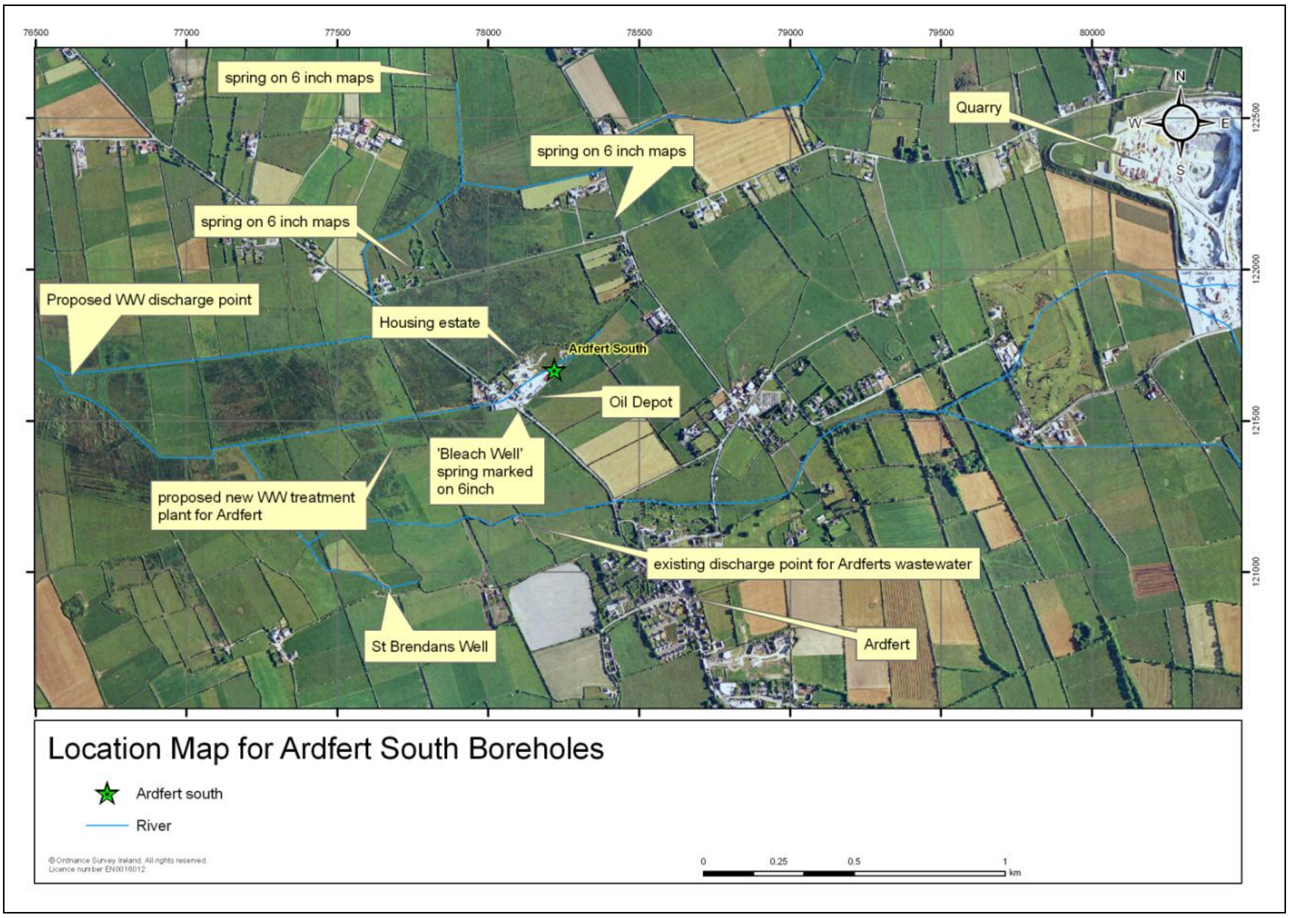
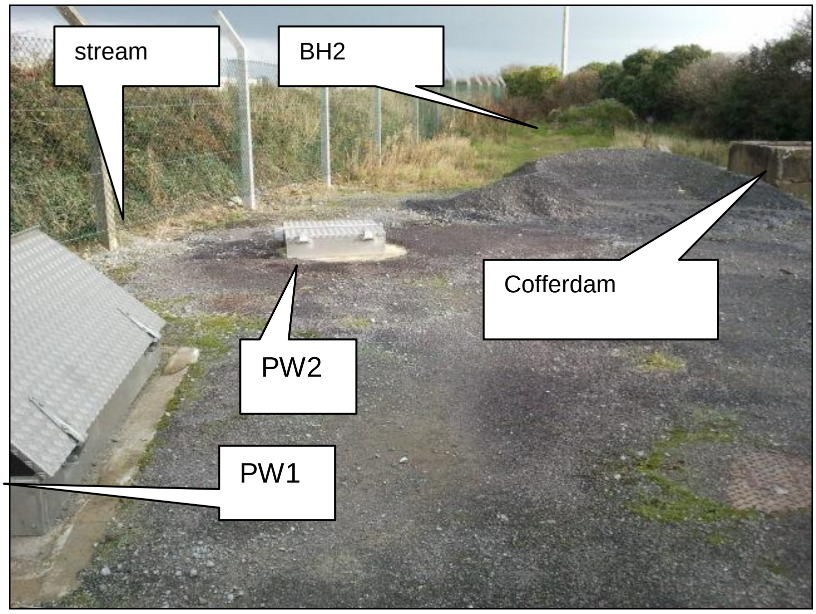


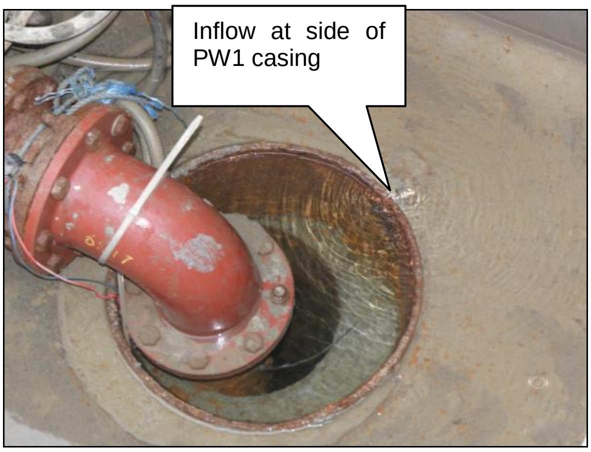
Figure 2 Land use in the vicinity of Ardfert South Boreholes



Photograph 2 PW1, PW2 and Abandoned Boreholes (Cofferdam & BH2) looking north.

Photograph 3 PW1 showing the well head and the dry chamber during pumping (Nov 2011)

Photograph 5 Two boreholes within 'Cofferdam'



Photograph 4 PW1 showing the flooded well head and the chamber — non pumping (Feb 2012)

Photograph 6 'BH2'

4 Summary of borehole details

As indicated PW1 and PW2 are the current abstraction boreholes. Previously, there were a number of other boreholes that are now decommissioned. It is difficult to match what is on site with the 'old' borehole nomenclature in previous reports and council records, the majority of which are either no longer extant.

The following understanding is based on assessing all of the available information and discussions with council personnel. The original source was used as a supply for the local creamery and the earliest council records of it are found in a preliminary water services report from about 1966, which describes 'exhaustion tests' of trial pits, and drilling of three boreholes at the site around 1961 (Kerry County Council, 1966). There is no report describing or logging of the boreholes in the cofferdam which may be the site of the original BH1. It seems that BH2 in the 1966 report is BH2 indicated in Photograph 2 and 6.

Table 1 provides summary details of PW1 and PW2 and what is understood to be BH1 which appears now to be where the 'Cofferdam' is located in which there are two boreholes. The detailed construction of PW1 and PW2 is not known.

Table 1 Summary Borehole details

	Ardfert South PW 1	Ardfert South PW 2	BH 1 (original well)
Drinking Water code	1300PUB1002		
EU Reporting Code			
GSI Geodata number			0511NEW027
Grid reference	E 78148 N 121655	E 78148 N 121660	E 78155N 121664
Townland	Skrillagh		
Source type	Borehole		
Owner	Kerry County Council		
Ground level at borehole	6 mOD	6 mOD	6 mOD
Depth of Borehole	18 m	14 m	18.6 m
Construction	12" steel inner casing 24" outer casing	12" steel inner casing 24" outer casing	Cofferdam – 4 m by 2m by 2 m deep with 2 x 8" boreholes within cofferdam
Drilled	2000 (TJ Cross)	2004 (TJ Cross)	1961
Depth to rock	Approximately 18 to 20m	Approximately 18 to 20m	18.2 m
Static water level (bgl)	Within 1 m of the ground surface	Within 1 m of the ground surface	1.05 m bgl July 1961
Pumping water level Pumping in PW 1 @ 80 m^3/hr	6.62 m bgl 14th Nov 2011	4.4 m bgl	Decommissioned
Pumping water level Pumping in PW 2@ 50 m^3/hr	1.48 m bgl	3.2 m bgl 16th Feb 2012	Decommissioned
Yield	1200-1920 m^3/day	1200-1920 m^3/day	2182 m^3/day
Current abstraction rate (Co Co records)	1200-1920 m^3/day (pump 24 hours per day; alternating boreholes daily) Average demand is approximately 1600 m^3/day (RPS, 2011)		N/A
Specific Capacity (SC)	342 m^3/d/m (using current pumping regime: 1900 m^3/day for a drawdown of 5.6 m; 2011)	545 m^3/d/m (using current pumping regime: 1200 m^3/day for a drawdown of 2.2 m; 2011) …………………… 834 m^3/d/m (3,312m^3/d, drawdown 4m, 44hr test, RPS, 2008)	BH 1 - 750 m^3/d/m (1630 m^3/day for a drawdown of 2.2 m; 1961)
Transmissivity of Gravels	418 m^2/d (Logan estimate:1.22* 342 m^3/d/m)	654 m^2/d (Logan estimate:1.22* 545 m^3/d/m) …………………….. 1017 m^2/d (44hr test, RPS, 2008)	915 m^2/d (Logan estimate (1.22*SC)

5 Topography, surface hydrology and land use

5.1 Topography

The topography around the source comprises a relatively flat plain (<10 m OD), gently rising from the coast towards the east and north, at Ardconnell, Clogher, Ballyrobert and Lerrig. To the west of the boreholes, an extensive, flat floodplain of the Tyshe River extends for 3 km to the coastal sand dunes along Banna Beach. To the south of the river, the land rises gently towards Ardfert village. The topographic gradient is approximately 0.006 in the vicinity of the source, steepening to 0.01 in the vicinity of Ardconnell.

