Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Kilmuckridge Water Supply Scheme

Ballygarran II 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 Ballygarran II borehole 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 ‘Ballygarran II’ Borehole is the groundwater source for Kilmuckridge Public Water Supply. The borehole supplies approximately 460 m^3/day to Kilmuckridge. Two other production wells, Newtown (2.4 km to the east of Ballygarran II) and Ballygarran I (1.1 km to the northeast) previously supplied the Kilmuckridge area but are now no longer used due to iron and manganese water quality problems.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Kilmuckridge area.
- To delineate source protection zones for the Ballygarran II borehole.
- To assist the Environmental Protection Agency (EPA) and Wexford County Council in protecting the water supply from contamination.

The protection zones are intended to provide a guide in the planning and regulation of development and human activities to ensure groundwater quality is protected. More details on protection zones are presented in ‘Groundwater Protection Schemes’ (DELG/EPA/GSI, 1999).

2 Methodology

The methodology for this study consisted of data collection, desk studies, site visits and field mapping. Analysis of the information collected during the studies was used to delineate the Groundwater Source Protection Zones.

The initial site visit and interview with the caretaker took place on 31/06/2010. Site walk-overs and field mapping (including measuring the electrical conductivity and temperature of streams in the area) of the study area were conducted on 31/06/2010, 14/07/2010 and 23/07/2010.

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.

3 Location, site description and well head protection

The Ballygarran II borehole, operated by the Wexford County Council since 2005, is located 400 m west of Kilmuckridge Village (see Figure 1). The site is located along a farm road, with access from the R742, and is surrounded by agricultural lands. Groundwater is pumped from the borehole source, and is chlorinated before being pumped to Kilmuckridge Reservoir, 1 km to the south, for storage and distribution throughout the network.

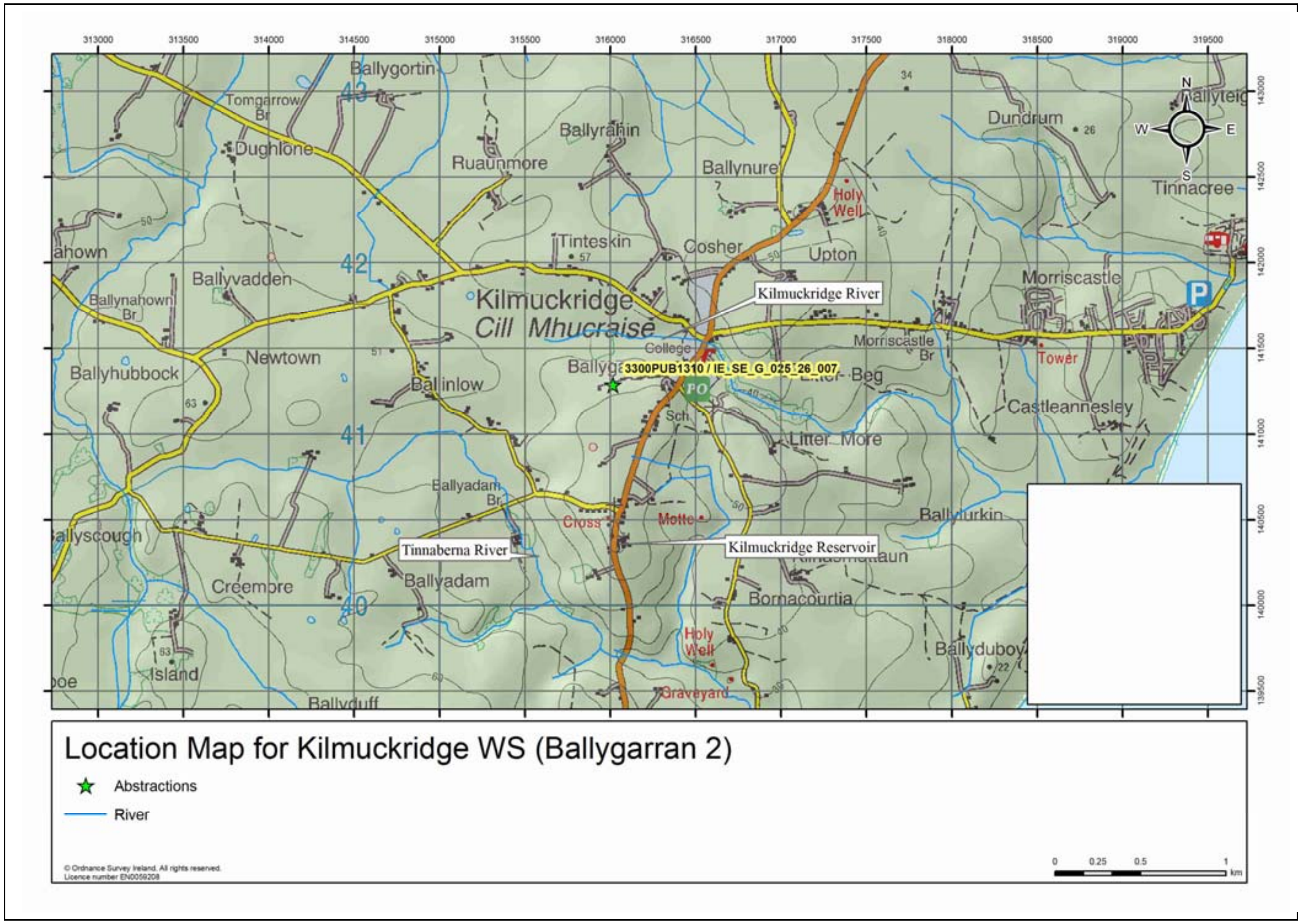

Figure 1 Location map for the area around Ballygarran II borehole

Photograph 1 Borehole cover of Ballygarran II

The borehole has a cover which is securely fixed with no access to the inner borehole but the site is unfenced (Photo 1). The annulus around the borehole is not grouted.

4 SUMMARY OF WELL DETAILS

A trial borehole (TW1) was drilled approximately 5 m from the current location of Ballygarran II in the late 1990's. A production borehole, Ballygarran II, was subsequently drilled and pump tested in 2004 by O'Donohue Bros. Ballygarran II is now the only council water supply for Kilmuckridge. A summary borehole log is provided in Appendix I.

It is proposed to connect Kilmuckridge to the Gorey water supply in 2013 to supplement the high water supply demand in Kilmuckridge. Water demand and a shortage of storage capacity in Kilmuckridge reservoir currently require the pump to operate continuously.

Table 3.1 provides a summary of details as currently known. Photograph 1 shows the site and location of production borehole.

Table 3.1 Summary Details

	Ballygarran II borehole
EU Reporting Code	IE_SE_G_025_26_007
Grid reference	E315922 N141293
Townland	Ballygarran
Source type	Borehole
Drilled	2004
Owner	Wexford County Council
Elevation (Ground Level)	c. 54.5 mOD
Depth	54.2 m
Depth of casing	Inner casing 54.2 m, outer casing 23.5 m Open hole at 0.2 m from 23.5 m to 54.2 m
Diameter	Inner casing 0.152 m uPVC, outer casing 0.205 m Steel
Depth to rock	25.9 m
Static water level	Approximately 12 m bgl
Pumping water level	Greater than 35 m bgl
Consumption (County Council records)	460 m^3/d Pumping 24 hours per day
GSI Productivity Rating	Class II
Specific capacity	13.1 m^3/day/m (July 2010)
Transmissivity	24.4 m^2/day (Logan T)

5 Topography, surface hydrology and landuse

Ballygarran II borehole is located within the catchment of a small, unnamed coastal river (Hydrometric Area 11). For the purposes of this report the stream will be referred to as the Kilmuckridge River. Refer to Figure 1 which shows the location of Ballygarran II borehole and the Kilmuckridge River.

Ballygarran II borehole is located on the northern edge of a moderately steep, oval shaped ridge with elevations varying between 26 m and 72 mOD. The topography of the ridge in the vicinity of the Ballygarran II is moderately sloping to the north, with the surrounding Kilmuckridge area also comprising moderately sloping topography. The land rises to the south of Kilmuckridge village towards a topographical high at Kilmuckridge Reservoir (72 m OD). Gradients in the study area are between 1:20 and 1:100.

The Kilmuckridge River is located 0.3 km to the north of the source and flows towards the east. In general, the natural drainage density is moderate. Drainage ditches are absent from the sand and gravel areas, with ditches becoming common however in the till areas to the north. The Tinnaberna River and its tributary flows along the eastern, western and southern boundaries of the ridge (See Figure 1).

Agricultural land currently extends on all sides from the source. Land use in the study area in general is a mixture of urban and agricultural, as tillage and grazing. Extensive building has taken place in Kilmuckridge within the last 5 years. A valid planning permission is in place for a large housing estate adjacent to the eastern and southern boundaries of Ballygarran II. A number of farmyards have been noted in the area, though no farmyards were identified within 200 m of the borehole. No major industries or IPPC licenses were identified in the environs of the source.

