Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Carraig na bhFear Group Water Supply Scheme

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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 (SPZ) are delineated for the Carraig na bhFear source according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

The Carraig na bhFear Water Supply is provided by two boreholes BH-1 (IE_SW_G_005_04_005) and BH-2 (no code) situated approximately 50 m apart. BH-1 was installed in 1994. Due to increasing demand the borehole was unable to meet the supply required and therefore in 2004, BH-2 was installed and added to the Carraig na bhFear Water Supply.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Carraig na bhFear area.
- To delineate source protection zones for the both boreholes.
- To assist the Environmental Protection Agency and Cork County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the source. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

While there was specific fieldwork carried out in the development of this report, the maps produced are based largely on the readily available information in the area 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 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The wells are located approximately 200 m north of Carraig na bhFear village, 10 km north of Cork City (Figure 1). The wells are located in a green area which can be access via a lane leading off to the northeast from the third class road which runs through the centre of the village. There is a school located 100 m to the south of BH1, a GAA pitch 50 m to the east of BH2 and seven houses (7 No.) located approximately 50 m to the north and west (Photo 1).

Photo 1: Borehole locations

BH1 was drilled in 1994 and is approximately 50 m deep. The borehole is located at the rear of the pump house and is protected by a cap on the well steel casing and by a concrete manhole set 30 cm above ground level with a steel manhole cover (Photos 2 and 3). There is no information available (e.g. a borehole or well construction log) to establish whether or not the borehole is adequately sealed.

BH2 was drilled in 2004 and is approximately 70–75 m deep. The borehole is located at the side of the green (Photo 4), 50 m north of the pump house, under a steel manhole cover. The steel casing is capped also (Photo 5). There is no information available (e.g. a borehole or well construction log) to establish whether or not the borehole is adequately sealed to prevent shallow subsurface inflow or to determine the precise depths of inflow to the well.

Both boreholes are liable to overflow in winter and flood the chamber but given the information of the caretaker, only the borehole BH2 is artesian during winter time. Piping was installed at the wells to send the overflow to storm drains. A chlorine dosing treatment system is located in the pump house (Photo 6).

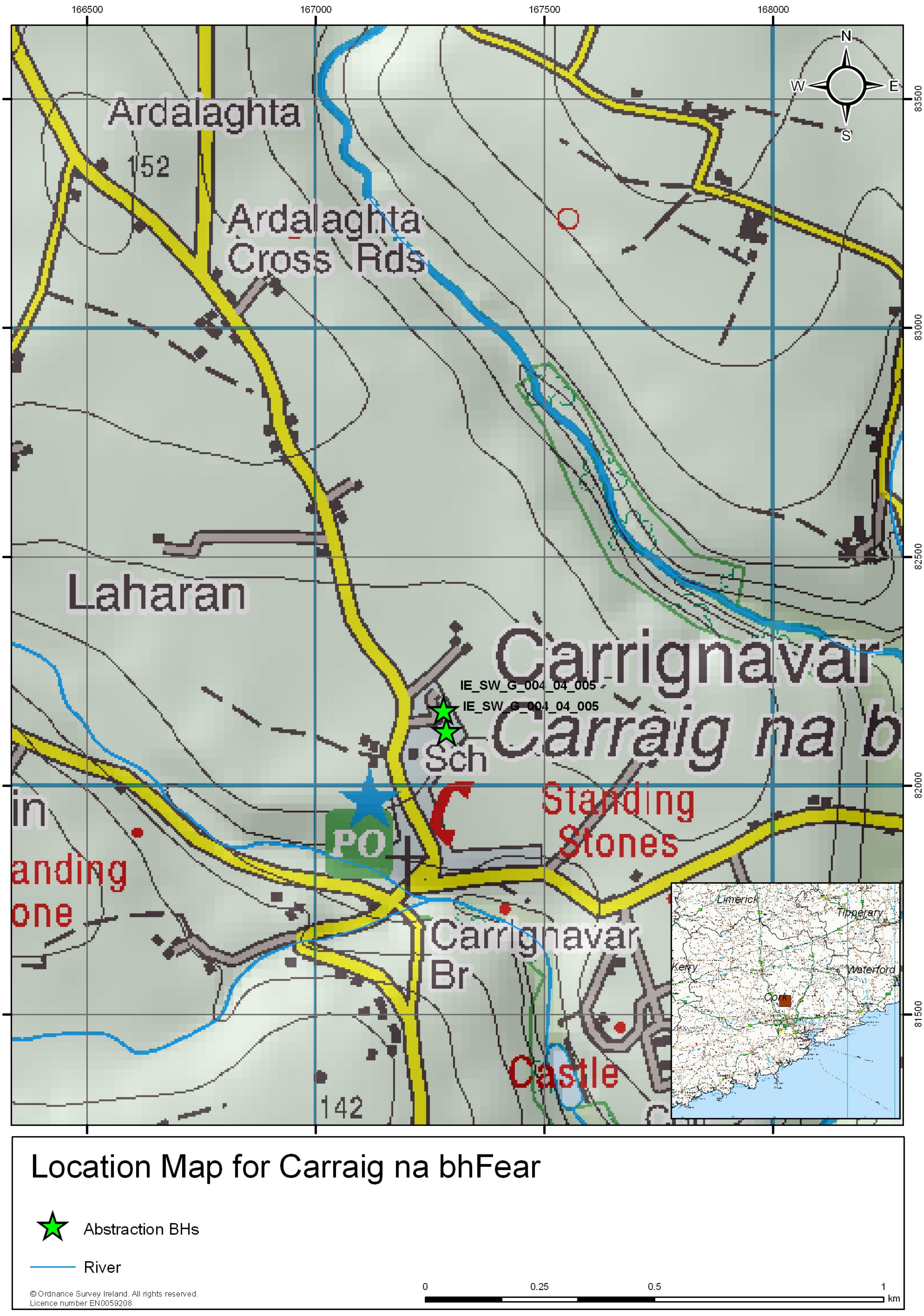

Figure 1: Location Map

Photo 2: BH1 Well Head

Photo 3: Pump House and the BH1 Concrete Manhole at the rear

Photo 4: BH2 Steel Manhole Cover

Photo 5: BH2 Steel Manhole Cover

Photo6: Chlorine Treatment in the Pump House

3 SUMMARY OF WELL DETAILS

Water is pumped simultaneously from BH-1 and BH-2 to a reservoir (81 m^3) located 750 m to the south southeast of the site. The abstraction rate automatically responds to demand and therefore the abstraction is known to fluctuate. The average combined abstraction for the wells is recorded by the Council as 280 m^3/d (140 m^3/d from each well). This abstraction rate however, is not achievable during the summer months and has to be reduced to a combined rate of 180 m^3/d. This rate is considered by the Council based on experience to be more sustainable. The average combined abstraction rate for the boreholes is approximately 14 m^3/h during the winter and 9 m^3/h during the dry period, operating around 20 hours per day in winter and more during the drier periods of the year.

Table 3-1 provides a summary of the details as currently known.

Table 3-1: Well Details

EU Reporting Code	IE_SW_G_004_04_005	IE_SW_G_004_04_005
Grid ref. (GPS)	167287 82119	167281 82165
Townland	Carraig na bhFear	Carraig na bhFear
Source type	Borehole	Borehole
Drilled	~1994	2004
Owner	Cork Co Co	Cork Co Co
Elevation (Ground Level)	~ 120m OD	~ 120 m OD
Depth	~ 50m	~ 70–75 m
Depth of casing	unknown-	unknown-
Diameter	150 mm	150 mm
Depth to rock	unknown	unknown
Static water level	Probably the same as BH2[1] but is not artesian during winter[2]	~2.30 m and artesian during winter time
Pumping water level	7.35 m bgl (02/11/2009)	-
Consumption (Co. Co. records)	140 m^3/d	140 m^3/d
Pumping test summary: (i) abstraction rate m^3/d	unknown	72 h constant rate test (~140 m^3/d) done in June 2004. Drawdown ~8 m but didn't stabilize. (Section 8.5 and Appendix 1)
(ii) specific capacity	Approx 19 $m^3/d/m$ (November 2009; estimated Q)	<18 $m^3/d/m$ (June 2004; 72 h pumping test)
(iii) transmissivity	~8 m^2/d (estimated from the 15 min recovery , the 02/11/09) (section 8.5)	~20 m^2/d (estimated from the 72 h constant rate test, the 03/06/04) (section 8.5)

[1] pumping during the field visit
[2] Caretaker information

4 METHODOLOGY

The methodology consisted of data collection, desk studies, site visits and field mapping. Analysis of the information collected during the studies was used to delineate the SPZ.