5.2 Surface Hydrology

There are a number of streams, rivers and springs in the area, shown in Figures 1 and 2. Immediately obvious are three streams flowing east to west in the vicinity of the source. The source is located adjacent to the middle stream – an unnamed stream flowing alongside the western boundary of the site compound, seen in Photographs 1 and 2, that originates some 200m west of the boreholes. This stream flows on to meet the Tyshe River, the main surface water feature in the area, flowing from east to west approximately 400 m south of the boreholes, and discharging to the sea at Black Rock on Banna Beach. This stream appears to dry up for much of the year, based on local information and site visits. During the site visit in November 2011 the stream was dry, but it was flowing during the February 2012 visit. There are number of streams that flow east of the higher ground around Ardrahan and Ballybromen indicating that the elevated areas function as surface water divides.

There are a number of springs in the area located on the six inch maps (OSI 1:10,560), shown in Figure 2. One, named Bleach spring, is marked on the OSI 6 inch maps at the source. No evidence of this spring was found during the site visits as the area around its locality was dry. Approximately 1 km to the southwest, a spring known as Brendan's Well emerges immediately to the south of the Tyshe River. There are also a number of small springs between the Clogher and Ardconnell hills that join the stream located approximately 1 km north of the source.

All of the streams and spring outflows join the Tyshe River, approximately 1 km west of the source.

5.3 Land use

Agricultural land use in the vicinity of the source is mainly pasture (Figure 2). Immediately to the north and west of the source, a number of large poorly drained, rough grazing fields are present. Further to the east, fields are large and free draining, with few drainage ditches outside areas of rough ground and agriculture. The boreholes are located in a Local Authority compound with a hard standing base, adjacent to an oil storage facility, garages and workshops. A creamery/warehouse is located to the west of the R551, 200 m west of the source.

An active limestone quarry, with its base at -25 mOD, is located 2 km to the northeast of the boreholes and is shown in Figure 2. The quarry is being dewatered to keep the working areas dry.

A new housing estate comprising 10 houses is located immediately to the northeast of the council compound, across the stream, with its' own wastewater collection treatment system connected to the public sewer. The main part of Ardfert is located south of the Tyshe but it extends north east beyond the Tyshe. All of the village area is connected to the foul sewer network which extends as far as the new housing estate adjacent to the source. A new sewerage scheme is proposed with a locations of a new discharge point and treatment plant shown in Figure 2 (RPS, 2011). However, housing to the north and northeast along the road to the quarry is unsewered. In summary, land use pressures are moderate principally due to the intensive farming.

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 Eiréann.

Annual rainfall: taken to be 1043 mm using nearby historical rain gauge at Ardfert and contoured data map of rainfall (Met Éireann, 1961 to 1990 dataset).

Annual evapotranspiration losses: 475 mm. Potential evapotranspiration (P.E.) in the north Kerry area is estimated to be 500 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 amount of 475 mm.

Annual Effective Rainfall: 568 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. The annual effective rainfall, or potential recharge, is therefore 568 mm/year.

For more discussion on the proportion of effective rainfall that enters the aquifer, see also Section 10 Recharge.

7 Geology

This section briefly describes the relevant characteristics of the geological materials that underlie the area around the Ardfert South Boreholes. It provides a framework for the assessment of groundwater flow and source protection zones. The geological information is based on:

- The Geological Survey of Ireland (GSI) bedrock geological map of Dingle Bay Area, Sheet 20, 1:100,000 Series and accompanying booklet (Pracht *et al*, 1995).
- The GSI Well, Borehole and Karst Databases.
- Teagasc Soils and Subsoils (Teagasc, 2006).
- Water services preliminary report 1966 (Kerry County Council).
- Investigation of Sand and Gravel aquifer by Geophysical Surveying for Ardfert Regional Water supply scheme (Minerex, 1984).
- North Kerry Aquifer Study (Fehily Timoney & Co., 2000).
- Ardfert Sewerage EIS (RPS, 2011).
- Bedrock outcrop and subsoil exposures encountered and mapped during site visits.

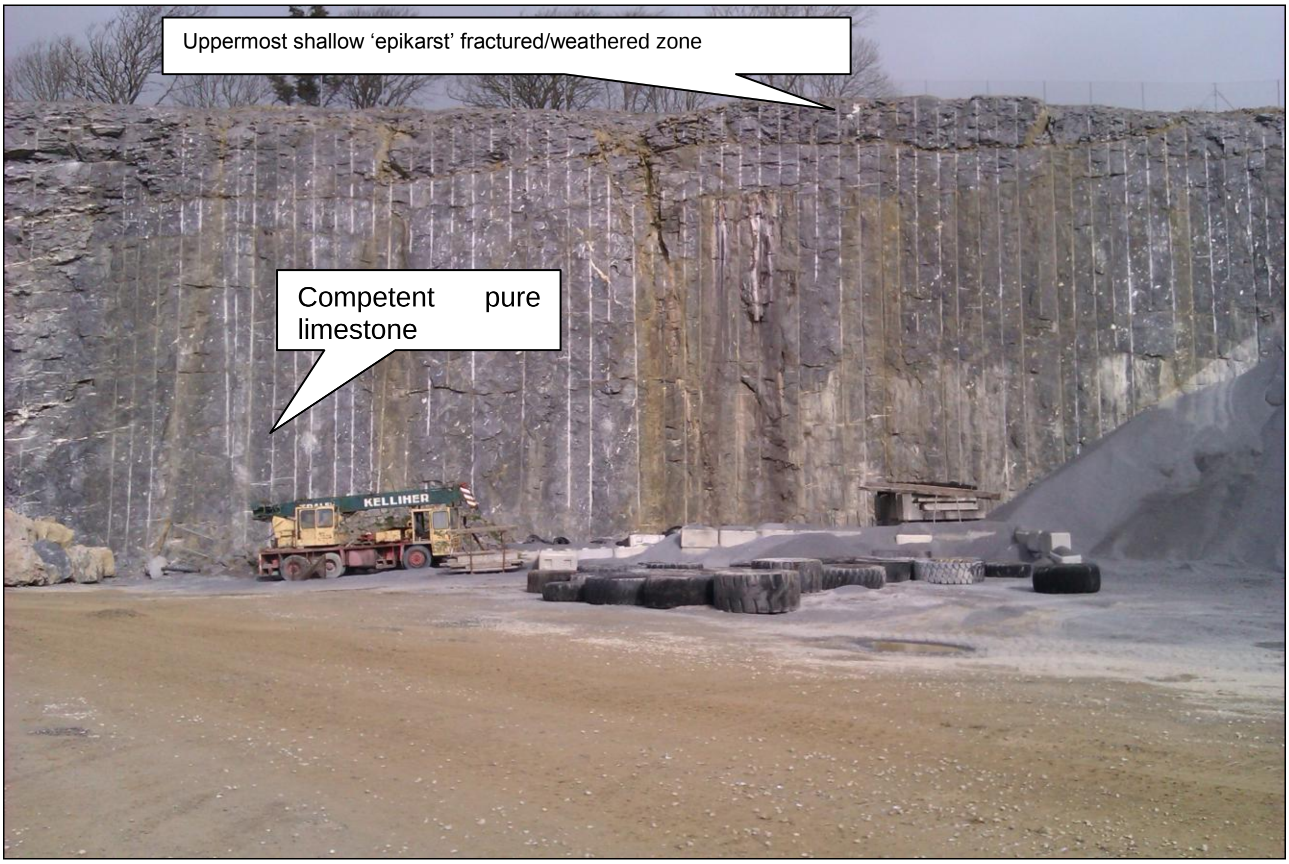
7.1 Bedrock

The bedrock geology, shown in Figure 3, comprises Dinantian Pure Unbedded Limestones, Dinantian Upper Impure Limestones, and Namurian Shales. The source boreholes are located in an area underlain by Dinantian Pure Unbedded Limestones, specifically the Cloonagh Limestone Formation. Dinantian Upper Impure Limestones of the Dirtoge Formation occurs both to the north and south of the source.

Based on the GSI booklet (Pracht et al., 1995) the boundary between these two rock units is well constrained along the coast but less so in the vicinity of the source owing to few bedrock exposures and deep soil/subsoil deposits in the lowermost portions of the landscape. According to the council report, 1966, available from Kerry County Council, bedrock reported at the base of BH1 at 18.3 m consists of *'soft black rock and shale'*. It is possible that the Dirtoge limestones underlie the site as a result of intense folding of the bedrock during the Variscan Orogeny period (>280 million years ago). Approximately 1.8 km to the east of the source, a cross cutting NNW/SSE fault is mapped.

The GSI 6 inch historical bedrock field sheets describe outcrop to the south of the site at Ardfert Village, and correspond to the Cloonagh Formation, as light grey, flaggy limestones. Field mapping for this project shows that the Cloonagh Formation, where exposed in the surrounding area, is karstified in the upper 5 m, as seen in a quarry 2 km to the northeast of the source. The limestone in the quarry is generally competent, massive, unbedded; however subsoil-filled paleokarst features were present in the quarry to -25 mOD. The near vertical paleokarst features appeared to trend northeast-southwest, possibly reflecting the fold/syncline planes. Groundwater discharged from the quarry is reportedly at a rate of approximately 2,500 m^3/day. Photographs of limestone in the quarry faces is shown in Photographs 7 and 8.

Outcrops of Dirtoge Limestone Formation on Clogher Hill, 1.7 km to the northeast of the source, locations of which are given on Figure 3 and shown in Photographs 9, 10, 11, 12 were examined as part of the field mapping. The weathered exposures outcropping in the fields initially appear to indicate that the rocks are significantly karstified, however, fresher deeper 2-4m vertical exposures indicate frequent thinly laminated shales, argillaceous limestones interbedded with thick-bedded, clean limestones. In addition significant folding and faulting are present and the uppermost 1-2 metres appear to be significantly more fractured and weathered than the deeper rock exposed. The clean limestones within the Dirtoge Formation exhibited minor karst solution features.



Photograph 7 East Quarry face

Photograph 8 North and West faces

Photograph 9 steeply dipping thinly bedded shales and impure limestone (Dirtoge Lst Fmn)

Photograph 10 uppermost weathered zone of a purer bed of Dirtoge Lst Fmn

Photograph 11 Dirtoge Lst Fmn; upper most 2m indicate increased weathering and fracturing

Photograph 12 steeply dipping thinly bedded shales and impure limestone (Dirtoge Lst Fmn)

As part of the development of this SPZ report, field-scale mapping was undertaken in the study area by TOBIN Consulting Engineers in February 2012. No swallow holes, dolines or sinking streams were found. To the south of Ardfert village, undifferentiated Namurian bedrock described as black shales and sandstones underlie the hills.

