Establishment of Groundwater Zones of Contribution

Update Report 2016

Ballyboy Group Water Scheme, Co. Offaly

March 2017

and

Ballyboy Group Water Scheme

Groundwater Sources Protection Zones

April 2001

‘Note:
Since the Ballyboy Group Water Scheme Groundwater Source Protection Zones report was published (2001), the water usage had significantly reduced. The Ballyboy Group Water Scheme established the Groundwater Zone of Contribution in 2017 based on new information.
The most up-to-date version of the Zone of Contribution (ZOC) for the scheme and other maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).’

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and

Geological Survey of Ireland, Groundwater Programme

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Project description

Since the 1980s, 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 'Zone of Contribution' (ZOC) 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.

This report has been prepared for Ballyboy Group Water Scheme as part of the Rural Water Programme funding initiative of grants towards specific source protection works on Group Water Schemes (DECLG Circular L5/13 and Explanatory Memorandum). The GSI previously delineated Groundwater Source Protection Zones for the Ballyboy Group Water Scheme in 2001 (Kelly, C. 2001). Ballyboy Group Water Scheme, Groundwater Source Protection Zones. Geological Survey of Ireland).

However since this time the available scientific understanding and knowledge has evolved and this current report has revisited the original 1996 report and updated it to include new data.

The report has been prepared in the format developed during an earlier pilot project "Establishment of Zones of Contribution" which was undertaken by the Geological Survey of Ireland (GSI), in collaboration with the National Federation of Group Water Schemes (NFGWS), and with support from the National Rural Water Services Committee (NRWSC).

The methodology undertaken by the GSI included: liaising with the GWS and NFGWS to facilitate data collection, a desk study, a site visit to inspect the supply, the local area, and to record groundwater level(s). The data was then analysed and interpreted in order to delineate the ZOC.

The maps produced are based largely on the readily available information in the area, a field walkover survey, 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.

The report and maps are hosted on the GSI website (www.gsi.ie).

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1 Overview: Groundwater, groundwater protection and groundwater supplies

Groundwater is an important natural resource in Ireland. It originates from rainfall that soaks into the ground. If the ground is permeable, the rainfall will filter down until it reaches the main body of groundwater, which is usually within either the bedrock, or a sand/gravel deposit. If the bedrock or sand/gravel deposit can hold enough groundwater and allow enough flow to supply a useful abstraction, it is referred to as an aquifer.

In Irish bedrock aquifers, groundwater predominantly flows through interconnected fractures, fissures, joints and bedding planes, which can be envisaged as a 'pipe network', of various sizes, with varying degrees of interconnectivity. The speed of flow through this network is relatively fast, delivering groundwater, and a large proportion of any contaminants present in the groundwater, to its destination *e.g.* borehole, spring, river and sea.

In sand/gravel aquifers, the groundwater flows in the interconnected pore spaces between the sand/gravel grains. Generally, this is equivalent to a filter system that may physically filter out contaminants to varying degrees, depending on the nature of the spaces and grains. It also slows down the speed of flow giving more time for pathogens to die off before they reach their destination *e.g.* borehole, spring, river and sea.

Further filtration of contaminants may occur where overlying soil and subsoil protects the aquifers; thick, impermeable clay soil and subsoil provide good protection while thin, very permeable gravel will provide limited protection. Therefore, variations in subsoil type and thickness are important when characterising the 'vulnerability' of groundwater to contamination.

The karst limestone aquifers provide significant and important groundwater supplies in Ireland. Karst landscapes develop in rocks that are readily dissolved by water *e.g.* limestone (composed of calcium carbonate). Consequently, conduit, fissure and cave systems develop underground[1]. Groundwater typically travels very fast in karst aquifers, which has a significant impact on the water quality; neither filtration nor pathogen die-off are associated with these aquifers.

The interaction between abstraction and geology is shown in **Diagram 1**. In this scenario, a borehole is pumping groundwater from the bedrock aquifer. As the water is abstracted through the well, the original water table (a), is drawn down to level (b), where it induces a drawdown curve of the natural water table (c). The shape of this curve depends on the properties of the aquifer, for example, if the borehole is intersecting an aquifer with few fractures that are poorly interconnected, the groundwater from that system will soon be exhausted, and therefore the pumping will have to pull from deeper depths to maintain supply, which results in the steep, deep drawdown curve. Alternatively, if the borehole is intersecting an aquifer with a large number of well connected groundwater-filled fractures, the abstraction will be met by pulling water from farther away, at a shallower depth, resulting in a shallow, wide drawdown curve.

By knowing the rate of abstraction (output), how much rainfall there is (input), and by assessing the geological elements outlined above (nature of the bedrock fractures or sand/gravel deposit; how permeable the soil and subsoil are) to determine what happens in between input and output, the catchment area, or 'Zone of Contribution' (ZOC), to any groundwater water supply can be determined.

Ballyboy GWS is supplied by a shallow dug well abstracting groundwater from the subsoils that overlie limestone bedrock that is categorised as a Regionally Important Karstified Aquifer with diffuse flow (Rk_d).

[1] Geological Survey of Ireland, 2000.

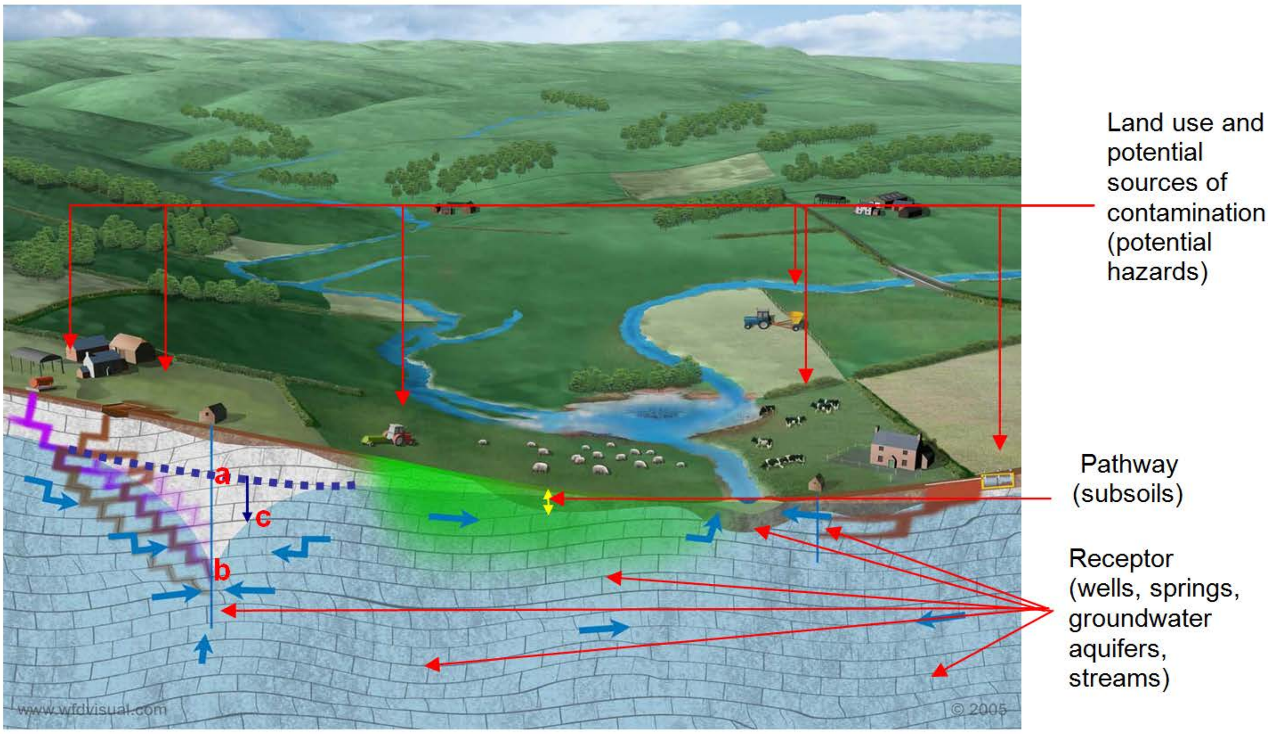

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

2 Location, Site Description, Well Head Protection and Summary of Borehole Details

The Ballyboy Group Water Scheme (GWS) is currently supplied by one large diameter, shallow dug well in the townland of Ballywilliam, Co. Offaly (Figure 1). The GWS is located 2 km to the north east of Kilcormac village. The well is located in a small pumphouse alongside a track 500 m north of the N52 Kilcormac to Tullamore Road. A small stream flows immediately beside the pump house and well.

The GWS was founded around 45 years ago and currently supplies 140 connections, 90 of which are domestic. A spring historically flowed into the stream at the site and this spring was opened up by the GWS and held open with two 1 m diameter concrete rings. The sump, or dug well, is 2.8 m deep and is housed within a metal manhole cover that is flush with ground level (**Photo 2**).

The small pump house holds the treatment units consisting of chlorination and ultra-violet treatment. The chlorine dosing system includes a contact tank with 30 minutes residence time. The scheme has a storage reservoir which is generally maintained at 50 % of its capacity to ensure two days water requirement. There are three pumps in the pump house (**Photo 3**). They operate on a rotating basis with Pumps 1 and 2 operating for one week, then Pumps 2 and 3 for the following week and the Pumps 3 and 1 for the week after that. They pump at night-time only. The current usage is approximately 90 m^3/d. This is significantly less than the abstraction noted in the GSI 2001 report which, at that time, was 176 m^3/d. This reduction in usage is largely due to the elimination of leaks around the system.

Photo 1 – Ballyboy GWS Pump House

Photo 2 – Well Head

Photo 3 – Three pumps in pump house

Table 1 provides a summary of all known information about the wells, including estimates of hydraulic parameters.

