Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Glanbia (Ballyragget) Water Supply Scheme

Ballyconra Boreholes

September 2010

Prepared by:
Dr. Robbie Meehan, Consultant Geologist

With contributions from:
John Dillon and Coran Kelly, Tobin Consulting Engineers;
Jenny Deakin TCD

And with assistance from:
Glanbia Ingredients, Ballyragget, County Kilkenny

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 Ballyconra 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 Source Protection Zone Delineation.

The Ballyconra boreholes are the main water supply source for the Glanbia Ingredients Plant at Ballyragget. The source was initiated in 1972 when 3 no. 10-inch boreholes were drilled and subsequently put into production. A fourth borehole was drilled on the same site in 1978. All 4 boreholes have been used intermittently in the past, with generally 3 operating at any one time, however borehole no. 4 is not used at present. The 3 no. boreholes supply approximately 3,840 m^3/day to the plant.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Ballyconra area.
- To delineate source protection zones for the Ballyconra Boreholes.
- To assist the Environmental Protection Agency and Glanbia Ingredients 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 Ballyconra Boreholes comprise a well-field located c. 1.7 km to the northwest of the centre of Ballyragget Village as shown in Figure 1, and have operated as a water supply to Glanbia Ingredients (previously Avonmore Creameries Ltd.) since 1972. Access to the boreholes is *via* a trackway leading off to the west-southwest from the main N77 road. The source comprises 4 no. boreholes, 3 no. of which are currently being utilised.

The main use of water from the scheme is for plant washing, but the water is also mixed with river water and used for drinking within the plant. At the time of writing, 3 no. boreholes were active and are pumped at a combined rate of 130m^3/hr, 24 hours a day, resulting in a combined volume of 3,120 m^3/d. A maximum usage of 3,840 m^3/d is recorded from the site. The groundwater is pumped to a reservoir with a storage capacity of approximately 3,800 m^3, and subsequently chlorinated and fluoridated. A tap is present on the third of the initially-bored wells for raw water samples.

The boreholes were cased with 12-inch casing to *c.* 12m depth, and the remaining depth to bedrock completed in 10-inch casing. No information exists as to the size, shape and intensity of the slotting, but development of the boreholes was minimal.

The boreholes are housed in pump-houses of various sizes and are poorly maintained, with unlocked doors in poor condition. The boreholes are not sealed and have open tops, and with the gaps present in the walls for feeder pipes rodents and birds can access the boreholes' area freely. The site area is fenced/walled, but cattle graze the field and can walk within 2 m of the boreholes.

Plate 1 The well-field, viewed from the north. The 4 no. pump-house structures are clearly seen.

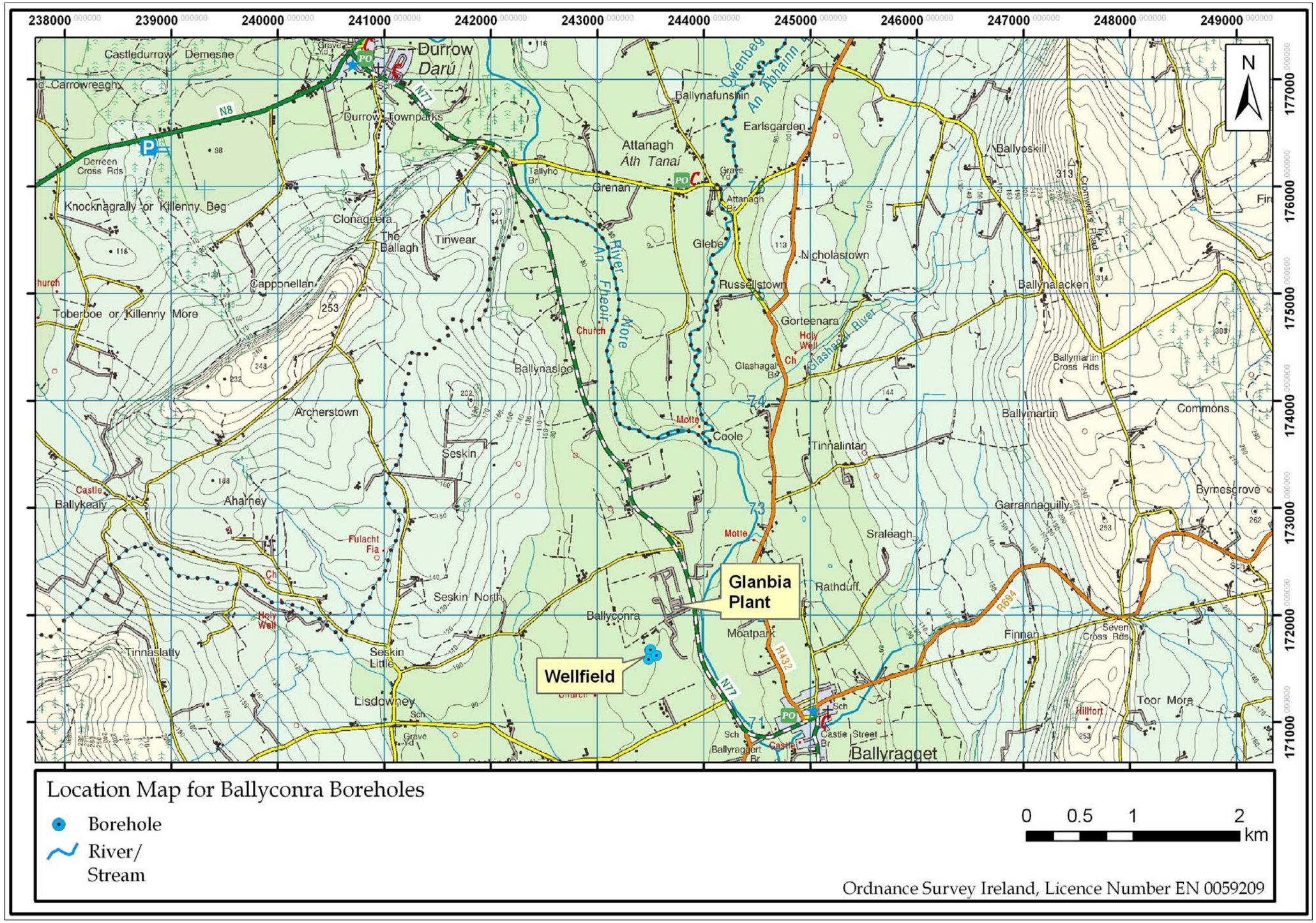


Figure 1 Location Map showing the region around the Ballyconra Boreholes.

3 SUMMARY OF BOREHOLE DETAILS

Table 3.1 provides a summary of borehole details currently known at Glanbia Ingredients, Ballyconra.

Table 3.1 Summary of Boreholes' Details at the Ballyconra Source

Well details	Well Name	
	PW1	PW2
EU Reporting Code	Not applicable	Not applicable
GSI No.	2317SW W422	2317SW W421
Grid reference	E243481 N171589	E243553 N171623
Townland	Ballyconra	Ballyconra
Source type	Borehole (as part of well-field)	Borehole (as part of well-field)
Drilled	1972	1972
Owner	Glanbia Ingredients Ltd.	Glanbia Ingredients Ltd.
Elevation (ground level)	81.5m OD.	79.8m OD.
Depth	26.5m	27.4m
Depth of casing	c. 12m	c. 12m
Diameter	12-inch to 12m, 10-inch below	12-inch to 12m, 10-inch below
Depth to rock	c. 11m-12m	c. 11m-12m
Static water level	13.6m below gr. level (1973)	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	203.9 $m^3/d/m$[1]	Unknown
Normal abstraction	c. 1,040m^3/d	c. 1,040m^3/d
Maximum Abstraction	c. 1,280m^3/d	c. 1,280m^3/d
Hours Pumping	24	24

Well details	Well Name	
	PW3	PW4
EU Reporting Code	IE_SE_G_059_10_001	Not applicable
GSI No.	2317SW W420	2317SW W453
Grid reference	E243500 N171678	E243492 N171669
Townland	Ballyconra	Ballyconra
Source type	Borehole (as part of well-field)	Borehole (as part of well-field)
Drilled	1972	1978
Owner	Glanbia Ingredients Ltd.	Glanbia Ingredients Ltd.
Elevation (ground level)	81.2m OD.	80.8m OD.
Depth	33.5m	12.8m
Depth of casing	c. 12m	Unknown
Diameter	12-inch to 12m, 10-inch below	8-inch inner, 13-inch outer
Depth to rock	c. 11m-12m	11.9m
Static water level	12.6m below gr. level (1973)	Unknown
Transmissivity	Unknown	Unknown
Specific capacity	Unknown	Unknown
Normal abstraction	c. 1,040m^3/d	None currently
Maximum Abstraction	c. 1,280m^3/d	None currently
Hours Pumping	24	None currently

[1] It must be noted that this specific capacity estimate utilises pumping water level data from 2009 and static water level data from 1973.

Plate 2 Detail of borehole PW2.

4 METHODOLOGY

The methodology consisted of collection of data from the Glanbia Plant records and from GSI Archival Records, desk studies of relevant maps and reports, site visits and field mapping. Analysis of the information collected during the various stages of review was used to delineate the Groundwater Source Protection Zones.

The initial site visit and interview with the Glanbia Environmental Officer took place on 23/11/2009.

Site walkovers and field mapping (including measuring the electrical conductivity and temperature of streams in the area) of the study area were conducted on 04/12/2009 and 11/12/2009.

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE

The boreholes' area seems to constitute an extensive area of well drained soils upon first inspection, being situated within the hummocky to gently undulating, deglacial outwash plain of the River Nore. The Ordnance Survey six inch map of the 1860's shows the land as well drained pasture, as the landholding of the adjacent Ballyconra House Demesne.

The outwash plain is 3-4 km wide around Ballyragget with its' constituent sands and gravels filling a wide, deep valley bounded on either side by high, bedrock-cored ridges, at Seskin-Ballynaslee to the west and Toor More-Ballyoskill to the east. The lowest area of this plain forms the floodplain of the current river, as a narrow alluvial strip oriented north-south in the centre of the valley.

On these flanking ridges, the land rises to 202 m and 313 m at Seskin and Ballyokill respectively, with elevations in the outwash plain between c. 65 m and 83 m. Typical topographic gradients in the wide valley area range between 1:50 and 1:70, but are in the order of 1:15-1:20 on the flanking ridges. Gradients are moderate (c. 1:25) in the area around the boreholes.