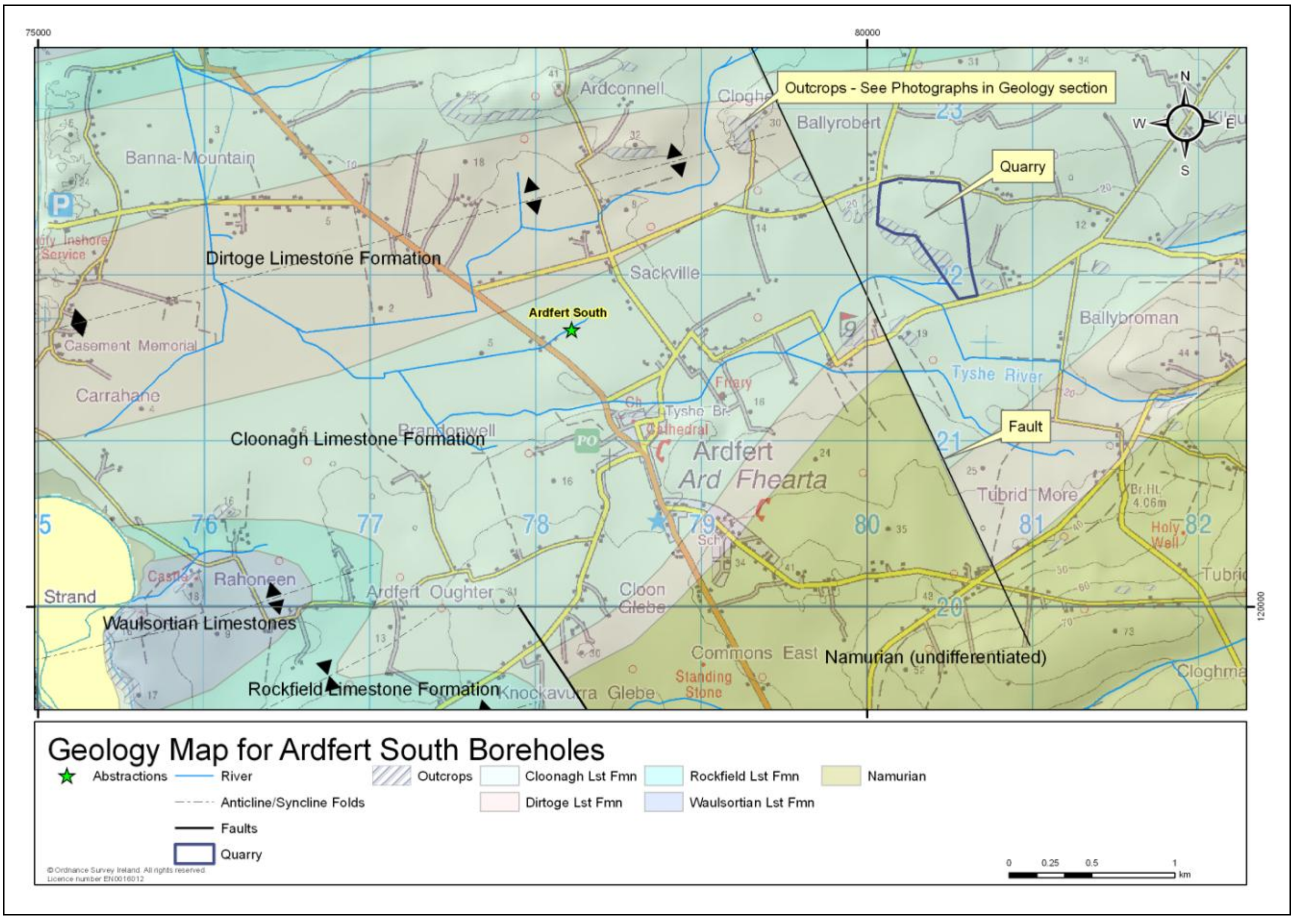


Figure 3 Bedrock Geology in vicinity of Ardfert

7.2 Soils and subsoils

The mapped soils and subsoils are shown in Figure 4 and Figure 5. In general, wet, poorly drained soils and peats occupy the lower areas of the landscape and in particular, the area from the source westwards to the coast. The subsoils are dominated by Till derived from Namurian shales and sandstones (Teagasc, 2006) with cutover peat occupying the lowlying 'wet' area immediately around the source and west toward the coast. Based on field observations the cutover peat is relatively thin, approximately 0.4 m and is underlain by till derived from Namurian shales and sandstones. Shallow rock and outcrops coincide with the higher portions of the landscape and alluvium is present along the Tyshe river. Small exposures into Gravels approximately 2 km east of the source were mapped and are marked in Figure 5. According to the six maps there were a small number of small gravel pits present, shown in Figure 5.

The available information and specifically the Kerry County Council report from 1966, suggest the presence of an interbedded sequence of till and sand and gravel across a '*twelve acre'* site under investigation at the time. Unfortunately there is no map in the report. The information in the report is outlined in Table 2. The report also indicates that there is a deeper sand and gravel lens which is finer grained than the upper sand and gravel lens and that both were fully saturated.

Table 2 Borehole information from Kerry County Council (1966)

Borehole	Horizon	Feet bgl	Metres bgl
BH1	Till	0-3.5	0- 1.1
	Gravel	3.5-14	1.1-4.3
	Till	14-31	4.3-9.4
	Gravel	31-60	9.4-18.3
	Soft Black rock and Shale	60-61	18.3-18.6
BH2	Till	0-11	0-3.4
	Gravel	11-15	3.4-4.6
	Till	15-27	4.6-8.2
	Gravel	27-45	8.2-13.7
BH3	Till	0-15	0-4.6
	Gravel	15-18	4.6-5.5
	Till	18-24	5.5-7.3
	Gravel	24-50	7.3-15.2

Information gathered from the well audit of the area indicated that a borehole drilled in 2011 to 20 m bgl, 0.5 km northeast of the source comprised 10 m of till overlying 10 m of saturated sand and gravels. The Minerex report (1984) also refers to another private borehole approximately 400m northeast of the source that reportedly comprised two layers of gravels at similar intervals to the source boreholes. Site investigation data from the Ardfert Sewerage Scheme EIS (RPS, 2011) though shallow, indicates clayey till over clayey gravels. Based on the information obtained, the sand and gravel deposit at the source comprises two sand and gravel lenses separated by till. However geometry and lateral continuity is not known. It is considered that the deposit rapidly thins eastwards, shown in Figure 5, and it is assumed that over whole of the deposit, that the two lenses are connected.

Based on British Standards 5930 and secondary indicators of subsoil permeability, the tills are classed as '***Moderate Permeability***' in the vicinity of the source. The sand and gravel deposit is classed as '***High Permeability***'.

7.3 Depth to rock

The information available for the source indicates that bedrock is at approximately 18 to 18.5 bgl and some 400 m to the northeast it varies from 13 to 20m. The Minerex report indicates that the depth to bedrock decreases northeastwards. Given the information for the private wells some 400 to 500m northeast of the source it is likely that the depth to bedrock varies over short distances. It is assumed that the general thickness in the relatively flat area in the vicinity of the source is deep and that in line with the inclining topography to the east decreases, and dramatically decreases approaching the 20m topographic contour.

Bedrock is at or close to the surface immediately to the south of the Tyshe River, 0.4 km south of the source, as well as underlying Ardfert Abbey. On the hill crests to the north and northeast, bedrock outcrop or rock close to the surface is also mapped.

It is considered that a saturated sand and gravel deposit interbedded with till up to 18m to 20m thick (in total including the till units) occurs in a low lying trough orientated northeast – southwest, bounded by rock cored higher ground to the north, northeast and south. This is shown in Figure 5.