6 Hydrometeorology

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:* 841 mm.** Data from the Met Eireann website show that the source is located between the 800 mm and 1000 mm average annual rainfall isohyets. The nearest rainfall gauging station to Ballygarran II borehole is located at Morriscastle, which recorded an average annual rainfall of 841 mm during the period 1961 to 1990 (Fitzgerald and Forrestal, 1996).

***Annual evapotranspiration losses:* 450 mm.** Potential evapotranspiration (P.E.) is estimated to be 500 mm/yr (based on data from Collins and Cummins, 1996). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

***Annual Effective Rainfall:* 391 mm**. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 391 mm/year.

7 Geology

7.1 Bedrock geology

This section briefly describes the relevant characteristics of the geological materials that underlie the Ballygarran II borehole. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based the Bedrock Geological Map of South Wexford Sheet 23, 1:100,000 Series (Tiestzsch-Tyler et al, 1994).

The Bedrock Geological Map of South Wexford indicates that this area is principally occupied by Lower Palaeozoic Rocks (Cambrian Metasediments) of the Newtown Formation. The Newtown Formation is comprised of grey green turbiditic greywacke and shaly mudstone. Slate and greywacke was encountered in the Ballygarran II borehole, with the main water bearing fractures present between 33 and 39 m bgl. Bedrock exposures of the Newtown Formation are limited in the Kilmuckridge area due to extensive overlying subsoil.

Refer to Figure 2 for the Geology Map of the area. The Lower Palaeozoic rocks extend over a large area along the east Wexford coastline (Tiestzsch-Tyler et al, 1994) and are comprised of primarily of greywacke sandstones, siltstone, shale and mudstones.

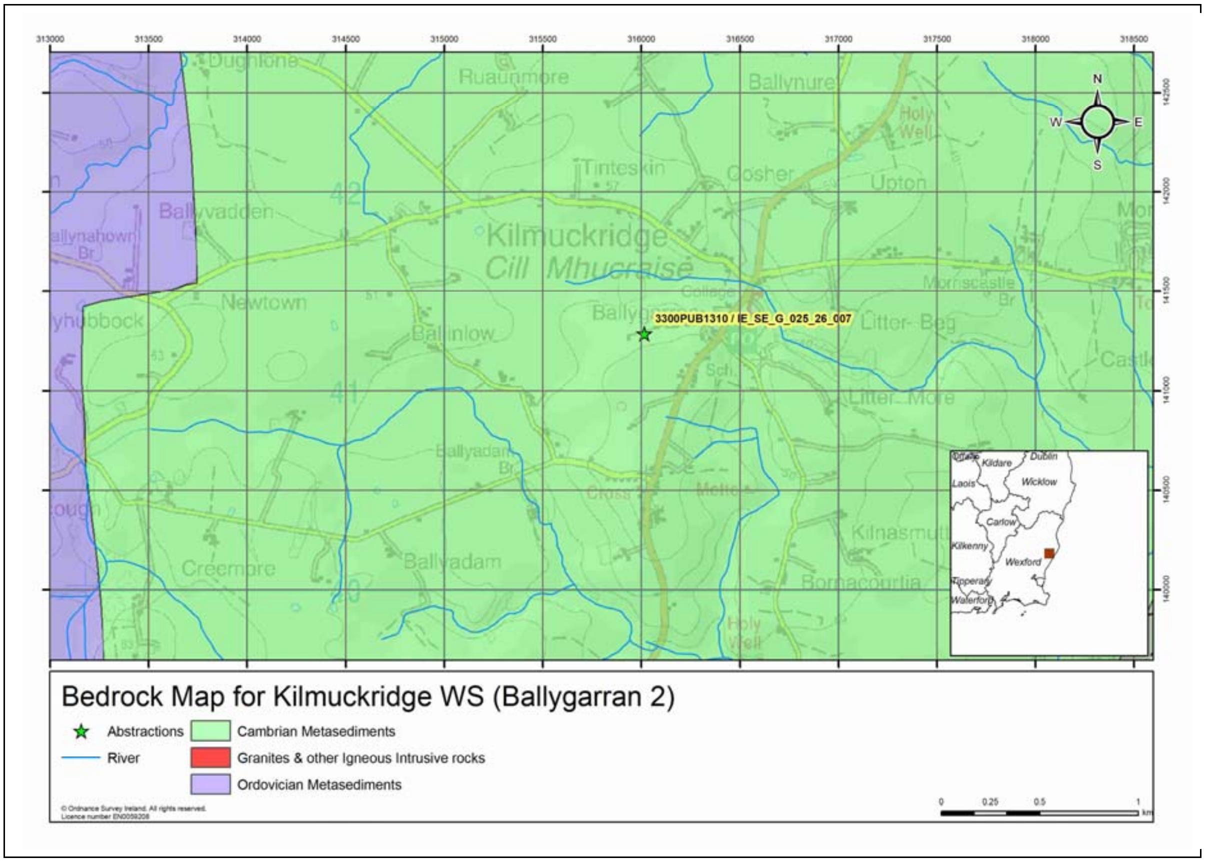

Figure 2 Geology map for the area around Ballygarran II borehole

7.2 Subsoils geology

According to GSI and EPA web mapping, the subsoils of the study area are dominated by sand and gravel deposits derived from Lower Palaeozoic Sandstone and Shales (GLPSsS). To the north of the Kilmuckridge River, 0.3 km to the north of the source, till derived from Irish Sea Basin origin, and dominated by limestone (IrSTLs), occurs.

During the last glacial period (~16,000 years BP) Irish Sea ice advanced onto land and moved forward crossing the present position of the Wexford coast (An Foras Talúntais, 1964). The tip of the glacier reached its northern limit at Kilmuckridge and moved over and possibly deformed some Irish Sea Till deposits. At this stage the ice began to melt and in doing so deposited material of a very sandy nature throughout the area.

The Irish Sea till located 0.3 km to the north of the Ballygarran II borehole is comprises of stiff, slightly gravelly sandy CLAY with occasional sand units. Excellent exposures of Irish Sea till and 'Screen gravels' occur to the east and southeast of Kilmuckridge along 9 km of the coastline between Ballyduboy and Curracloe (Thomas and Summers, 1982). The sea cliffs which are up to 50 m in height, expose the Irish Sea Tills and the Screen Gravels. The screen gravels consist of a complex suite of sands and gravels. Facies within the Screen Gravels consist primarily of massive to poorly bedded gravels, cross laminated sands, flat bedded sands, planar cross bedded sand and massive to laminated sand/silt. The contact between the Irish Sea Tills and overlying Screen gravels is evident along the coastline. In a number of places the contact is deformed and is either sharply folded or dragged over into overlying members (Thomas and Summers, 1982).

The stratigraphy of subsoil in the ridge is also complex, based on site visits. Within the mapped sand and gravel deposits, pockets of SILT/CLAY have identified in surface soil exposures and using a hand auger. Pockets of SILT/CLAY were identified overlying the sand and gravel deposits; towards the centre section of the ridge; around the borehole; and along the Tinnaberna River (see Figure 3). The depth of till is thought to be limited due to the general absence of surface water drains.

At location S1, to the south of the ridge, the Tinnaberna River bank exposed a till subsoil sequence directly overlying bedrock. Ponding/poorly drained areas corresponded to the till locations identified during site visits at S2 and S3, as well as around Ballygarran II borehole seem to show the lateral extend of this material. Based on information from the borehole log of Ballygarran II, the underlying subsoils at the borehole are comprised of clay, marl, sand and occasional gravels to 25.9 m bgl. Exposures elsewhere on the ridge encountered gravelly SAND deposits, in keeping with the mapped, sorted sands and gravels.

The soils on the sand and gravel areas are predominately well drained shallow soils (BminSW) while the till areas to the north of Kilmuckridge River are predominately 'wet' soil types: typically poorly drained deep mineral soils (AminPD) (EPA webmapping).