Owing to the well drained nature of the sands and gravels in the outwash plain, there are few natural, or anthropogenic, surface water features around the boreholes. The Nore River flows north-south 500 m to the east and c. 20 m lower in elevation. A stream rises in Seskin North Townland, 1.3 km west-northwest of the boreholes, and also flows north-south before joining another stream at Grange, 2 km to the southwest of the boreholes. It is interesting to note that, further north in Seskin Townland, a small surface water stream partially sinks into 3 no. swallow holes, as well as disappearing into sands and gravels, at the edge of the major scarp. Drainage ditches are generally absent from the sands and gravels, with ditches becoming common however on the till slopes to the west. Rushes occur sporadically on these till slopes also, but are absent from the areas of sands and gravels.

A small pond occurs at the base of a hollow 800 m to the northwest of the boreholes; this seems to be no more than an area where the water table breaks the surface, and has no inflow or outflow features. As well as this, the extensive hollow 200 m northwest of the boreholes was flooded at the time of assessment, owing to the recent heavy rains.

Land use in the area is primarily agricultural, with the majority of the lands set to pasture for dairying (c. 80%) or used for tillage (c. 15%). Small areas of scrub, broadleaf forestry and bedrock outcrops (hosting a few small, disused quarries) also occurs (5%). A number of farmyards occur in the area, with the nearest *c.* 350 m northwest of the boreholes. Many of these farmyards host slatted units, milking parlours and silage pits. Grazing of areas hosting small pockets of scrub, and with bedrock at the surface, was noted in Ballynaslee, to the north. Animal feeding was also noted in a disused quarry here.

The major industry in the area is the Glanbia Plant itself, which employs up to 500 people, and operates under the auspices of an IPPC licence. Single houses discharge to ground *via* septic tank systems and mechanical aeration systems along the base and flanks of the valley. A sand and gravel pit also operates 2.5 km to the north, but is on the eastern side of the River Nore.

6 GEOLOGY

6.1 BEDROCK GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the area around the Ballyconra boreholes. The geological information is based the bedrock geological map of Tipperary, Sheet 18, 1:100,000 Series (Archer *et al*., 1996) and the Geological Survey of Ireland (GSI) Karst Database.

According to the 1:100,000 bedrock sheets of the region (Archer *et al*., 1996, see Figure 2), this area is underlain principally by limestones of the Ballyadams Formation, which are also described as the Dinantian Pure Bedded Limestones for the purposes of the generalised rock unit map prepared for the WFD in characterising and describing groundwater bodies in Ireland by the GSI. These rocks are crinoidal wackestones and packstone limestones, and are the classic 'Burren' type limestone.

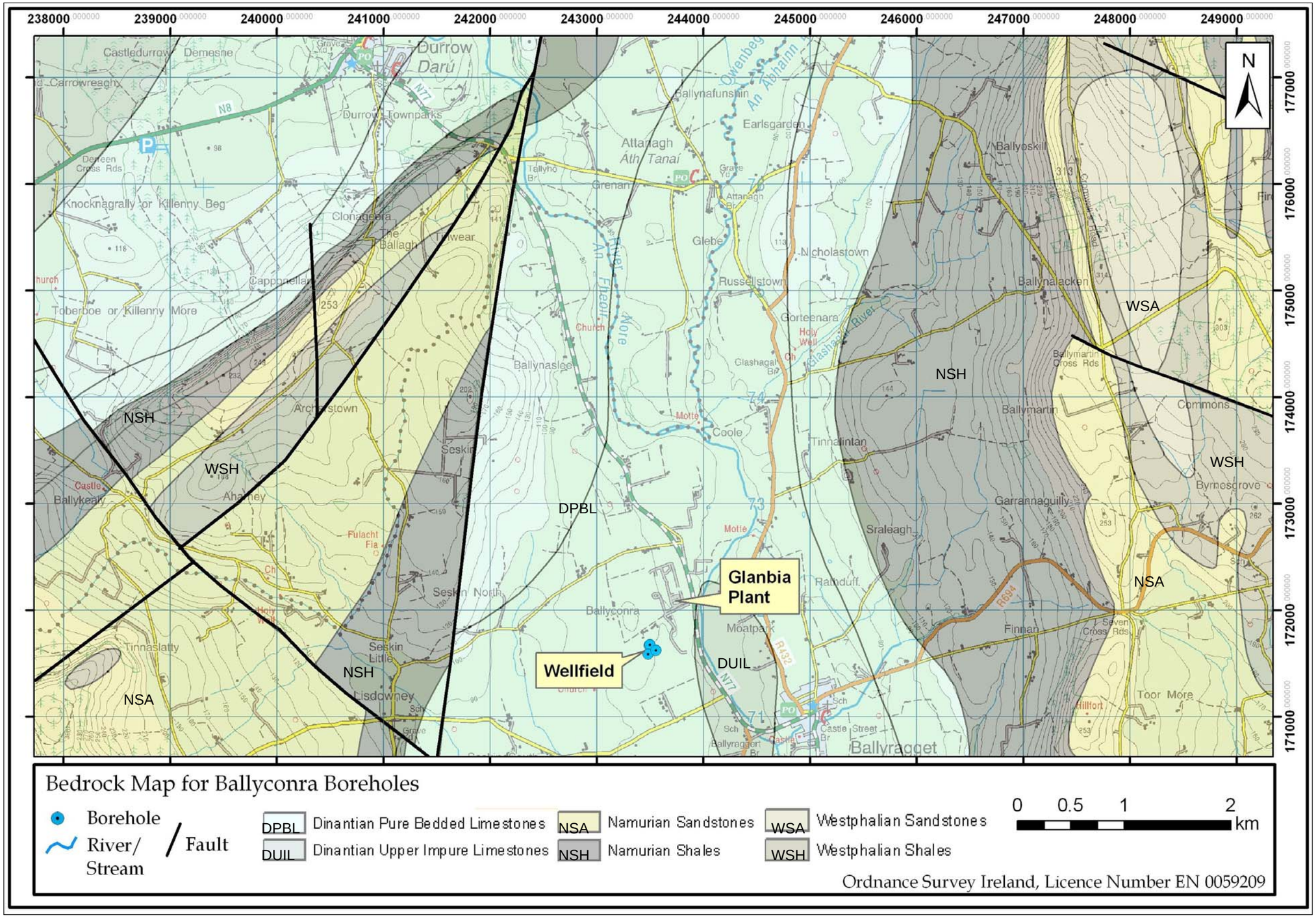


Figure 2 Bedrock geology of the area around the Ballyconra Boreholes.

The Dinantian Pure Bedded limestones of the Ballyadams Formation are composed of clean-bedded limestone which is generally homogenized, comminuted shelly debris, cemented by fine spar. Some oolithic and even micritic beds may occur near the base, just above the highest shales which define the top of the underlying Durrow Formation. The formation is over 200 m thick.

The Ballyadams Formation rocks outcrop rarely in the area and extend to the north and south along the valley by at least 5 km in each direction, and to the northwest by almost 2 km. A thin strip of cherty, muddy, calcarenitic limestone of the Cloghrenan Formation then occurs at the base of the scarps on either side of the valley, overlying the Ballyadams Formation. This has thinner beds and more chert than the Ballyadams Formation, but is still classed as Dinantian Pure Bedded limestone.

A small, ovoid area of Dinantian Upper Impure limestones occurs approximately 350 m to the east of the boreholes, covering just over 1 square kilometre. These rocks are the shaly fossiliferous and oolithic limestones of the Durrow Formation.

Numerous surface exposures of limestone were mapped during field studies conducted in December 2009. Small, disused quarries which have no current rock outcrop occur 800 m and 1 km northwest of the boreholes respectively. The most significant exposures noted were, however, a disused quarry at Ballynaslee (NGR 242555 174260), which extend to over 10 m of a vertical face. The bedrock units comprised thinly bedded bluish-grey, clean limestones, generally dipping less than 5^0 to the southeast.

To the west of the boreholes by 1.75 km, and forming generally the higher ground, the limestones are succeeded by Upper Carboniferous (Namurian) age shales of the Killeshin Siltstone Formation, as well as thick, flaggy sandstones of the Bregaun Flagstone Formation further west. These are separated from the limestone by a marked north-south oriented fault. Faulting has occurred in this 'Namurian' upland region west of the boreholes (Figure 2), but no faults have currently been delineated in the limestones in the immediate source locality.

To the east of the boreholes, also in the upland areas, a similar succession of Killeshin and Bregaun Formation Namurian-age rocks has been mapped.

6.1.1 Karst Geology

Hydrogeological mapping (December 2009) included checking existing, known karst features in the district around the source and searching for possible new features. The karst features listed in Table 6.1 are those recorded in the GSI Karst Feature Database within a 5 km radius of the Ballyconra boreholes: no new features were mapped in December 2009.

The locations of these features are shown in Figure 8. At Seskin, 3 no. swallow holes occur adjacent to each other, where a stream sinks into the ground having flowed off the Namurian Outlier. At Gorteenara to the northeast, St. Finians Well is a karstic spring, as is Donaghmore Well to the southeast.

Table 6.1 Karst features within a 5 km radius of the Ballyconra Boreholes Source (GSI Karst Database)

Number	Feature type	Feature name	Easting	Northing	Distance to source	Townland
K1	Spring	St. Finians Well	244943	174479	3 km northeast	Gorteenara
K2	Spring	Donaghmore Well	246194	170259	3 km southeast	Donaghmore
K3	Swallow Holes	Seskin Swallow Holes	241930	173190	2 km northwest	Seskin

Within the area of the deep sand and gravel deposits of the Nore Valley, karst features are less evident. Solutionally enhanced karst features were noted in the top 5 m bgl within the disused quarry at

Ballynaslee and typically ranged from 10 mm to 25 mm wide. A marked decrease in karstification was noted with depth, as the widths of karstified joints generally decreased from 10 mm to 3 mm at 5 m bgl.

Adjacent to this, clints and grikes were seen during the current mapping along outcropping karstified limestone in a field at NGR 242610 174400.

While drilling the boreholes in 1972 a 6m deep 'cavern' was recorded by the driller from 1m depth into the bedrock. No chippings were recovered, suggesting potential flow in the 'cavern', or fissure.

6.2 SUBSOILS GEOLOGY

The subsoils around the source comprise a mixture of coarse- and fine-grained materials. Sand/gravel, limestone tills and tills derived from Namurian shales and sandstones are the dominant subsoils in the area, with more restricted areas of bedrock outcrop, lacustrine clay and alluvium occurring (Figure 3). In general, subsoils are relatively shallow on the hillslopes east and west of the source, but are considerably deeper in the valley and around of the source on the more low lying and gently undulating terrain.