The site visit and interview with the caretaker took place on 02/11/2009. Field mapping of the study area (including measuring the electrical conductivity and temperature of the source and streams in the area), and a short term recovery test were carried out.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The area around the sources comprises relatively low lying undulating ground with elevations ranging from 120 m to 200 m O.D. The topographic high points in the local catchment are situated 4.4km and 4.2km to the northwest (Dromboy North, 200meter high) and the west (Dromgariff South, 199meters high) of the boreholes. Drainage density is low with well draining pasture lands dominating. The land slopes gently to the southeast with an estimated topographic gradient of around 0.02.

The catchment area of the boreholes is drained by the Cloghagashee River located 400 m west of the boreholes. This river is a tributary of the Glashaboy River located approximately 500 m to the east of the boreholes. The Cloghagashee River joins the Glashaboy approximately 1.5 km south of the site. Both rivers flow broadly parallel in a southeasterly direction on either side of the wells (Figure 1).

The wells are located in the northern outskirts of the Carraig na bhFear village and the landuse in the immediate surround is light residential. Land use beyond the village within the catchment is dominated by agriculture, primarily dairy farming.

6 GEOLOGY

6.1 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 source protection zones that will follow in later sections.

Geological information was taken from a desk-based survey of available data, which comprised the following:

- Geology of South of Cork. Bedrock Geology 1 : 100,000 Map series, sheet 25, Geological Survey of Ireland (M. Pracht and A.G. Sleeman 1994).
- Forest Inventory and planning system – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2002).

6.2 BEDROCK GEOLOGY

The bedrock geology is illustrated on Figure 2. The area is underlain by the Gortanimill Formation (green fine-grained siltstone and sandstone) from the Devonian Old Red Sandstones. The Ballystrana Devonian Sandstone Formation (purple mudstone with some sandstone) is mapped 450 m to the south of the site.

The geological map indicates that the rocks have been folded into anticlines and synclines, with approximately East-West axes, by the Variscan Orogeny. Carraig na bhFear is located on the limb of an anticlinal, whose axis situated approximately 2 km to the north of the village. The formations are in a sub vertical position with the bedding dip direction to the south. The rocks are also broken by a strong system of steeply-dipping cross faults running approximately NNW-SSE, roughly at right angles to the fold axes. Faults are mapped to the north and south of the water supply wells. Two faults (2 No.) are located 1 km to the southwest and west of the village with other faults roughly parallel to the fold axes 2 km to the north. Two faults (2 No.) are situated at 1.5 km to the north and south of the village. The widespread faulting and folding has likely given rise to zones of enhanced permeability.

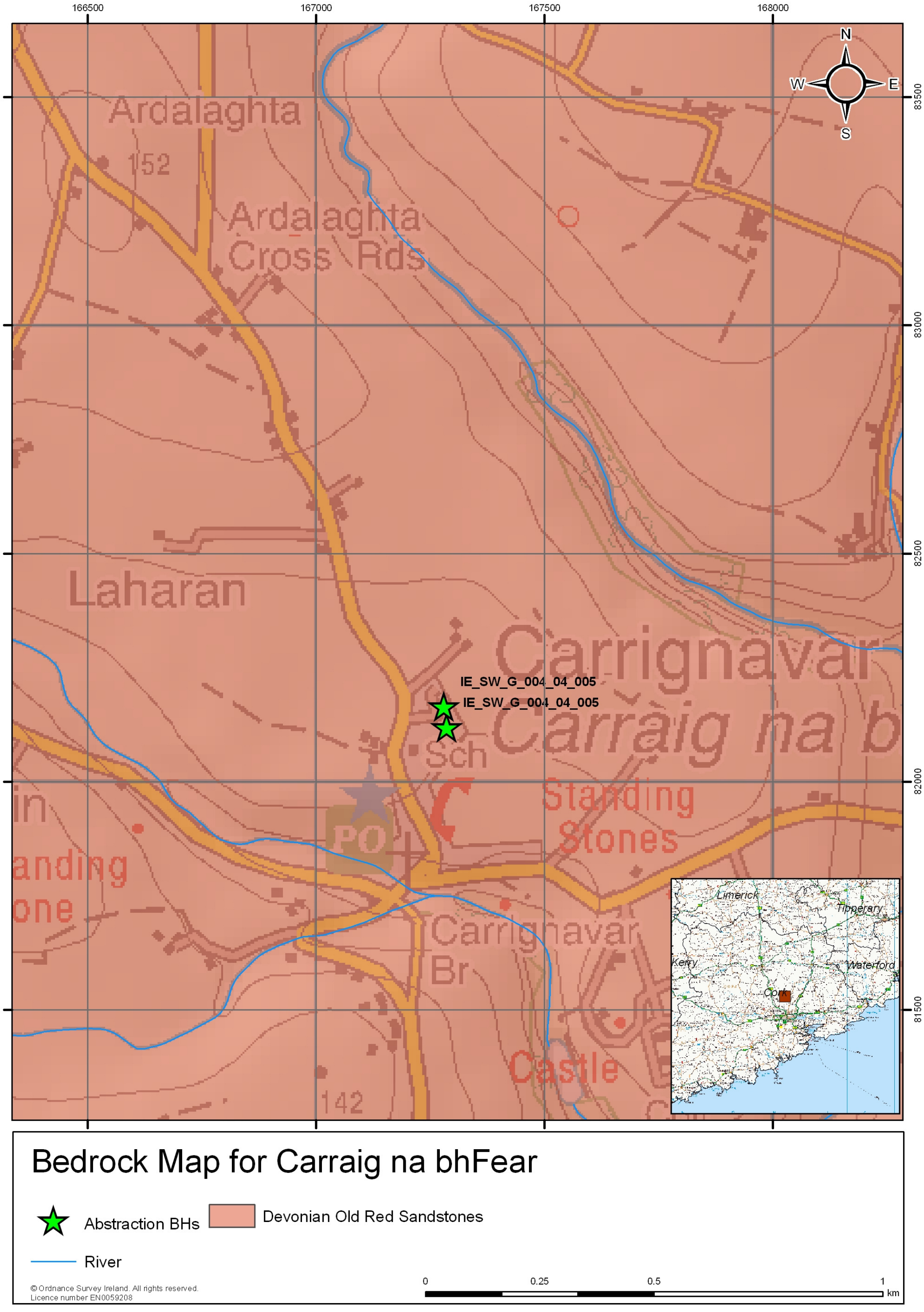

Figure 2: Bedrock/Rock Unit Map

6.3 SUBSOIL GEOLOGY

The bedrock is overlain by Devonian Sandstone Tills (TDSs) derived from the underlying Devonian bedrock. Along the Cloghagashee to the south and the Glashaboy Rivers to the east of Carrignavar the subsoils are thin or absent with bedrock outcropping along the river channel (Rck Nca). The subsoil permeability is characterised as moderate permeability (high confidence). This is supported by field observations of the well drained lands. in the catchment (Photo 7). The subsoil is overlain by a soil classified as Acid Mineral Deep Well Drained (AminDW).
The soil and subsoil are illustrated in Figures 3 and 4, respectively.

Photo 7: Grassland area up hydraulic gradient of the boreholes

6.4 DEPTH TO BEDROCK

There are no depth to bedrock data for the boreholes drilled to install the water supply and no subsoil exposures were evident during the site walkover. The logs from 3 other wells (GSI Groundwater data base) located in the vicinity of the wells, but not within their catchment area, indicate that the depth to bedrock there is between 2.1 and 3.1 m (Table 6–1). Based on the GSI vulnerability classification for this area of High, it is probable that the depth to bedrock within the catchment area is between 3 m and 10 m.