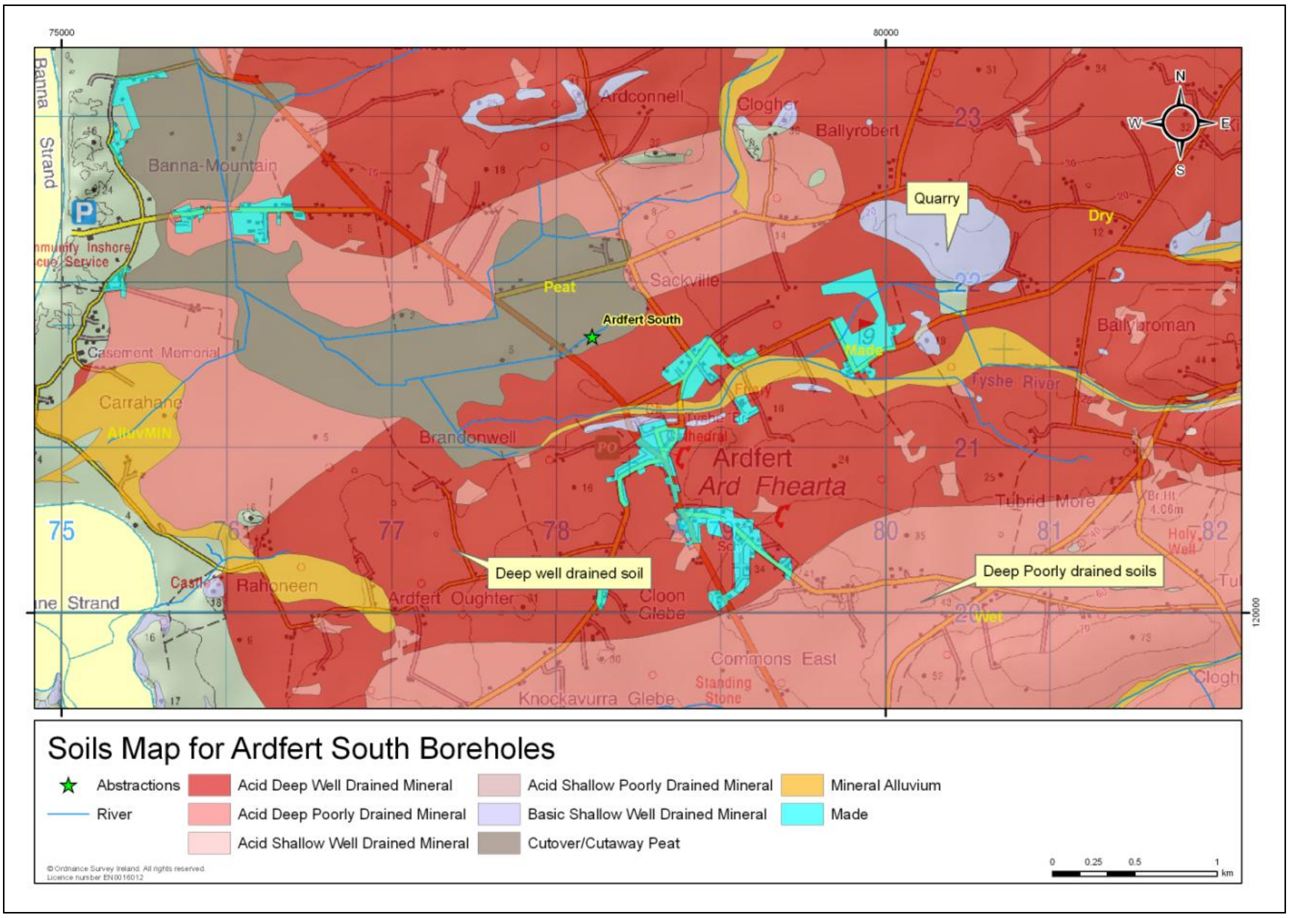


Figure 4 Soils in the vicinity of Ardfert

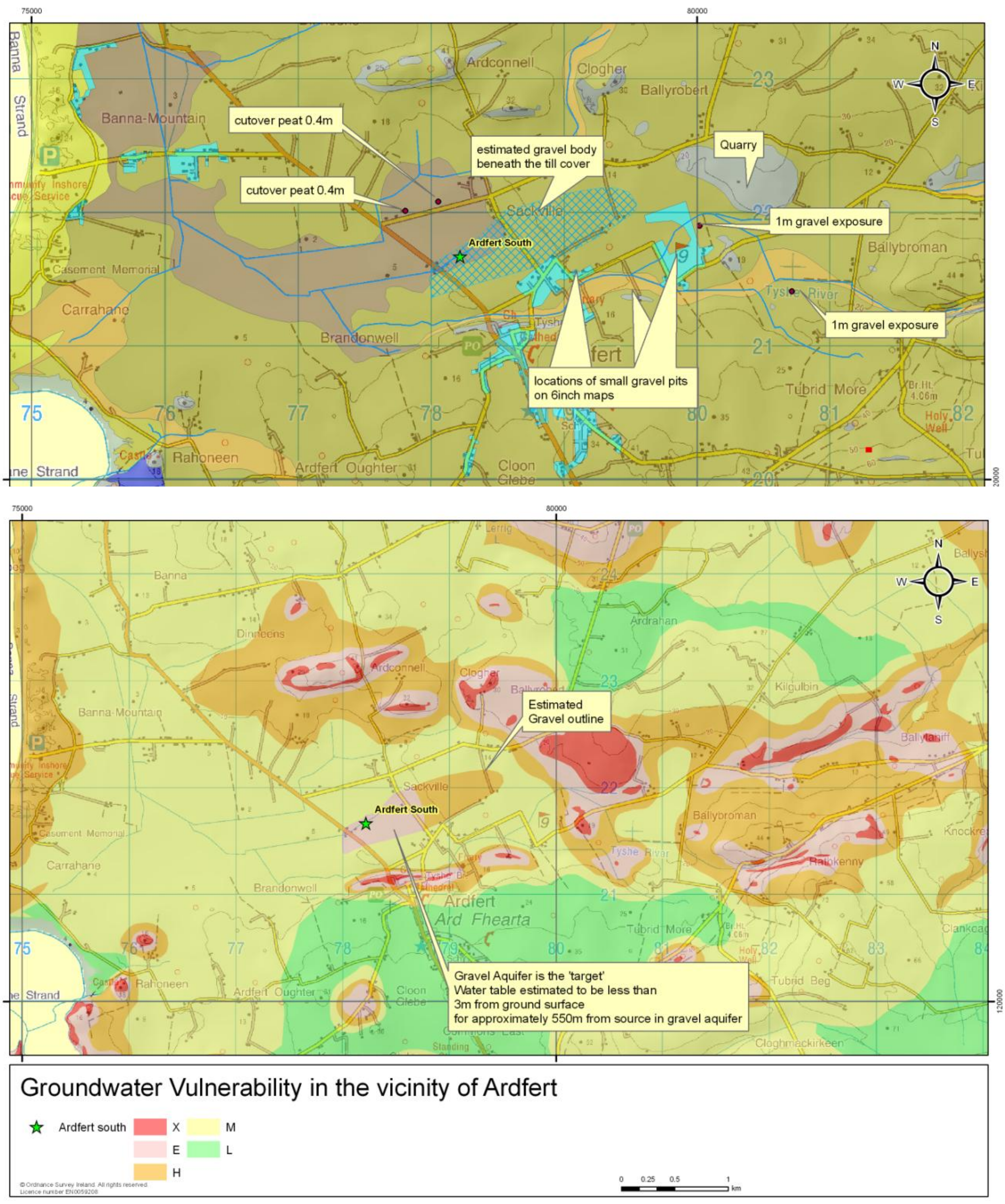


Figure *6*.

Across the crests and upper flanks of the Clogher and Ardconnell hills, the vulnerability is mapped as 'Extreme', which includes the area that is designated as rock at or close to surface. These areas are denoted as 'X - Extreme' vulnerability. Areas of high vulnerability are present on the upper backslopes of the hills north and west of the source, becoming 'Moderate' as the tills deepen towards the lowland areas and surrounding the source.

For the purposes of vulnerability mapping, in the immediate vicinity of the source, the sand and gravel aquifer is the target and therefore the “water table” is measure of vulnerability. In the vicinity of the source the water table is within 1 m of the ground surface, therefore ‘***extremely’*** vulnerable. Using the topographic gradient and the estimated gradient in the sand and gravel it is estimated that the water table is within 3 m of the surface for approximately 550 to 600 m to the east and northeast. There is uncertainty due to the unknown extent of the gravels. This calculation is shown in Table 3, which assumes a relatively flat groundwater gradient in the gravels of 0.001. For the remaining portion of the gravel deposit the groundwater vulnerability is considered ‘**high**’.

Table 3 Estimation of depth to water table in sand and gravel aquifer

slope (i) = opposite / adjacent							
slope (i) * adjacent = opposite							
		1m	150m	250m	300m	550m	600m
water i	0.001	0.001	0.15	0.25	0.3	0.55	0.6
topo i	0.00641	0.00641	0.9615	1.6025	1.923	3.5255	3.846
difference		0.00541	0.8115	1.3525	1.623	2.9755	3.246

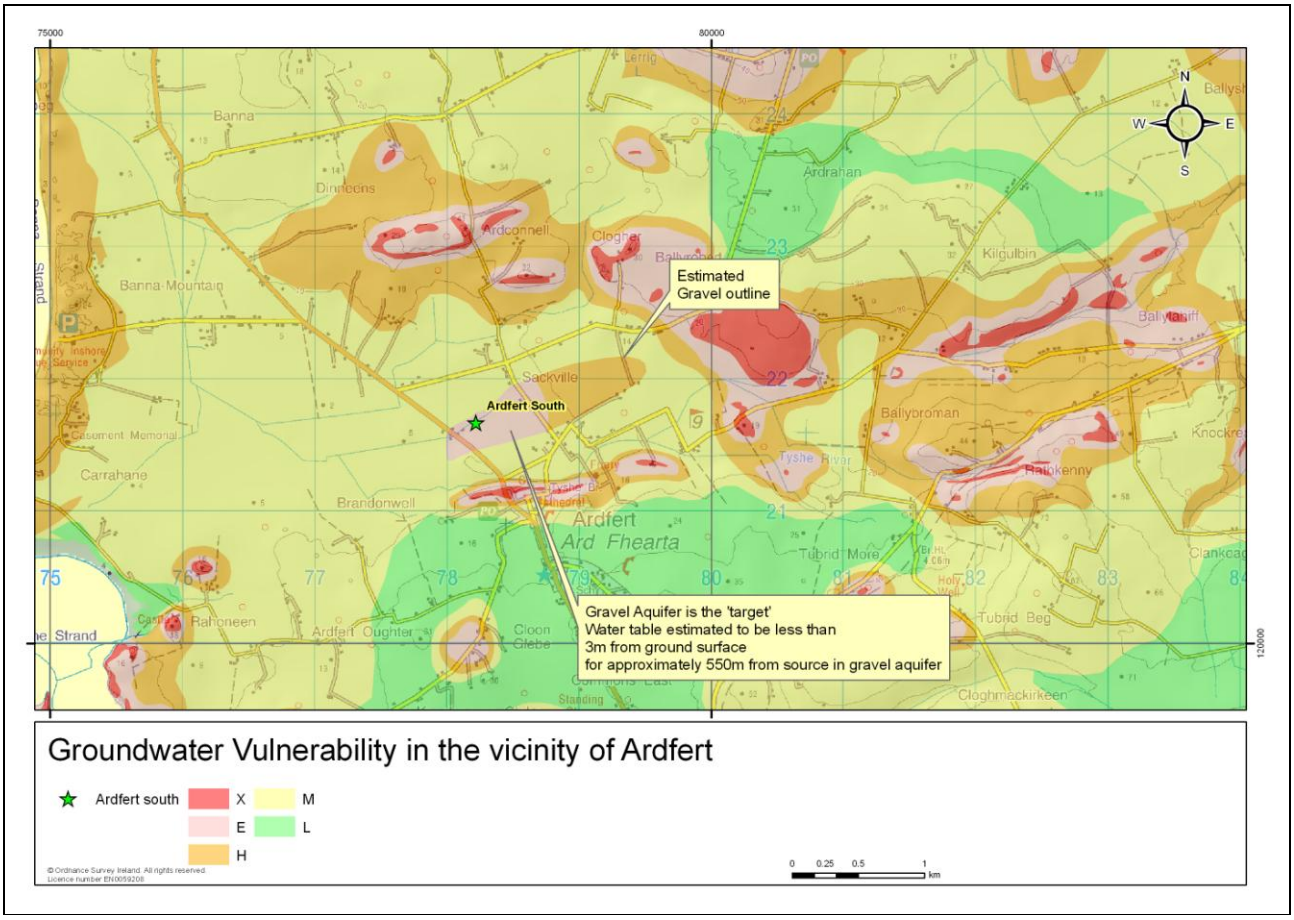


Figure 6 Groundwater Vulnerability in the vicinity of Ardfert

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 databases
- Local Authority Drinking Water returns
- Ardfert Sewerage Scheme EIS (RPS, 2011)
- North Kerry Aquifer Study (Fehily Timoney & Co, 2000)
- Minerex (1984) "*Investigation of Sand and Gravel Aquifer by Geophysical Surveying for Ardfert Regional Water Supply Scheme, Co. Kerry.*"
- Kerry County Council – water services preliminary report 1966.
- Hydrogeological mapping by TOBIN Consulting Engineers in 2011 and 2012.

9.1 Groundwater body and status

The source is located in the Ardfert Groundwater Body, a karstified bedrock Groundwater Body (GSI, 2010). However, the boreholes abstract from a sand and gravel deposit which is not defined as a separate Groundwater Body. The Ardfert Groundwater Body is classified as having 'Poor Status', failing principally due to related surface water tests (Tyshe River water body) for nutrient loadings and for the Drinking Water Status tests; however, it no longer fails this latter test, revised in 2011. For the general groundwater quality test the Groundwater Body is at Good Status (high confidence) (www.wfdireland.ie; www.watermaps.wfdireland.ie).

9.2 Groundwater levels, flow directions and gradients

The static water level at the source is within 1m of the ground surface and the original 'Bleach Well' marked in Figure 2 indicates that groundwater originally issued at ground surface. The stream that flows adjacent to the source is groundwater fed and the static water level is similar to the level in the stream. It is considered that this area is a groundwater discharge zone.

Groundwater levels in PW1 (November 2011) were 6.62 m bgl while PW1 was being pumped at a rate of 80 m^3/h. Groundwater levels in PW2 (February 2012) were 3.2 m bgl while PW2 was being pumped at 50 m^3/h (Table 1). Pumping levels are approximately 2-4 m below the level in the adjacent stream when it is flowing. It is assumed that conditions are unconfined, and that there is hydraulic connection between the sand and gravel deposit and the river and the underlying bedrock.