The area around the boreholes comprising the gently undulating to hummocky outwash plain flanking the Nore River is mapped on the Teagasc subsoil map as being underlain by deep glaciofluvial sands and gravels derived from limestones. These were deposited by a wide meltwater river in the Nore Valley during deglaciation, when the ice sheets of the last Ice Age melted. From examination of gravel pit faces in Russelstown, Coole and Glebe (County Laois) 2-3 km to the north of the boreholes, the sands and gravels are generally deep at >10 m, with depths of c. 12 m interpreted by Eugene Daly of GSI Groundwater Section in 1978, when re-interpreting the boreholes logs from 1972.

Till or 'Boulder clay' is an unsorted mixture of coarse and fine materials laid down by glacier ice during the last Ice Age. Till is the dominant subsoil type on the hillslopes west and east of the source boreholes. The tills are varied in their dominant lithology, being dominated by Namurian shale and sandstone on the hillslopes to the west, and by limestone on the hillslopes to the east. A gently undulating, low lying area of till derived from limestone also occurs to the west of the source in Lisdowney-Lisduff.

Immediately adjacent to the River Nore itself, a long, narrow, flat, low-lying strip of postglacial alluvial deposits occur. These have accumulated from repeated flooding of the river in this low lying area since the last Ice Age. The alluvium material seems to be dominated by SAND but also hosts interbedded GRAVELS and CLAY, and seems to overlie glaciofluvial sands and gravels, as seen in the borehole logs from the unsuccessful well-field to the northeast of the factory. Small areas of lacustrine CLAY occur 1.5 km north of the boreholes, at the base of 2 no. hollows <100 m across. These materials have accumulated in the hollows since deglaciation by repeated flooding there, similar to the alluvium along the Nore.

To the northwest of the boreholes by 800 m and 100 m, bedrock protrudes through the deep glacial and postglacial subsoils at 2 no. localities. Bedrock outcrop and subcrop (within 1 m of the surface) is also common on the summits of the upland ridges to the west and east.

In and around the Glanbia plant itself, much of the subsoils have been covered by 'Made' ground; built land and concreted/tarmacadamed areas. This 'Made' material is underlain by sands and gravels, similar to the areas immediately adjacent to it.

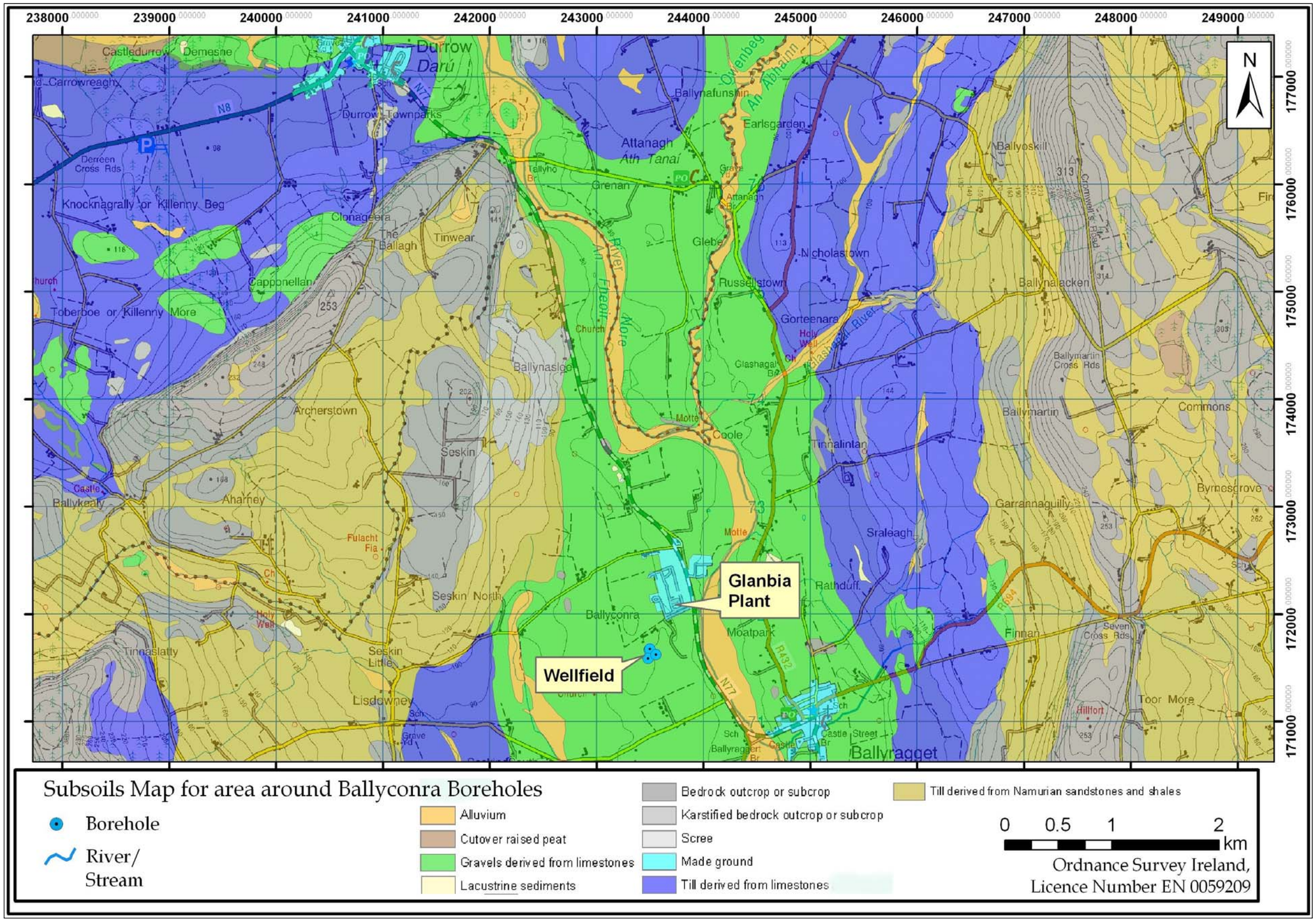


Figure 3 Subsoil Map for the area around the Ballyconra Boreholes.

The valley is dominated by the sands and gravels (green), with a narrow strip of alluvium along the river (orange) and much bedrock outcrop and subcrop on the flanking ridge crests (grey).

The soils on the sand and gravel areas are dominated by 'dry' soil types: typically well drained deep mineral soils of brown earths and grey brown podzolics, and well drained shallow brown earth soils (Conry, 1974, 1987; Gardiner and Radford, 1980). The tills derived from limestone in the region are also characterized by generally well drained grey brown podzolic soils, whereas the Namurian ridges to the west and east are dominated by poorly drained gleys. Within the areas of bedrock outcrop/subcrop and alluvium, the soils are widely variable in their depths and drainage status.

Within the study area of the source, the only subsoil exposures discovered were in gravel pits within the sand and gravel areas.

6.3 DEPTH TO BEDROCK

Depth to bedrock varies greatly throughout the study area, as seen from consultation of the depth to bedrock maps produced by GSI from the Counties Kilkenny and Laois Groundwater Protection Schemes (2002).

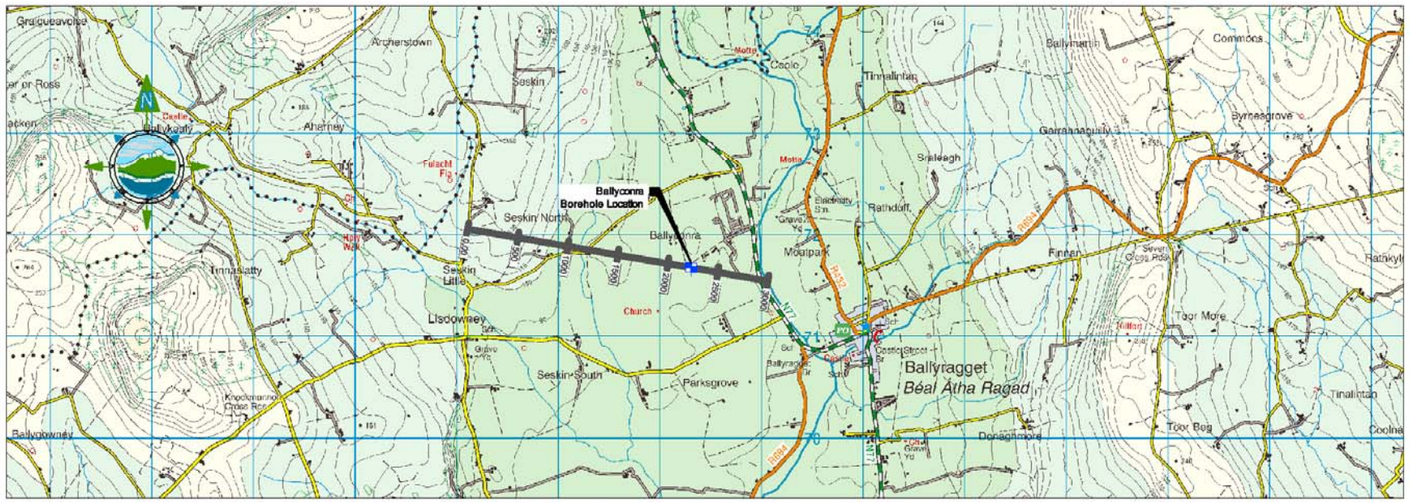
Within the low lying terrain around the boreholes, depths to bedrock are highly variable as the karstified limestone has a jagged, uneven surface and has been overlain by sands and gravels of complex geometry and varying depths.

Eugene Daly, formerly of Groundwater Section of the GSI re-interpreted the drillers' logs in 1978 as part of a project aiming to augment the water supply at the plant. The logs were thought now to be recording sand/gravel-filled cavities in limestone bedrock, rather than being sand and gravel subsoil. The depths-to-bedrock in all 3 no. initially-drilled boreholes was revised to around 11—12 m, and a drilling programme initiated on-site and at a second potential well-field adjacent to the River Nore, 450 m to the northeast. Boreholes were drilled at 5 no. localities at this second field, and geophysical well logging and pumping tests were conducted. Both the quantity and quality of the groundwater in this well-field was poor, and it was subsequently abandoned.