Table 6-1 : Depth to Bedrock

	BH1	BH2	1407NEW193	1407NEW162	1407NEW194
Location	On site	On site	Side/Downgradient 450 m to the west (in a farm)	Downgradient 800 m to the south-west (College)	Side/up Gradient 2.5 km to the northwest (in a farm)
Use	Drinking Water	Drinking Water	Agriculture and Domestic use	Agriculture and Domestic use	Agriculture and Domestic use
Bedrock Depth (m)	unknown	unknown	2.1	3	3.1

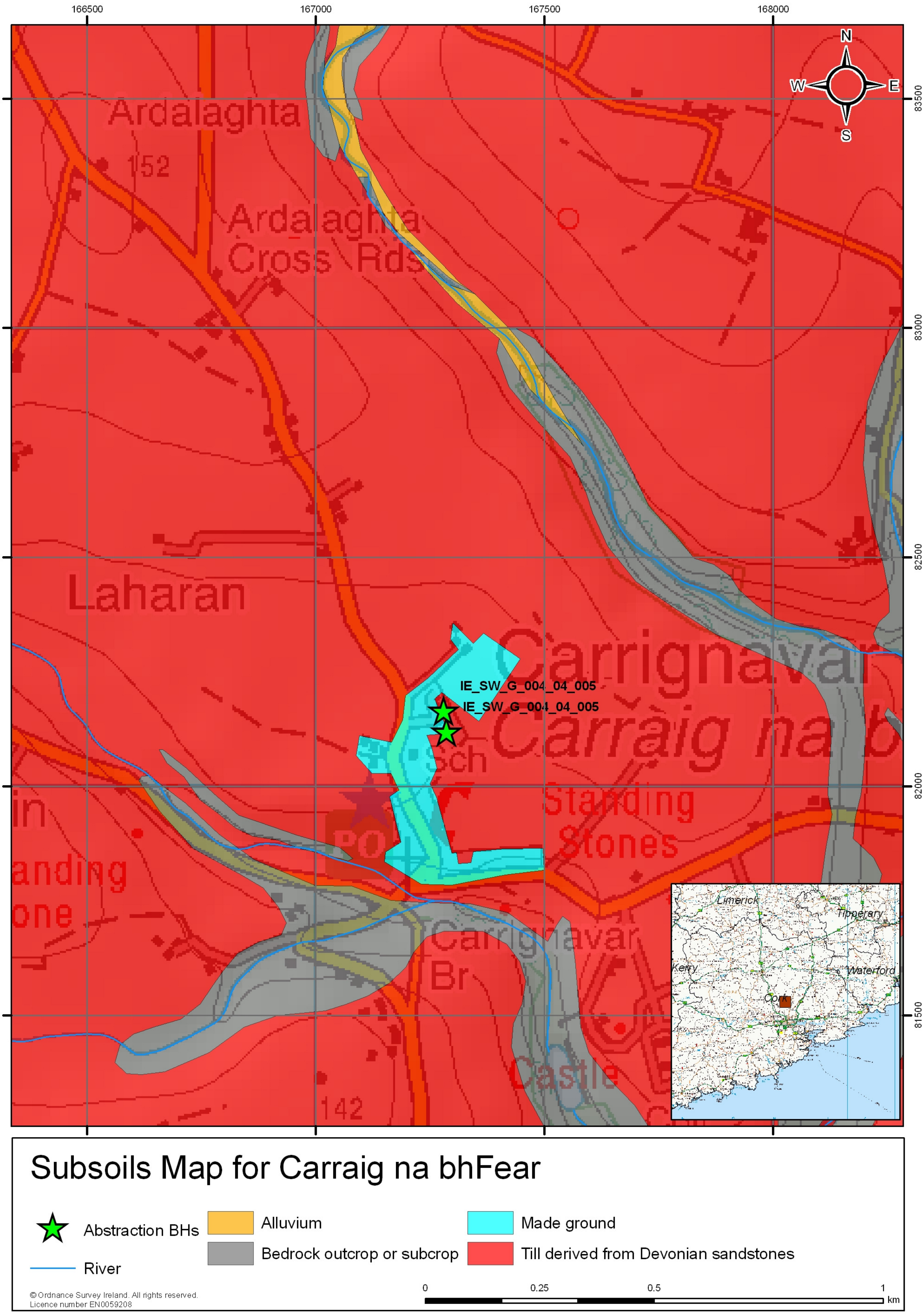

Figure 3: Subsoils Map

7 GROUNDWATER VULNERABILITY

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

The lands around the wells comprise Devonian Sandstone Till subsoil which is expected to be of moderate permeability based on the presence of well draining lands. Depth to bedrock within the catchment area is unknown but within the surrounding area is of the order of 3–10 m. The subsoil in the vicinity of the wells is classified as High vulnerability on the existing GSI maps. Field observations and the available data appear to support this classification. There are however zones of extreme vulnerability where rock outcrop is mapped along the Cloghagashee river channel approximately 300 m to the southwest and the Glashaboy River channel 350m to east of the wells.

The vulnerability map is shown in Figure 4.

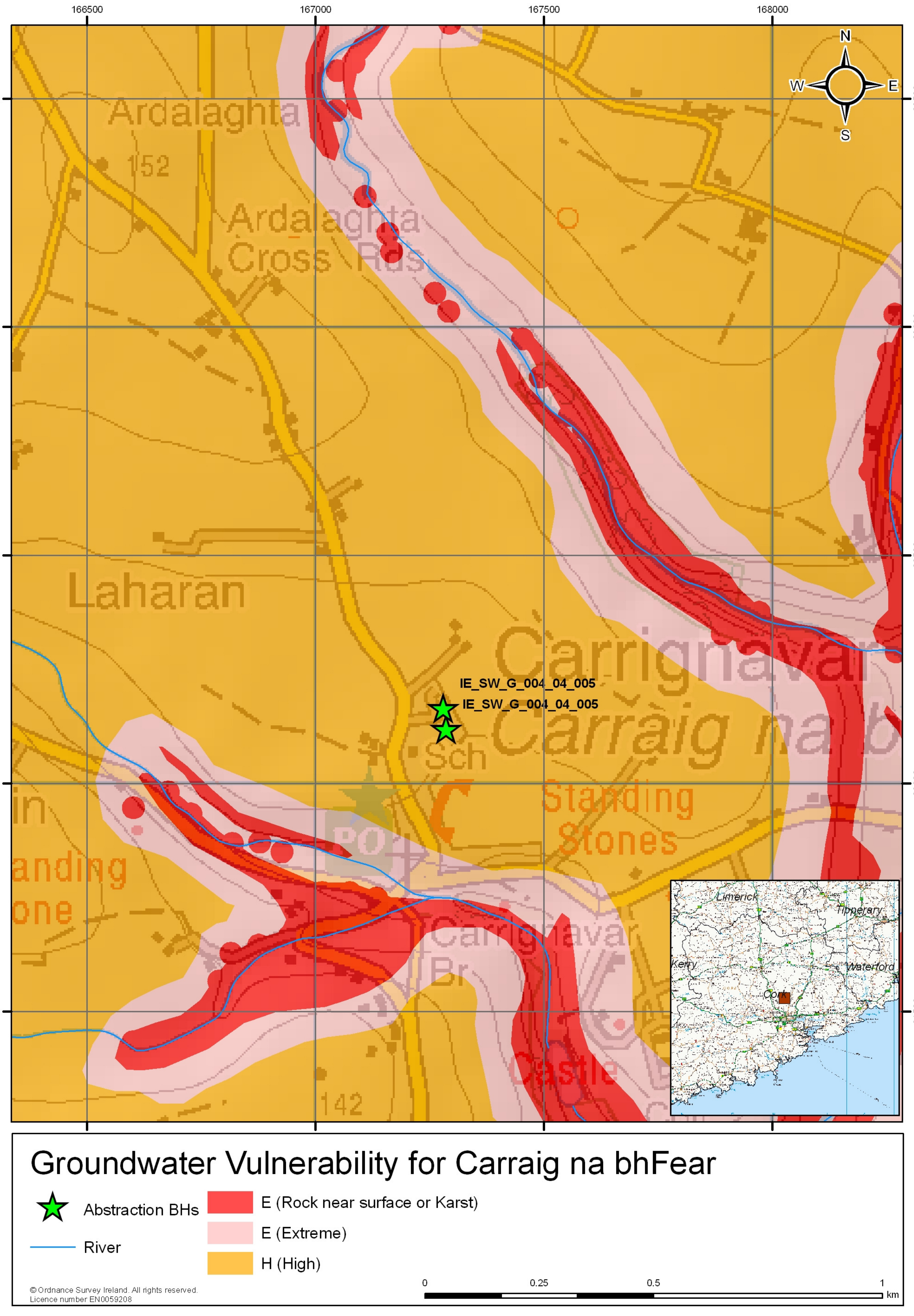

Figure 4: Vulnerability Map

8 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 Database
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- 72 h constant rate test of BH-2 done in 2004
- Short recovery test of BH-1 done the 02/11/2009 during the walkover.

8.1 GROUNDWATER BODY AND STATUS

The Carraig na bhFear boreholes are located within the Ballinhassig_1 Groundwater Body which has been classified as being of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

8.2 METEOROLOGY

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. Meteorological information was obtained for this study from Met Eireann.

Annual rainfall: 1340 mm. The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961–1990) shows that the source is located between the 1400 mm and 1200 mm average annual rainfall isohyet.

Annual evapotranspiration losses: 475 mm. Potential evapotranspiration (P.E.) 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.

Annual Effective Rainfall: *865* mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 865 mm/year.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Based on the groundwater levels measured during the field work, in wells located in the vicinity of the two production wells (Table 8–1), the un-pumped groundwater table (pumps were switched off during our visit) in the area is shallow with a depth of approximately between 2 and 3 m below the ground. OCM were informed by the caretaker that during the winter, BH–2 is artesian. The water flows up over the well head and has to be drained away to a storm drain.

During the drier summer months it is likely however, that the water table declines significantly which is a characteristic of poorly productive aquifers. The need to reduce pumping rates during the summer period due to declining water volumes supports this assumption.