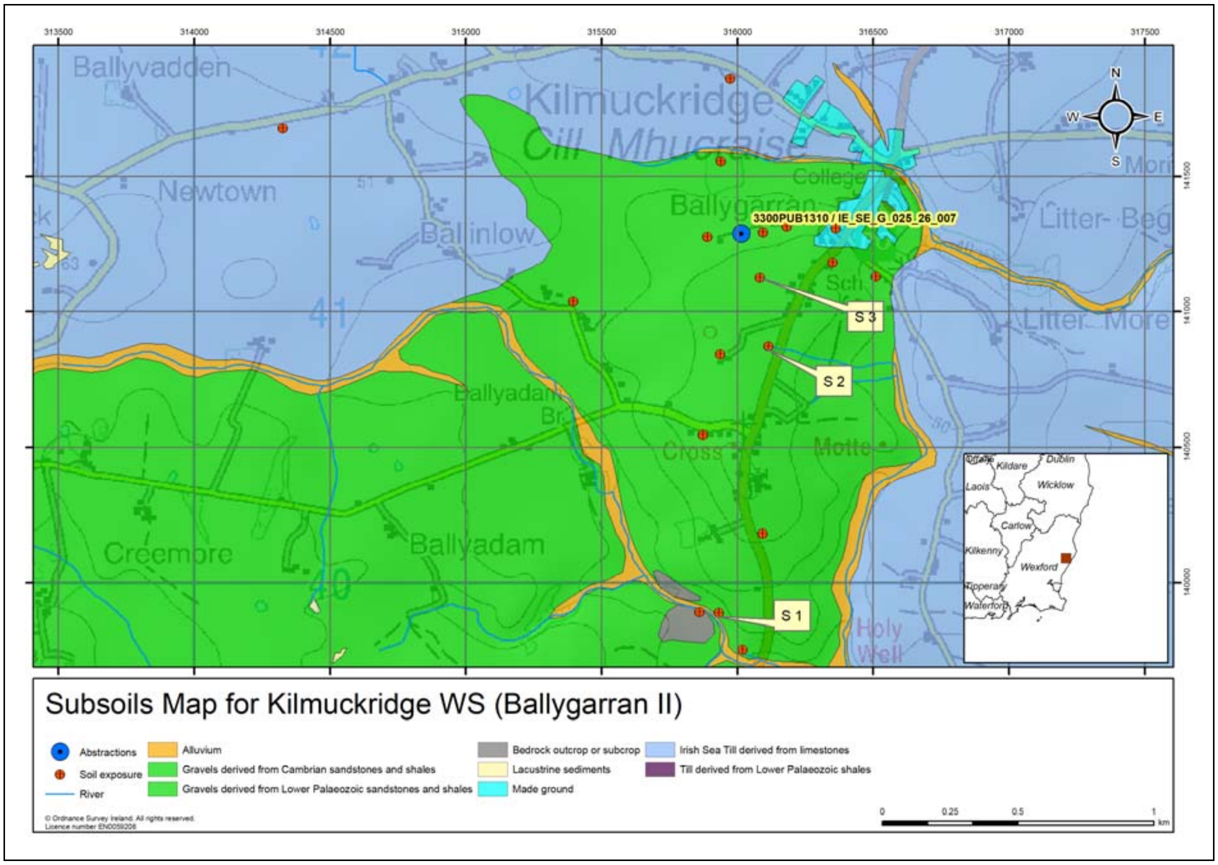

Figure 3 Subsoil Map for the area around Ballygarran II borehole

7.3 Depth to bedrock

Based on the geological information acquired from the GSI Well Database, the depth to bedrock in the area around the borehole is in general greater than 10 m. Depth to bedrock at the production borehole Ballygarran II is 25.9 m, from the borehole log.

Additional information was also obtained from previous drilling data as part of the Newtown borehole and Ballygarran I borehole drilling programmes. Drilling encountered between 25 m and 29 m of subsoil above bedrock at Ballygarran I and Newtown, 1 km to 2 km east of the source. The only known bedrock outcrops within 5 km of Ballygarran II occurs in the Tinnaberna River, 1.5 km to the south.

8 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 sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. 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 Groundwater Vulnerability map (2010) for the region, as mapped by Tobin Consulting Engineers on behalf of GSI, is dominated by 'low' and 'high' vulnerability and is shown in Figure 4. The permeability of the sand and gravel subsoil at Kilmuckridge is interpreted as 'high'. However, following field inspections, small pockets of 'low' permeability material are seen to occur throughout the sand and gravel areas; these are pockets where the surface layer is a clayey till. While areas of lower permeability till exist within the sand and gravel deposits, the overall subsoil permeability is 'high'.

The permeability of the Irish Sea Till subsoil to the north of Kilmuckridge River is interpreted as 'low', based on the presence of permanent surface water features and secondary indicators of low subsoil permeability.

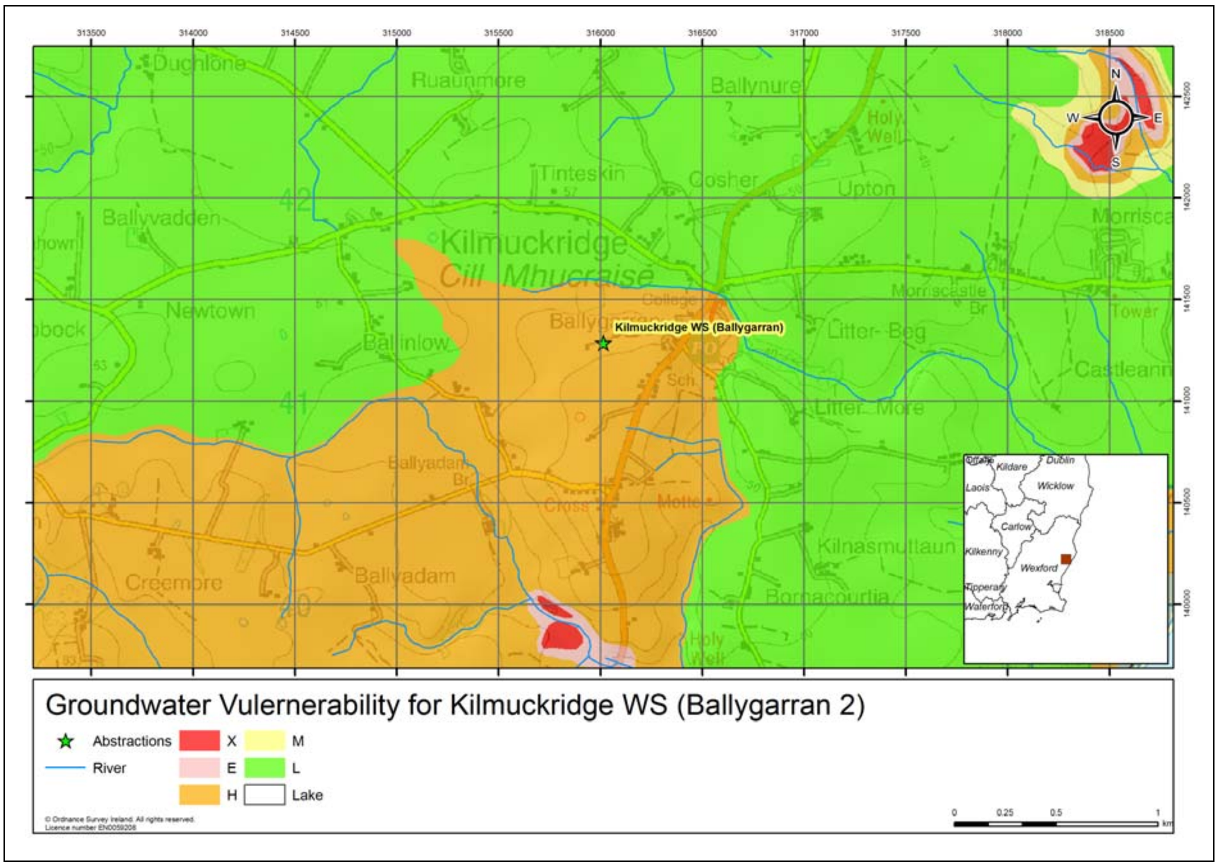

Figure 4 Groundwater Vulnerability for the area around Ballygarran II borehole (GSI)

9 Hydrogeology

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

- GSI Website and Well Database

- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan in June and July 2010.

9.1 Groundwater body and status

The Ballygarran II borehole is located within the Kilmuckridge 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 .

9.2 Groundwater levels, flow directions and gradients

Groundwater levels in the subsoils in the area surrounding Ballygarran II borehole are between 1.5 m bgl and 35 m bgl.

In the vicinity of the source, groundwater flow is assumed to follow topography and flow northwards towards the Kilmuckridge River. Adjacent to the Kilmuckridge River, approximately 300 m to the north of Ballygarran II borehole, a small spring (SW1) discharges from gravels, which overlie a low permeability till layer. Due to the limited groundwater discharge, the spring is assumed to be intercepting shallow groundwater flow.

A well survey was conducted in August 2010 to establish the water levels under the ridge and in the surrounding area. During the well survey it became evident that few domestic wells are present surrounding Kilmuckridge. Based on local information, previous wells drilled on the ridge had a tendency to 'clog up' with fine sand from the underlying subsoil. All wells monitored during a well survey were drilled through the overburden and completed in bedrock so as to prevent sand clogging of the wells. Water levels are presented below in Table 8.1 and borehole locations shown on Figure 10.