As indicated by the three main streams in the vicinity of the source, shown in Figures 1 and 2, the regional surface water flow direction is mainly to the west-southwest with the biggest stream being the Tyshe. It is assumed that the main groundwater flow direction is subparallel to the surface water direction with more localised components toward each of the streams.

The area immediately around the source is considered to be a groundwater discharge zone and it is assumed that there is an upward gradient at the site due to the groundwater entering the well chamber for PW1 (Photograph 4) and that there was a spring (Bleach Well) at the site and that a stream originates in the vicinity of the site. Across the estimated extent and assumed geometry of the sand and gravel deposit the water table is assumed to be relatively flat and estimated to be approximately 0.001. It is also considered that groundwater in the bedrock enters into the sand and gravel deposit.

9.3 Hydrochemistry and water quality

Hydrochemical analyses are available from the Local Authority and the EPA. The EPA have recently included Ardfert in the Groundwater Monitoring suite and there are 3 EPA untreated groundwater monitoring samples available, taken during 2010. The readily available Local authority data comprises data from 1993 to 2009. The data up to 2004 is assumed to cover the older boreholes and since 2004 the data is for PW1 and PW2. Groundwater samples taken show that the water is very hard, with total hardness values of 255–388 mg/l (equivalent CaCO3) and electrical conductivity (EC) values of 532–795 µS/cm (average 745 µS/cm), indicating that the groundwater has a calcium bicarbonate hydrochemical signature (EPA data). Alkalinity ranges from 288 to 332 mg/l CaCO3. The pH ranges 7.1–7.8, with an average of 7.3, which is slightly alkaline. Figure 7 shows the data for the key indicators of contamination and the main points are as follows:

- Nitrate concentrations range from 20.5 to 41.7 mg/l with a mean of 30 mg/l, from a total of 90 samples over 1993 to 2010. The mean is less than the groundwater Threshold Value (Groundwater regulations S.I. No. 9 of 2010) of 37.5 mg/l and there are no peaks above the standard (50 mg/l) set out in the Drinking Water Regulations (S.I. No. 278 of 2007). Over the entire dataset, since 1993, there is a downward trend in the data, as illustrated in Figure 7. The nitrate concentrations suggest that unconfined conditions are present around the boreholes.

- 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 40 to 50.5 mg/l with a mean of 46.5 mg/l. Given that the boreholes are approximately 3 km from the coast and are positioned at a low elevation it is likely that the elevated concentrations are due to the proximity to the coast.

- The highest 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.

- 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 Potassium: Sodium (K:Na) ratio is low at less than 0.1. Based on the data available, concentrations of sulphate, potassium, sodium, magnesium and calcium are within normal ranges.

- Faecal coliforms counts exceeded 0 counts per 100ml in 4 of the 22 samples available but none were greater than 100 counts per 100ml (indicative of gross contamination) and there have been no detections since 2002. Total coliforms were detected in 13 of the 22 samples available; the majority of the exceedances and higher counts were prior to the new boreholes being installed. PW1 and PW2 were installed in 2004 with greater improved wellhead protection than the previous boreholes on site.

- The concentrations of trace metals are low and / or below laboratory detection limits or within normal ranges expected. Iron, Manganese and Ammonia concentrations were below the standard set out in the Drinking Water Regulations (S.I. No. 278 of 2007).

In summary, the general groundwater quality is good, and bacteriological exceedances are associated with historical data relating to the older boreholes which had relatively poor well head protection. Chloride concentrations appear to be reflective of coastal location and low elevation. Nitrate concentrations are likely to be reflective of agricultural and on-site wastewater treatment systems pressures across the catchment and suggest unconfined groundwater conditions.

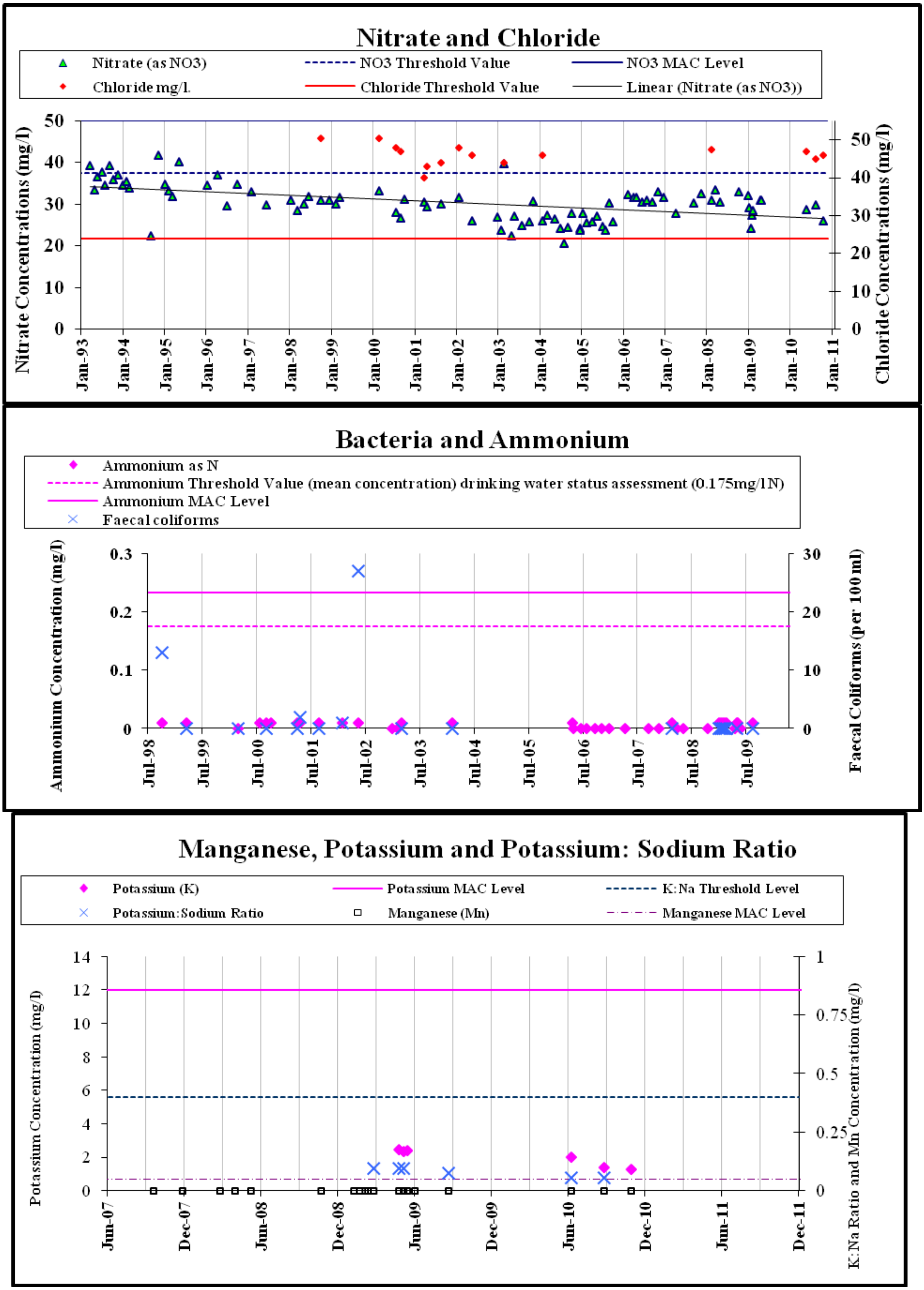


Figure 7 Key Contaminant Indicators at Ardfert South Boreholes

9.4 Gravel Aquifer characteristics

The boreholes PW1 and PW2 are 'Excellent' yielding boreholes abstracting from a Locally Important Sand and Gravel Aquifer (Lg). The available geological information suggest that there are two sand and gravel lenses present, separated by a till unit. However, it is not known what the geometry is across any distance; the logs indicate considerable variability over short distances and anecdotal information suggests just one gravel lens is present to the northeast of the site. Both gravel lenses are saturated and it appears from the known construction details that PW1 and PW2 are lined and grouted, suggesting that the lower sand and gravel lens is the main contributing zone in the immediate vicinity of the boreholes. The static water level is close to ground surface and the pumping water level varies from 3 to 6 m approximately below the ground surface depending on which borehole is pumping. The sand and gravel deposit is considered to be unconfined in the vicinity of the boreholes, due to the hydrochemistry, the variability of the sand and gravel lenses and the unknown geometry. Given the rapid lateral changes, that both sand and gravel lenses are likely to be connected and part of the one overall deposit, and the overall size of the deposit which is relatively small, the gravel lenses are considered as one. It is considered that the deposit occurs in a low lying trough orientated northeast – southwest, bounded by rock cored higher ground to the north, northeast and south. The aquifer map is given in Figure 9.

Data on the specific capacity and transmissivity are given in

	Ardfert South PW 1	**Ardfert South PW 2**	**BH 1 (original well)**
Drinking Water code	1300PUB1002		
EU Reporting Code			
GSI Geodata number			0511NEW027
Grid reference	E 78148 N 121655	E 78148 N 121660	E 78155N 121664
Townland	Skrillagh		
Source type	Borehole		
Owner	Kerry County Council		
Ground level at borehole	6 mOD	6 mOD	6 mOD
Depth of Borehole	18 m	14 m	18.6 m
Construction	12" steel inner casing 24" outer casing	12" steel inner casing 24" outer casing	Cofferdam – 4 m by 2m by 2 m deep with 2 x 8" boreholes within cofferdam
Drilled	2000 (TJ Cross)	2004 (TJ Cross)	1961
Depth to rock	Approximately 18 to 20m	Approximately 18 to 20m	18.2 m
Static water level (bgl)	Within 1 m of the ground surface	Within 1 m of the ground surface	1.05 m bgl July 1961
Pumping water level Pumping in PW 1 @ 80 m^3/hr	6.62 m bgl 14th Nov 2011	4.4 m bgl	Decommissioned
Pumping water level Pumping in PW 2@ 50 m^3/hr	1.48 m bgl	3.2 m bgl 16th Feb 2012	Decommissioned

Yield	1200-1920 m^3/day	1200-1920 m^3/day	2182 m^3/day
Current abstraction rate (Co Co records)	1200-1920 m^3/day (pump 24 hours per day; alternating boreholes daily) Average demand is approximately 1600 m^3/day (RPS, 2011)		N/A
Specific Capacity (SC)	342 m^3/d/m (using current pumping regime: 1900 m^3/day for a drawdown of 5.6 m; 2011)	545 m^3/d/m (using current pumping regime: 1200 m^3/day for a drawdown of 2.2 m; 2011) …………………… 834 m^3/d/m (3,312m^3/d, drawdown 4m, 44hr test, RPS, 2008)	BH 1 - 750 m^3/d/m (1630 m^3/day for a drawdown of 2.2 m; 1961)
Transmissivity of Gravels	418 m^2/d (Logan estimate:1.22* 342 m^3/d/m)	654 m^2/d (Logan estimate:1.22* 545 m^3/d/m) …………………….. 1017 m^2/d (44hr test, RPS, 2008)	915 m^2/d (Logan estimate (1.22*SC)

Table 1. The original BH1 indicated a yield of 2182 m^3/d with little drawdown reported. According to the 1966 Kerry County Council report an attempt to pump test BH1 was conducted in 1961, and the report suggests highly productive gravels present. The abstraction rate was 1600 m^3/d, with drawdown recorded at 2.2 m, giving a specific capacity of 750 m^3/d/m.