Table 8-1: Groundwater levels in the vicinity

	BH1	BH2	1407NEW193	1407NEW162	1407NEW194
Location	On site	On site	Side/Downgradient 450 m to the west (in a farm)	Downgradient 800 m to the south-west (College)	Side/up Gradient 2.5 km to the northwest (in a farm)
Date	02/11/09	03/06/04	02/11/09	02/11/09	02/11/09
Water level (m bgl)	3.65 (but had not stabilized 15 minutes after pump switched off)	2.30 and artesian during winter time	3.65	1.50	2.10

Based on the topography, surface water drainage and levels recorded in the production wells and three (3 No.) other wells located in the vicinity of the boreholes, the groundwater flow direction is to the south-east. Based on the topography at the site, the water levels in both the Cloghagashee and Glashaboy Rivers are likely to be lower than the pumping water level in the bores.

Given that the Gortanimill Formation is not very permeable, it is anticipated that the groundwater gradient is likely to reflect the valley topography. Thus a value of 0.02 has been assumed.

8.4 HYDROCHEMISTRY AND WATER QUALITY

The well is included in the EPA operational chemical network since 2007. The sample point is a tap located outside the pump house on the wall. The water sample is collected after the water has been pumped from BH-1 and BH-2 and mixed together. The data are summarized graphically in Figure 5 to 7 below.

The following key points have been identified from these data:

- Analysis of hardness indicates a medium hard calcium bicarbonate hydrochemical signature (average 105 mg/l $CaCO_3$). The average conductivity is 251 µS/cm and pH is around 6.5 which is indicative of siliceous bedrock material.

- There are only one reported incidents of Faecal Coliforms in the analysis, (6/100 ml on the 09/10/07). As well as this, on no occasions were ammonium values greater than the Threshold level value (0.175 mg/l) recorded. It is inferred from the available data that the presence of Total Faecal only are isolated and do not indicate ongoing contamination or specifically highlight any on-going problems. The values are summarized graphically in Figure 5.

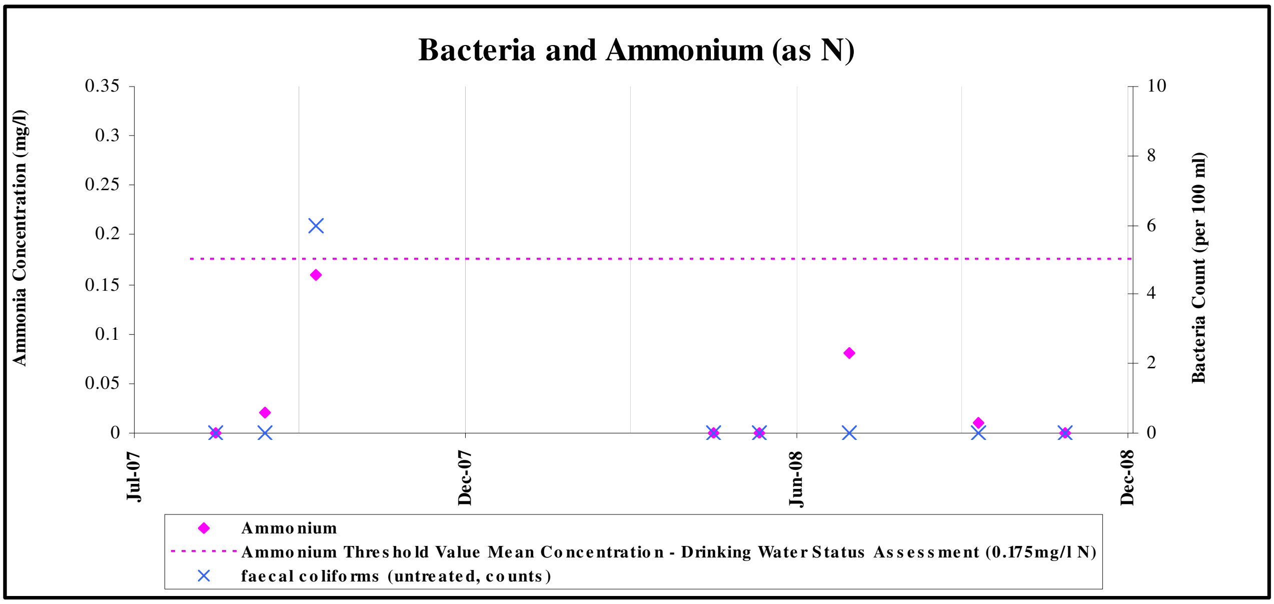

Figure 5: Key Indicators of Agricultural and Domestic Contamination : Bacteria and Ammonium Graph

- The concentration of nitrate ranges from <38.3 mg/l to 23.3 mg/l with a mean of 33.8 mg/l (as NO_3). Though there are no reported exceedances above the EU Drinking Water Directive maximum admissible concentration of nitrate 50 mg/l, the Interim EPA threshold value of 37.5 mg/l has been exceeded on 2 no. out of 8 no. occasions. Though the area around the boreholes is relatively sparsely populated and served by on-site wastewater treatment systems discharging to ground, the surrounding lands are primarily used for agricultural activities. Given that levels of ammonia, chloride, bacteria for example are not elevated the relatively high nitrate levels at Carraig na bhFear are probably related to agricultural practices in the catchment

- Chloride is a constituent of organic wastes and levels higher than threshold value 24 mg/l may indicate contamination, with levels higher than the MAC value 250 mg/l usually indicating significant contamination. Chloride concentrations range from 13.4 mg/l to 19 mg/l, with a mean of 15.9 mg/l which is considered to be below the threshold value. The values are summarized graphically in Figure 6.

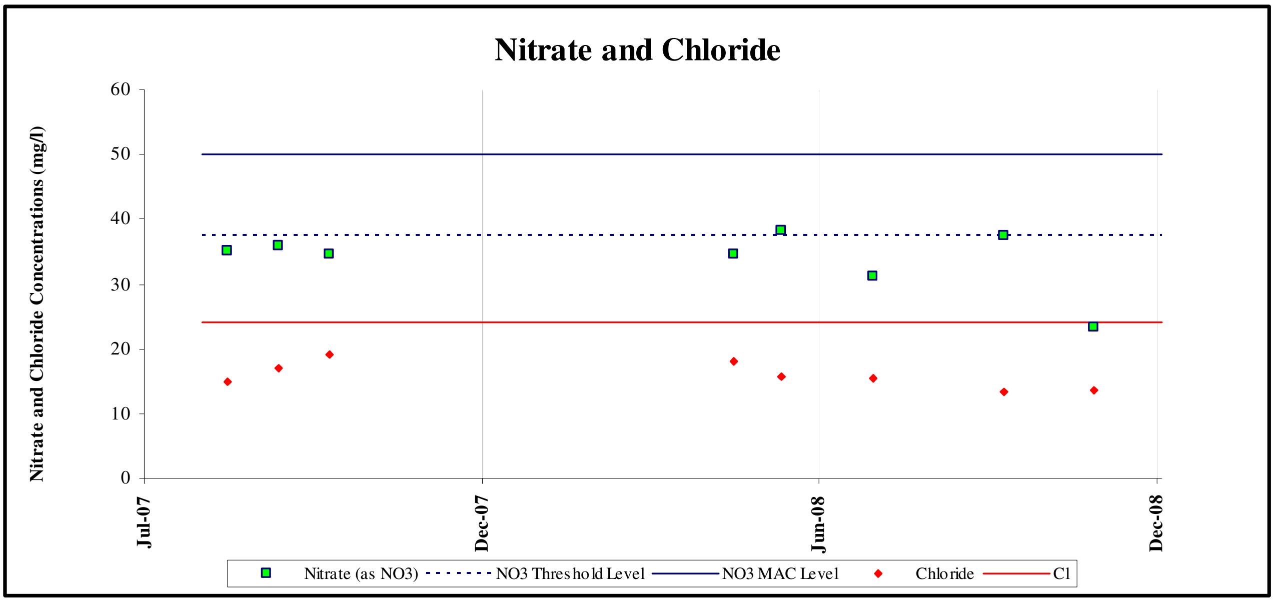

Figure 6:Key Indicators of Agricultural and Domestic Contamination : Nitrate and Chloride Graph

- The turbidity is sometimes above the MAC limit with a maximum on the 09/06/07 of 4.9 NTU. This is likely due to the presence of very fine clay particles within the water. The turbidity of the water may indicate that the well was not fully developed before being used or that some of the water gets to the well at times along quicker pathways than would be expected in this type of bedrock e.g. along the faults or fissures.

- The concentration of sulphate, potassium, sodium, magnesium and calcium are within normal ranges. The potassium: sodium (K:Na) ratio is low, consistently less than 0.15, never exceeding the GSI threshold of 0.35. The values are summarized graphically in Figure 7.