Table 8.2 Water levels in the area surrounding Ballygarran II borehole

Well ID	Location	Elevation (m OD)	Water level (m bgl)	Groundwater elevation (m OD)
TW 1	5 m from Ballygarran II	54.5	34.89	19.61
Ballygarran II borehole	-	54.5	Inaccessible	-
Seafield estate borehole	0.2 km SE of source	62	Inaccessible	-
DW1	1.1 km S of source	63	25.54	37.46
DW2	1.7 km S of source	26	Artesian	26.6 (top of casing)
Ballygarran I	1.2 km NW of source	47.5	4.38	43.12
Newtown	2.5 km W of source	56.5	10.82	45.68
SW1	0.4 km N of source	50.5	49	49

The groundwater flow direction is assumed to radiate from the apex of the ridge. Local groundwater flow within the subsoil and bedrock aquifers at Ballygarran II borehole may be controlled by the pumping of the well, as the drawdown is relatively large at 23 m. During site visits, the flow within the Kilmuckridge River was seen to be small (less than 1 litre/second).

In September 2010, following an extended period of dry weather, a pumping water level of 35 m bgl was measured in the borehole TW1 whilst pumping at 460 m^3/d. Water levels and temperature within TW1 were monitored using a data logger between 14th July 2010 and 22nd July 2010 with results included below in Figure 5. Trial borehole TW1 is located approximately 5 m away from Ballygarran II borehole. Water levels are corrected to account for atmospheric pressure. Water levels in TW1 did not respond to the heavy rainfall events during the period of monitoring. Approximately 90 mm fell between 14th July 2010 and 22nd of July 2010. Water levels in TW 1 actually decreased by 0.1 m during this period with a maximum variation of 0.4 m over 8 days of monitoring. The sudden fall and rise in TW1 during the first three days is believed to correspond to pumping in the Seafield borehole.

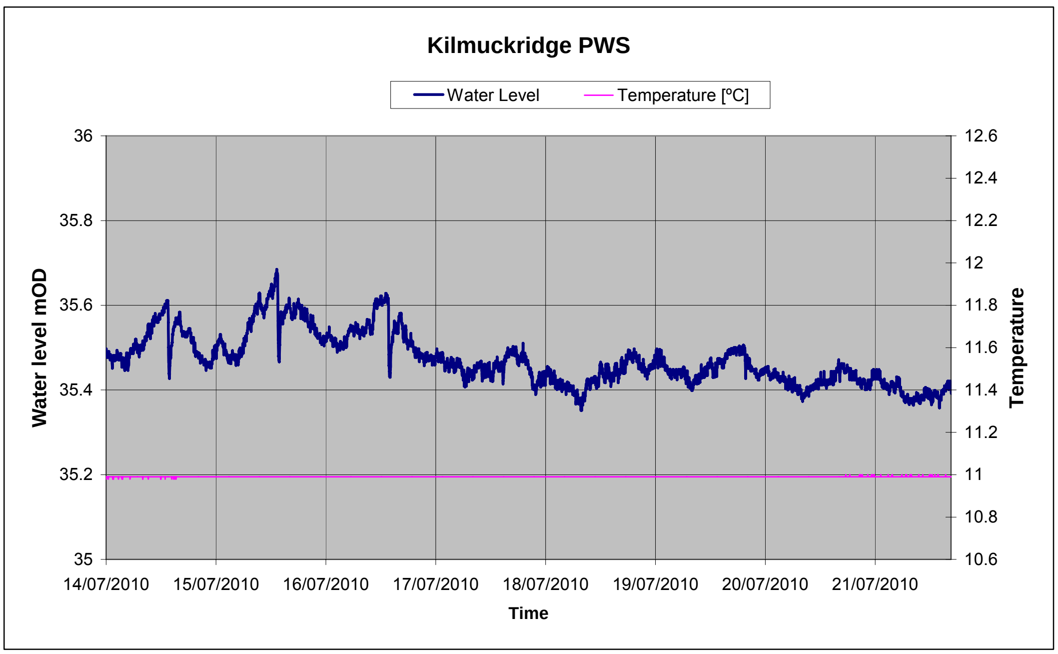

Figure 5 Groundwater levels and Temperature in TW1 (14/07/2010 – 22/07/2010)

The natural groundwater gradient is considered to be relatively low, approximately 0.01, reflecting the topographical gradients. There are limited well data for the bedrock aquifer in the vicinity of the Ballygarran II borehole.

9.3 Hydrochemistry and water quality

Eight sample analyses from Ballygarran II were available from the EPA Groundwater Monitoring Network between 2008 and 2009. The water quality is hard (232 to 278 mg/l $CaCO_3$). Alkalinity ranges from 215 to 237 mg/l $CaCO_3$. The pH ranges between 7.6 and 8.0, which is alkaline. Electrical conductivity ranges from

516 to 535 μS/cm @ 25^{o}C. The hydrochemical signature of the Ballygarran II groundwater is therefore of calcium bicarbonate.

The concentrations of nitrates are generally low, with most concentrations below 10 mg/l (as NO_3) There is no reported exceedance of the EU Drinking Water Directive maximum admissible concentration of 50 mg/l, however one abnormally high concentration on 30/10/08 (47.1 mg/l as NO_3, see Figure 6) was just below the MAC.

Chloride concentrations range from 20 to 35.5 mg/l, with a mean of 30 mg/l, which is considered to be above the mean natural background level of 18 mg/l (Baker *et al.,* 2007). Given the proximity of Kilmuckridge to the coast (3 km to the east) the chloride levels are thought to reflect the elevated chloride levels in coastal rainfall rather than contamination.

Faecal coliforms were below detection limits in all water samples analysed. The presence of deep gravels suggests a relatively low likelihood of faecal contamination occurring, due to the filtration. Elevated concentrations of total coliforms were detected on five occasions. However, due to the absence of faecal coliforms, such values may be due to sampling or analysis error. The installation of greater wellhead protection with a dedicated sampling port, may help resolve the coliform issues at Ballygarran II borehole.

The concentration of sulphate, potassium, iron, manganese, magnesium and calcium are within normal ranges. The Potassium: Sodium (K:Na) ratio is low at less than 0.1 and never exceeds the GSI threshold of 0.35. A low K/Na ratio suggests that organic wastes derived from farmyards or landspreading of agricultural wastes are not a major cause for concern.