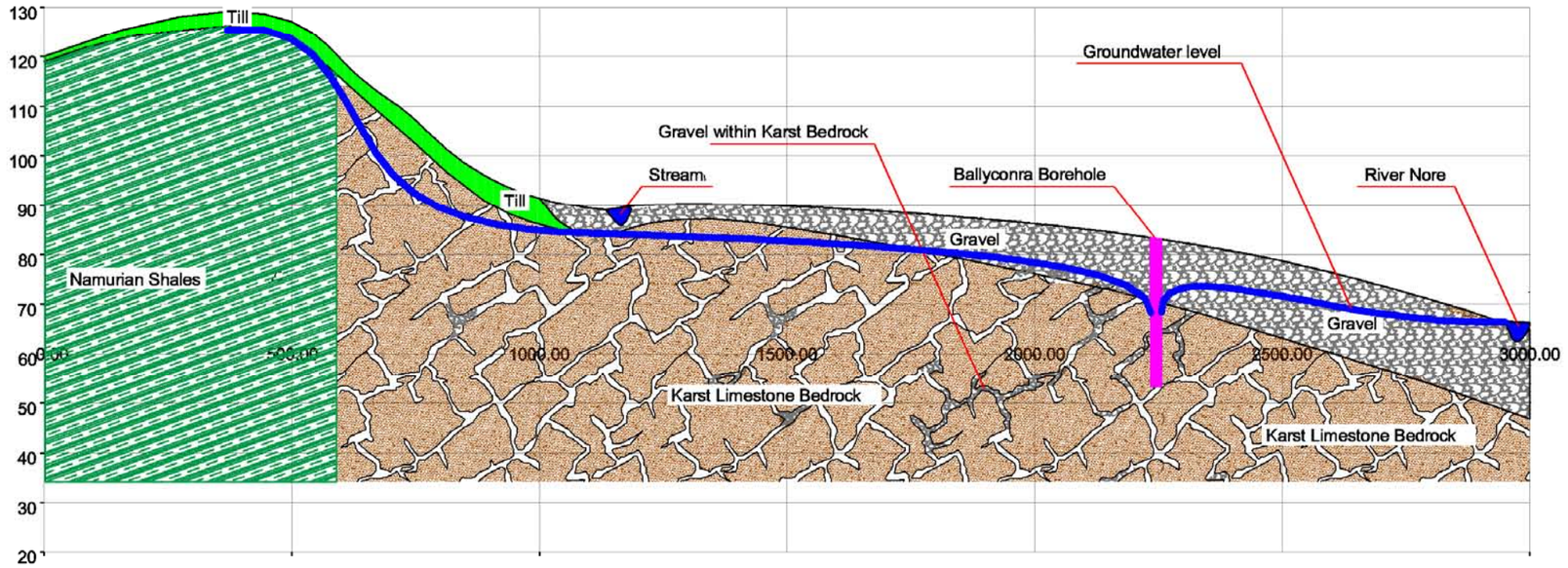
At that time the fourth of the current boreholes on-site was drilled, with depth-to-bedrock at 11.9 m in a 12.8 m hole, and production continued utilising this and the initially-drilled 3 no. boreholes intermittently, generally pumping 3 no. out of 4 at any one time.

The depths to bedrock in the boreholes in the well-field are therefore given as 11.9 m, 25.9 m, 27 m and >26.5 m, and those in the unsuccessful well-field to the northeast are 3–12.2 m. In general, the sands and gravels in the area are >10 m thick.

The depth to bedrock mapping indicates that the depth of subsoil is generally less than 3 m on the ridge summits west and east of the source, increasing in depth towards the centre of the valley and the source area. A conceptual cross section through the subsoil/bedrock is shown in Figure 4.



LOCATION MAP SHOWING LOCATION OF LONGITUDINAL SECTION
Scale 1:50,000



LONGITUDINAL SECTION SHOWING GEOLOGY AND GROUNDWATER LEVELS
Scale H: 1:10,000 V: 1:1,000

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL DRAWINGS TO BE CHECKED BY THE CONTRACTOR ON SITE
3. ENGINEER TO BE INFORMED BY THE CONTRACTOR OF ANY DISCREPANCIES BEFORE ANY WORK COMMENCES
4. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.
B	11.11.09	DRAFT ISSUE FOR REVIEW	MN	JD

Client: EPA / GSI

Project: BALLYCONRA

Title: CONCEPTUAL LONGITUDINAL SECTION W - E

Scale @ A3: As Shown

Prepared by:	Checked:	Date:
M. Nolan	J. Dillon	Jan 2009

Project Director: D. Grehan

TOBIN
Patrick J. Tobin & Co. Ltd.
Consulting, Civil and Structural Engineers,
Block 10-3, Blanchardstown Corporate Park,
Dublin 15, Ireland.
tel: +353-(0)1-8030406
fax:+353-(0)1-8030409
e-mail: info@tobin.ie
www.tobin.ie

Drawing No.: 5604-2810 | Issue: B

Figure 4 Cross Section W to E through the Nore Valley within the Ballyconra Boreholes area.

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 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 supply source is the bedrock aquifer beneath the sands and gravels. The gravels were reported to be dry in 1973 when the holes were drilled and the static water level was 2-3 m below the top of bedrock. For the purposes of vulnerability mapping in the immediate vicinity around the boreholes, as well as in the wider area around them, the "top of the rock" is considered to be the target at risk.[2].

West of the source, the permeability of the till subsoil on the ridge flanks and in the gently undulating area to the west is interpreted to be "**moderate**", based on the general absence of permanent surface water features or secondary indicators of low subsoil permeability (see Figure 3 for the pattern of subsoils in these areas). Northeast of the source to the east of Attanagh, the permeability of the till subsoil is interpreted to be "**low**" owing to the opposite being the case. In the sands/gravels subsoil, the permeability is interpreted as "**high**".

Depth to bedrock varies from being greater than 10 m around the boreholes to zero where the bedrock outcrops occur along the cliffs to the west and southwest. At subsoil thickness of less than 3 m, as indicated by the outcrop, subcrop and Groundwater Protection Scheme data, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites). This is because infiltration is more likely to occur through 'bypass flow' mechanisms such as cracks in the subsoil. Based on the general depth to bedrock, a vulnerability classification of **"extreme"** has been assigned in these areas of shallower subsoil.

The Groundwater Vulnerability Map as mapped by the GSI for relevant Local Authorities as part of the Counties Kilkenny and Laois Groundwater Protection Schemes (2002) is consequently dominated by 'high' vulnerability in the sand and gravel area within the valley, as shown in Figure 5. On the high, flanking ridges where bedrock is at or relatively close to the surface, the vulnerability is classed as 'Extreme'. Relatively restricted areas of moderate vulnerability occur along the River Nore floodplain and east of Attanagh village to the north.

[2] In areas such as this where the water table is below the top of the bedrock, the thickness of the unsaturated zone within the bedrock is not taken into consideration in vulnerability mapping, as there is no attenuation of contaminants in the fractured bedrock.

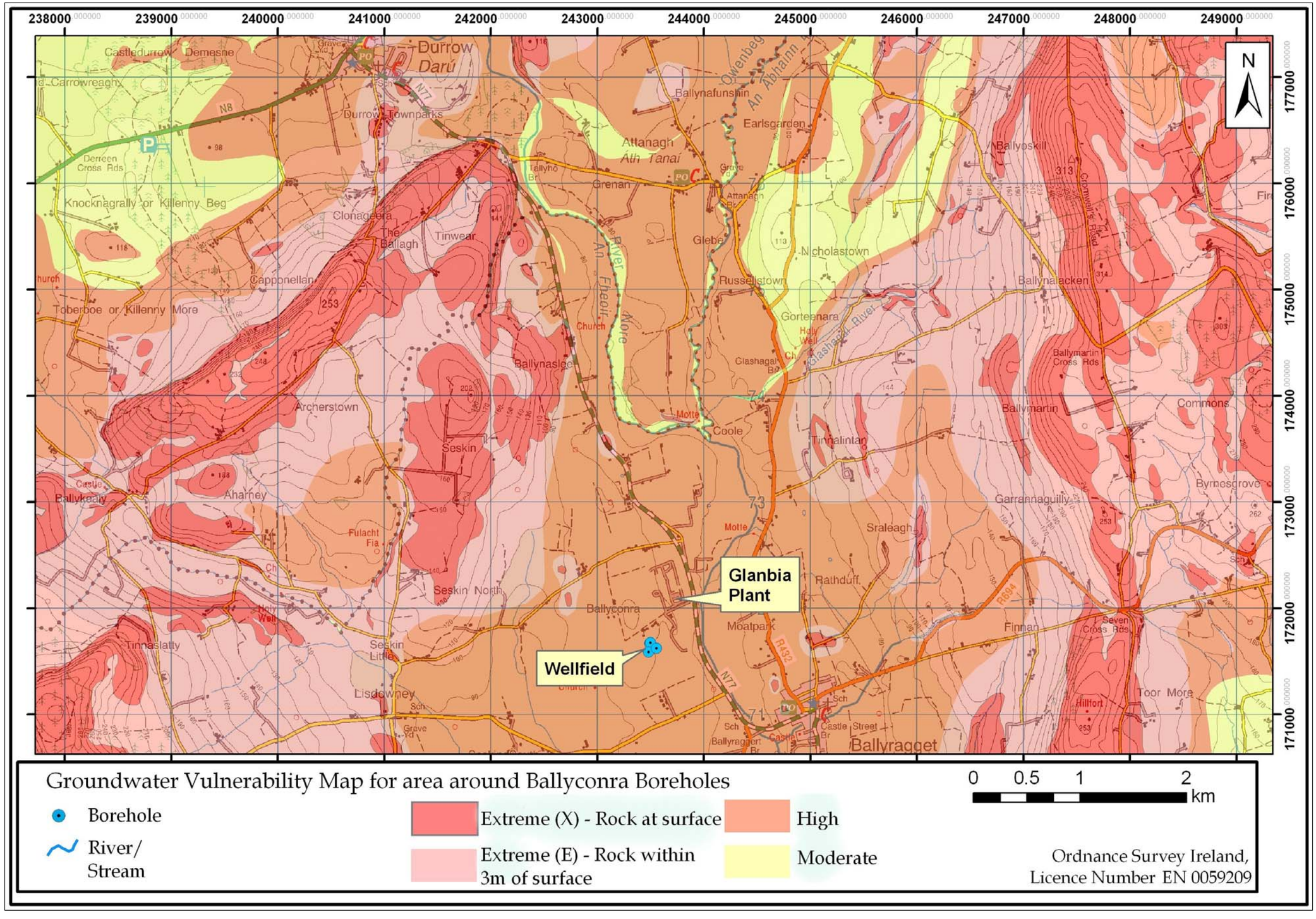


Figure 5 Groundwater Vulnerability Map for the area around the Ballyconra Boreholes.