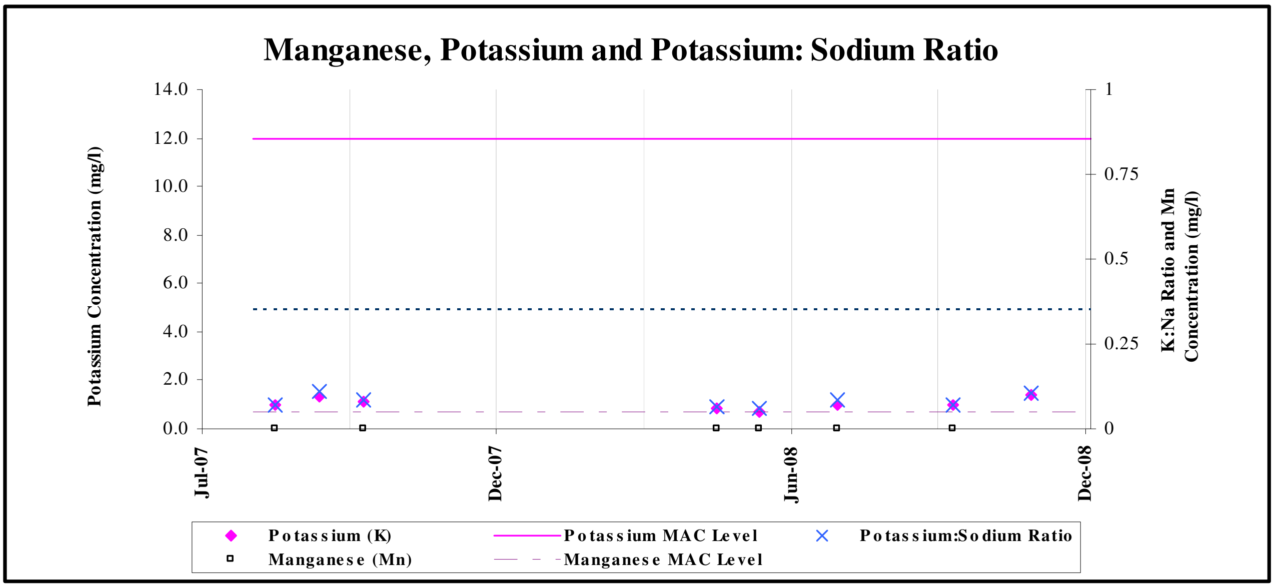

Figure 7: Key Indicators of Agricultural and Domestic Contamination : Manganese, Potassium and K/Na ratio

- The concentration of iron and manganese is also within normal ranges, for groundwater.
- Trace metals were within either within the normal range for good quality drinking water or levels are below the detection limit of the laboratory. The concentration of all organic compounds and herbicides is below the detection limit of the laboratory.

Monitoring of field chemistry at the two boreholes and the rivers to the east and west indicates similar, relatively low ranges for pH and electrical conductivity. This may indicate that the aquifer is in hydraulic connection with the rivers. However, the subsoil is also derived from sandstone and the chemical signature of the run off may not be much different from that of the groundwater. The results are outlined in Table 8–2:

Table 8-2: Groundwater and Surface Water Quality

	BH1	BH2	Cloghagashee River	Glashaboy River
Location	On site		Bridge 1.5 km to the northwest	Bridge 1 km to the east
pH	Ave 6.5 Range: 6.2-7		6.64	7
Conductivity (µS/cm)	Ave 251 Range: 118-306		193	163

8.5 AQUIFER CHARACTERISTICS

The boreholes abstract water from the Gortanimill sandstone/siltstone Formation. The aquifer is classified as a *Locally Important aquifer which is moderately productive only in Local Zones (Ll)*. The Carraig na bhFear wells provide an average of 140 m^3/d from each well. The average pumping rate is not however achievable during the drier months and needs to be reduced to a combined rate of approximately 180 m^3/d.

The water table in the aquifer appears to be close to the surface based on the borehole data obtained from wells in the local area (Table 7.1). In the winter period, the aquifer appears to fill up and discharge to the surface water system based on the overflows in BH-2 observed by the caretaker. In the summer, water tables decline in the aquifer but the extent of decline is not known.

The groundwater flow occurs in fractures and faults in the sandstones and siltstones. The permeability of individual fractures and the degree of interconnection is expected to be low based on long term well yields, with fracturing confined to local zones. The Ballinhassig GWB description compiled by the GSI indicates that in general in this aquifer type, the groundwater flow is concentrated in the upper 15 m of the aquifer, although deeper inflows from along fault zones or connected fractures can be encountered. The location of the water strikes encountered in the wells (from GSI groundwater data base) located in the vicinity of the source (Table 8-3), suggest that the groundwater inflows in this formation are at depths of approximately 7–8 m and 27 m below ground level.

The groundwater flow paths in Ll aquifers are generally relatively short, typically from 30 to 300 m, with groundwater discharging to the rivers that traverse the aquifer (GSI GWB description).

Table 8-3: Depth and Yield from the wells in the vicinity

	BH1	BH2	1407NEW193	1407NEW162	1407NEW194
Location	On site	On site	Side/Downgradient 450m to the west (in a farm)	Downgradient 800m to the south-west (College)	Side/up Gradient 2.5km to the northwest (in a farm)
Borehole Depth (meters)	~50	~70-75	38	91.6	38.1
Bedrock Depth (m)	unknown	unknown	2.1	3	3.1
Depth of Water Strikes (meters)	unknown	unknown	7.6 and 27.4	unknown	12.2 and 27.4
Yield (m^3/d)	140	140	218	unknown	54.5

OCM understand that a pumping test was undertaken after the wells were installed, however the Council only have the data from the 72 hours yield test of BH-2 in 2004. The constant rate was approximately 6 m^3/h or 140 m^3/d; the water level did not stabilize completely and decreased very slowly (from 2.30 mbgl to 10.15mbgl) at the rate of approximately 0.11 m/hour. The test results are presented in Figure 8 and Appendix 1.

During the walkover in November 2009, OCM undertook a short-term recovery test on BH-1. The pump was turned off for 15 minutes. The caretaker would not allow the pumps to remain switched off for a longer period so the recovery test was terminated at 15 minutes. While water level didn't stabilize, a rise in water level from 7.35 m bgl to 3.65 m bgl, was measured over the testing period. The test results are presented in Figure 9 and Appendix 1.

Given the drawdown is < 0.3 of the thickness of the aquifer, the CE Jacob Formula can be applied for unconfined condition. A transmissivity value has been estimated based on both the pumping and short term recovery tests (Figure 6 and 7) :

$$T= (0.183 \times Q) / c$$

Where Q=yield and c= drawdown. A constant rate of 140m^3/d in BH-2 and 165m^3/d in BH-1 has been assumed.