Table 1. Supply Details

	Ballyboy GWS Well
Grid reference	ING E219794 N215740
Townland	Ballywilliam
Source type	Dug well
Constructed	Early 1970s
Constructed By	Unknown
Owner	Ballyboy GWS
Elevation (m aOD)	65 m
Total depth (m)	2.8 m
Construction details	1 m diameter concrete rings
Depth to rock (metres below ground level, m bgl)	2.0 m [2]
Static water level (m bgl)	2.28 m bgl – 09/05/2016
Pump intake depth	Unknown
Current abstraction rate (GWS)	90 m^3/d
Reported yield (m^3/d)	Unknown but > 176 m^3/d
Number of connections	140
Estimated specific capacity (m^3/d/m)	Unknown
Estimated transmissivity (m^2/d)	Unknown

A rough measurement of the flow in the small stream adjacent to the well was made. The cross sectional area of the stream was measured as 0.56 m^2 (width 2.25 m, depth of water 0.25 m) and the velocity was 0.05 m/s (based on a small float travelling 2 metres in 18 seconds). The flow rate in the stream was estimated as 0.028 m^3/s.

[2] Kelly, C. (2001). Ballyboy Group Water Scheme Groundwater Source Protection Zones. Geological Survey of Ireland.

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical characteristics of the area

A summary of the relevant information on rainfall, land use, topography, hydrology and geology for the area is provided in Table 2.

Table 2. Physical Characteristics of the Area of Interest

	GWS Well	Description/Comments
Annual Rainfall (mm)	850	Met Eireann average annual rainfall data 2012 - 2015
Annual Evapotranspiration Losses (mm)	327	Met Eireann (www.met.ie)
Annual Effective Rainfall (mm)	523	National Groundwater Recharge Data (www.gsi.ie)
Topography	The dug well is located next to a small stream at the edge of an esker ridge that runs east – west and southwest – northeast. The topography is gently undulating and slopes gently from the southeast.	
Land use	Agricultural land surrounds the site with grazing and grassland the predominant activities. A number of houses and farm yards are located in the area. A large area of Bord na Mona worked bog lies to the north of the site. There is a small area of forestry north of the site and some small gravel pits located in the esker ridge.	
Surface Hydrology	A small stream flows alongside the site (the original spring at the location discharged into the stream prior to it being excavated and used by the GWS). The stream flows south-westwards where it forms a tributary of the Silver River, at Barnaboy Bridge just north of Kilcormac village. The Silver River then flows northwards where it joins the River Brosna (and ultimately the River Shannon). To the north of the source the land is poorly drained with numerous small streams and drainage ditches criss-crossing the boggy landscape. The land to south of the site is well drained with fewer surface water features present.	
Topsoil	Peat (Teagasc 2006). Large areas of Till to the south with a band of glaciofluvial sands and gravels in between the Peat and Till.	
Subsoil (**Figure 2**)	Peat (Teagasc 2006), with a band of glaciofluvial sands and gravels to the south.	
Groundwater Vulnerability (**Figure 3**)	High (H) (See **Appendix 2**). Seven auger holes installed by the GSI (Kelly 2001) indicate varying subsoil conditions from sandy silt to sandy clay to gravel with depth to bedrock varying from 2 – 8 m. Auger Hole No. 4 was the closest to the well – the log of this auger (**Appendix 1**) indicates the presence of 1 m of low permeability sandy clay with silt which is underlain by 1 m of high permeability silty sand with gravel.	
Geology (**Figure 4**)	The bedrock type in this area is classified as Visean undifferentiated limestones. This limestone is part of the Dinantian Pure Bedded Limestones rock unit group. Movements in the earths crust have caused the rocks to be folded, faulted and jointed. Two major fault sets are present in this area; NE – SW trending and SE to NW trending. A SE – NW trending fault is mapped a short distance (175m) to the north of the Ballyboy GWS source. It is likely that this fault has many small fractures and fissures associated with it.	
Aquifer (**Figure 5**)	**Regionally Important Karstified Aquifer (Rk_d) – with diffuse flow.** The GWB description: this rock unit group is permeable with modelled transmissivities of 140 – 650 m^2/d (Kelly 2001) with zones of higher permeability associated with fracturing and faulting. Yield testing on the Kilcormac GWS borehole within the same aquifer reported transmissivities of 20 – 40 m^2/d. Permeability is also enhanced where the rocks have undergone karstification. Groundwater flow occurs through these zones of enhanced permeability and generally within the upper 30 m.	
Groundwater Body	Tullamore GWB. Categorised as 'at risk of not achieving good status' (www.epa.ie)	
Recharge Coefficient (**Appendix 3**)	85 %	High permeability subsoil overlain by 'well drained' soil – underlain by Regionally Important Karstified Aquifer. Hydrogeological setting 2.ii (see **Appendix 3**).
Average Recharge (mm/yr)	478	

3.2 Hydrochemistry and water quality

Four sources of water quality data are available for the Ballyboy GWS:

- Data from the previous GSI report (Kelly 2001);
- Offaly County Council check and audit monitoring data of treated water samples from 2014 – 2015 (**Appendix 4**);
- Field measurements of some parameters recorded on day of site visit, 09.05.2016, including pH, electrical conductivity and temperature, of both the groundwater in the shallow dug well and the water in the adjacent stream (**Table 3**);
- Raw water sample collected as part of this project by the NFGWS in June 2016 (**Table 4 and Appendix 4**).

The analytical results have been compared to the Threshold Values from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010); and/or the drinking water limits from the Drinking Water Regulations (SI No. 122 of 2014), whichever is the lower. A summary of the main parameters is presented in Table 4 while full details are presented in Appendix 3.

The 2001 GSI report (Kelly) reported that analyses of 12 samples indicated that the water was hard to very hard with total hardness values of 357 – 405 mg/l and electrical conductivity values of 562 – 700 µS/cm, indicating a typical signature from groundwater travelling through limestone bedrock. Throughout the late 1980's and 1990's the nitrate concentrations ranged from 25 – 41 mg/l (based on 36 samples), with the average being 32.9 mg/l. It was reported that for the period 1989 to 1997 there was a general increase in nitrate concentrations but from 1997 to 2001 the concentrations had begun to decrease.

Chloride was also high, ranging from 24 – 30 mg/l (based on 12 samples). The potassium to sodium ratio of 19 samples taken between 1997 – 1999 was on average 0.4 or in many cases above 0.4; indicating organic contamination probably from farmyard derived waste.

Sixty-eight samples were analysed for bacteriological parameters and positive faecal coliform counts were recorded in 21 of the 68.

The audit and check monitoring data from Offaly County Council (**Appendix 4**) represents treated water only. Chloride was high, but within acceptable limits, on two occasions. The bacteriological water quality showed no evidence of contamination; which, given that the samples are treated water indicate that the treatment unit was operating efficiently at the time of the sampling.

Field measurements of physio-chemical parameters, including pH, electrical conductivity and temperature, were collected on 09.05.2016 from the dug well and from the adjacent surface water stream (**Table 3**). The conductivity values are similar, which is to be expected as the spring and the stream are likely to be supplied by the same groundwater originating within the Regionally Important karstified aquifer. This is also reflected in the low temperature of the water in the stream.

Table 3. Summary of field measurements of physio-chemical parameters

Parameter	Ballyboy GWS Well	Stream
pH (pH units)	09/05/2016 – 8.03	09/05/2016 – 7.32
Conductivity @ 20C (µS/cm)	09/05/2016 – 733	09/05/2016 – 751
Temperature (deg C)	09/05/2016 – 13.5	09/05/2016 – 10.1

A raw water sample was collected as part of this project by the NFGWS on 29.06.2016. The results suggest that the groundwater in the Ballyboy GWS dug well is being contaminated by organic waste. The chloride concentration is high; 45.5 mg/l, above the threshold value of 24 mg/l. The E.Coli count was very high, 62.4, as was the total coliform count of 94.8. The potassium to sodium ratio is also elevated at 0.38.

Table 4. Summary Raw Water Quality Data

Parameter	Number of Samples	Minimum	Maximum	Average	Drinking Water Limit (DWL) or Threshold Value (TV)
Conductivity @ 20C (µS/cm)	7	629	682	651	800 (TV)
Sodium (mg/l)	3	9.83	11.5	10.8	150 (TV)
Chloride (mg/l)	3	22.2	**45.5**	**30.4**	24
Ammonium NH_4	7	<0.015	0.1	0.027	0.3
Nitrate as NO_3 (mg/l)	3	18	20.15	18.95	37.5 (TV)
Nitrite as NO_2 (mg/l)	7	<0.009	0.2	0.03	0.5 (TV)
Potassium, total (mg/l)	1	3.76			
Total Hardness (Kone) (mg/l $CaCO_3$)	1	367.1			
Iron (µg/l)	7	<3.6	26	6.8	200 (DWL)
Manganese, dissolved (µg/l)	3	<2.6	<5	3.4	<50 (DWL)
E Coli (cfu/100ml)	7	0	**62.4**	**8.9**	0
Total Coliforms (cfu/100ml)	7	0	**94.5**	**13.5**	0
Potassium: Sodium	0.38				>0.4 indicative of contamination from organic waste

In summary, the available hydrochemical data indicates the water is very hard with a typical limestone signature. There is evidence that the groundwater is being contaminated by organic waste; most likely of farmyard origin.

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is given as follows (see cross section **Diagram 2)**.

Groundwater is replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. Although the dug well itself is underlain by peat the land area supplying groundwater to it (i.e the zone of contribution, ZOC, that extends to the southeast, **Figure 6**) is underlain by higher permeability sands and gravels that are in turn overlain by well drained topsoils. This means that approximately 15 % of the rainfall falling over the land surface will runoff to streams and ditches. The remaining portion (85 %) of rainfall that percolates downwards will enter the bedrock through its upper weathered zone which is likely to have a well developed network of fractures and fissures. The deeper bedrock will have less fractures and fissures but some groundwater will access these deeper layers. The groundwater will then move through the bedrock under the influence of gravity until it reaches a discharge point such as the small network of streams to the west that flow towards the Silver River. The dug well is effectively a spring that was excavated by the GWS and held open by large concrete rings. A small stream flows adjacent to the well just outside the pump house.