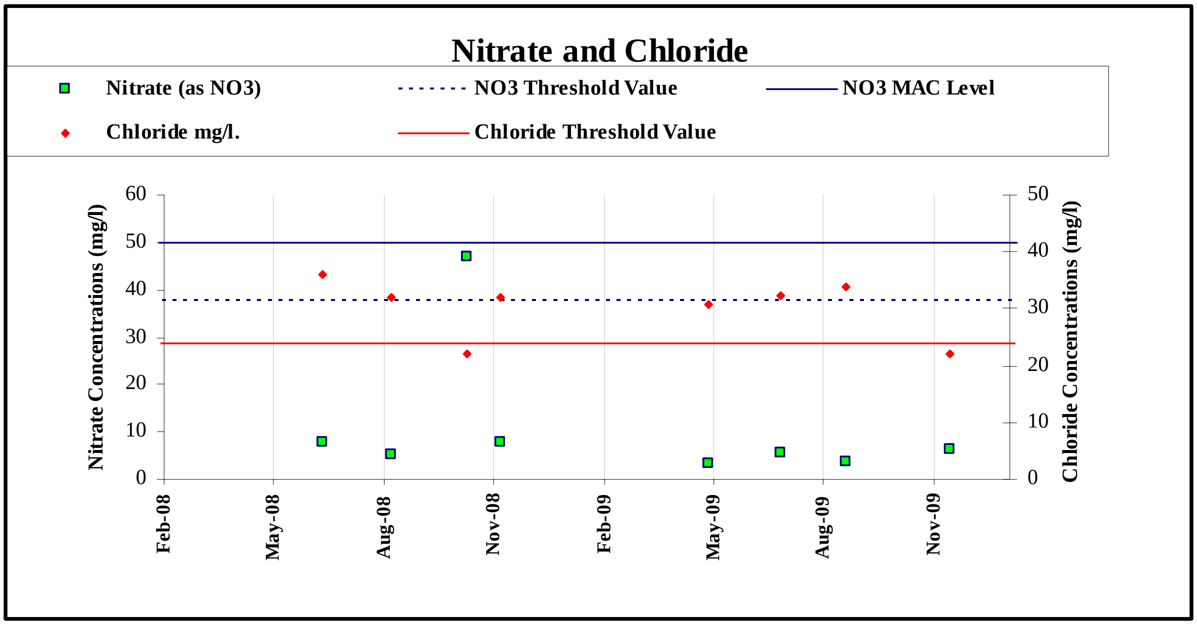

Figure 6 Nitrate and Chloride Concentrations for Ballygarran II borehole

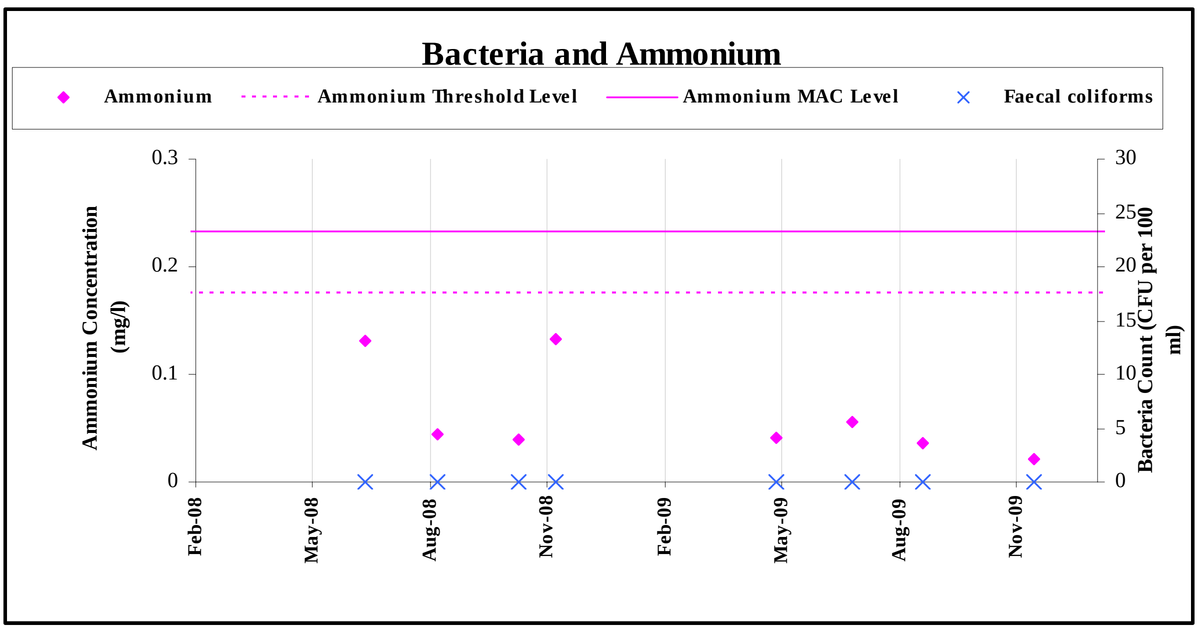

Figure 7 Ammonium and Faecal Coliform Concentrations for Ballygarran II borehole

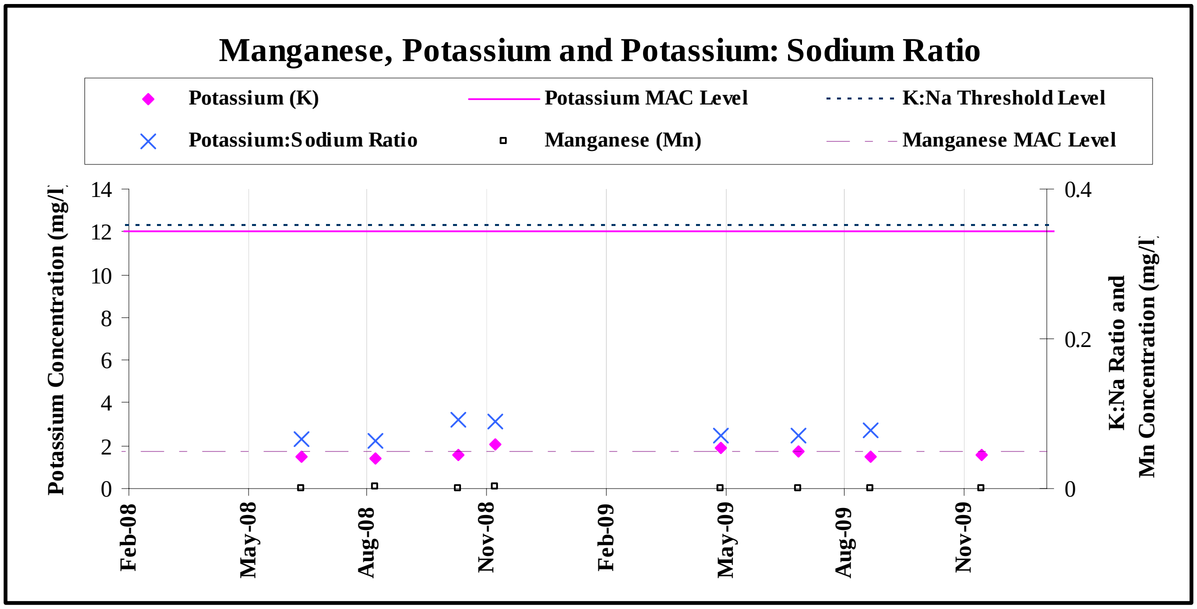

Figure 8 Magnesium and Potassium Concentrations for Ballygarran II borehole

The concentrations of all other trace metals are below groundwater thresholds. The concentration of all organic compounds is below the detection limit of the laboratory.

In summary, low concentrations of nitrate, an absence of faecal coliforms and low K:Na ratios indicate a high quality groundwater source, with minimal anthropogenic impacts.

After a number of years pumping, groundwater quality issues arose in the previous Wexford County Council abstraction boreholes at Newtown and Ballygarran I. High concentrations of ammonium, as well as odour problems (possibly hydrogen sulphide gas) increased over time resulting in the need for additional water treatment. Additionally, elevated iron and manganese levels were recorded in the Newtown Borehole. Redox processes can generate undesirable by-products, such as dissolved manganese (Mn^{2+}), ferrous iron (Fe^{2+}), ammonium and hydrogen sulphide (H_2S). The hydrochemical signature of the Ballygarran II (calcium bicarbonate) groundwater is appreciably different from the hydrochemical signature of the Ballygarran I (magnesium bicarbonate). The different hydrochemical zones are potentially significant as hydrochemical signatures can be used to delineate probable sources of recharge and determine ground-water flow paths within the aquifer system. Based on the hydrochemical signature the recharge area and groundwater flow paths to each well is different.

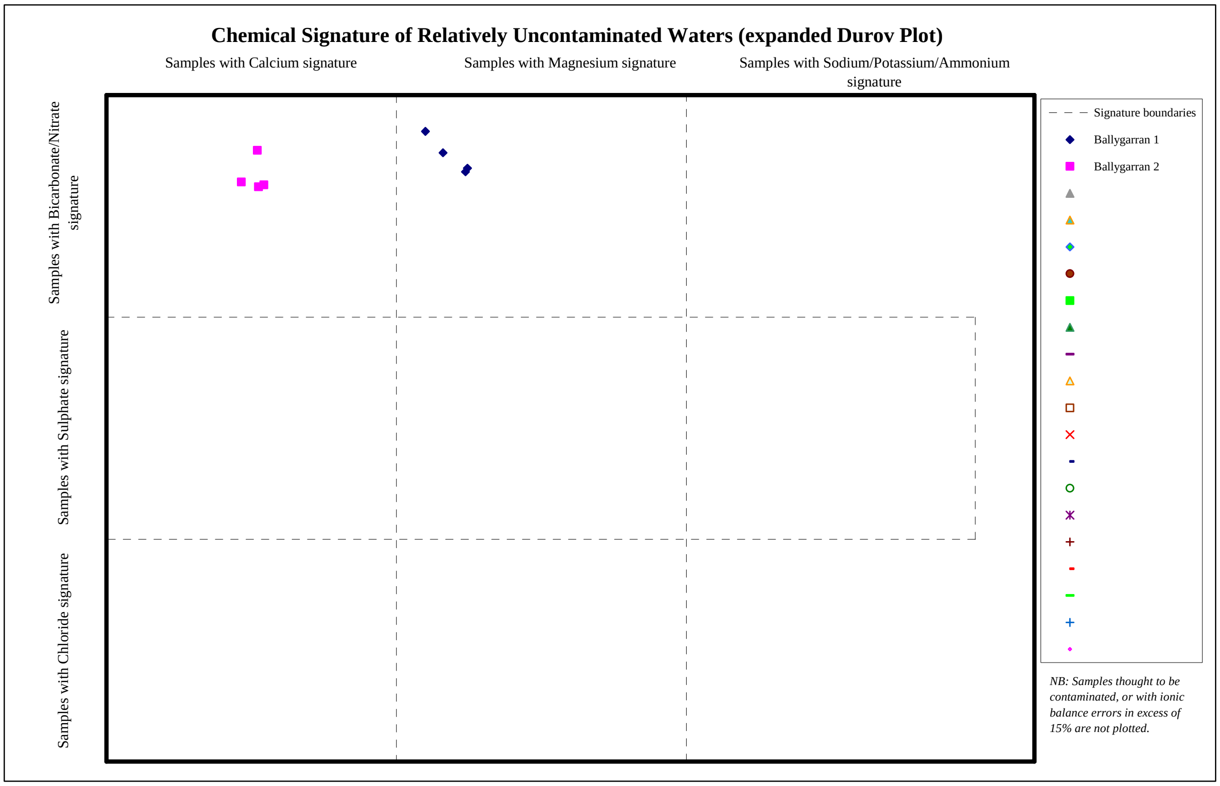

Figure 9 Hydrochemical signature of groundwater in Ballygarran I and Ballygarran II boreholes

9.4 Aquifer characteristics

The GSI bedrock aquifer map of the area indicates that the Lower Palaeozoic rocks of the Newtown Formation are classified as a Poor Aquifer which is generally unproductive except for local zones (Pl). The overlying sand and gravel subsoil deposits is classified as a Regionally Important sand and gravel aquifer.