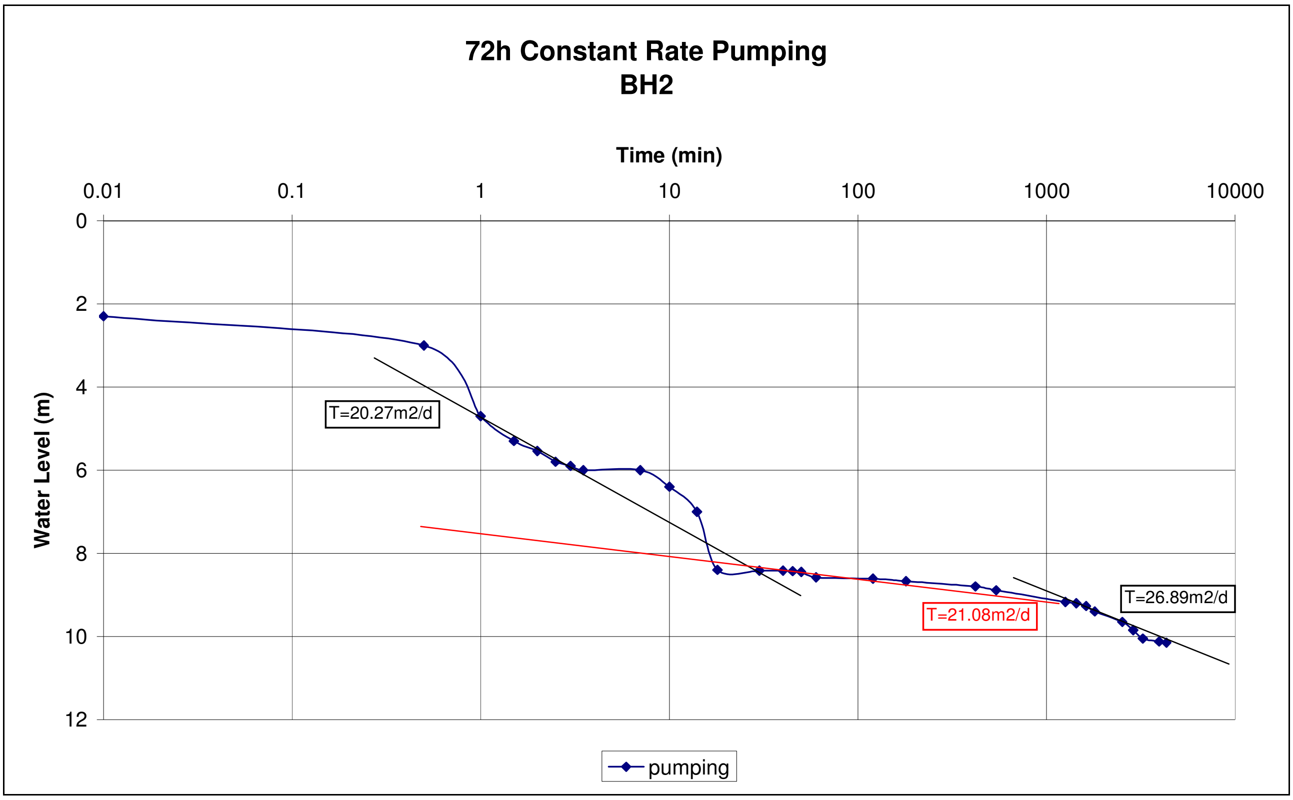

Figure 8: Constant Rate Pumping in BH-2

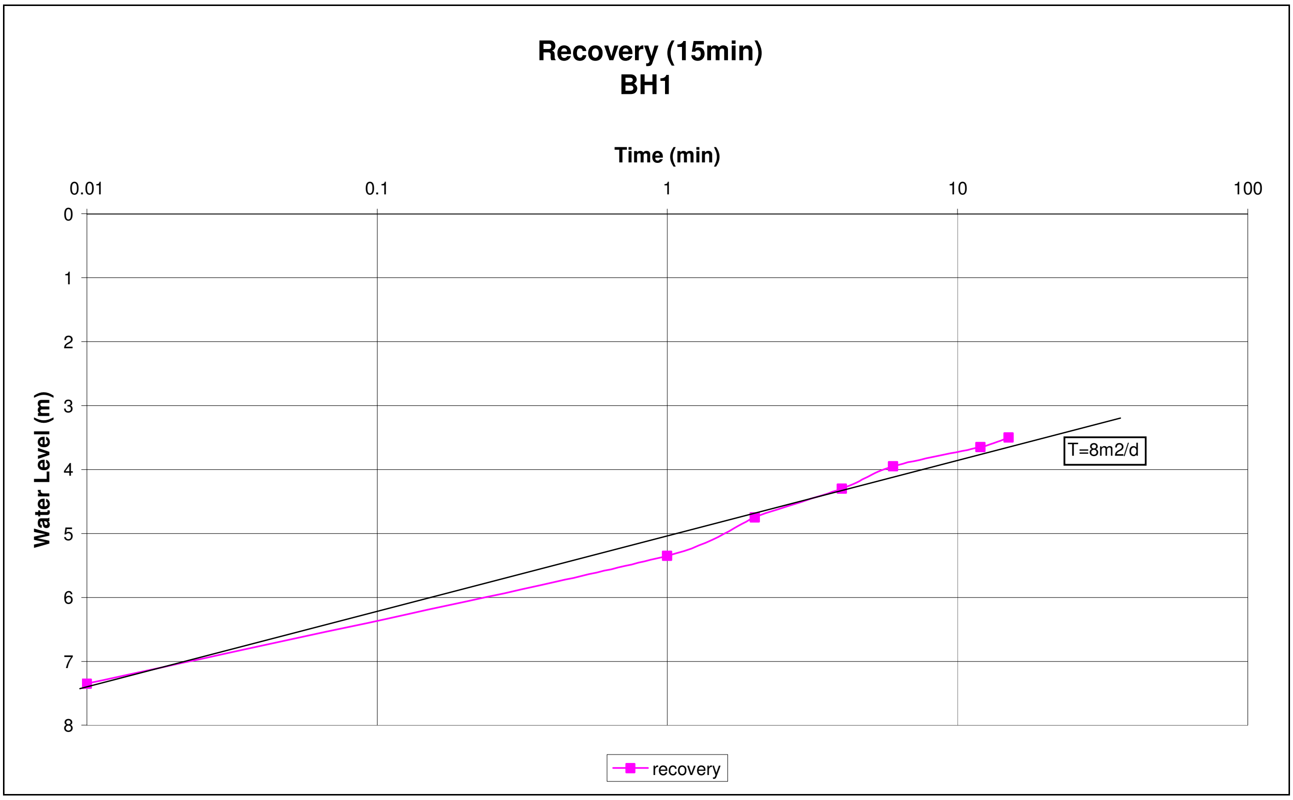

Figure 9: Recovery in BH-1

The pumping test data interpretations indicate a transmissivity of c. 8 m^2/d for BH1 and a transmissivity range from 20.27 m^2/d to 26.89 for BH-2. Because of the limitations of the pumping test data in BH2 (yield not constant) and the short time test in BH1 (only 15 minutes), confidence in the data is low. It is likely that the data for BH-2 is at best an upper end of the range of transmissivity. The range of transmissivity described by GSI for the GWB is from 2-20 m^2/d. For this study a transmissivity range from 2–8 m^2/d has been adopted.

Bedrock permeability for an Ll aquifer is expected to be low to moderate. The permeability is highest in the upper few metres but generally decreases rapidly with depth. The permeability can be calculated by dividing the transmissivity by the saturated thickness of the aquifer. In this aquifer type the groundwater flow, in general, is concentrated in the upper 15 m of the aquifer. However, given the lack of information available about the wells (e.g. a borehole or well construction log), the more sensible saturated thickness of the aquifer for the area is estimated as the depth of the deeper water strike encountered in the vicinity of the boreholes (30 meters). Therefore the bulk permeability (K) is estimated as follows:

Table 8-4: Permeability Range for BH1 and BH2

	Local Minimum Assumption	Local Maximum Assumption
Transmissivity (m^2/d)	2	8
Permeability (m/d)	0.04	0.16

The range of permeability for the aquifer is 0.04–0.16 m/d.

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

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

The natural gradient is estimated at 0.02 (described in section 8.3). The typical effective porosity (n) range for Old Red Sandstones in Ireland, based on previous source protection zone reports is 1–5%, with an average of 2.5%. Thus the velocity is summarized in the Table 8-5 below.

Table 8-5: Velocity Range for BH1 and BH2

Velocity (m/d)	Local Minimum K Assumption (0.04 m/d)	Local Maximum K Assumption (0.16 m/d)
Local Minimum Effective Porosity (1%)	0.15	0.61
Local Maximum Effective Porosity (5%)	0.03	0.12

The range of velocity is estimated between 0.03 and 0.61 m/d.

The aquifer parameters are summarized in Table 8–6 below.

Table 8-6: Indicative Parameters for the Gortanimill sandstone/siltsone Formation Aquifer in Carraig na bhFear

Parameters	Source of Data	BH1/BH2
Transmissivity (m^2/d)	Assumed (based on pumping test data)	2-8
Permeability (m/d)	Assumed (estimated from T value)	0.04 - 0.160
Effective Porosity	Assumed (based on other ORS sources)	1-5%
Groundwater gradient	Assumed based on topography	0.02
Velocity (m/d)	Assumed (calculated based on above)	0.03– 0.61

8.6 RECHARGE

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).

At Carraig na bhFear therefore, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration and a recharge coefficient. The recharge is estimated as follows.

Potential recharge is equivalent to 865 mm/year i.e. (Annual Effective Rainfall as outlined in Section 8.2).

Recharge Cap: *200mm/*yr The Gortaninimill formation is classified as a moderately productive only in Local zones (Ll). Applying the aquifer cap to moderate productive aquifers (GWG 2008) the recharge is estimated to be 200 mm/yr. The recharge cap is considered to be appropriate here given as the permeability of the rocks is low and the borehole becomes artesian in winter suggesting the aquifer is full. The bulk ***recharge coefficient*** for the area is therefore estimated to be 23%.

Runoff losses: *665* mm. Runoff losses are assumed to be 77% of potential recharge. This value is based on an assumption the minimum recharge coefficients proposed by the GWG (23%).