Data based on the current pumping regime for PW1 and PW2 indicate that the specific capacity is 340 to 545 m^3/d/m. Figure 9 is a plot showing specific capacity against discharge in 2011 and in 2012 which is a measure of ‘productivity’, developed by GSI (Wright, 1997). It takes account of drawdown, rather than relying on yield alone. The source plots in Class I, indicating a highly productive aquifer. A pumping test in 2008 (RPS, 2008) used PW2 as the pumping well and it discharge 3,312 m^3/d for 44 hours with a drawdown of 3.97 m in the pumping well. This indicates a specific capacity of 834 m^3/d/m.

The data indicate that equilibrium conditions are reached rapidly thus it useful to estimate the aquifer properties using equilibrium methods of approximation such as Logan (Misstear, 1998). Transmissivity based on the specific capacity for the current pumping regime indicates values of approximately 400 to 650 m^2/day. The pumping test (RPS, 2008) indicates a transmissivity of 1,000 m^2/d, using Logan. Transmissivity ranges from approximately 400m^2/d to 1000 m^2/d.

Based on the geological information the vertical thickness of the sand and gravel at the source ranges from approximately 7 m to 12 m. Therefore the permeability ranges from 35 to 90 m/day; 50 m/d is used for estimating velocity.

According to the Local Authority the current pumping regime comes under strain in dry summers, which appears evidenced by increasing drawdown probably due to a combination of demand and possibly indicating the limited extent of sand and gravel and also possibly an influence of dewatering at the quarry.

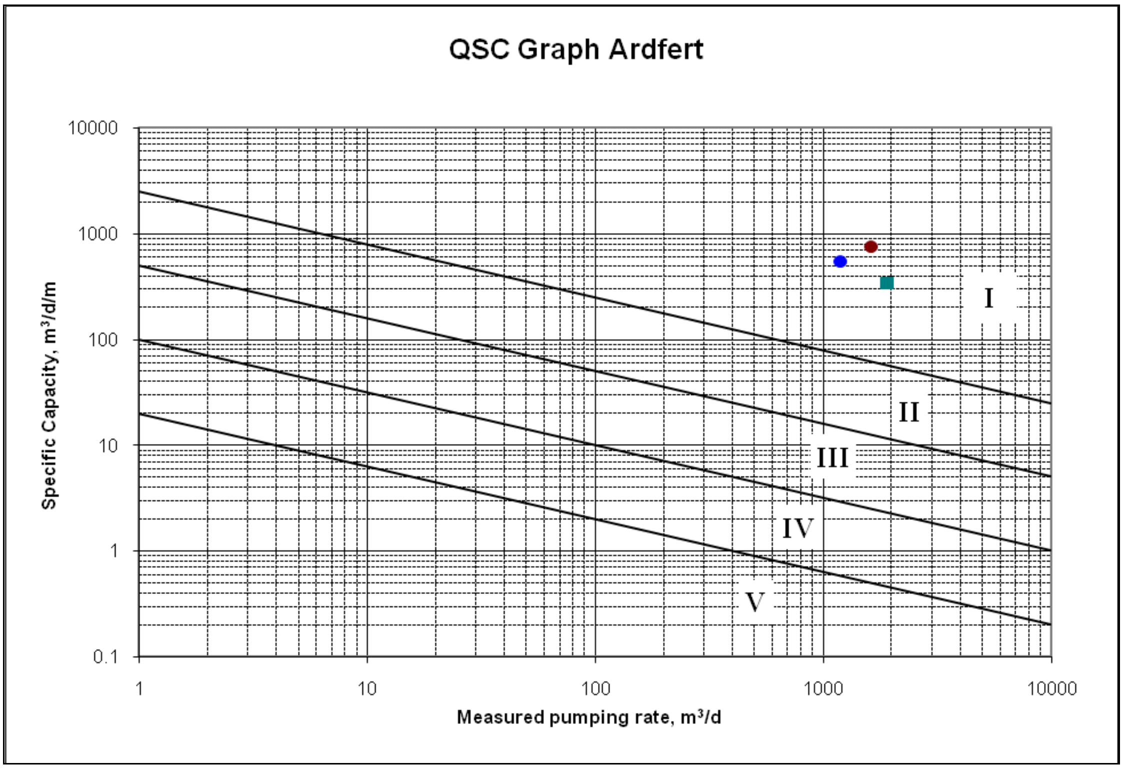


Figure 8 QSC Graph: Ardfert South Boreholes (sand and gravel)

9.5 Bedrock Aquifer characteristics

The sand and gravel deposit is located on limestone bedrock, classed as a Regionally Important Karst Aquifer (Rk_d), *i.e.*, dominated by diffuse rather than conduit flow. There are no hydrogeological data available for the Cloonagh Limestone of the Dinantian Pure Unbedded rock unit group in the area. The nearby quarry is active and being dewatered – approximately 2500 m^3/d on average but there are no detailed information on this. The base of the quarry is at -25mOD. In general the limestone is competent and pure with areas of the quarry apparently fractured and broken and potentially dolomitised. The uppermost portion is fractured to a greater extent. The relatively impure Dirtoge limestones (Dinantian Upper Impure Limestones) occupying the area to the north of the source are classed as a Locally Important Aquifer (Ll) and field observations indicating frequent and extensive shale bands appear to support this classification. There is no hydrogeological information on the main fault cross cutting the Cloonagh Limestone between the source and the quarry but is assumed not to be a hydraulic barrier.

Using an range of values for K, estimates of the radius of influence range considerably. It is quite likely given the level of the sump and the rock type that the zone of influence could extend several hundred metres west, at least to the NW-SE trending fault. This estimate is used to give a likely groundwater divide that currently exists under the current pumping regime. It is unlikely that flow east of the quarry flows past the quarry to the source. There is considerable uncertainty on the position of the groundwater divide. It is likely that the ZoC for the source overlaps with the radius of influence of the quarry.

The aquifer map is given in Figure 9.