The subsoils from which the shallow dug well is abstracting groundwater is in turn supplied with groundwater by the underlying Regionally Important Karstified Aquifer (Rk_d) which has a well developed network of fissures and fractures through which groundwater flows. The original spring, that now forms the dug well, occurs at this location due to a combination of the flat topography and shallow bedrock which has localized zones of higher permeability. Groundwater emerges at the surface through the fractures and fissures associated with these zones of higher permeability. The moderate to high permeability tills and sands and gravels that lie to the south are allowing groundwater to percolate downward and recharge the aquifer.

The vulnerability of the limestone bedrock to contamination is classified as High (H) immediately around the dug well while a small area of Extreme (E) vulnerability is mapped to the south. The shallow nature of the well and the proximity of the small stream increase the vulnerability of the Ballyboy well.

The Zone of Contribution (ZOC) will extend upgradient (upslope) from the wells in a southeasterly direction. Therefore the ZOC occupies an area underlain by a limestone aquifer whose vulnerability to contamination is High (H).

The delineation of the zone of contribution boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

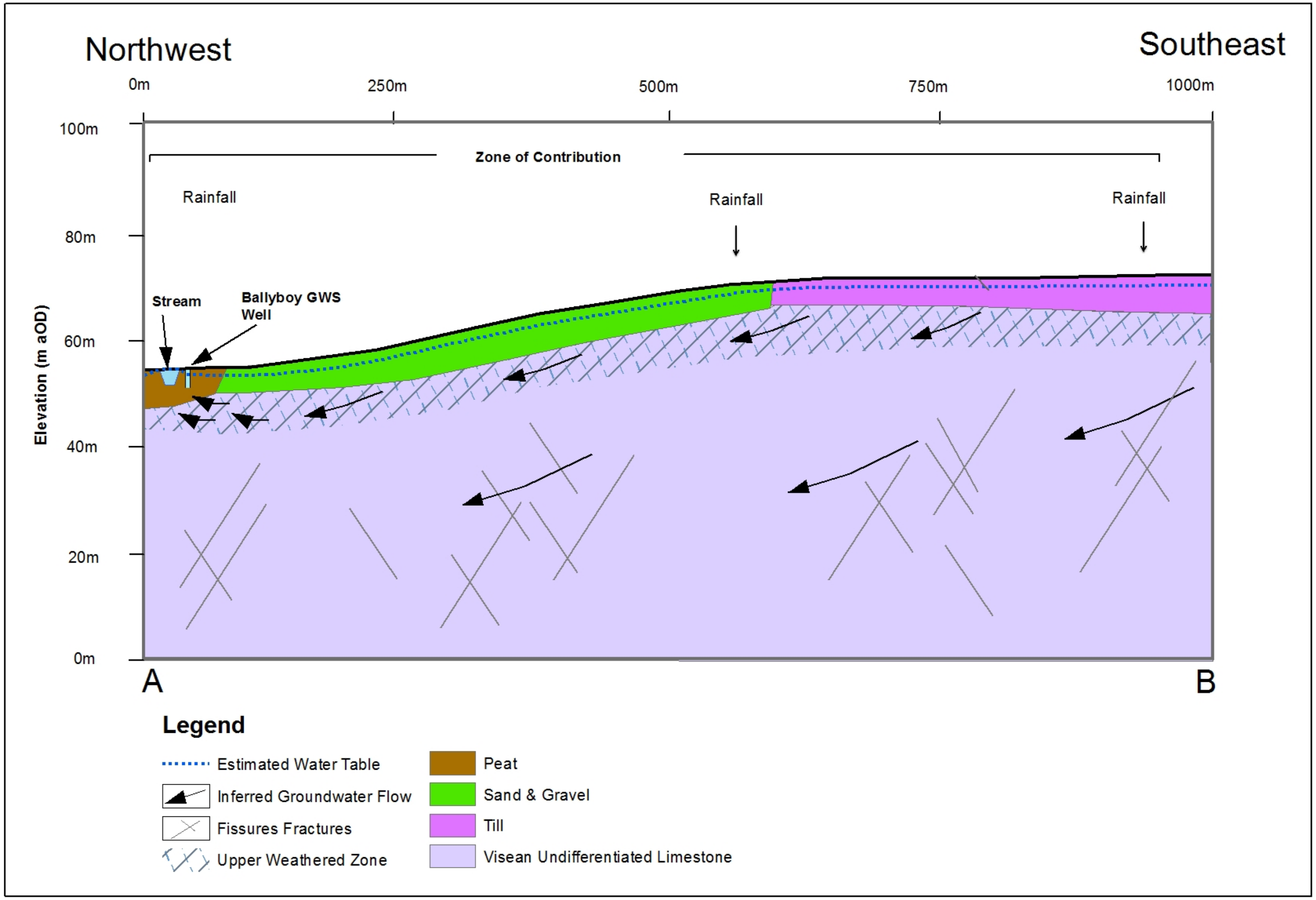

Diagram 2: Schematic Cross Section and Conceptual Model

4.2 Boundaries

The boundaries of the area contributing to the source are considered to be as follows (**Figure 6**).

All of the boundaries are based on a combination of hydrogeological mapping and topography.

The **Northern boundary**, is the 'downhill' limit', beyond which groundwater will not be drawn back uphill under the influence of the pump. In reality it will be constrained by the location of the small stream that flows adjacent to the dug well but a conservative 30 m buffer is applied as the downgradient boundary.

The **Southern Boundary**, represents the uphill boundary of the zone of contribution. This is based on the estimated groundwater flow to the well, which in turn is influenced by the amount of water that is being abstracted. There are no geological features mapped that can assist in delineating this boundary (such as a rock unit divide or geological fault) and so there is a degree of uncertainty associated with it.

The **Western and Eastern Boundaries** define the width of the ZOC. There is a degree of uncertainty associated with these boundaries but they are generally parallel to the inferred direction of groundwater flow. The two boundaries meet on the downgradient side of the boreholes at the ‘downhill limit’.

The delineation of the boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

4.3 Recharge and water balance

The current abstraction rate from the Ballyboy GWS well is 90 m^3/d. In order to account for seasonal fluctuations in abstraction volumes plus uncertainties in the groundwater flow direction, a conservative approach is adopted and therefore the water balance has been calculated based on a daily abstraction rate of 135 m^3/d i.e. 150% of the known current abstraction rate.

The available recharge is estimated at 478 mm/yr (see Table 2). The minimum geographical area required to sustain an abstraction of 135 m^3/d (or 49,275 m^3/yr) based on the available recharge of 478 mm/yr (or 0.478 m/yr) is 0.1 km^2 (or 103,085.77 m^2). The delineated ZOC measures 0.48 km^2 (or 488,597 m^2) which is considered more than adequate.

5 Conclusions

The Ballyboy GWS currently abstracts 90 m^3/d from one shallow dug well abstracting groundwater from subsoil deposits that are in turn supplied with groundwater from the underlying limestone bedrock classified as a Regionally Important Karstified Aquifer with diffuse flow (Rk_d). The scheme currently has 140 connections.

The vulnerability of the groundwater supplying the well is to High (H) to Moderate (M). There is evidence in the recent raw water sampling that the groundwater in the well is being contaminated by organic waste.

The ZOC extends to the southeast of the well and is occupied by agricultural land, farm yards and houses. Potential sources of contamination to the well include septic tanks (in particular old or inefficient tanks that have not been emptied in many years) and agricultural activities e.g. grazing, landspreading, slurry pits or slatted units.

Any landuse changes or planning permissions within the ZOC should be carefully monitored and assessed for likely impacts on the well.

6 Recommendations

The recommendations below have been subdivided into higher and lower priority; ideally the higher priority recommendations should be addressed immediately.

Essential:

- Routine untreated groundwater monitoring should be undertaken for the source for a specified period of time (e.g. monthly/quarterly for a year, to include sampling immediately after at least one rainfall event). The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist.

- Ideally, the well head should be finished above ground in order to provide maximum protection against the ingress of contamination arising at the surface. Ideally the concrete apron around the well head should slope outwards ensuring that runoff flows away from the well rather than towards it.

- Any future planning applications made within the ZOC should be assessed for their potential impact on the quality of groundwater (refer to the local authority's county development plan and Groundwater Protection Schemes Document, 1999). Similarly any significant changes in land use, such as forestry clearance, should be monitored.

- Licensed landspreading must only take place within the context of the guidelines as specified in the document entitled "Groundwater Protection Schemes" published by the Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland in 1999 and 'Landspreading of Organic Wastes' Guidance on Groundwater Vulnerability Assessment of Land, Environmental Protection Agency 2004.

Desirable:

- Comprehensive hazard mapping (e.g. septic tanks, slatted units and slurry pits) within the delineated ZOC should be undertaken. This should ideally include septic tank inspections to clarify their condition and inspections of high risk features in farm yards such as slatted units and slurry pits, particulary along the upgradient length of the small stream adjacent to the well.

- The GWS well and its ZOC should be assessed to establish the level of risk, if any, posed by cryptosporidium.

- Further investigation to establish whether or not there is a connection between the dug well and the adjacent stream would assist the GWS in managing sources of contamination to the groundwater in the well. A pumping test together with detailed monitoring of temperature and conductivity within both the dug well and the stream would be required.

Other:

- The following EPA guidelines may serve as future useful reference documents for the Ballyboy GWS:

    - EPA Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources. Of particular interest would be Section 4.1 – Step 2 – Hazard Mapping[3].

    - EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans. This document contains checklists for hazards which would assist in hazard mapping within the ZOC[4].

    - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

[3] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp

[4] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo

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EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans.

EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

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FIGURES

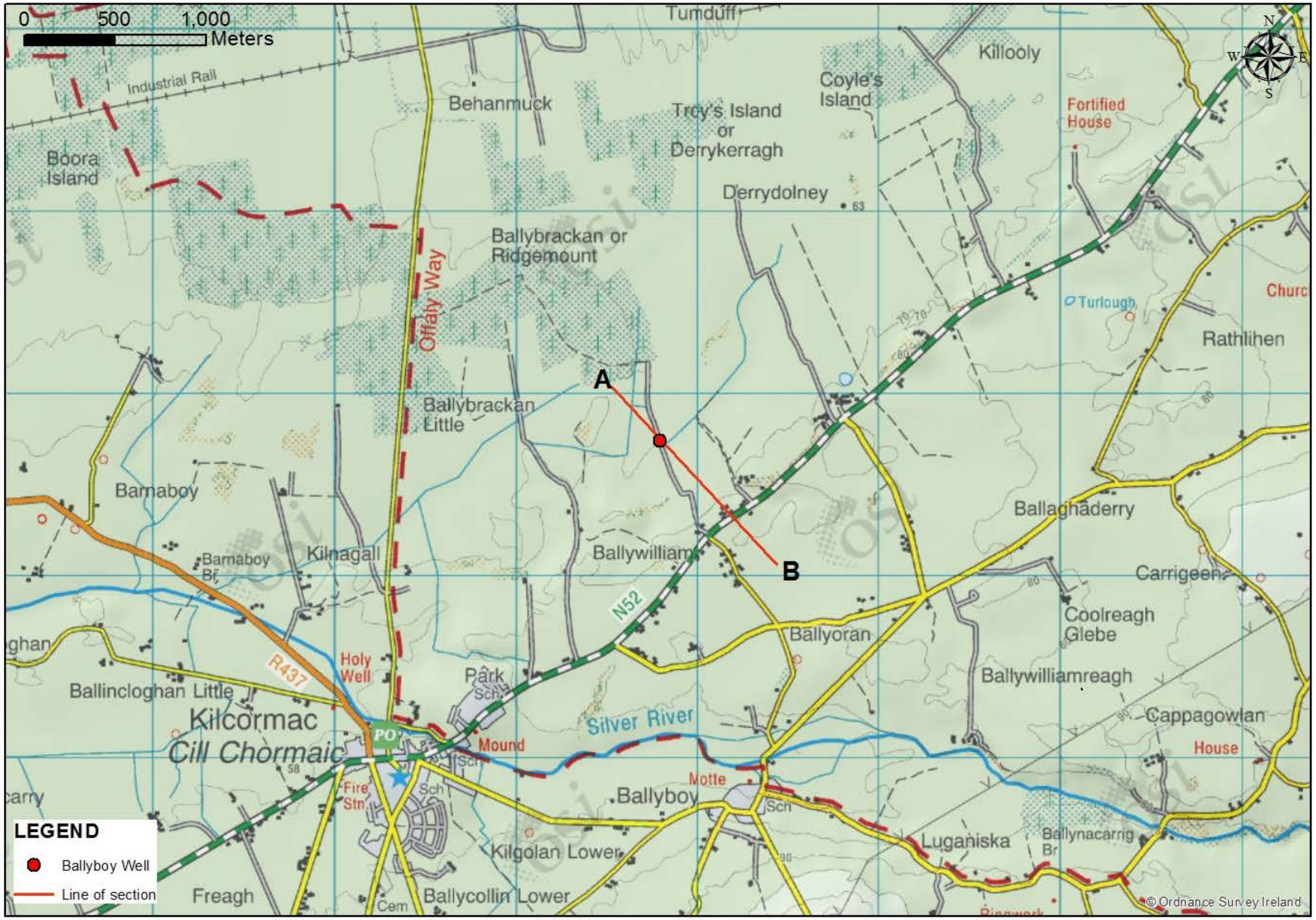

Figure 1. Location Map

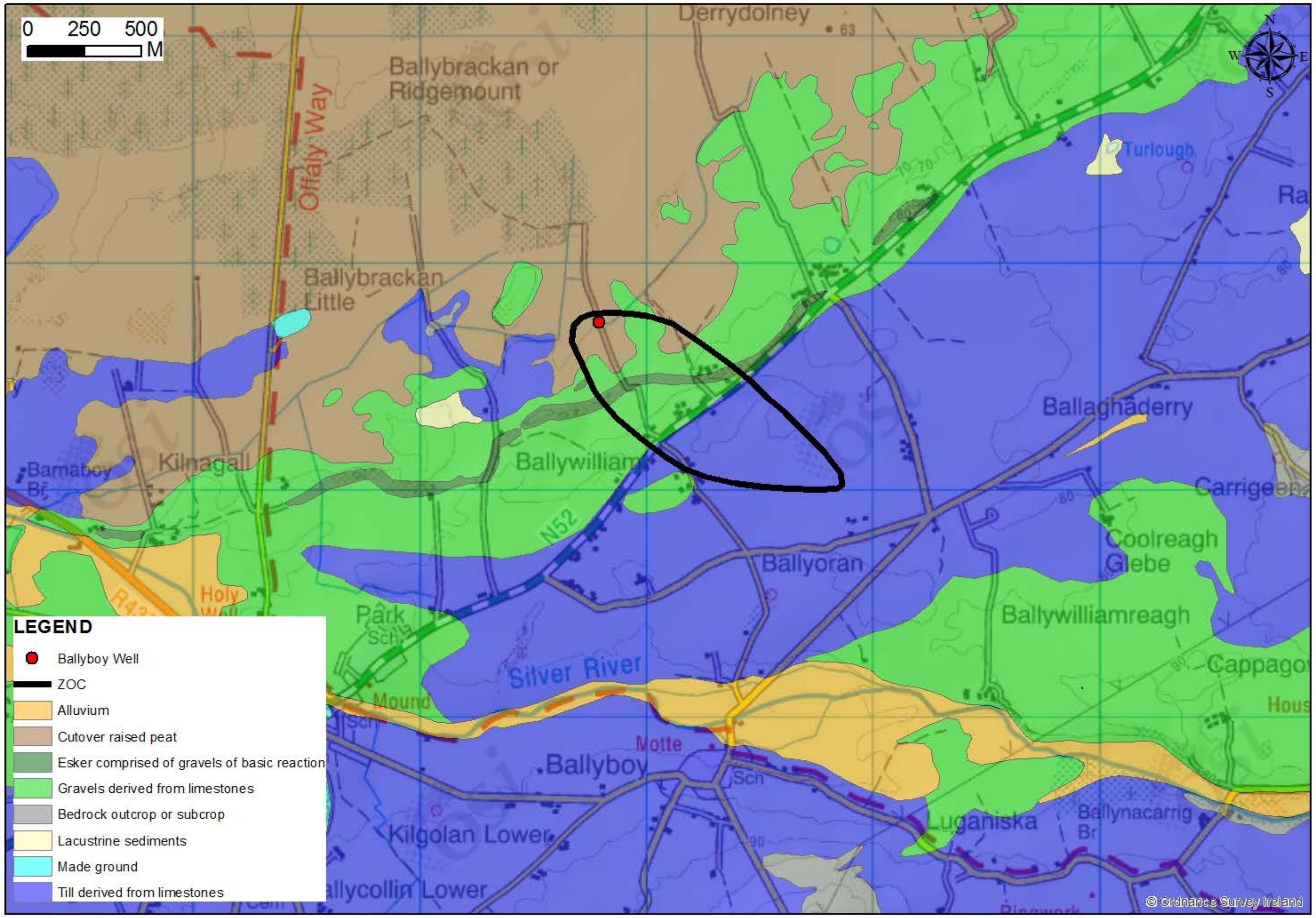

Figure 2. Subsoils Map

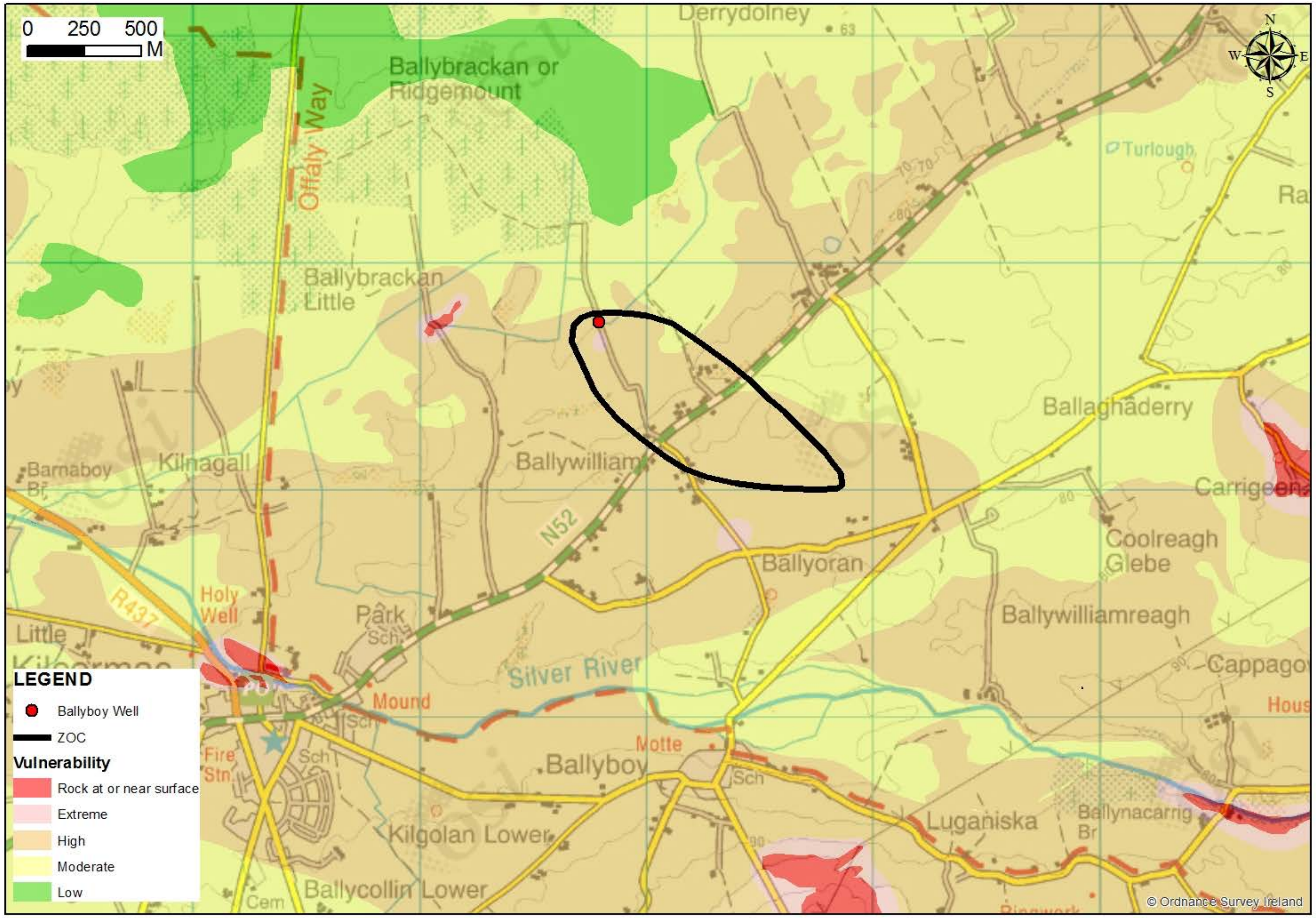

Figure 3. Groundwater Vulnerability Map

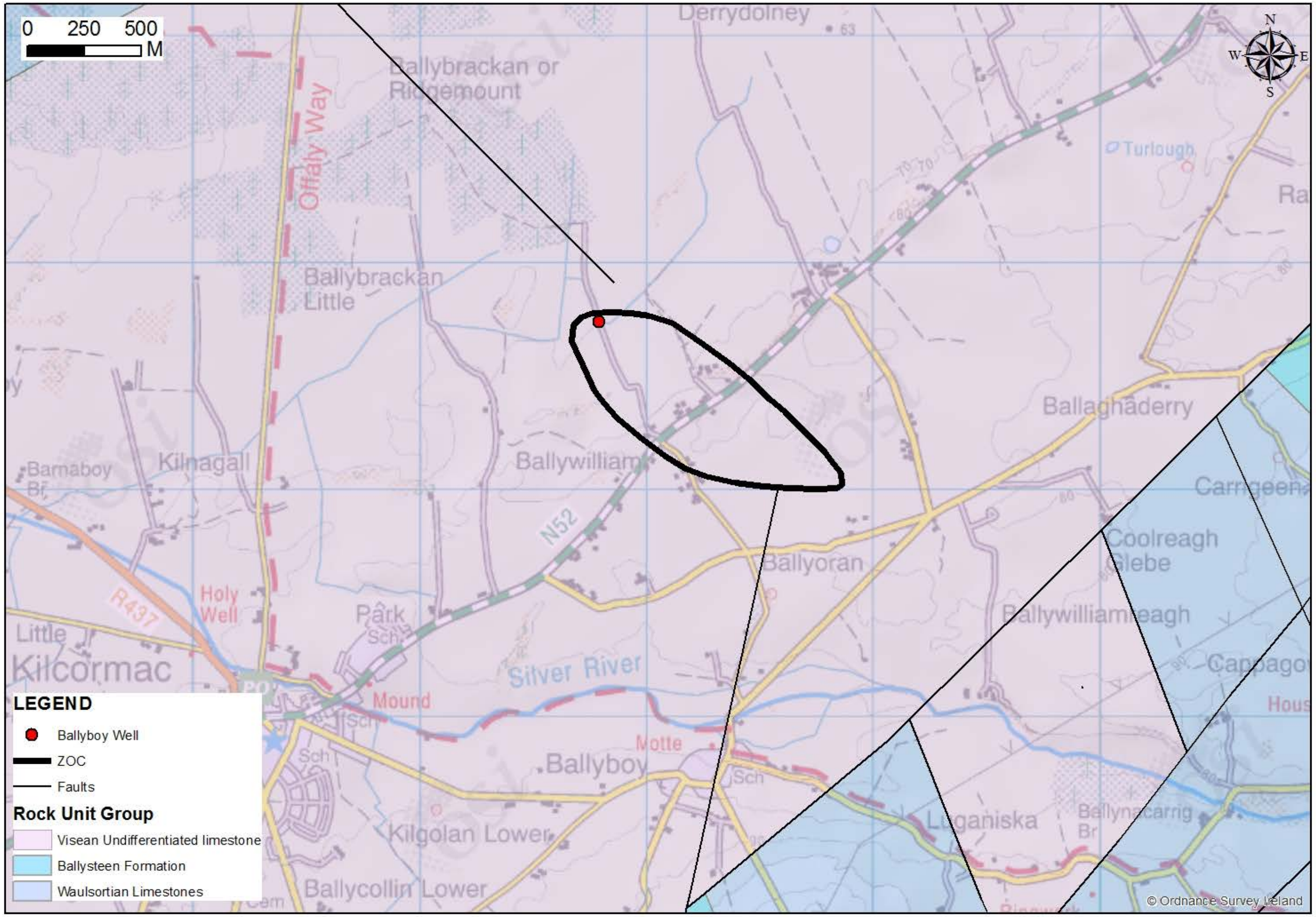

Figure 4. Rock Unit Group Map

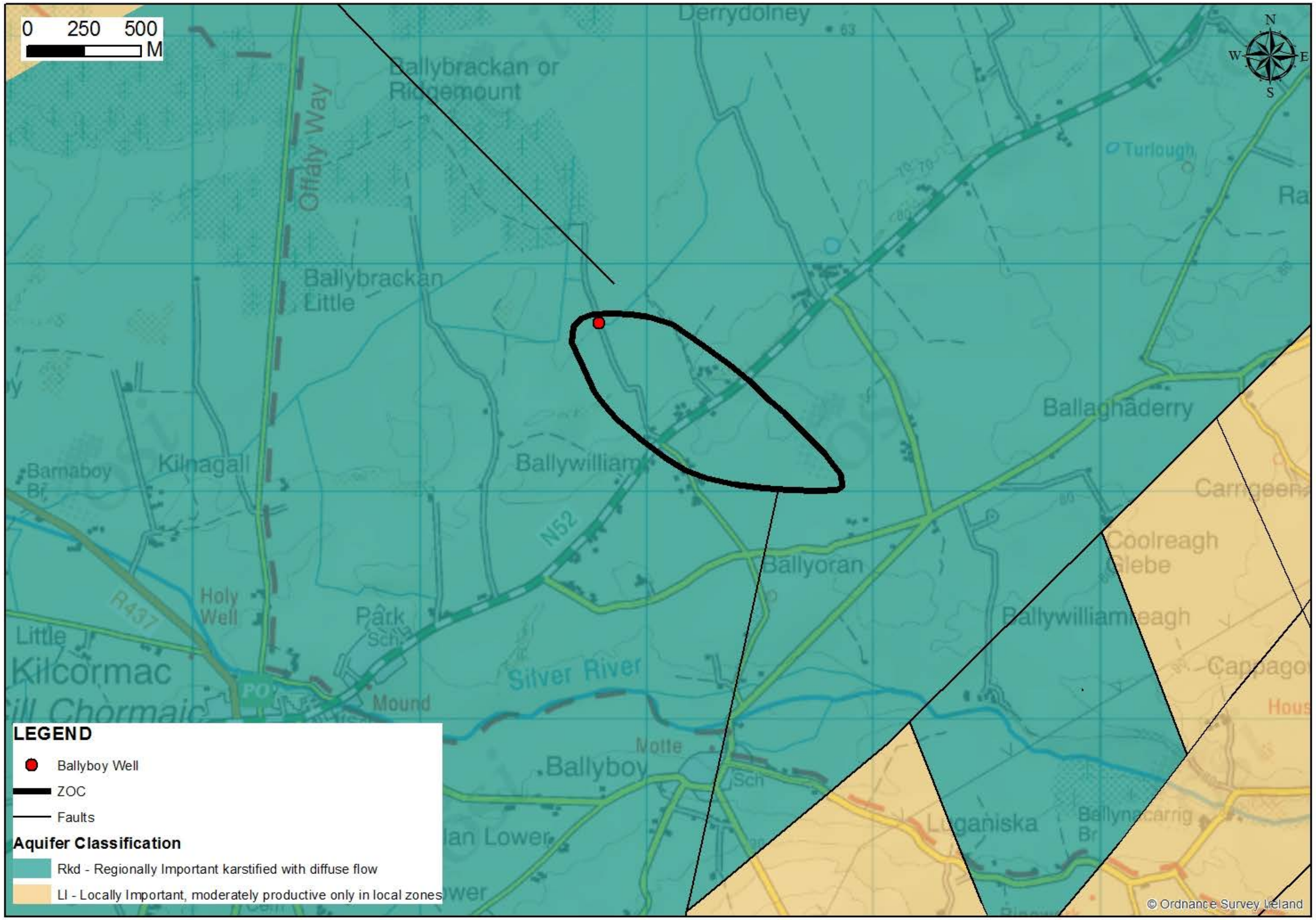

Figure 5. Aquifer Map

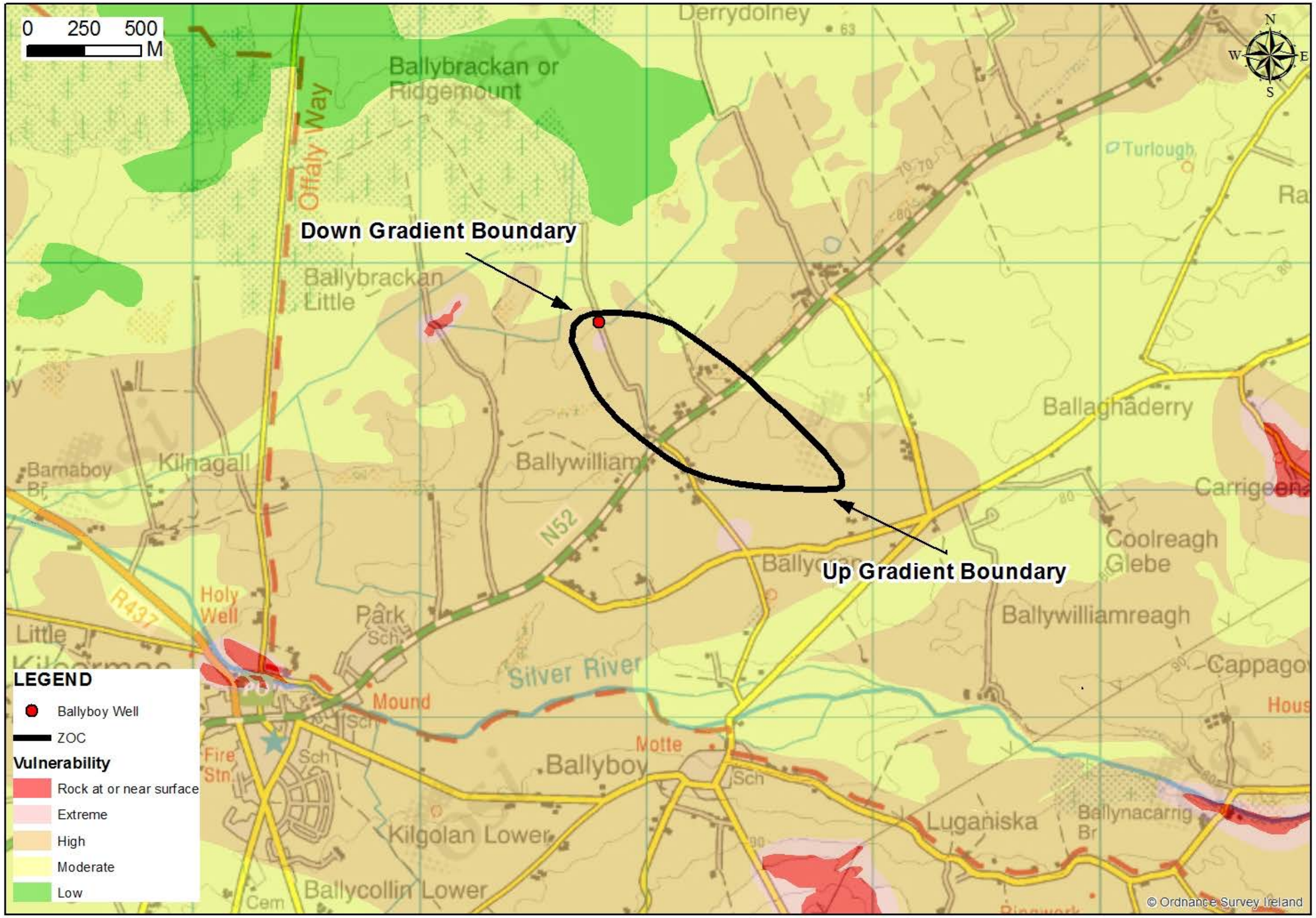

Figure 6. ZOC Boundary Map

Acronyms and glossary of terms

BGL	Below Ground Level
EPA	Environmental Protection Agency
DEHLG	Department of Environment Heritage and Local Government
EQS	Environmental Quality Standard
EU	European Union
GPZ	Groundwater Protection Zone
GSI	Geological Survey of Ireland
GWB	Groundwater Body
GWD	Groundwater Directive (European Union)
GWS	Group Water Scheme
IGI	Institute of Geologist of Ireland
MOD	Metres Ordnance Datum
MRP	Molybdate-Reactive Phosphorus
NRG	National Grid Reference
NRWMC	National Rural Water Monitoring Committee
PVC	Polyvinyl Chloride
SPZ	Source Protection Zones
TOT	Time of Travel
TVs	Threshold Values
UV	Ultra-Violet
ZOC	Zone of Contribution
WFD	Water Framework Directive (European Union)

Glossary of Terms

Aquifer

A subsurface layer or layers of rock, or other geological strata, of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (Groundwater Regulations, 2010).

Attenuation

A decrease in pollutant concentrations, flux, or toxicity as a function of physical, chemical and/or biological processes, individually or in combination, in the subsurface environment.

Borehole

A particular type of well - a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system.

Conceptual Hydrogeological Model

A simplified representation or working description of how a real hydrogeological system is believed to behave on the basis of qualitative analysis of desk study information, field observations and field data.

Confined Aquifer

A confined aquifer occurs where the aquifer is overlain by low permeability "confining" material. Once all the void space in the aquifer is full of water up to the confining layer, the addition of more water to the aquifer causes the stored water to become pressurised and, the additional water is stored by compression, sealed in by the overlying confining layer (the water is added upgradient where the confining layer is absent). Where a borehole punctures the confining layer, the water will rise up into the borehole to equalise the confining pressure.

Diffuse Sources

Diffuse sources of pollution are spread over wider geographical areas rather than at individual point locations. Diffuse sources include general land use activities and landspreading of industrial, municipal wastes and agricultural organic and inorganic fertilisers.

Direct Input

An input to groundwater that bypasses the unsaturated zone (e.g. direct injection through a borehole) or is directly in contact with the groundwater table in an aquifer either year round or seasonally.

Doline

Or enclosed depressions are relatively shallow bowl or funnel shaped depressions that form in karst landscapes, and serve to funnel or concentrate recharge underground. Their presence indicates that subterranean drainage is in operation.

Dolomitisation

Is a process, whereby the calcite crystals in limestone is replaced by magnesium. This results in an increase in the porosity and permeability of the rock. Dolomitised rocks are a highly weathered, yellow/orange/brown colour and are usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery. Dolomitisation often occurs preferentially in both fault zones and purer limestones.