These calculations are summarised as follows:

Average annual rainfall (R)	1340 mm
estimated P.E.	500 mm
estimated A.E. (95% of P.E.)	475 mm
effective rainfall	865 mm
potential recharge	865 mm
recharge cap	200 mm
run off losses	665 mm
runoff losses	77%
bulk recharge coefficient	23%
Assumed Recharge	**200 mm**

8.7 CONCEPTUAL MODEL

- ✓ The Carraig na bhFear Group Water Scheme (CGWS) consists of 2 boreholes (BH1 and BH2), which abstract an average of 280 m^3/d (140 m^3/d each) from the Gortanimill sandstone/siltsone Formation. The aquifer is classified as a *Locally Important aquifer which is moderately productive only in Local Zones (Ll)*. The sustainable yield decreases in the summer and is considered by the Council to be no more than 180 m^3/d combined. The decrease in sustainable yield is a function of the 200mm cap on recharge to the aquifer and the extent of the area from which groundwater can flow to the wells.

- ✓ The groundwater table is shallow with a depth of approximately between 2-3 m below the ground and shallower in the winter based on the artesian overflow in BH-2. In general, the aquifer is unconfined.

- ✓ The groundwater flow occurs in fractures and faults from north-west to south-east in direction of Cloghagashee River. The Cloghagashee and Glashaboy Rivers are considered to be in hydraulic connection with the aquifer; the water levels in both of the rivers are estimated to be lower than the pumping water level in the bores.

- ✓ The effective range of transmissvity is expected to be of the order of 2-8% based on limited pumping test data. The lower end of the potential range was selected in view of the decreasing yield in dry periods. Given the Gortanimill Formation is not very permeable, it is anticipated that the groundwater gradient is likely to reflect the valley topography. Thus a value of 0.02 has been assumed.

- ✓ Diffuse recharge occurs over most of the land surface through the Devonian Sandstone Tills subsoil (between 3 and 10 m). The recharge estimated is in the order of 200 mm/year which is the recharge cap applied for this type of low permeability aquifer.

- ✓ Water quality from this borehole is good although nitrate levels averaging 33 mg/l are elevated above background, reflecting the agricultural activity in the catchment and the high vulnerability.

9 DELINEATION OF SOURCE PROTECTION AREAS

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater pattern, as described in Section 8.7 Conceptual Model and presented in Figure 6.

Two source areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution.

- Outer Protection Area (SO), encompassing the zone of contribution to the source.

9.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete hydrologic catchment area to the source, i.e. **the zone of contribution (ZOC)**, which is defined as the area required to support an abstraction from long-term recharge. 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. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

The Western, eastern and Northern boundary are defined by conceptualised groundwater flow-lines, which are themselves defined by the topography of the area.

The Southern boundary – the Downgradient boundary is the maximum downgradient distance that the borehole can pump water from and is based on the uniform flow equation (Todd, 1980).

$xL = Q / (2\pi * T * I)$ where

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

Where the pumping rate is 140 m^3/d for each of the boreholes, the transmissivity ranges from 2 to 8 m^2/d and the hydraulic gradient is 0.02, the approximate downgradient distance range for each of the boreholes is from 556 to 139 m, respectively.

In general, the down-gradient distance for a Ll aquifer is estimated to be around 60 m (approximate downgradient distance estimated by GSI for ZOC delineation). However, the bores are located just 50 m from each other, with BH1 on the downstream side, and it is likely that there will be interference and a compounding affect. Therefore, a conservative distance of 140 m (instead of 139 m) down-gradient of BH1 is applied

To allow for daily variations in abstraction and to allow for expansion of ZOC during dry weather periods the GSI usually increase the abstraction rate for a source by a factor of safety of 50%. However, in this case it is not possible to apply this safety factor as the ZOC already encompasses the entire hydrologic catchment and the abstraction rate as to be reduced in the summer months to prevent the water levels from declining in the wells.

Water balance

The water balance calculations indicate that at a recharge of 200 mm/yr, an average discharge of 280 m^3/day would require a recharge area of 0.51 km^2.

The ZOC is based on maximum winter abstraction rates and is likely to be overestimated for summer time conditions when the rates of abstraction are reduced to main sustainable groundwater supply.

The boundaries of the ZOC are shown on Figure 10.

9.2 INNER PROTECTION AREA

According to "Groundwater Protection Schemes" (DELG/EPA/GSI 1999), delineation of the Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (ToT) to the supply.

Based on the indicative aquifer parameters outline in section 8.5, the groundwater velocity range is 0.03 to 0.61 m/d. Hence, the 100-day time of travel range is 3 to 61 m.

A 100 day ToT of 61 m for each boreholes is considered to be more representative and sensible than the 3 m zone, from a microbial and of the wells to each other (50 m apart).

The Inner Protection Zone is illustrated on Figure 10.

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Figure 10 and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the groundwater protection zones are SI/E, SI/H and SI/M. The majority of the area is designated SO/E.

Table 10-1 Source Protection Zones (%area, km^2)

Source Protection Zone	% of total area (km^2)
SI/High	3.28% (0.017 km^2)
SO/High	96.72% (0.493 km^2)

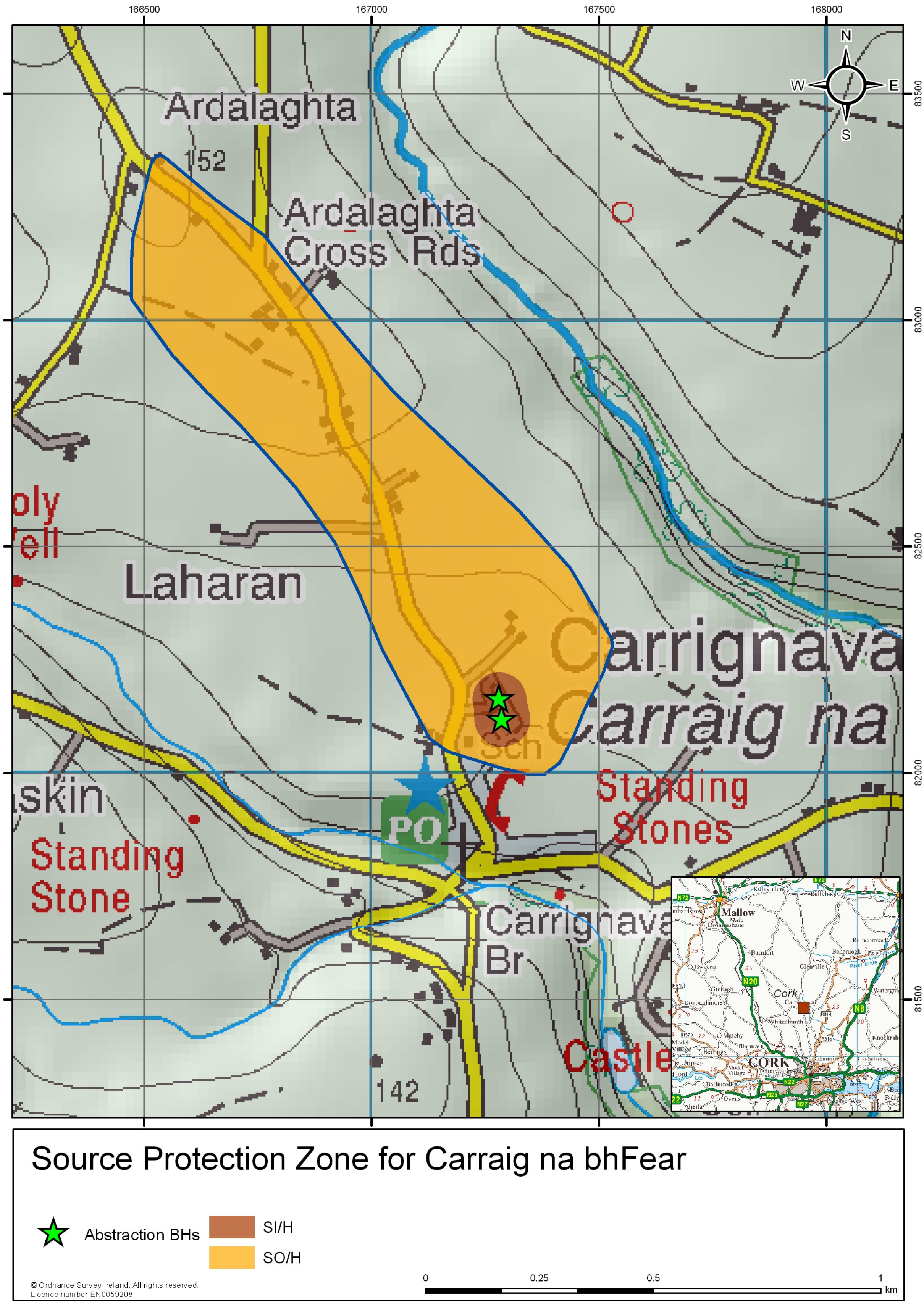

Figure 10: Groundwater Protection Zones

11 POTENTIAL POLLUTION SOURCES

11.1 INNER ZONE:

The wells are located in the northern outskirts of the Carraig na bhFear village. There is a school located 100 m to the south of BH1, a GAA pitch 50 m to the east of BH2 and seven houses (7 No.) located approximately 50 m to the north and west (Photo 6) of the both supply wells. The wastewater from the dwellings is piped to a waste water treatment plant located 350 meters to the south close to the Cloghnagashee River where the treated wastewater discharges into the river. There is a septic tank system which services the GAA pitch located 200 m to the northeast of BH-2.