Depth to rock and depth to the water table interpretations are based on the available data cited here. However, depth to rock can vary significantly over short distances. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. The mapping is intended as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

8 hydrogeology

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

- GSI Website, Well Database and Groundwater Section in-house archives
- Glanbia Ingredients staff
- EPA website and Groundwater Monitoring Database
- Local Authority Drinking Water returns
- Hydrogeological mapping by the author in December 2009.

8.1 GROUNDWATER BODY AND STATUS

The descriptions of groundwater bodies throughout Ireland 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.

The area around Ballyconra is included as part of both the Freshford Groundwater Body (as part of a Regionally Important sand and gravel aquifer), and the Durrow Groundwater Body (as part of a Regionally Important karstified bedrock aquifer). Both are classified as being of Good Status (December 2008).

8.2 METEOROLOGY

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

Annual rainfall: 882 mm.
The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the source is located between the 900 mm and 1000 mm average annual rainfall isohyets. The closest meteorological station to the Ballyconra Boreholes is 1.1 km to the southeast at Ballyragget, where detailed rainfall measurements for the same period are averaged at 882 mm per annum.

Annual evapotranspiration losses: 427 mm.
Potential evapotranspiration (P.E.) is estimated to be 450 mm/yr (based on data from Met Éireann at Johnstown Castle, Wexford). Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 455 mm.
The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 455 mm/year. Section 8.6 following (Recharge)

estimates the proportion of effective rainfall that enters the aquifer utilising other hydrogeological data for the area.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Groundwater in the area surrounding the boreholes is deep beneath the ground surface, recorded as a standing water level at 12.6 –13.6 m below ground level in the boreholes following drilling in 1972, but recorded as 13.2–18.7 m below ground level while pumping at average levels on 04/12/2009. There are no groundwater seeps or springs between the boreholes and the River Nore, and the land in the general vicinity to the south and east is dry. To the west and north, small ponds occur in the base of the disused quarries 800 m and 1000 m northwest of the boreholes, but this seems to be stagnant surface water rather than groundwater (conductivities of 589 µS/cm and 455 µS/cm, 11/12/2009).

The stream flowing off the ridge to the west at Seskin (conductivity 348 µS/cm, 11/12/2009) partially sinks into the karst network *via* swallow holes at Seskin, and also partially sinks into the sands and gravels. This watercourse seems to re-issue from ground as a series of seeps at the northern end of Seskin North Townland, around NGR 242320 172660, which are piped to a stream watercourse with a conductivity of 693 µS (NGR 242222 171798) and 709 µS further south (NGR 242676 170638). The relatively high conductivities suggest that this stream is largely groundwater-fed.

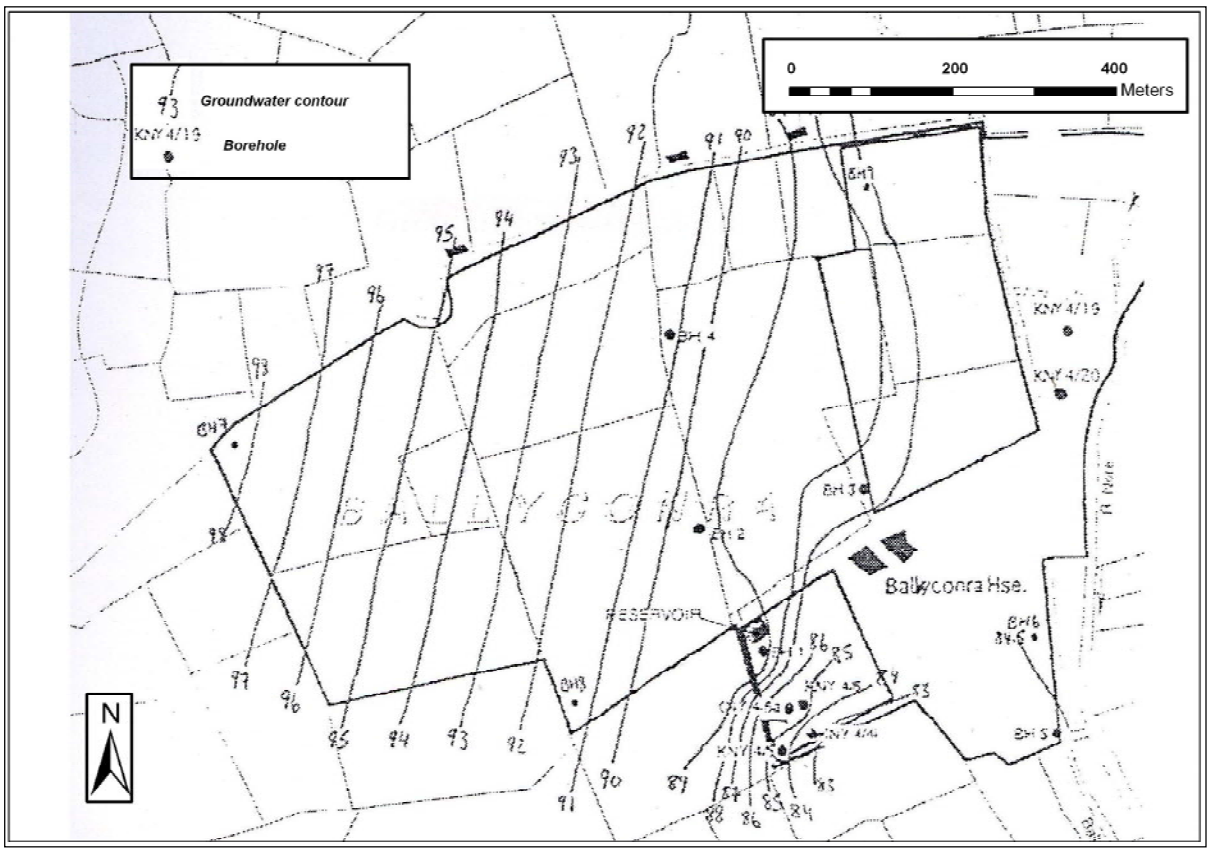


Figure 6 Groundwater Contour Map of the area around the Ballyconra Boreholes as drawn by GES Ltd. in 2001.

Using data from IPCC monitoring boreholes and the 2 no. well-fields around the site, GES Ltd. drew up groundwater contour lines for the site and its' environs in 2001. Groundwater levels were established in 14 no. boreholes to a common datum and the resultant contour map demonstrates a regular

groundwater gradient of approximately 0.01 from west to east across the site[3]. The pumping water gradient in the vicinity of the boreholes themselves was 0.017, along the same orientation. Groundwater is therefore expected to flow from just north of west to just south of east across the site. This flow direction therefore broadly focuses toward the River Nore discharge area, mirroring the valleys' macro- topography.

8.4 HYDROCHEMISTRY AND WATER QUALITY

The majority of the available water quality data for the Ballyconra boreholes source is from EPA Monitoring data, which has been collected several times a year at the source since 2007. As well as this, water quality results of some key parameters from the initial sampling following drilling of PW4 in 1978 were also included in the analysis. The data on trends in water quality across 10 no. samples are summarised in Table 8.1, while key indicators of agricultural and domestic contamination in 2007 and 2008 are shown graphically in Figure 7. The following key points are identified from the data.

The water quality is hard to very hard (293 to 438 mg/l, as $CaCO_3$), showing a calcium-bicarbonate chemical signature and corroborating the data from the Durrow Groundwater Body description of the GSI. These values are typical of groundwater from limestone. The hardness values are higher than the recommended EPA threshold value and Drinking Water Standard of 200 mg/l $CaCO_3$, which are however, based on palatability and formation of limescale, rather than on health grounds.

Table 8.1 Summary hydrochemical data for Ballyconra Borehole Source, 2007-2008.

Sample date	Conductivity µS/cm	Ammonia mg/l N	Chloride mg/l Cl	Iron µg/l Fe	Total coliforms No./100ml	Faecal coliforms No./100ml	Nitrate mg/l NO_3	Sodium mg/l Na	Potassium mg/l K	Total hardness mg/l $CaCO_3$
July 1978	n/a	n/a	*55*	<1	n/a	n/a	2.0	32.5	1.2	388
19/10/2007	798	0.010	*27*	3	<1	<1	27.1	10	1.9	347
13/11/2007	792	0.030	*28*	29	**2**	<1	24.1	19	2.8	393
13/12/2007	794	0.020	*26*	55	**4**	<1	25.2	19	2.8	293
30/01/2008	880	<0.01	*27*	<2	<1	<1	28.2	19	2.7	397
16/05/2008	782	0.010	*37*	<7	**1**	<1	28.6	35	4.1	364
23/06/2008	808	0.009	25	7	<1	<1	*37.9*	20	2.9	367
25/08/2008	846	0.031	*40*	6	<1	<1	27.8	44	3.8	382
01/10/2008	808	0.034	*34*	<5.0	<1	<1	28.1	56	4.7	128
18/11/2008	833	0.054	*39*	12	<1	<1	<0.53	42	3.9	401

The alkalinity of the groundwater ranges from 280 to 440 mg/l $CaCO_3$, and the pH ranges between 7.0 and 7.8, which is slightly alkaline. Electrical conductivity ranges from 782 to 880 µS/cm @ 25°C, with an average of 816 µS/cm.