The aquifer is not considered to have any primary porosity, with groundwater flow occurring predominantly through fractures, fissures and joints in the upper fractured and weathered zone. Aquifer storage is low based on the aquifer type, and groundwater flow paths are dependent on faulting/fracturing.

In this aquifer classification, it is unusual to achieve yields greater than 100 m^3/day. The overlying subsoil is considered to provide the main groundwater contribution to Ballygarran II. The upper fractured bedrock is thought to be hydraulically connected to the overlying subsoils. Groundwater is assumed to migrate through the subsoils and upper bedrock towards the borehole.

A pumping test was completed over a 72 hour period in February 2004. A short summary of the pumping test data was available. The borehole pumping rate was initially started at 650 m^3/day and cut back to 560 m^3/day after a larger than expected drawdown within the well. Water levels stabilized at 35 m bgl during the last 5 hours of the test. Similar drawdown levels were recorded in TW1 (34.5 m) and Ballygarran II (35 m). As no further detailed information was available from the pumping test, the Logan transformation was used to estimate Transmissivity, see above. The initially higher pumping rate suggests the removal of groundwater from storage in the gravels.

The yield of Ballygarran II borehole is ‘excellent’, according to GSI classification, and the productivity is Class II. Based on data from July 2010, the specific capacity of Ballygarran II is approximately 20 m^3/day/m (23 m drawdown).

Using the Logan transformation of T = Q/s x 1.22 (Misstear, 1998) and a calculated specific capacity (based on yield tests) of 20 m^3/m/day, the transmissivity in the vicinity of the borehole is estimated to be of the order of 24 m^2/day. This analysis is based on limited data and would require further monitoring to validate assumptions. However, the transmissivity values and specific capacity values used are lower than those achieved during the initial pump testing and are therefore conservative.

Permeability (K) is in the order of 1 m/day based on a minimum saturated thickness of 26 m, and a Transmissivity of 24.4 m/day. Effective porosity is assumed to be in the order of 5% (subsoil and bedrock). Velocity is determined using Darcy’s law, $v = K (dh/dl)/n_e$.

K is the Hydraulic Conductivity = (Transmissivity of 24.4 m^2/d/saturated thickness of 26 m)

gradient = 0.01

n_e is the effective porosity = 0.05

Therefore velocity is in the order of 0.2 m/day.

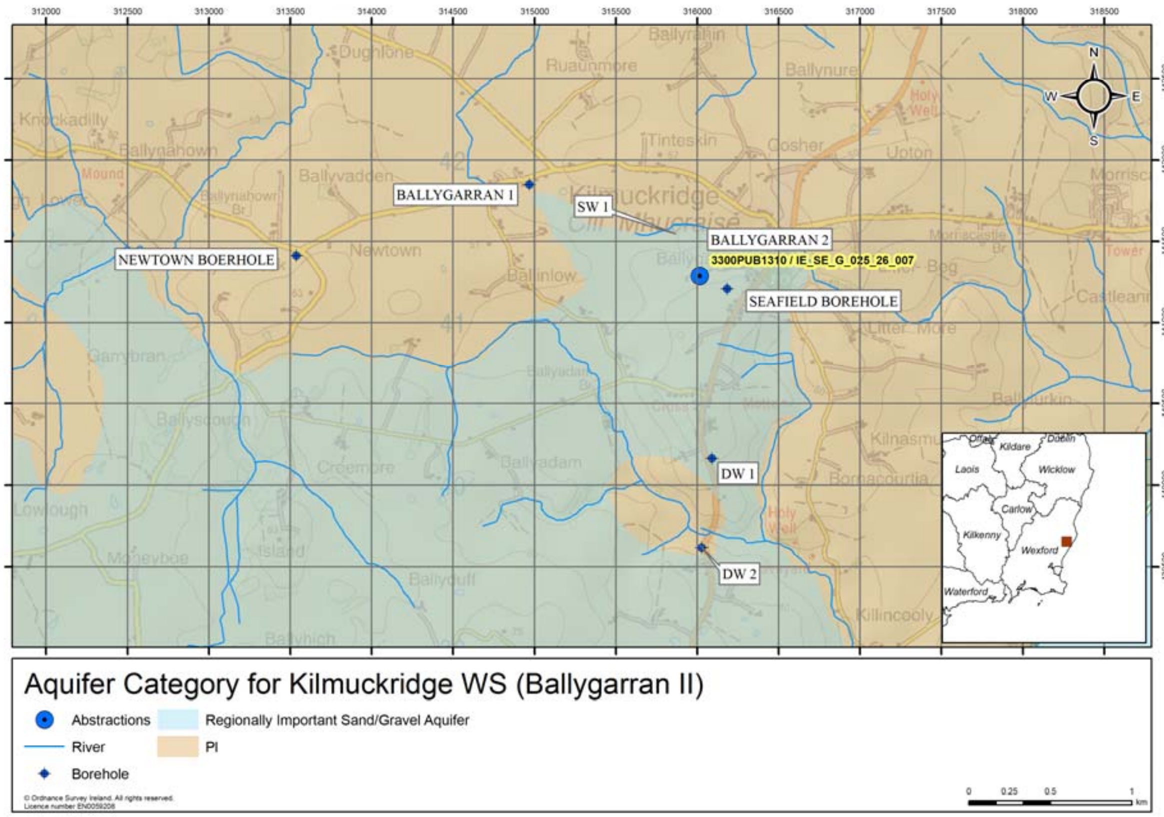

Figure 10 Aquifer map for the area around Ballygarran II borehole

10 Zone of contribution

The Zone of Contribution (ZOC) is the complete hydrologic catchment area to the source, or the area required to support an abstraction from long-term recharge. The size and shape of the ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. This section describes the conceptual model of how groundwater flows to the source, including uncertainties and limitations in the boundaries, and the recharge and water balance calculations which support the hydrogeological mapping techniques used to delineate the ZOC.

10.1 Conceptual model

Groundwater flows in a northerly direction towards the source. The bedrock aquifer is the Ordovician (Newtown Formation) which is mapped as a Poor aquifer; generally unproductive only in Local Zones (Pl). The overlying sand and gravel deposits (Regionally Important Sand and Gravel Aquifer) are deep and considered to be in hydraulic connectivity with the upper fractured/weathered bedrock. In this area, the high well yield, moderate to high transmissivity, moderate to high specific capacity and shallow gradients, all provide evidence that the sands and gravels overlying the bedrock provide groundwater to the borehole source. The aquifer is unconfined, has High vulnerability over all of the area, and is likely to be recharged locally, through highly permeable, deep sand and gravel subsoils and the upper weathered/fractured bedrock. This is reflected in the water quality results which show the absence of faecal bacteria in the untreated water.

Limitations to the conceptual model mainly lie with a lack of information on groundwater levels on the elevated ridge, and in our understanding of the complex relationship between the sand and gravel and the till subsoil units.