BH-1 is located at the rear of the pump house and is protected by a cap on the well steel casing and by a concrete manhole set 30 cm above ground level with a steel manhole cover. BH-2 is located at the side of the green 50 meters north of the pump house under a steel manhole cover. The steel well casing is set in a concrete manhole. The walls of the both chambers are not rendered and it is not clear if the base is fully sealed. It is possible therefore that shallow subsurface flow could enter the well head manhole chamber.

Given the protection of the boreholes and their location, the potential risk for contamination as a result of surface spills in the vicinity of the well head is low.

11.2 OUTER ZONE

The majority of land within the ZOC is agricultural grassland and the dominated farm activity is dairy farming. There are 5 farms located within the source protection zone. The main potential pollution sources are considered to be the presence of farm yard slurry storage areas, farmyard washings, grazing animals, landspreading of agricultural waste and the presence of individual septic tank systems in the catchment. Impacts from these potential sources usually result in elevated levels of a range of parameters including ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium. However these parameters are not elevated based on the results of monitoring.

Given the low levels or non detection of other parameters indicative of organic sources of contamination the high nitrate levels, which are around 33 mg/l as NO_3, most likely originate from agricultural activity within the ZOC.

There are approximately 20 isolated dwellings throughout the area which are served by individual septic tank systems. Given the high water table (between 2-3 meters) and presence of individual septic tanks there is the potential for microbial contamination of the water supply.

Within the ZOC, there are 2 (2 No.) third class road in the north and the east side. The main potential contaminants from this source are hydrocarbons and metals. However, the low traffic density locally indicates that the risk of such an incident is low.

12 CONCLUSIONS

The public water supply at Carraig na bhFear comprises 2 No. boreholes, situated approximately 50 m apart, drilled in 1994 and 2004, which are located in the north of Carraig na bhFear Townland, 10 km north of Cork.

The boreholes abstract water from the Gortanimill sandstone/siltsone Formation. The aquifer is classified as a Locally Important Aquifer that is Moderately Productive only in Local Zones (Ll). The Carraig na bhFear wells provide 280 m^3/d (140 m^3/d each). However, the sustainable abstraction rate for the wells is estimated by the Council to be no more than 180 m^3/d based on the need to reduce pumping rates to maintain supply over the annual cycle.

The groundwater vulnerability with the ZOC is mainly High. Water quality from the both boreholes is good although nitrate levels are elevated above background levels. Nitrate levels are considered to be associated with the presence of moderately intensive agricultural activity within the catchment.

The Zone of Contribution to the source has been delineated for both wells together and is estimated as 0.51 km^2. The inner and outer source protection zones delineated in the report are based on our current understanding of the groundwater conditions and the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.

13 RECOMMENDATIONS

A pumping test should be carried out to determine the sustainable yield of the wells and provide better data on the aquifer characteristics (Transmissivity, Specific Yield), which would in turn allow the protection areas to be refined.

14 REFERENCES

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APPENDIX 1

Pumping Test Data
72h Constant Rate (~6m3/h) in BH2
15min Recovery in BH1

Borehole 72 hr. yield test

Borehole name: BOREHOLE No. 2

O.S.S. No.:

Location: Corrignavoh

Diameter: 6"

Depth: 225'

County: Cork

Drawdown: ☑

Recovery: ☐

Pumping well: ☐

Observation well: ☐

Date: 3-6-04

Distance from pumping well:

Weather: Fine & Dry

Test conducted by: Declan Barry, Southern Pumps.

Time	Elapsed time	Days		Water level	Draw -- down		Meter reading	Quantity	Remarks
GMT	Mins/ hours			M	M		Gals /		
				2.30	0		246640		
12.57	0	0.00		2.3	0		246640	0	
	0.5 min.	3.47x10^{-4}		3.00	0.7		246500		
	1.0	6.95		4.70	1.7		246600	100	
	1.5	1.04 x 10^{-3}		5.30	0.6		246670	70	
	2.0	1.39		5.54	0.24		246690	20	
	2.5	1.74		5.80	0.26				
	3.0	2.08		5.90	0.10				
	3.5	2.43		6.00	0.10		246710	20	
	4.0	2.78		6.00	0.00				
	4.5	3.13		6.00	0.00				FILTER BLOCKED.
	5	3.47		6.00	0.00				
	6	4.17		6.00	0.00		246750	40	
	7	4.86		6.00	0.00				
	8	5.56							
	9	6.25							
	10	6.94		6.4	0.40		246820	70	
	13	8.33							
	14	9.72		[illegible].00					
	16	1.11 x 10^{-2}							
	18	1.25		8.40					
	20	1.39							
	22	1.53							
	24	1.67							
	26	1.80							
	28	1.94							
	30	2.08		8.42	0.02		247270	450	22.5 gpm
	35	2.43							
	40	2.78		8.42	0.00		247385	115	
	45	3.13		8.43	0.01		247453	68	
	50	3.47		8.45	0.02		247554	101	20.2 gpm

GMT	Elapsed time Mins/ hours	Days		Water level M	Draw – down M		Meter reading Gals /	Quantity	Remarks
	55	3.82							
12.57	1 hr.	4.17		8.58	0.13		247790	236	23.6gpm
	1.25	5.21							
	1.5	6.25							
	1.75	7.29							
15.00	2.0	8.83		8.61	0.03		249158	1368	22.8 gpm
	2.5	1.04×10^{-1}							
16.00	3.0	1.25		8.67	0.06		250508	1350	
~~[illegible]~~	3.5	1.46							
	4	1.67							
	5	2.08							
	6	2.5							
20.06	7	2.92		8.80	0.13		255999	5491	22.88gpm.
	8	3.33							
22.10	9	3.75		8.89	0.09		258169		
	10	4.17							
	12	5							
	14	5.83							
	16	6.67							
	18	7.5							
7.00	21	8.75		9.17	0.28		274020		
10.00	24	1.0×10^{0}		9.20	0.03		277924	3904	21.69gpm.
13.00	27	1.125		9.27	0.07		281828		
19.00	30	1.25		9.40	0.13		285702		
	36	1.5							
7.00	42	1.75		9.65	0.25		301425		21.80 gpm
13.00	48	2		9.85	0.20		309231		21.68
1900	54	2.25		10.05	0.20		317037		
	60	2.5							
7.00	66	2.75		10.12	0.07		332649		21.68 gpm.
1300	72	3		10.15	0.03		340455		

Comments

BH1 (Behind the Pump House)		
PUMPING		
time (minutes)	water level	Comments
0.01	2.3	
0.5	3	
1	4.7	
1.5	5.3	
2	5.54	
2.5	5.8	
3	5.9	
3.5	6	Filter blocked
7	6	
10	6.4	
14	7	
18	8.4	
30	8.42	22.5gpm
40	8.42	
45	8.43	
50	8.45	20.2gpm
60	8.58	23.6gpm
120	8.61	22.8gpm
180	8.67	
420	8.8	22.88gpm
540	8.89	
1260	9.17	
1440	9.2	21.69gpm
1620	9.27	
1800	9.4	
2520	9.65	21.80gpm
2880	9.85	
3240	10.05	21.68gpm
3960	10.12	
4320	10.15	21.68gpm
RECOVERY		
time (minutes)	water level	Comments

Depth

Yield

Transmissivity Formula CE Jacob	**T=(0.183*Q)/c**	**m2/s**
0.183*Q	0.000305	
During pumping		
c=	1.3	m
T=	**0.000234615**	**m2/s**
T=	**20.27**	**m2/d**
During Pumping		
c=	1.25	m
T=	**0.000244**	**m2/s**
T=	**21.08**	**m2/d**
During Pumping		
c=	0.98	m
T=	**0.000311224**	**m2/s**
T=	**26.89**	**m2/d**

BH1 (Behind the Pump House)		
PUMPING		
time (minutes)	water level	Comments
RECOVERY		
time (minutes)	water level	Comments
0.01	7.35	
1	5.35	
2	4.75	
4	4.3	
6	3.95	
12	3.65	
15	3.5	

Depth	**40m**
Yield	**165m3/d**

Transmissivity Formula CE Jacob	**T=(0.183*Q)/c**	
0.183*Q	0.000355833	
During pumping		
c=		m
T=		**m2/s**
T=		**m2/d**
During Recovery		
c=	3.05	m
T=	**0.000101667**	**m2/s**
T=	**8.78**	**m2/d**