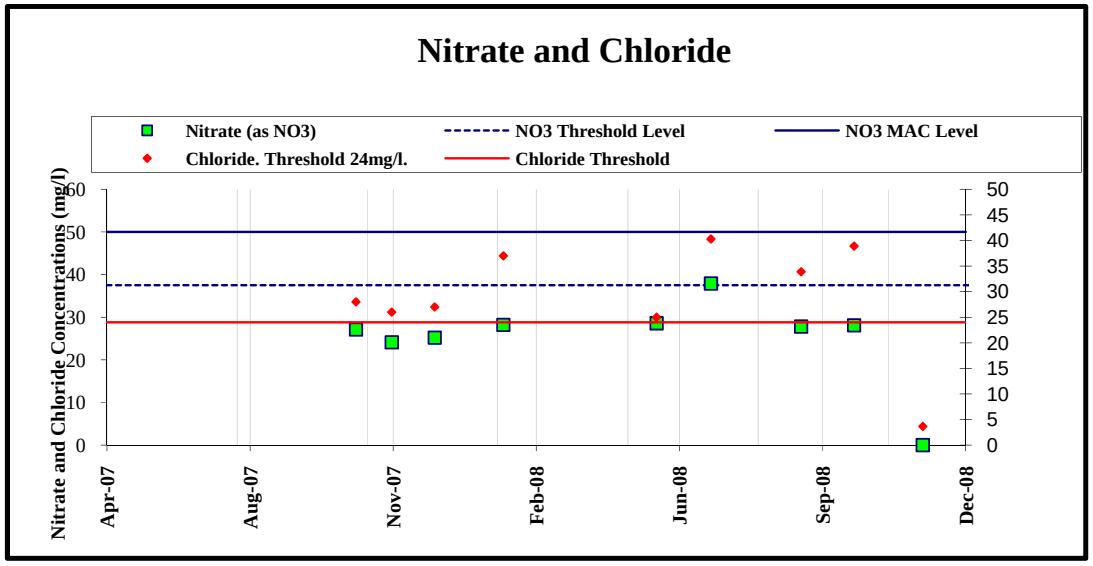
Faecal coliforms were absent from the water on all occasions sampled. As well as this, on no occasions were ammonia values greater than the GSI threshold value (0.15 mg/l) recorded; ammonia levels were consistently below 0.1 mg/l. The 'high' groundwater vulnerability around the source suggests a relatively low likelihood of faecal contamination occurring due to the filtration in the deep sands and gravels.

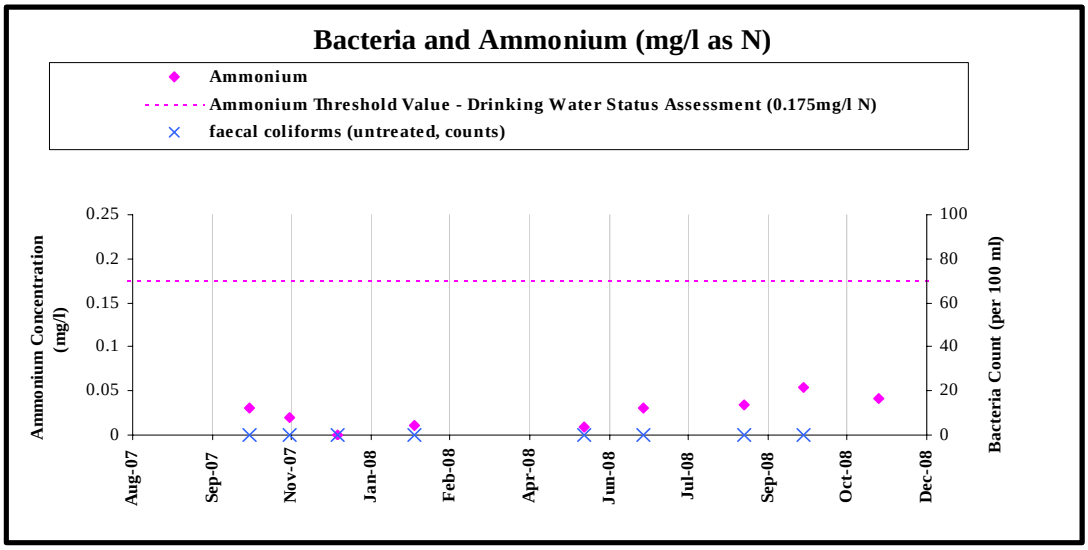
On 3 no. occasions, total coliforms were present in the samples taken (1, 2 and 4 no.). However, such low values may be due to sampling or analysis error so the results are not considered noteworthy.

[3] Within this contour map, the depression around the well-field as a result of pumping was also recorded.

The concentration of nitrate ranges from <0.53 mg/l to 37.9 mg/l with a mean of 25.2 mg/l (as NO_3). Though there are no reported exceedances above the EU Drinking Water Directive maximum admissible concentration of nitrate of 50 mg/l NO_3, the groundwater threshold value (Groundwater Regulations S.I. No. 9 of 2010) of 37.5 mg/l NO_3 has been exceeded on 1 no. out of 9 no. occasions, but is very close to the threshold generally. Though the area around the boreholes is relatively sparsely populated, and served by septic tank and mechanical aeration systems discharging to ground into deep sediment, there are many farms, and tillage is practiced in the general area. Therefore, the relatively high nitrate levels at Ballyconra are probably due to the proximity of large farms and intensive agriculture practices.

Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and levels 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 seem always to have been consistently high at Ballyconra, ranging from 25 mg/l to 55 mg/l, with a mean of 33.8 mg/l. This is considered to be above the mean natural background level of 18 mg/l (Baker *et al.*, 2007) and is also above the threshold value. Levels of chloride above the threshold value were recorded on all 10 no. occasions, with significant contamination occurring on 5 no. occasions. This, and the corresponding high nitrate levels, suggests that contamination from either organic wastes or fertilisers may be an issue at Ballyconra.





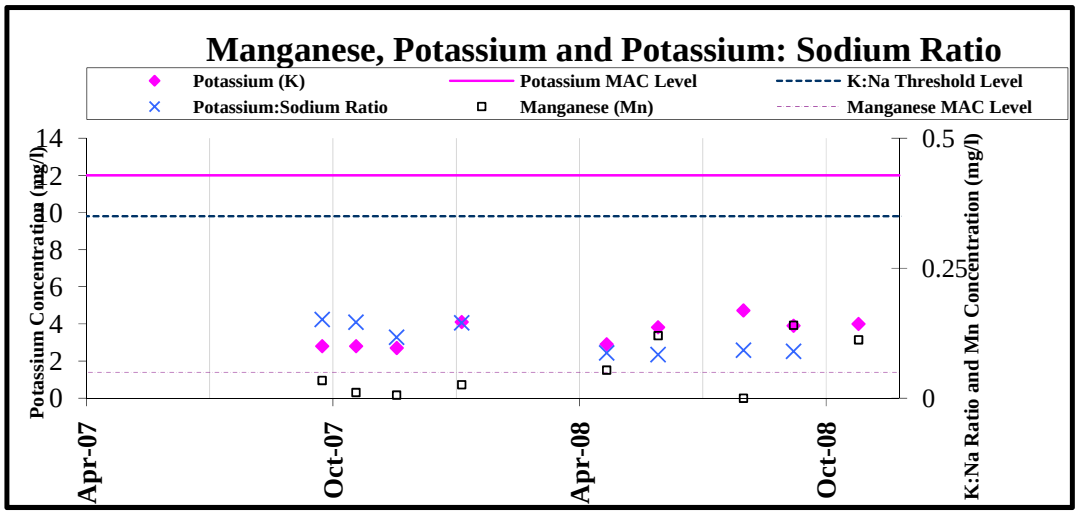


Figure 7 Key Indicators of Agricultural and Domestic Contamination at the Ballyconra Boreholes Source.

The concentrations of sulphate, potassium, sodium, magnesium and calcium are within normal ranges. The potassium: sodium (K:Na) ratio is low, consistently less than 0.2 and never exceeding the GSI threshold of 0.35. A low K/Na ratio suggests that organic wastes derived from vegetable matter (*e.g.* farmyards or landspreading of agricultural wastes) are not a major cause for concern.

The concentration of iron is also within normal ranges, which also suggests an absence of any influence of effluent from organic wastes. However, manganese concentrations were elevated on 4 no. occasions, exceeding the drinking water standards. This may be owing to naturally high concentrations in the sands and gravels in the area.

Normal levels of trace metals were identified or levels are below the detection limit of the laboratory, and the water is safe for drinking. The concentration of all organic compounds and herbicides is below the detection limit of the laboratory.

In summary, generally elevated chloride and nitrate suggest contamination from either an organic or inorganic waste source. Given the levels of iron and the potassium: sodium ratio, and the land use in the area, the most likely source is from artificial fertilizers.

8.5 AQUIFER CHARACTERISTICS

Initially in 1972, the first 2 no. boreholes produced water for the plant, with the third left redundant. From observations of the water level in this third borehole during 1974, where the level dropped and recovered rapidly when switching the pumps on-off in the other 2 no., it seemed that the aquifer was behaving more like limestone bedrock than sands and gravels.

Though situated underneath a regionally important sand and gravel aquifer, the limestone of the Ballyadams Formation technically provides the groundwater to the boreholes at Ballyconra, even though it must draw water also from the base of the saturated zone within the sands and gravels. The boreholes are considered to have an excellent yield and are interconnected as they tap the same water resource, with drawdown in one affecting the other. The boreholes are no more than 90 m from each other.

An extensively karstified bedrock underlies the source, extending in all directions with flow concentrated in conduits. The limestone bedrock is however deep under the surface, and is at its closest to the surface in the overall area on the high ridge at Seskin and to the north at Ballynaslee. The evidence for the karstification includes: the 6 m deep 'cavern' with associated flow recorded in the boreholes by the driller, the presence of swallow holes in Seskin to the northwest, the solutionally enlarged joints and adjacent clints and grikes in the disused quarry at Ballynaslee, and the non-productive nature of the later well-field to the northeast near the river.

Karstification is an important process in Irish hydrogeology. It involves the enlargement of rock fissures when groundwater dissolves the fissure walls as it flows through them. The process can result in significantly enhanced permeability and groundwater flow rates and can mean either very productive or generally-failed wells. It usually occurs in 'cleaner' limestones.