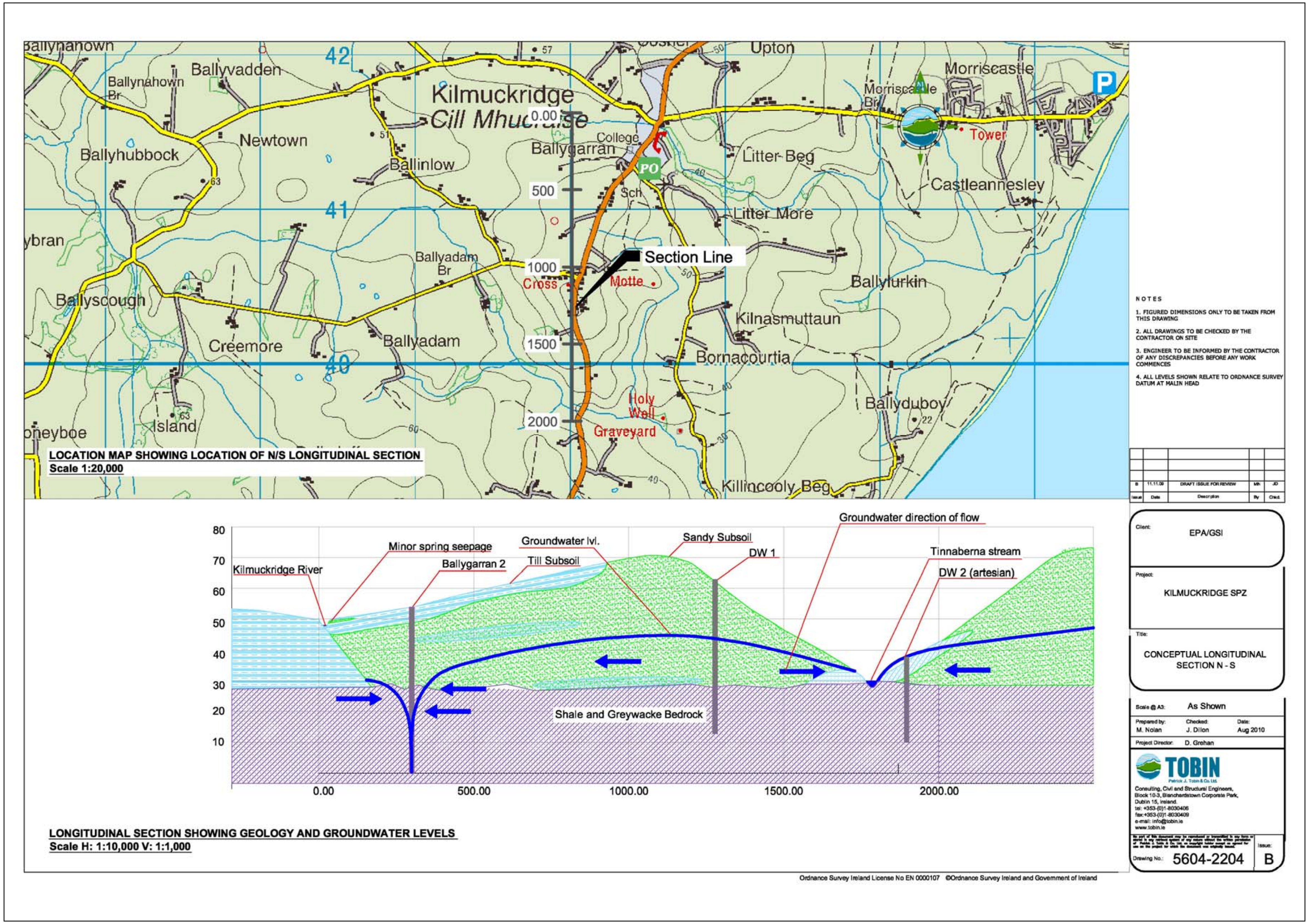

Figure 11 Conceptual model N/S through Ballygarran II borehole

10.2 Boundaries of the ZOC

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 boundaries of the area contributing to the source are considered to be as follows (Figure 12):

The **Northern Boundary** is based on a combination of hydrogeological mapping and the uniform flow equation (Todd, 1980).

The uniform flow equation (Todd, 1980) is:

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

where
Q is the daily pumping rate
T is Transmissivity (taken from the aquifer characteristics)
i is the background non-pumping gradient.

The uniform flow equation suggests the wells could pump from 300 m down-gradient (based on an approximate transmissivity of 24.4 m^2/day and a natural groundwater gradient of 0.01).

The **Southern Boundary** is primarily based on topography and groundwater levels. It is assumed that groundwater can flow from the topographical high at Kilmuckridge Reservoir towards the source. It is unlikely that the ZOC would extend past the topographical high.

The **Eastern Boundary** is difficult to delineate as it is uncertain as to the interplay between the sand and gravel, and the Irish Sea till, eastwards from the source. The eastern boundary is however primarily based on topography and a water balancing exercise. The headwaters stream is marked within the eastern boundary of the ZOC on the OSI map. However no surface flow was encountered within the stream during the site visits.

The **Western Boundary** is difficult to delineate as it is uncertain as to the interplay between the sand and gravel, and the Irish Sea till, westwards from the source. The western boundary is based on the presence of the Tinnaberna River, topography and a water balancing exercise.

10.3 Recharge and water balance

The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (i.e. annual rainfall) less water loss prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as it will dictate the size of the zone of contribution to the source (i.e. the outer Source Protection Area).

At Kilmuckridge, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

Runoff losses: 78 mm. Runoff losses are assumed to be 20% of potential recharge. This value is based on an assumption of *c*. 20% runoff for 100% of the area with high vulnerability, high permeability subsoils and soils) (Guidance Document GW5, Groundwater Working Group 2005).

The bulk ***recharge coefficient*** for the area is estimated to be 80%.

These calculations are summarised as follows:

Average annual rainfall (R)	841 mm
Estimated P.E.	500 mm
Estimated A.E. (95% of P.E.)	450 mm
Effective rainfall	391 mm
Potential recharge	391 mm
Runoff losses	20%
Bulk recharge coefficient	80%
Recharge	313 mm

Water balance: The water balance calculation states that the recharge over the area contributing to the source, should equal the discharge at the source. At a recharge of 313 mm/yr, an average yield of 460 m^3/day would require a recharge area of 0.54 km^2.

The ZOC described above is 0.54 km^2 and is based on the current understanding of the hydrogeology and in groundwater flow directions.

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.

The Inner Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999). Based on the indicative aquifer parameters presented in section 8.5, the groundwater velocity is 0.2 m/d, and hence the 100-day time of travel distance is 20 m. The Inner Protection Area is illustrated in Figure 12.

The Outer Protection Area (SO) encompasses the entire zone of contribution to the source i.e. 0.54 km^2.

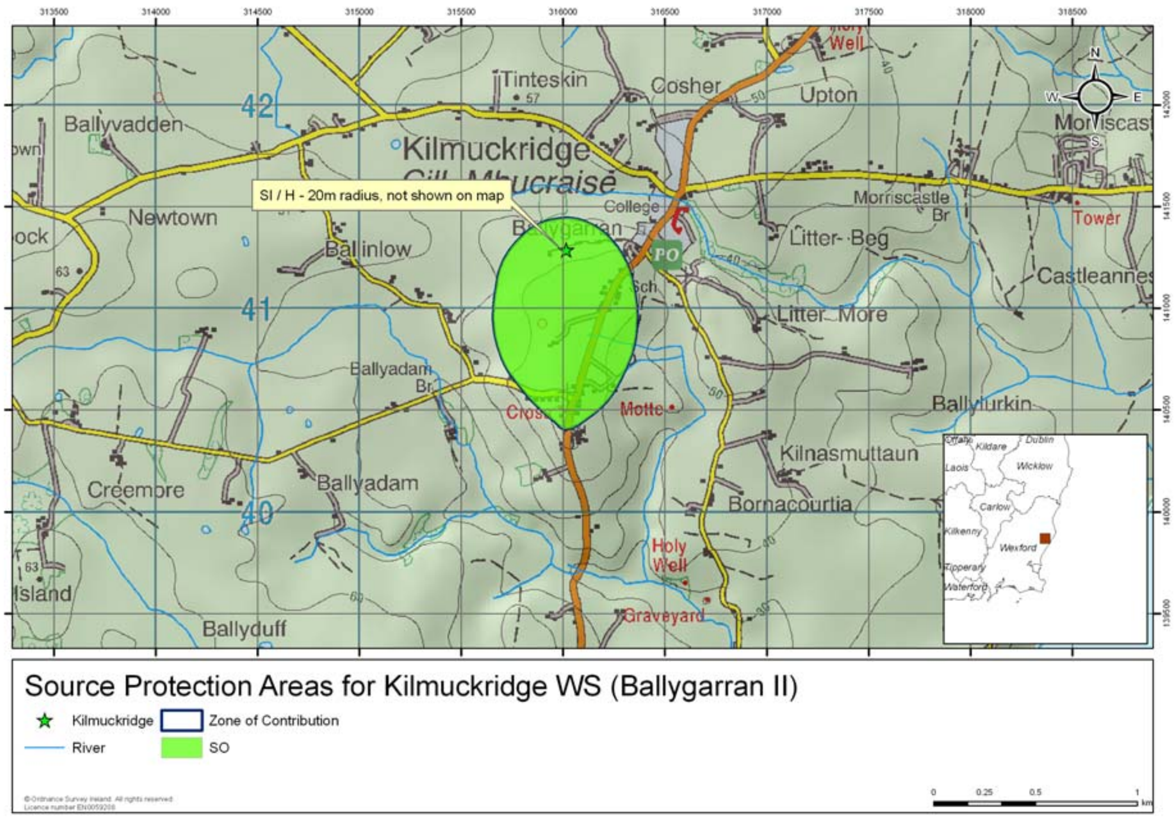

Figure 12 Source Protection Areas for Ballygarran II borehole

Groundwater protection zones are shown in Figure 12, and are based on an overlay of the groundwater vulnerability on the source protection areas. Therefore the groundwater protection zones are SI/H and SO/H. The majority of the area is designated SO/H.