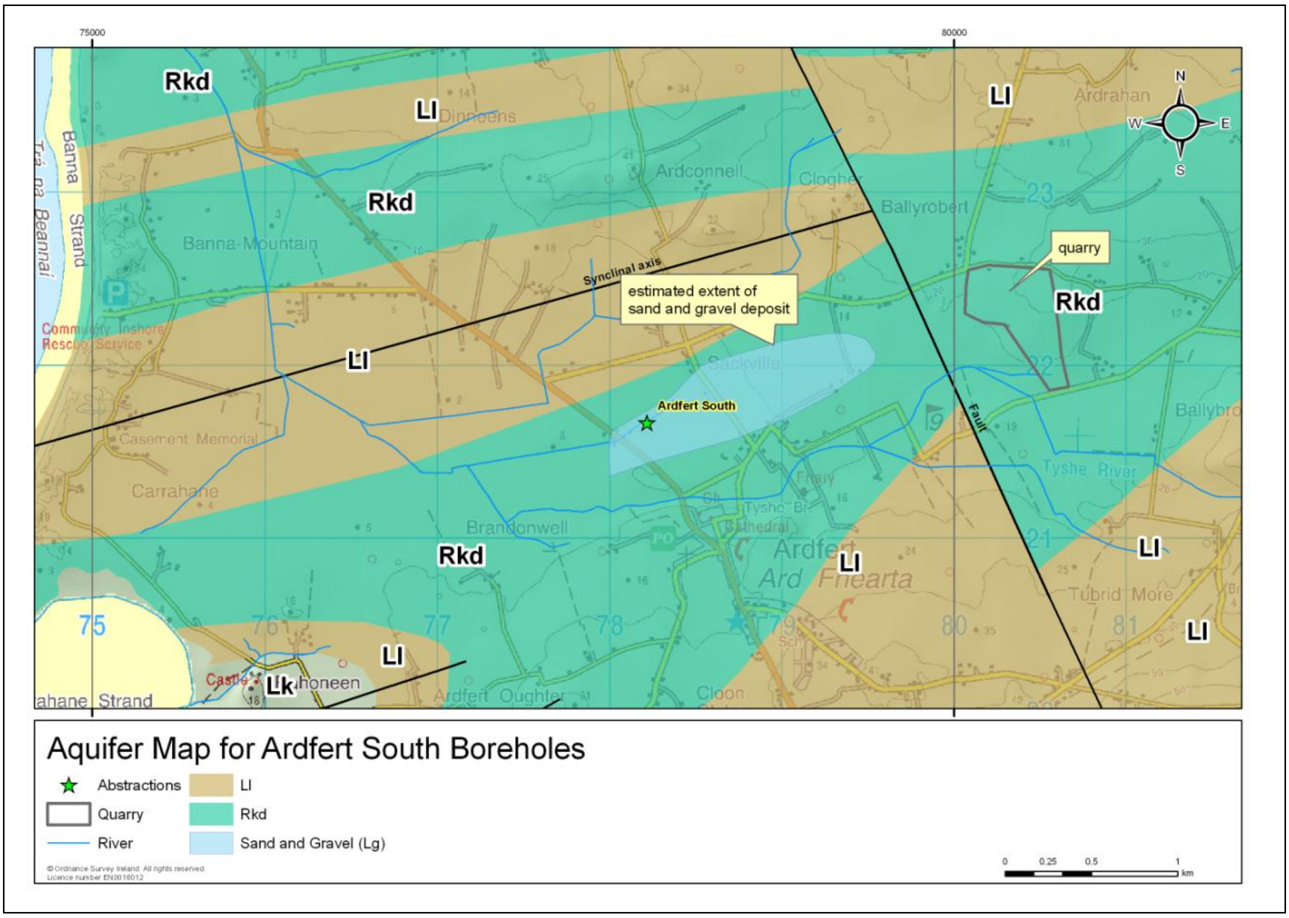


Figure 9 Aquifer Map for Ardfert South

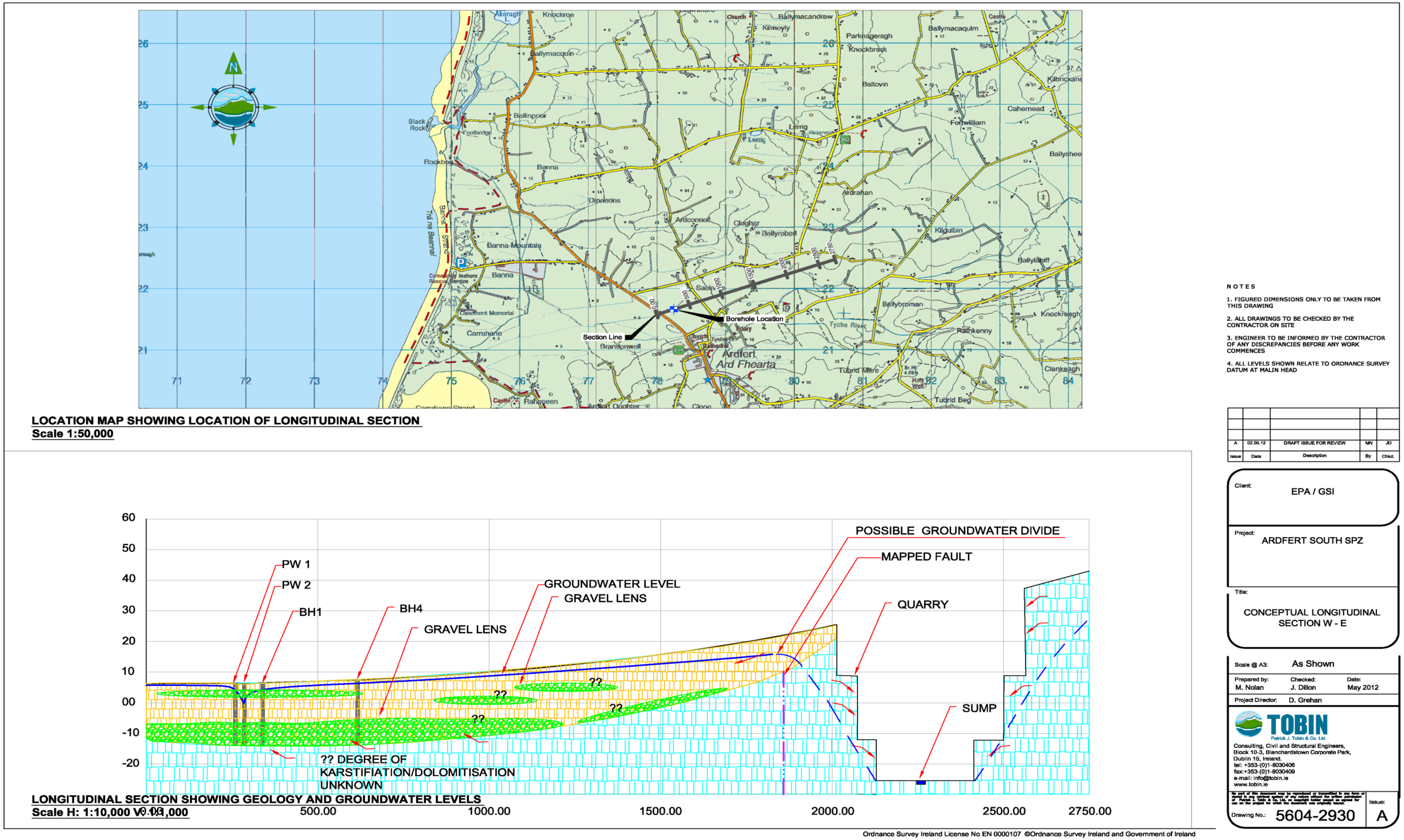


Figure 10 Cross Section illustrating conceptual model for Ardfert South Boreholes

10 Zone of contribution

10.1 Conceptual model

The current understanding of the geological and hydrogeological situation is given as follows. A schematic cross-section illustrating the conceptual model is shown in Figure 10. The source comprises two adjacent boreholes pumping alternatively, abstracting water from a sand and gravel deposit that is located on a limestone bedrock aquifer, occupying a relatively low lying area close to the coast. The full extent, geometry and nature of the sand and gravel deposit is unknown though it is considered based on the available information to occur in a low lying trough orientated northeast – southwest, underlain and bounded by an elevated rock-cored limestone bedrock catchment to the north, northeast and south. The limestone bedrock also underlies the sand and gravel. It is considered that the boreholes are located to the western end of the sand and gravel deposit in a groundwater discharge zone. It is considered that the regional groundwater flow is to the southwest. Recharge occurs directly from rainfall infiltrating to the gravel aquifer and from the surrounding bedrock. It is considered that the majority of groundwater flow is derived from the northeast and east with little contribution from the relatively impure limestones to the north of the source. It is likely given the depth, location and nature of the limestone in the quarry that the radius of influence overlaps with the zone of contribution to the source. It is not known where the current groundwater divide may be. The boundaries to the zone of contribution, described below are considered to represent the most likely zone of contribution.

Uncertainty exists in relation to the geometry and lateral extent of the sand and gravel aquifer and the nature of the bedrock in vicinity of the boreholes beneath the sand and gravel deposit. Uncertainty exists in relation to groundwater flow across the faulted boundary where a cross cutting fault is present, and groundwater flow within the bedrock aquifer surrounding the limestone quarry.

10.2 Boundaries

The boundaries of the area contributing to the source are considered to be as follows and shown in Figure 11.

The **Western boundary** is the downgradient boundary and is based on a combination of hydrogeological mapping and the uniform flow equation (Todd, 1980) and the estimated extent of the sand and gravel deposit.

The uniform flow equation (Todd, 1980) can take the form: $xL = Q / (2\pi * T * i)$, where:

> **Q** is the daily pumping rate (1200-1900 m^3/d with an average of 1600 m^3/d). According to the GSI guidelines a 150% of the abstraction rate is used for delineating SPZ's. In this case the average pumping rate is used, which gives a rate of 2400 m^3/d.
>
> **T** is Transmissivity (415-1000 m^2/d).
>
> **i** is the background non-pumping gradient (0.001).
>
> **xL** is the estimated downgradient extent that groundwater can be drawn from.

In this case, downgradient distance is taken to be the currently mapped position of the western boundary of the deposit, as the estimate of the downgradient distance is approximately 380 m which extends beyond the edge of the deposit, approximately 250 to 320m west of the source boreholes.

The **Southern boundary** is based on topography and the extent of the sand and gravel body and conceptualised flow lines. There is considerable uncertainty to this boundary.

The **Eastern boundary** is difficult to delineate. It is considered that there is overlap between the radius of influence of the active dewatering quarry and the zone of contribution to the gravels and hence to the source boreholes, but there is no information available on the likely position of the divide. It is not known what influence the fault has on the hydraulic behaviour. It is assumed that the boundary extends to the fault and an arbitrary 100m buffer is applied. There is considerable uncertainty to the boundary.

The **Northern and Northeastern boundaries** are based on a combination of topography and geology. It is assumed that the impure limestones to the north inhibit flow. The topographic divide at Clogher hill and in Ballyrobert townland is considered to coincide with the groundwater divide. Between this point and the source the geological boundary is used with an arbitrary boundary of 100m which is broadly coincident with the topographic divide (along the road). This allows for shallow groundwater flow and overland flow across the impure limestones into the purer limestones and the sand and gravel deposit.

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).

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 1. Taking account of the vulnerability across the zone of contribution the bulk recharge is estimated to be approximately 70%. These calculations are summarised as follows:

Average annual rainfall (R)	1043 mm
Estimated P.E.	500 mm
Estimated A.E. (95% of P.E.)	475 mm
Effective rainfall	568 mm
Recharge coefficient	70%
Recharge	**398mm**

Water balance: The area described above and shown in Figure 11 is 1.5 km^2, which is sufficient to support the current average pumping rate of 1600 m^3/d but insufficient to meet 150% of the current average abstraction rate of 2400 m^3/d. At this upper abstraction estimate the area and recharge would provide 70% of the abstraction.

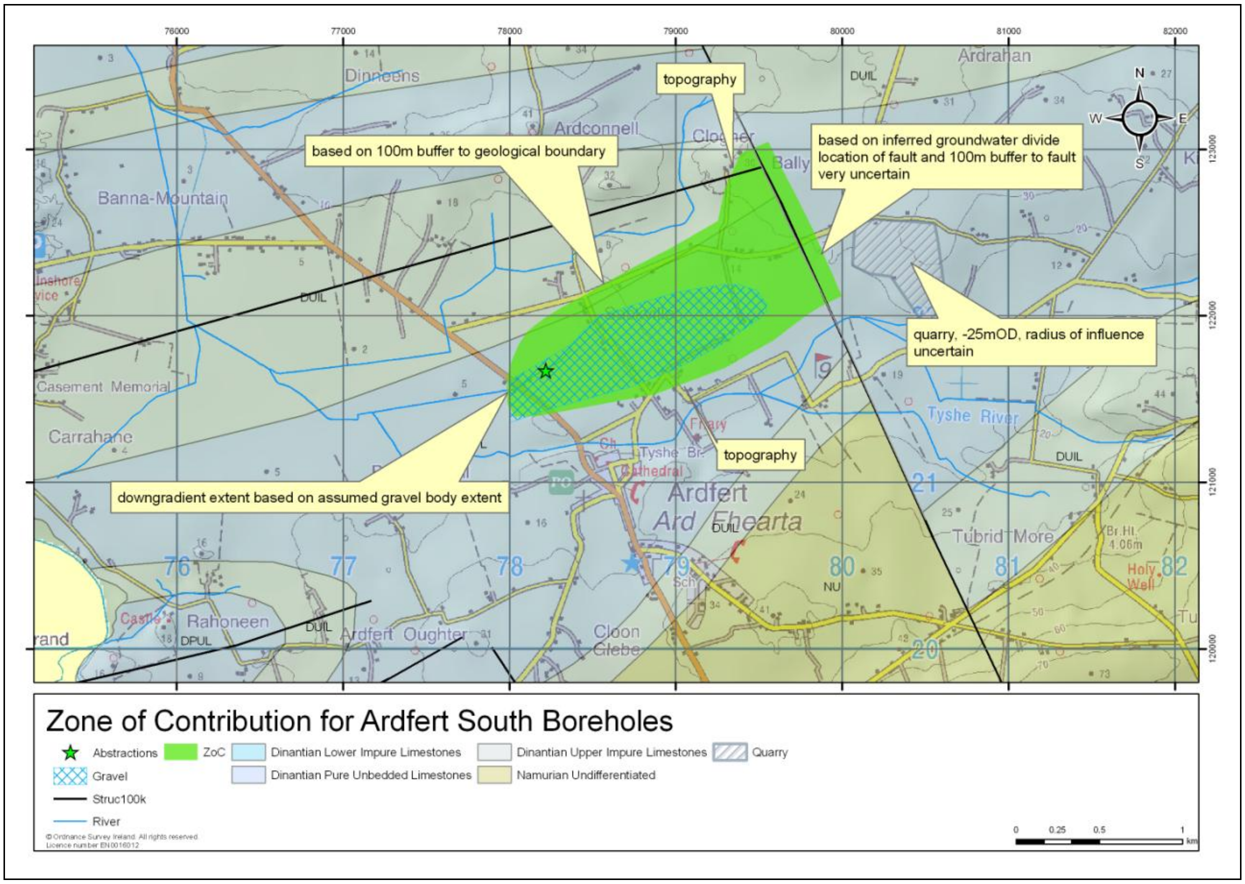


Figure 11 Zone of Contribution to Ardfert South Boreholes

11 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 12.