Down-gradient

The direction of decreasing groundwater levels, i.e. flow direction. Opposite of upgradient.

Dry Weather Flow (Receiving Water)

The minimum flow likely to occur in a surface water course during a prolonged drought.

Environmental Quality Standard (EQS)

The concentration of a particular pollutant or group of pollutants in a receiving water which should not be exceeded in order to protect human health and the environment.

Enclosed Depression

See doline

Fissure

A natural crack in rock which allows rapid water movement.

Good Groundwater Status

Achieved when both the quantitative and chemical status of a groundwater body are good and meet all the conditions for good status set out in Groundwater Regulations 2010, regulations 39 to 43.

Groundwater

All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Groundwater Regulations, 2010).

Groundwater Body (GWB)

A volume of groundwater defined as a groundwater management unit for the purposes of reporting to the European Commission under the Water Framework Directive. Groundwater bodies are defined by aquifers capable of providing more than 10 m3/d, on average, or serving more than 50 persons.

Groundwater Protection Scheme (GWPS)

A scheme comprising two principal components: a land surface zoning map which encompasses the hydrogeological elements of risk (of pollution); and a groundwater protection response matrix for different potentially polluting activities (DELG/EPA/GSI, 1999).

Groundwater Protection Responses (GWPR)

Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

Groundwater Protection Zone (GPZ)

A zone delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code, e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important karstified aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

Groundwater Recharge

Two definitions: a) the process of rainwater or surface water infiltrating to the groundwater table; b) the volume (amount) of water added to a groundwater system.

Groundwater Resource

An aquifer capable of providing a groundwater supply of more than 10 m3/d as an average or serving more than 50 persons.

Hydraulic Conductivity

The rate at which water can move through a unit volume of geological medium under a potential unit hydraulic gradient. The hydraulic conductivity can be influenced by the properties of the fluid, including its density, viscosity and temperature, as well as by the properties of the soil or rock.

Hydraulic Gradient

The change in total head of water with distance; the slope of the groundwater table or the piezometric surface.

Igneous

Igneous rock is formed through the cooling and solidification of magma or lava.

Indirect Input

An input to groundwater where the pollutants infiltrate through soil, subsoil and/or bedrock to the groundwater table.

Input

The direct or indirect introduction of pollutants into groundwater as a result of human activity.

Karst

A distinctive landform characterised by features such as surface collapses, sinking streams, swallow holes, caves, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits.

Karstification

Karstification is the process whereby limestones are slowly dissolved by acidic waters moving through them. This results in the development of an uneven distribution of permeability with the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones. Karstification results in the progressive development of distinctive karst landforms such as caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime. It is an important feature of Irish hydrogeology.