Table 10.3 Source Protection Zones

Source Protection Zone	% of total area
SI/High	<1%
SO/High	>99%

12 Potential pollution sources

The borehole area is currently unfenced and the borehole is not grouted. A secure borehole cover is in place. The landuse within the Inner Source Protection Area is primarily tillage and pastureland for grazing animals. The main potential microbial pollution sources are considered to be the presence of cattle grazing in the field surrounding the water treatment works. Faecal coliforms have not been detected in the untreated water.

Land use in the Source protection areas is a mixture of urban and rural activities. The majority of land within the Inner and Outer Source Protection Area is agricultural and the dominant farm activity is tillage and dairy farming. The main potential pollution sources associated with farming activities are animal slurry storage areas, grazing animals and landspreading of agricultural waste. The possible impacts to the water quality of the public supply associated with these activities within its Inner Source Protection Area are elevated levels of ammonia, nitrate, phosphate, chloride, potassium, BOD, COD, TOC and pesticides. These parameters are not generally elevated in the untreated water supply. The area to the east of the outer source protection area is partially urbanized with many suburban type dwellings within the ZOC. These residential areas are served by a main sewer network. The main potential contaminants from sewerage leaks are ammonia, nitrates, phosphates, chloride, potassium, faecal bacteria, viruses and cryptosporidium. These parameters are not generally elevated in the untreated water supply.

Finally, there are one regional road and 2 No. third class roads in the south and the east of the ZOC. The main potential contaminants from this source are surface water runoff contaminated with hydrocarbons and metals. However, the low traffic density locally indicates that the risk of such contamination is low.

In summary, the presence of the gravels at the source are probably the reason for the relatively good water quality, as they filter and attenuate the direct recharge.

13 Conclusions

The borehole is a high yielding borehole that abstracts from the sand and gravel deposits, but takes some of the water from bedrock at depth. The bedrock is overlain by approximately 26 m of interbedded till/sand and gravels. Groundwater is thought to infiltrate slowly through the subsoils and upper fractured bedrock towards the borehole.

The untreated groundwater is currently of good microbial quality. Quality trends for iron, manganese, nitrate and ammonia should continue to be monitored as they are indicative of the reducing conditions that have occurred in other older (disused) boreholes in the Kilmuckridge area.

The Outer Source Protection Area or the Zone of Contribution is calculated to extend to 0.54km^2. The Inner Source Protection Area or the 100-day horizontal travel time is calculated to extend 20 m from the abstraction source.

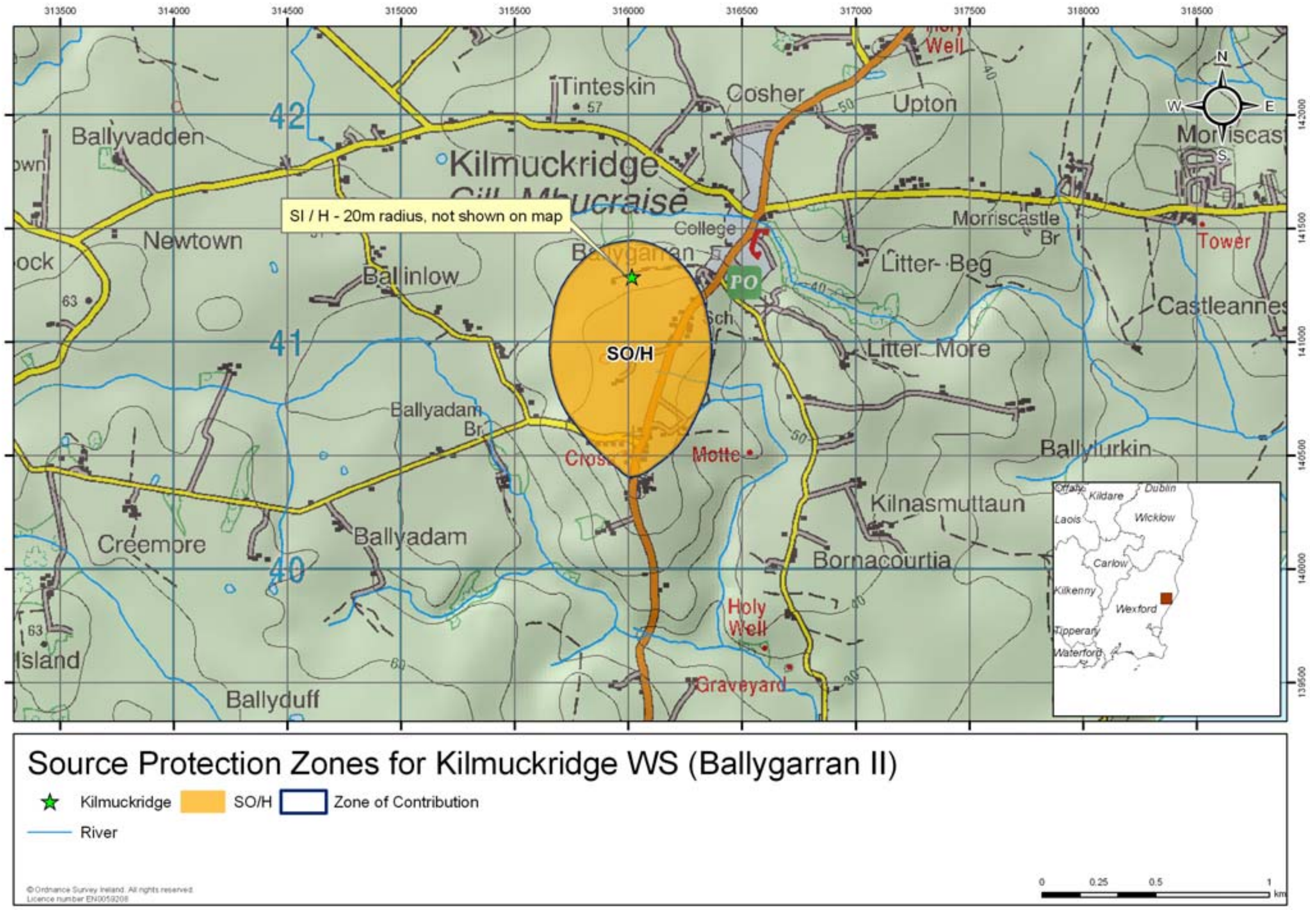

Figure 13 Source Protection Zones around Ballygarran II borehole

14 Recommendations

The protection of the source site involves prevention of access and prevention of activities in the immediate proximity of the abstraction boreholes. A cordon around the source is recommended in order to ensure that potentially polluting materials are not stored or deposited in the immediate vicinity of the source. Secure, anti-intrusion fencing should be erected around the source site, which acts to protect the integrity of the borehole headwork's and ancillary infrastructure.

Monitoring of nitrate, ammonium, iron and manganese trends should continue at Ballygarran II to assess redox conditions. Monitoring water levels during the operation of the scheme should be continued to develop a real-time database of hydrogeological information.

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APPENDIX 1

Borehole Log & Pumping test

**New Borehole for proposed housing development at
Ballygarran, KILMUCKRIDGE
Results of 3 day Pump Testing January 2004 (1st New Borehole)**

Borehole Data

Total Depth:	67m (220ft)
Static Water Level:	11.95m
Surface Casing Diameter (Int):	6.25” (159mm) steel
Surface Casing Length:	27m (90ft)
Borehole Casing Diameter (ext):	125mm PVC (blue)

(Note this specification is now the standard specification for a domestic well locally.)
Driller’s estimated yield at end of drilling: 3,000-4,000 gallons/hour (320-430m^3/day)
Water Inflow Location: Main inflow at approx. 140ft (43m)

Pump Testing

A 3 day continuous test was carried out from 9 January 2004 to 12 January 2004.
As the drilling had shown that bore produced a large quantity of water so the available largest submersible pump which will fit in a 4” (or 5”) borehole was utilised, which has a 5.5kW motor.
In order to monitor the water level during the test using a dipmeter, the rising main used was 1.5” rather than 2”, which had the effect of restricting the pump.
At test end, as for much of the test, the result was

Yield	371m^3/day (3,400gallonshour)
Drawdown:	11.05m (from a static of 12m) implying 23.05m total dynamic level.

Clearly this borehole is capable of yielding a greater volume of water, which it is not possible to predict. However when one notes that the total drawdown occurred in the first hour or so it would suggest that there is notable spare capacity in it.
Conservatively there is likely to be a yield of 500m^3/day, although it cannot be physically pumped from this borehole using an electric submersible.
While there had been considerable rainfall in the previous few weeks the depth of the water inflow level to the borehole would point to some independence from rapid reaction to rainfall.