The **Outer Protection Area (SO)** encompasses the entire zone of contribution to the source, described in the previous section.

The **Inner Source Protection Area (SI)** 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 source is calculated from the velocity of groundwater flow in the sand and gravel.

The velocity is estimated using the following equation:

V (velocity, m/d) = k (permeability sand and gravel, m/d) * i (water table gradient) / n (porosity)

For the purposes of this report 50 m/d is used which gives a 100 day time of travel of 50 m, based on a porosity of 10%, gradient of 0.001.

The groundwater source protection zones are shown in Figure 13, and are based on an overlay of the source protection areas on the groundwater vulnerability. Groundwater source protection zones are shown in Figure 13 and the percentage breakdown for the categories is given in Table 4.

Table 4 Source Protection Zones

SPZ	% total area (1.52km2)
SI/E	0.51%
SO/X	1.13%
SO/H	23.60%
SO/M	44.22%
SO/E	30.54%

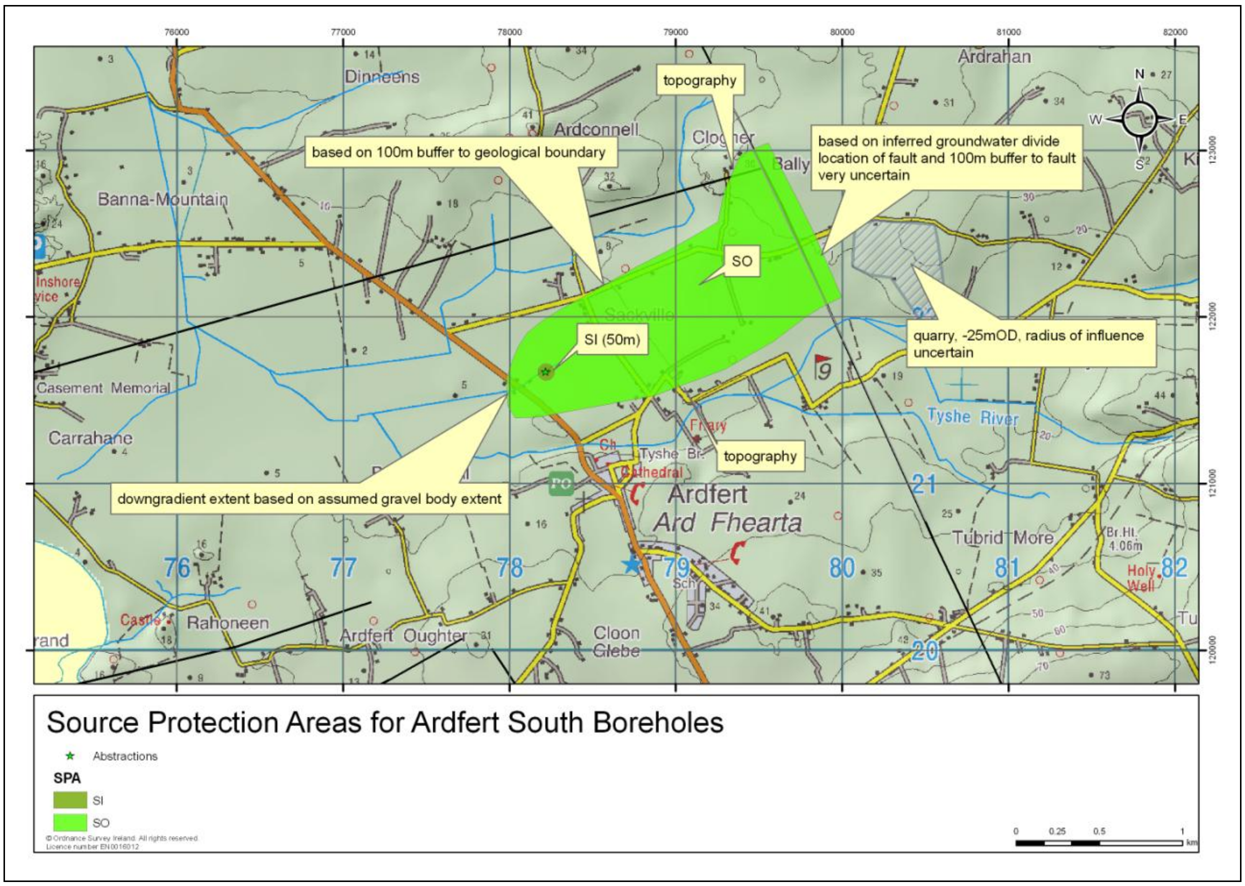


Figure 12 Ardfert South Groundwater Source Protection Areas

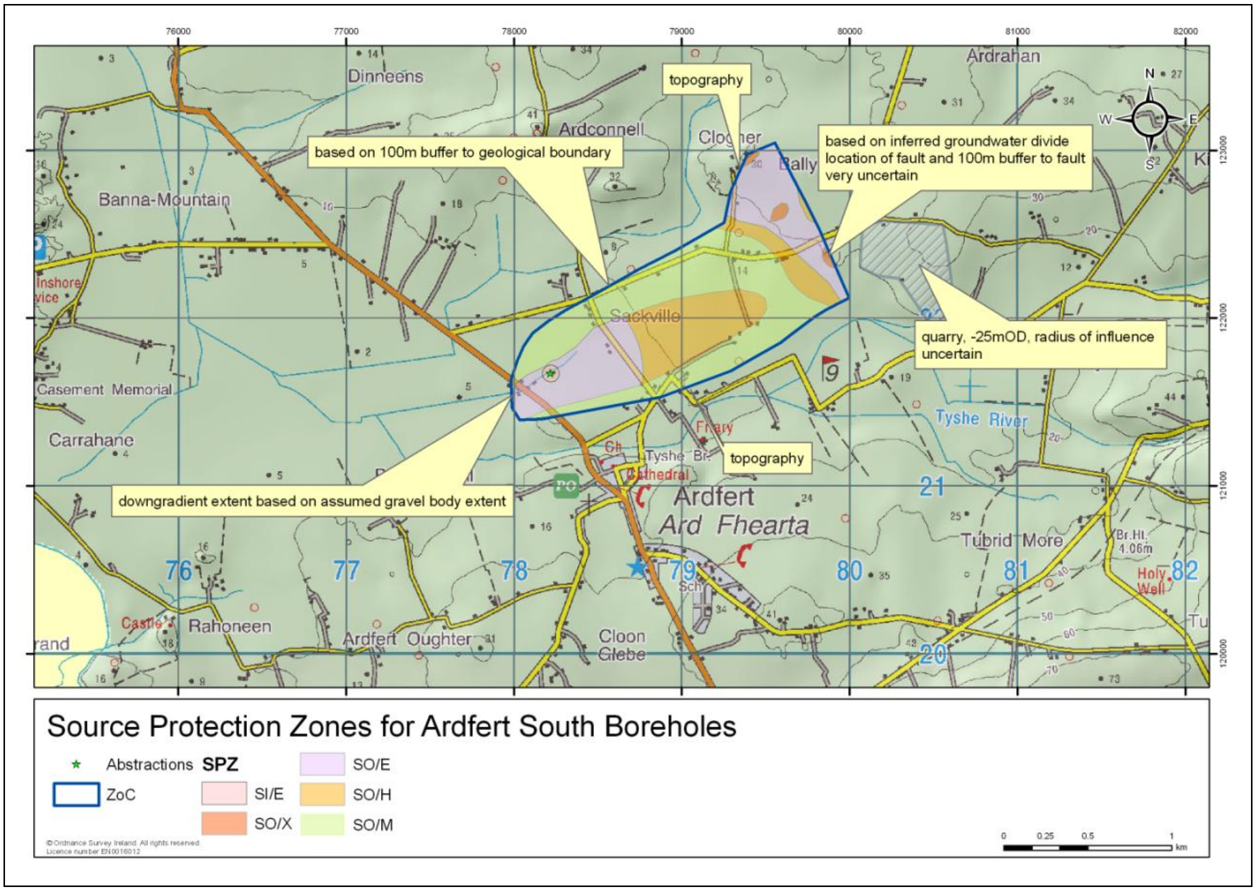


Figure 13 Ardfert South Groundwater Source Protection Zones

12 Potential pollution sources

The boreholes, which are covered, are finished below ground level. The boreholes are contained in a concrete chamber, which is in a fenced and gated Local Authority compound. The boreholes (PW1 and PW2 are installed since 2004 and are grouted and there has been no evidence of faecal coliforms since then.

Land use in this area is predominantly agricultural with a significant number of upgradient single houses with on-site wastewater treatment systems. In general the water quality is good with evidence of elevated nitrate concentrations.

There are a number of houses, farms and farm yards across the area which pose a risk of nutrients and bacteria to the source. There are also a number of roads present in the ZOC from which there is a risk of surface water runoff contaminated with hydrocarbons and metals. The traffic density is low indicating that the risk of contamination is low.

The presence of the gravels at the source are probably the reason for the relatively good water quality, as they filter and attenuate the water discharging from the karstified bedrock and direct recharge.

13 Conclusions

Ardfert South comprises two boreholes (PW1, PW2) drawing from a sand and gravel deposit that overlies a karstified aquifer, at a variable rate of 1200 to 1900 m^3/day at 24 hours per day depending on which borehole is pumping and what the demand is. The Zone of Contribution as currently delineated meets 100% of the demand but not 2400 m^3/day - 150% of the average rate.

The groundwater vulnerability in the Inner Source Protection Area is ‘extreme’ as the water table is within 3m of the ground surface and the sand and gravel aquifer is the target at risk. Over the majority of the remainder of the area, the vulnerability varies from ‘extreme’ to ‘moderate’. Nitrate concentrations are consistently high. Chloride concentrations are consistently high, but are likely to reflect the location close to the coast.

The ZOC encompasses an area of 1.5 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.

There is considerable uncertainty in relation to the geometry and extent of the sand and gravel deposit and to the inferred groundwater divide delimiting the eastern boundary.

14 Recommendations

It is planned to seal the non-pumping wells which will improve the protection around the source.

Further delineation and definition of the sand and gravel deposit using drilling and geophysics to explore its extent and relationship with both the bedrock and the till is required to improve the understanding and conceptual model of the hydrogeology, and nature of limestone beneath the source and the sand and gravel upgradient of the source.

Further detailed information on the dewatering should be obtained and boreholes west of the quarry into the bedrock would provide information on the current eastern boundary of the ZoC.

The pumping water level should be continuously recorded to confirm sustainability, particularly over dry weather periods.

A hazard survey within the ZOC should be carried out.

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APPENDIX 1 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

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear.
C