Pathway

The route which a particle of water and/or chemical or biological substance takes through the environment from a source to a receptor location. Pathways are determined by natural hydrogeological characteristics and the nature of the contaminant, but can also be influenced by the presence of features resulting from human activities (e.g., abandoned ungrouted boreholes which can direct surface water and associated pollutants preferentially to groundwater).

Permeability

A measure of a soil or rock‘s ability or capacity to transmit water under a potential hydraulic gradient (synonymous with hydraulic conductivity).

Point Source

Any discernible, confined or discrete conveyance from which pollutants are or may be discharged. These may exist in the form of pipes, ditches, channels, tunnels, conduits, containers, and sheds, or may exist as distinct percolation areas, integrated constructed wetlands, or other surface application of pollutants at individual locations. Examples are discharges from waste water works and effluent discharges from industry.

Pollution

The direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment (Groundwater Regulations, 2010).

Poorly Productive Aquifers (PPAs)

Low-yielding bedrock aquifers that are generally not regarded as important sources of water for public water supply but that nonetheless may be important in terms of providing domestic and small community water supplies and of delivering water and associated pollutants to rivers and lakes via shallow groundwater pathways.

Preferential Flow

A generic term used to describe water movement along favoured pathways through a geological medium, bypassing other parts of the medium. Examples include pores formed by soil fauna, plant root channels, weathering cracks, fissures and/or fractures.

Saturated Zone

The zone below the water table in an aquifer in which all pores and fissures and fractures are filled with water at a pressure that is greater than atmospheric.

Soil (topsoil)

The uppermost layer of soil in which plants grow.

Source Protection Area

The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO). The SI is designed to protect the source against the effects of human activities that may have an immediate effect on the source, particularly in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source. The SO covers the remainder of the zone of contribution of the groundwater source.

Specific Yield

The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table.

Spring

A spring is a natural feature where groundwater emerges at the surface. Springs usually occur where the rate of flow of groundwater is too great to remain underground. The position of a springs usually reflects a change in soil or rocktype or a change in slope.

Subsoil

Unlithified (uncemented) geological strata or materials beneath the topsoil and above bedrock.

Surface Water

An element of water on the land‘s surface such as a lake, reservoir, stream, river or canal. Can also be part of transitional or coastal waters. (Surface Waters Regulations, 2009.).

Swallow Hole

The point where concentrated inflows of water sink underground. They are found in karst environments.

Threshold Values (TVs)

Chemical concentration values for substances listed in Schedule 5 of the Groundwater Regulations (2010), which are used for the purpose of chemical status classification of groundwater bodies.