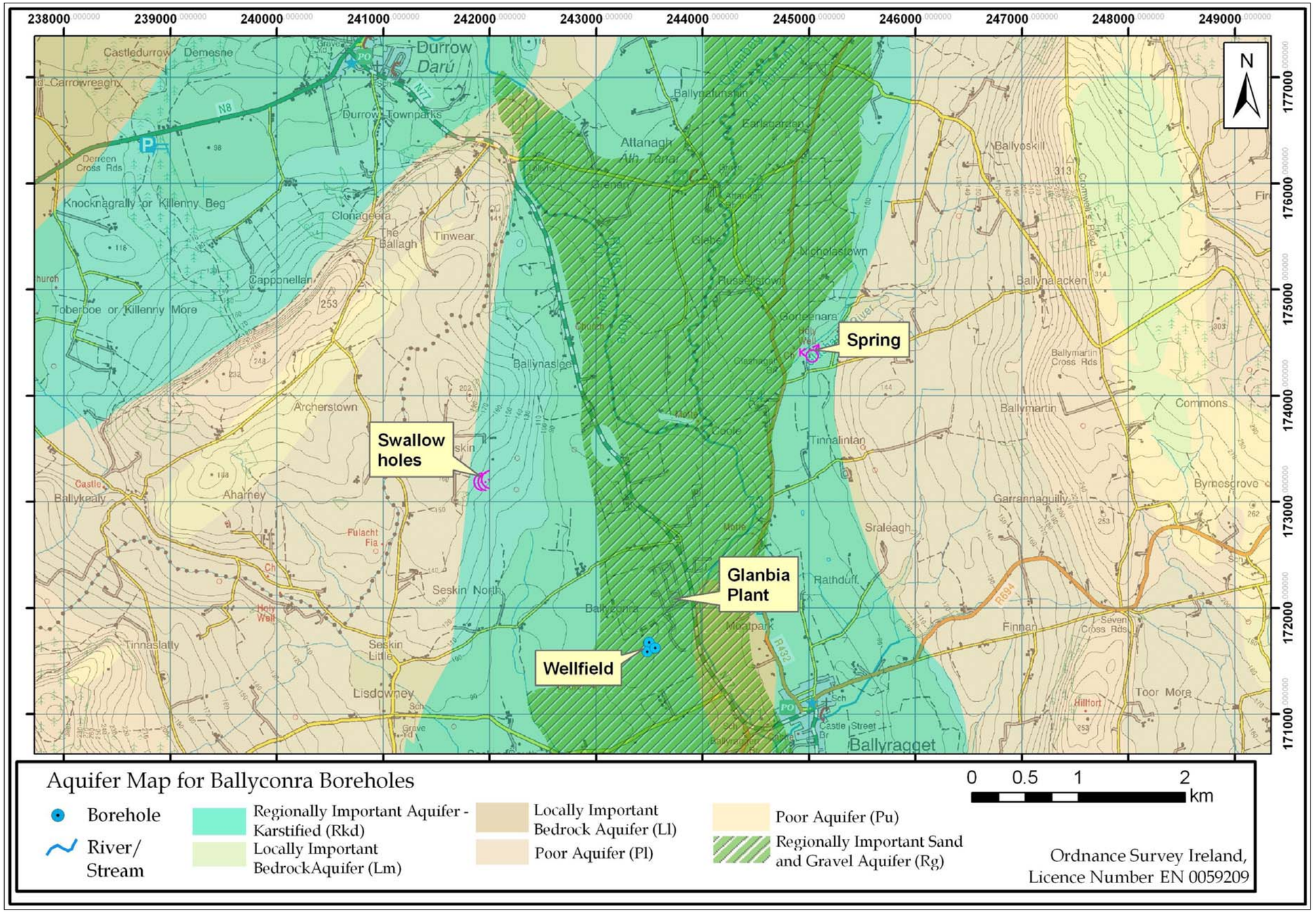


Figure 8 Aquifer Map of the area around the Ballyconra Boreholes.

Though the site overlies a Regionally Important Sand and Gravel Aquifer, the water is drawn from an underlying Regionally Important Karstified Aquifer characterized by conduit flow. Karst features are recorded in the GSI Karst Database to the northwest at Seskin (swallow holes) and to the northeast at Gorteenara (spring).

The bedrock aquifer in the Ballyconra area seems likely to be characterised by:

- groundwater flow in solutionally enlarged bedding plane partings, joints, faults and conduits;
- high groundwater velocities, several orders of magnitude greater than in granular (sand/gravel) aquifers;
- concentration of groundwater flow into zones of high permeability;
- a combination of diffuse and point (through swallow holes) means of recharge;
- the potential for extreme vulnerability to contamination in particular localities from point recharge *via* swallow holes which by-pass the potential attenuation capability of the subsoil;
- relatively short response times when pollution incidents occur in areas of extreme vulnerability.

The Ballyadams Formation bedrock under the site is classified by the GSI as a Regionally Important Karstic Aquifer, which is characterised by diffuse flow (**Rk^{d}**). Groundwater velocities through fissures/conduits in this aquifer may be high. Aquifer storage is frequently low in these rocks, but owing to the sands and gravels overlying and infilling cavities within them, storage is much higher in this particular area. Storage and permeability within the aquifer in this area is also expected to be enhanced by the presence of dolomitised limestones in places. Flow through this aquifer is likely to be comprised of both diffuse and conduit flow. Most groundwater flow is likely to be concentrated in this upper zone of the rock, with Daly (1994) estimating that the maximum saturated and permeable part of the aquifer is 75 m thick.

As with most karstic systems, permeability and transmissivity data are very variable. Daly (1994) cites a range in permeability of 0.1 m/day to 100 m/day in the karst limestones within the Nore Basin as a whole, with ranges in transmissivity of 5 m^2/day to 3,000 m^2/day. Calculations of transmissivity of 1,280 m^2/day and 2,675 m^2/day and specific yields of 9.7% and 11.6% were calculated following pumping tests on the failed well-field across the road to the northeast in 1978 (E. Daly report, GSI Archival Records). These calculations were completed on similar aquifer characteristics *i.e.* an aquifer of several metres of sands and gravels, overlying fissured limestone. Calculations based on representative values for permeability and aquifer thickness, which are based primarily on data from the Nore Basin study (1994) and on test pumping in nearby County Laois, are shown in Table 8.2.

Table 8.2 Estimated Aquifer parameters for the Ballyadams Limestone at Ballyconra Boreholes.

Parameter	*Source of data*	*Ballyadams Fm.*
Transmissivity (m^2/day)	E. Daly report on Ballyconra (Pumping test data across the road, GSI Archives)	1,280-2,675
Permeability (m/day)	Using regional data (Nore Basin and Laois) (T / 75 m saturated thickness from E. Daly report)	15[4]
Porosity	Regional	0.025
Velocity (m/day)	Regional (Nore Basin and Laois)	6
Hydraulic Gradient	Local (Water table map drawn by GES 2001)	0.01

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

[4] 15 m/day was taken as a conservative estimate for the permeability at Ballyconra.

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 Ballyconra, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient. Owing to the highly permeable nature of the bedrock type and the additional storage in the overlying sands and gravels, no recharge cap is applied. The recharge is estimated as follows.

Runoff losses are assumed to be 20% of potential recharge (effective rainfall). This value is based on an assumption of *c*. 15% runoff for 80% of the area (extreme vulnerability with bedrock at surface, or high vulnerability, permeable sands and gravels), and 40% runoff over 20% of the area due to high vulnerability, moderate permeability and deep subsoil (Misstear *et al*., 2009).

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

These calculations are summarised as follows:

Average annual rainfall (R)		882 mm
estimated P.E.		450 mm
estimated A.E. (95% of P.E.)		427 mm
effective rainfall		455 mm
potential recharge		455 mm
recharge coefficient for Extreme Vul rock at surface	85%	387 mm
recharge coefficient for High Vul Sands/Gravels	85%	387 mm
recharge coefficient for High Vul Till/Well dr. soil	60%	273 mm
Averaged runoff losses	20%	111 mm
Bulk recharge coefficient	80%	
Recharge		**364 mm**

8.7 CONCEPTUAL MODEL

The current understanding of the geological and hydrogeological setting around the Ballyconra Boreholes is as follows:

- The Ballyconra wells, with combined extraction of 3,120 m^3/day (max 3,840 m^3/d), are pumping from the limestone bedrock of the Ballyadams Formation, which is classified as a **Regionally Important Karstic Aquifer, which is characterised by diffuse flow (Rk^d).** The aquifer is overlain by glaciofluvial sands and gravels which are classified as a **Regionally Important Sand and Gravel aquifer (Rg).**

- The limestone as seen in the adjacent quarry at Ballynaslee has a well developed fracture system, which has undergone significant karstification in places. The cavern met during drilling, the presence of swallow holes at Seskin to the northwest and the 'hit and miss' nature of well drilling in the area also supports this view. However, a water table contour map has been drawn for the area which suggests groundwater flow is more regular than might be expected in a highly karstified aquifer.

- Groundwater flow within the sand and gravel aquifer is intergranular, whereas in the bedrock beneath this it is through enlarged conduits and smaller fractures and fissures in the limestone. The two aquifers are hydraulically interconnected with the gravels providing additional storage to the limestone aquifer. Both aquifers therefore effectively act as one, with filtration and storage

occurring in the deep sands and gravels, and rapid travel times characterising the limestone (and reflected in the hydrochemistry).

- The area around the Ballyconra Boreholes has few surface streams and rare drainage features. The subsoil over the majority of the area is highly permeable, and to the west and northwest of the source is relatively thin (<3m), with much of the area around the boreholes being of thick, high permeability sands and gravels. These characteristics suggest that recharge is diffuse and relatively high at 364 mm/year.

- The water table at the source was below the top of bedrock in 1973 which suggests that the sand and gravel aquifer must be, at times unsaturated. The aquifer is unconfined and has a saturated aquifer thickness at the source is at least 19.9 m, as seen from PW3.

- Groundwater flow to the source area through the gravels and bedrock is expected to be from the higher ground to the west, from just north of west to just south of east towards the River Nore discharge zone, following topography. The natural hydraulic gradients in the aquifer are likely to be approximately 0.01, reflecting the generally high transmissivities in the area of 1,280-2,675 (E. Daly's GSI Archival notes and report). Permeability is conservatively estimated at 15 m/d based on the measured transmissivity values and a regional aquifer thickness of 75 m.

- The groundwater vulnerability is 'extreme' to 'high' around the boreholes. Where bedrock is at or close to the surface, there is little protection for groundwater in bedrock fractures, and the vulnerability is 'extreme'. The vulnerability to contamination is 'high' in the surrounding areas, owing to the presence of high permeability sands and gravels.

- The groundwater is of calcium bicarbonate signature and hard. Chloride and nitrate are elevated but the bacteriological water quality is relatively good. Manganese is high but is expected to be naturally present in the sands and gravels. The groundwater appears to be impacted by either an organic or inorganic waste source. Given the low levels of iron and the potassium: sodium ratio, and the land use in the area, the most likely source is from artificial fertilizers. This is likely due to the extreme and high vulnerability over the majority of the area contributing to the source.

Limitations to the conceptual model mainly lie with a lack of information on some of the aquifer properties, such as porosity, and in our understanding of the relationship between the sand and gravel aquifer and the limestone.

9 DELINEATION OF SOURCE PROTECTION AREAS

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

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 catchment area to the source, or **the zone of contribution (ZOC).** This is defined as the area required to sustain abstraction from the boreholes considering 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 boundary is based on the topographic divide along the topographical high in Seskin and Seskin North Townlands, that is assumed to coincide with the groundwater divide. Within this, an area of Namurian-age bedrock is included, as the surface water flowing off this area sinks into the groundwater system at Seskin. The entire surface water catchment area to the swallow holes and the sinking stream has been included.

The Northern boundary is also based on topography, as a west-east spur extends off the main Seskin Ridge at Ballynaslee, separating the area at Ballyconra from a small catchment to the north, in the northern portion of Ballynaslee Townland. The latter is the catchment area to a spring to the north.

The **Eastern boundary** is relatively complex. The southern portion of this is basically the down gradient side of the boreholes. Using the Uniform Flow Equation:

$$X = \frac{Q}{2\pi Kbi} = \frac{1280}{2 \times 3.1416 \times 15 \times 19.9 \times 0.01} = \frac{1280}{18.75} = 68.2 \text{ m}$$

Therefore estimates from semi-analytical equations indicate that the boreholes could draw water from up to 68 m distant, however this is uncertain and it is considered that a precautionary arbitrary distance of 100 m is used to allow for cumulative effects from the rest of the well-field, other errors and variability in the aquifer parameters. The northern portion of the eastern boundary is somewhat arbitrary, and includes an allowance for some contribution to the flow from the sands and gravels.

The Southern boundary allows for the fact that the small southerly flowing stream is likely to be connected to the shallow sand and gravel aquifer and that, while hydraulically-connected, the principle aquifer to the source is the limestone underneath. The boundary is based on the more regionally important topographic divide between stream mini-catchments in Seskin North and Seskin Little Townlands, the interpreted groundwater flow, and a water balancing exercise as follows.

Based on a maximum abstraction of 3,840 m^3/day and the estimated recharge of 364 mm/year, a zone of contribution of 3.85 km^2 in area is calculated. Hydrogeological field mapping and the conceptual model determined an area of 4.1 km^2. The ZOC presented is therefore conservative and allows for the unpredictability of heterogeneous flow in a karstified aquifer.

For Ballyconra, a 50% increase in abstraction rate has not been factored in to the ZOC delineation, as the source is so large and there is no guarantee that the ZOC would support such an increase. The ZOC presented is also relatively conservative, and allows for the unpredictability of heterogeneous flow in a karstified aquifer.

9.2 INNER PROTECTION AREA

The Inner Source Protection Area 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 delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

The 100-day time of travel is calculated from the velocity of groundwater flow in the bedrock. The velocities are normally based on the results of the hydraulic test programme, however, in this instance, the aquifer category of Rk^d, suggests that very rapid groundwater velocities are likely in this area due

to karstification of the limestones. Groundwater flow can be focused and travel very fast. Results from tracing programmes in similar rock types indicate velocities in the order of hundreds of metres/day. On this basis, all of the ZOC is designated as part of the Inner Protection Area to the source.

From this, it is therefore likely that any of the groundwater within the delineated catchment could reach the source in less than 100 days.

10 GROUNDWATER PROTECTION ZONES

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones (see Table 2). In practice, this is achieved by superimposing the vulnerability map (Figure 5) on the source protection area map. Each zone is represented by a code *e.g.* **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source.

Two groundwater protection zones are present around the source as illustrated in Table 10-1. The final groundwater protection zones are shown in Figure 9.

Table 10-1 Source Protection Zones

Source Protection Zone	% of total area (4.1 km^2)
SI/Extreme (Rock close)	19.6% (0.8 km^2)
SI/Extreme	28.6% (1.17 km^2)
SI/High	51.8% (2.13 km^2)

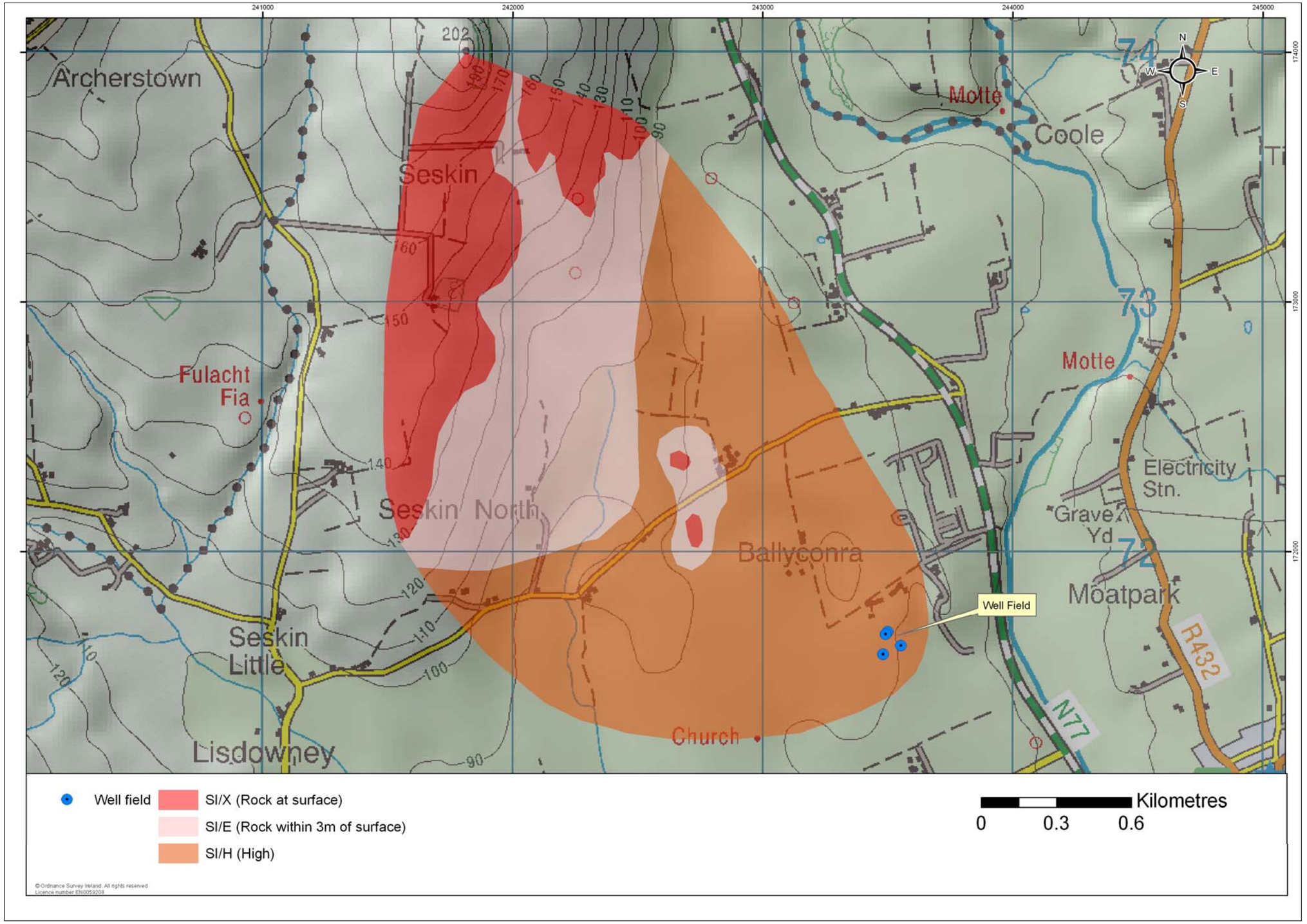


Figure 9 Source Protection Zones for the Ballyconra Boreholes Source.

11 POTENTIAL POLLUTION SOURCES

Though detailed assessments of hazards have not been carried out as part of this study, it is noted that there are a number of houses and farmyards within the ZOC. Land use in the vicinity of the source is described in Section 5; within the ZOC, agriculture is the main land use. A disused quarry occurs to the north and the Glanbia Plant itself is 250 m to the northeast.

Owing to the poor protection of the boreholes at the source, direct microbial contamination of the source by animals and birds can occur. The main potential contaminants from these sources are faecal bacteria, viruses and Cryptosporidium.

The hydrochemical data do not indicate significant contamination or pollution of the boreholes currently at the source. However, nitrate and chloride levels are generally high, and above the GSI threshold values. These levels should be monitored closely.

The main hazards associated with the ZOC are considered to be agricultural (farmyard leakage, landspreading of organic and inorganic fertilisers) and potential oil/petrol spills. Though domestic septic tank and other treatment systems are not a major problem as is, the installation of any new systems should be monitored closely. The location of any of these activities in any part of the ZOC categorised as 'extremely' vulnerable presents a potential risk, given rapid travel time through the underlying bedrock and lack of attenuation by subsoils. These are delineated as red zones on Figures 5 and 10, and the main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and Cryptosporidium.

As well as this, there are some private home heating fuel tanks located within the catchment area. The main potential contaminants from this source are hydrocarbons. There is currently no evidence of any contamination from hydrocarbons at the source.

Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

12 CONCLUSIONS

- The 4 no. boreholes at Ballyconra are located in the Dinantin Pure Bedded limestones of the Ballyadams Formation which is a Regionally Important Karstified Aquifer. The aquifer is overlain by a Regionally Important sand and gravel aquifer.

- The ZOC has been delineated for the 4 no. boreholes together. This approach is necessary due to the close proximity of the wells and the likely interconnected zones of contribution to each well. The ZOC has been delineated using hydrogeological mapping techniques and is larger than the area required to sustain the source. The ZOC is therefore considered to be conservative and takes into consideration the unpredictability of groundwater flow in karst areas.

- Due to the rapid groundwater velocities, it is considered that groundwater within approximately 600 m of the source could potentially reach the source within 100 days. An inner protection area has therefore been delineated.

- The groundwater in the Source Protection Area ranges in vulnerability from Extreme to High.

- Available data shows generally elevated chloride and nitrate at the source, suggesting contamination from either an organic or inorganic waste source, the most likely source is from artificial fertilizers.

- The Protection Zones delineated in this report are based on the current understanding of groundwater conditions and on the available data. Additional data obtained in the future might indicate that amendments to the boundaries are necessary, and the conclusions should not be used as the sole basis for site-specific decisions.

13 RECOMMENDATIONS

1. A full chemical and bacteriological analysis of the **raw** water should be carried out on a regular basis by Glanbia Ingredients Ltd.

2. As the sanitary protection of the Ballyconra boreholes is less than satisfactory, the bores should be securely covered by lockable, galvanised steel lids. The pumphouses should also be secured to prevent access by animals and birds.

3. The potential hazards in the ZOC should be located and assessed, especially given the relatively high number of farmyards and houses up-gradient of the source in the ZOC.

4. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the boreholes.

5. Test pumping could be completed on the source boreholes to provide greater certainty to the conceptual model.

6. Karst mapping should be carried out both within the ZOC and the wider area around Ballyconra to locate any further potential point recharge localities.

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