Till

Unsorted glacial Sediment deposited directly by the glacier. It is the most common Quaternary deposit in Ireland. Its components may vary from gravel, sands and clays.

Transmissivity

Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer.

Unsaturated Zone

The zone between the land surface and the water table, in which pores, fractures and fissures are only partially filled with water. Also known as the vadose zone.

Vulnerability

The intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (Fitzsimmons et al, 2003).

Water Table

The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

Weathering

The breakdown of rocks and minerals at the earth's surface by chemical and physical processes.

Zone of Contribution (ZOC)

The area surrounding a pumped well or spring that encompasses all areas or features that supply groundwater to the well or spring. It is defined as the area required to support an abstraction and/or overflow (in the case of springs) from long-term groundwater recharge.

APPENDIX 1

Geolological Logs of Auger Boreholes, GSI 2001

Geological Logs of Auger Boreholes – sourced from 2001 GSI Report.

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It was assumed that the auger had reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Auger I.D	BS 5930 Description	Permeability Category
Kilcormac No. 1 National Grid Reference 219050 215000		
0 – 6.0 m	Sandy SILT with clay	MODERATE
Kilcormac No. 2 National Grid Reference 219050 214500		
0 – 2.0 m	Silty SAND	HIGH
2.0 – 7.3 m	GRAVEL with sand and silt	HIGH
Kilcormac No. 3 National Grid Reference 219500 215200		
0 – 6.5 m	Sandy SILT with clay	MODERATE
Kilcormac No. 4 National Grid Reference 219800 215650		
0 – 1.0 m	Sandy CLAY with silt	LOW
1.0 – 2.0 m	Silty SAND with gravel	HIGH
Kilcormac No. 5 National Grid Reference 220100 215200		
0 – 4.0 m	Silty SAND with gravel	HIGH
4.0 – 5.0 m	Sandy SILT with clay	MODERATE
Kilcormac No. 6 National Grid Reference 220400 214800		
0 – 1.5 m	SILT with clay	MODERATE
1.5 – 2.6 m	Clayey SAND with gravel	HIGH
Kilcormac No. 7 National Grid Reference 219200 213700		
0 – 4.0 m	Clayey SAND with frequet small stones	HIGH
4.0 – 6.0 m	SILT with gravel (small angular stone)	HIGH

APPENDIX 2

Groundwater Vulnerability

Introduction

The term 'vulnerability' is used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (DELG *et al.,* 1999). The vulnerability of groundwater depends on:

- the time of travel of infiltrating water (and contaminants)
- the relative quantity of contaminants that can reach the groundwater
- the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- the type and permeability of the subsoils that overlie the groundwater
- the thickness of the unsaturated zone through which the contaminant moves
- the recharge type – whether point or diffuse.

In other words, vulnerability is based on evaluating the relevant hydrogeological characteristics of the protecting geological layers along the pathway, and the possibility of bypassing these layers. In summary, the entire land surface is divided into four vulnerability categories: **E**xtreme, **H**igh, **M**oderate and **L**ow, based on the geological and hydrogeological characteristics. Further details of the hydrogeological basis for vulnerability assessment can be found in 'Groundwater Protection Schemes' (DELG et al., 1999).

The Groundwater Vulnerability Map shows the vulnerability of the first groundwater encountered, in either sand/gravel or bedrock aquifers, by contaminants released at depths of 1-2 m below the ground surface. Where the water-table in bedrock aquifers is below the top of the bedrock, the target needing protection is the water-table. However, where the aquifer is fully saturated, the target is the top of the bedrock. The vulnerability map aims to be a guide to the likelihood of groundwater contamination, if a pollution event were to occur. It does not replace the need for site investigation. Note also that the characteristics of individual contaminants are not considered.

Except where point recharge occurs (*e.g.* at swallow holes), the groundwater vulnerability depends on the type, permeability and thickness of the subsoil.

The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown in Table 1.

Table 1 Vulnerability mapping guidelines (adapted from DELG et al, 1999)

Thickness of Overlying Subsoils	Hydrogeological Requirements for Vulnerability Categories				
	Diffuse Recharge			**Point Recharge**	**Unsaturated Zone**
	Subsoil permeability and type				
	High permeability (*sand/gravel*)	moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	*(swallow holes, losing streams)*	(*sand & gravel aquifers only*)
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

Notes: (i) N/A = not applicable.
(ii) Release point of contaminants is assumed to be 1–2 m below ground surface.
(iii) Permeability classifications relate to the engineering behaviour as described by BS5930.
(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability
(amended from Deakin and Daly (1999) and DELG/EPA/GSIa (1999))

Sources of Vulnerability Data

Specific vulnerability field mapping and assessment of previously collected data were carried out as part of this project. Fieldwork focused on assessing the permeability of the different subsoil deposit types (Figure 3), so that they could be subdivided into the three permeability categories. This involved:

- Describing selected exposures/sections according to the British Standard Institute *Code of Practice for Site Investigations* (BS 5930:1999).
- Collection of subsoil samples for laboratory particle size analyses
- Assessing the recharge characteristics of selected sites using natural and artificial drainage, vegetation and other recharge indicators.

The following additional sources of data were used to assess the vulnerability and produce the map:

- Subsoils Map (EPA/Teagasc Subsoil Map, 2006), which is the basis for the main permeability boundaries. ‘Clean’ sands and gravels are usually high permeability. Alluvium deposits are either moderate or low permeability.
- Depth to bedrock map, compiled by the mapping team for the current project in the Geological Survey of Ireland, using data compiled from GSI, consultant and county council reports, along with purpose-drilled auger holes
- Geological Survey of Ireland Bedrock Geology Map
- Geological Survey of Ireland well and karst database, which supplied information on well yields and depth to bedrock, as well as locations of point recharge.
- General Soils Map of Ireland (Gardiner and Radford, 1980). This gives additional, indirect information on subsoil permeability in the areas mapped by Teagasc as ‘till’.

Thickness of the Unsaturated Zone

The thickness of the unsaturated zone, or the depth of ground free of intermittent or permanent saturation, is only relevant in vulnerability mapping over unconfined sand and gravel aquifers. As described in Table 6.1, the critical unsaturated zone thickness is 3m; unconfined gravels with unsaturated zones thicker than 3m are classed as having a ‘high’ vulnerability, while those with unsaturated zones thinner than 3m are classed as having an ‘extreme’ vulnerability.

APPENDIX 3

Groundwater Recharge

Introduction

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using Hunter Williams et al (in press) (see also Guidance Document GW5 Groundwater Working Group 2005; Hunter Williams et al 2011).

Groundwater vulnerability category	**Hydrogeological setting**		**Recharge coefficient (RC)**		
			Min (%)	*Inner Range*	*Max (%)*
Extreme (X or E)	1.i	Areas where rock is at ground surface	30	80-90	100
	1.ii	Sand/gravel overlain by 'well drained' soil	50	80-90	100
	1.iii	Sand/gravel overlain by 'poorly drained' (gley) soil	15	35-50	70
	1.iv	Till overlain by 'well drained' soil	45	50-70	80
	1.v	Till overlain by 'poorly drained' (gley) soil	5	15-30	50
	1.vi	Sand/ gravel aquifer where the water table is ≤ 3 m below surface	50	80-90	100
	1.vii	Peat	1	15-30	50
High (H)	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	50	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by 'well drained' soil	50	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil	15	35-50	70
	2.iv	Sand/gravel aquifer, overlain by 'poorly drained' soil	15	35-50	70
	2.v	Moderate permeability subsoil overlain by 'well drained' soil	35	50-70	80
	2.vi	Moderate permeability subsoil overlain by 'poorly drained' (gley) soil	10	15-30	50
	2.vii	Low permeability subsoil	1	20-30	40
	2.viii	Peat	1	5-15	20
Moderate (M)	3.i	Moderate permeability subsoil and overlain by 'well drained' soil	35	50-70	80
	3.ii	Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil	10	15-30	50
	3.iii	Low permeability subsoil	1	10-20	30
	3.iv	Peat	1	3-5	10
Low (L)	4.i	Low permeability subsoil	1	5-10	20
	4.ii	Basin peat	1	3-5	10
High to Low (HL)	5.i	High predicted permeability subsoils (Sand/gravels)	30	80-90	100
	5.ii	Moderate permeability subsoil overlain by well drained soils	35	50-70	80
	5.iii	Moderate permeability subsoils overlain by poorly drained soils	10	15-30	50
	5.iv	Low permeability subsoil	1	5-10	20
	5.v	Peat	1	5	20

Note: Areas of 'made ground' are assigned a recharge coefficient of 20%. Before full national groundwater vulnerability coverage was achieved in 2012, in unmapped regions the Extreme and 'High to Low' vulnerability categories were used.

APPENDIX 4

Hydrochemistry and Water Quality

Raw Water Data, Ballyboy GWS, June 2016

Parameter	Ballyboy GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	<1	mg/l	
Turbidity	0.25	N.T.U.	No abnormal change
pH	7.0	pH units	6.5 – 9.5
Conductivity @ 20C	632	µS/cm	800 (TV)
Alkalinity	286.83	mg/l $CaCO_3$	
Sodium	9.83	mg/l	150 (TV)
Chloride	**45.50**	mg/l	24 (TV)
Ammonium NH_4	0.10	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	20.15	mg/l	37.5 (TV)
Nitrite as NO_2	0.20	mg/l	0.5 (TV)
Dissolved Oxygen (%)	7.10	%Sat	
Potassium, total	3.76	mg/l	
Total Hardness (Kone)	367.1	mg/l $CaCO_3$	
Magnesium, total	8.57	mg/l	50 (DWL)
Colour, apparent	19.1	mg/l Pt Co	No abnormal change
Silica as SiO_2	6.40	mg/l	
Sulphate	13.40	mg/l	187.5 (TV)
Orthophosphate as PO4-P	0.03	mg/l	
Calcium, total	132.9	mg/l	
Aluminium, dissolved	50	µg/l	150 (TV)
Iron	26	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
Copper, dissolved	<10	µg/l	1500 (TV)
Lead, dissolved	<1	µg/l	10 (DWL)
Chromium, dissolved	<5	µg/l	37.5 (TV)
Nickel, dissolved	4	µg/l	15 (TV)
Cadmium, dissolved	<0.5	µg/l	3.75 (TV)
Arsenic, dissolved	<10	µg/l	7.5 (TV)
Zinc, dissolved	34	µg/l	
Barium, dissolved	42	µg/l	
Total Organic Carbon	3.0	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	273	µg/l	
E Coli	**62.4**	cfu/100ml	0
Total Coliforms	**94.5**	cfu/100ml	0
Fluoride	0.00011	mg/l	0.8 (DWL)

Local Authority Compliance Monitoring Data – treated water – 2014 - 2015

Parameter	Units	Drinking Water Limit (DWL) or Threshold Value (TV)	28.04/14	12.05.14	06.10.14	02.02.15	11.05.15	07.09.15
1,1,1-Trichloroethane	µg/l						<0.04	
1,2-Dichloroethane	µg/l	2.25 (TV)		<0.07			<0.07	
2,3,6-TBA Trichlorobenzoic Acid	µg/l			<0.009			<0.009	
2,4-D Acid Herbicide	µg/l			<0.003			<0.003	
Aluminium, dissolved	µg/l	150 (TV)	6.1	<0.9	6.9	2.5	7.2	4.9
Ametryn	µg/l			<0.002			<0.002	
Ammonium	mg/l	65 – 175 (TV)	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Antimony	µg/l	5 (DWL)		<0.072			<0.071	
Arsenic, dissolved	µg/l	7.5 (TV)		0.33			0.37	
Atrazine	µg/l	0.075 (TV)		<0.002			<0.002	
Benzene	µg/l	0.75 (TV)		<0.02			<0.02	
Benzo(a)pyrene	µg/l	7.5 (TV)		0			<0.00032	
Boron	mg/l	0.75		0.018			0.018	
Bromate	µg/l			<0.4			0.8	
Bromoxynil	µg/l			<0.003			<0.003	
Cadmium, dissolved	µg/l	3.75 (TV)		0.084			0.08	
Chloride	mg/l	24		**22.2**			**23.6**	
Chromium, dissolved	µg/l	37.5 (TV)		1.96			2.69	
Clopyralid	µg/l			<0.011			<0.011	
Clostridium Perfringens	cfu/100ml	0	0	0	0	0	0	0
Coliform Bacteria	MPN/100ml	0	0	0	0	0	0	0
Colony Count @ 22degC	no./ml	No abnormal change		0			0	
Colour, apparent	mg/l Pt Co	No abnormal change				<0.7	0.7	<0.7

Parameter	Units	Drinking Water Limit (DWL) or Threshold Value (TV)	28.04.14	12.05.14	06.10.14	02.02.15	11.05.15	07.09.15
Conductivity @ 20C	µS/cm	800 (TV)	653	645	682	629	645	672
Copper, dissolved	µg/l	1500 (TV)		0.01			0.009	
Cyanide	µg/l	37.5 (TV)		<0.5			<0.5	
Dicamba	µg/l			<0.008			<0.008	
Dichlobenil	µg/l			<0.001			<0.001	
Diuron	µg/l	0.075 (TV)		<0.003			<0.003	
E Coli	cfu/100ml	0	0	0	0	0	0	0
Enterococci	cfu/100ml	0		0			0	
Fluoride	mg/l	0.8 (DWL)		0.09			0.1	
Iron	µg/l	200 (DWL)	<3.6	<3.6	<3.6	<3.6	<3.6	<3.6
Lead, dissolved	µg/l	18.75 (TV)		0.53			0.34	
Malathion	µg/l			<0.002			<0.002	
Manganese, dissolved	µg/l	<50 (DWL)		<2.6			<2.6	
MCPA	µg/l	0.075 (TV)		<0.002			<0.002	
Mecoprop Total	µg/l	0.075 (TV)		<0.002			<0.002	
Mercury	µg/l	0.75 (TV)		<0.02			<0.02	
Metazachlor	µg/l			<0.002			<0.002	
Nickel, dissolved	µg/l	15 (TV)		3.83			2.15	
Nitrate as NO_3	mg/l	37.5 (TV)		18			18.7	
Nitrite as NO_2	mg/l	0.5	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Odour	Odour units		0	0	0	0	0	0
PAHs	µg/l	0.075 (TV)		0			<0.00201	
Permethrin cis	µg/l			<0.002			<0.002	
Permethrin trans	µg/l			<0.001			<0.001	
Pesticides total	µg/l	0.375 (TV)		<0.5			<0.5	
pH	pH units	6.5 – 9.5	7.25	7.21	7.2	7.5	7.14	7.21
Propazine	µg/l			<0.002			<0.002	
Selenium	µg/l	10 (DWL)		0.94			1.29	
Simazine	µg/l	0.075 (TV)		<0.003			<0.003	

Parameter	**Units**	**Drinking Water Limit (DWL) or Threshold Value (TV)**	**28.04.14**	**12.05.14**	**06.10.14**	**02.02.15**	**11.05.15**	**07.09.15**
Sodium	mg/l	150 (TV)		11.2			11.5	
Sulphate	mg/l	187.5 (TV)		13.1			13.5	
Taste	Taste units	No abnormal change	0	0	0	0	0	0
Tecnazene	µg/l			<0.001			<0.001	
Tetrachloroethane & Trichloroethane	µg/l	7.5 (TV)		<0.1			<0.1	
Total indicative dose	mSv/year	0.10 (DWL)		<0.1				
Total Organic Carbon	mg/l	No abnormal change		1.04			1.2	
Triclopyr	µg/l			<0.007			<0.007	
Trihalomethanes (total)	µg/l	0.075 (TV)		20.7			21.78	
Tritium	Bq/L	100 (DWL)		<5				
Turbidity	N.T.U.	No abnormal change	0.19	0.11	<0.04	0.11	0.08	0.06.

Ballyboy Group Water Scheme

Groundwater Source Protection Zones

(April 2001)

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Offaly County Council

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1 Introduction

The Ballyboy source is the only supply for the Ballyboy Group Water Scheme. It supplies water to 61 houses, 17 farms and 1 pub (as of 09/05/2000).

The objectives of the report are as follows:

- To delineate source protection zones for the Ballyboy source (DELG/EPA/GSI, 1999).
- To outline the principle hydrogeological characteristics of the Ballyboy area.
- To assist Offaly County Council in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

Ballyboy well is located within a small pumphouse alongside a track 500 m north of the main Kilcormac-Tullamore road in the townland of Ballywilliam about 2 km east of Kilcormac village. The well occurs on the outside of a sharp kink in a small perennial stream.

A spring originally flowed into the river at the site, this was dug to almost 3 m and a cylindrical concrete sump was installed and is protected by a manhole. A small pumphouse was built around the sump. The pumphouse and well are located alongside a narrow dirt track. The sump now acts as a shallow large diameter pumping well.

The sump is protected by the pumphouse that is padlocked. The pumped water is chlorinated. A discharge meter is located about 15 m in the field behind the pumphouse.

3 Summary of Well / Spring Details

Grid ref. (1:25,000)	:	N 1980 1565
Townland	:	Ballywilliam
Well type	:	Large diameter dug well
Diameter	:	1 m
Depth	:	2.8 m
Owner	:	Ballyboy Group Water Scheme
Elevation (ground level)	:	65.03 m OD (213.34 ft OD)
Depth to rock	:	2.0 m
Static water level	:	1.5-2.0 m below ground
Present Abstraction	:	176 $m^3 d^{-1}$ (30,800 gallons per day)

4 Methodology

4.1 Desk Study

Details about the borehole such as elevation, and abstraction figures were obtained from GSI records and County Council personnel

4.2 Site visits and fieldwork

This included carrying out depth to rock drilling and subsoil sampling. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

4.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source. Due to the proximity of the source for the Kilcormac Water Supply Scheme much of the work for the two sources was done in parallel, in particular the numerical modelling exercise as discussed in Section 8.2. Details of the Kilcormac Water Supply Scheme may be referred to in Kelly 2000.

5 Topography, Surface Hydrology and Land Use

The source is located next to a small stream next to the edge of an esker ridge that runs east-west and southwest-northeast, roughly parallel to the main Kilcormac-Tullamore road. The topography is gently undulating rising at a low gradient to the east. A large bog occurs 0.5 km to the north of the source.

The surface hydrology changes on either side of the main Kilcormac-Tullamore road. Bogs and streams are frequent to the north of the source – the area to the west of the main road. To the east of the main road and the source there are very few surface streams and the land is free draining.

Small streams run off the bog flowing southwest, one of which passes by the source, where they drain to the Silver River. The Silver River is the largest stream in the area draining to the north toward the River Shannon. In general there are few surface stream to the east and south of the source.

Turf cutting is carried out in the bog to the north of the source. An area of forestry (1 km^2)occurs just to the north of the source. Kilcormac village lies about 2 km southwest of the source. Grassland farming dominates the area to the east and south of the source. The main Kilcormac-Tullamore road occurs 500 m away along which several houses are located. There are a few gravel pits in the esker ridge.

6 Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

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

- County Offaly Groundwater Protection Scheme (Daly *et al*, 1998)
- Information from geological mapping in the nineteenth century (on record at the GSI).

Subsoils information was taken from the Offaly Groundwater Protection Scheme (Daly *et al*, 1998) and gathered from a drilling programme that was undertaken by GSI personnel to investigate the subsoils of the area.

6.2 Bedrock Geology

Limestones occupy the whole area and a brief description of the individual rock units in the vicinity of the source is given in Table 1.

Table 1 The Bedrock Geology of the area surrounding the Ballyboy source.

Name of Rock Unit	*Rock Material*	*Occurrence*
Borrisokane	Thick-bedded, coarse grained, pale LIMESTONE with some darker fine grained beds and with occasional thin clayey bands	Underlies the source.
Allenwood	Pale-grey, poorly bedded, medium to coarse grained LIMESTONE	Occurs as a narrow band 500 m north of the source.
Waulsortion	Fossiliferous, pale-grey, poorly bedded fine-grained LIMESTONE	Occurs 1 km east of the source.

Movements in the earth's crust have caused the rocks to be folded, faulted and jointed. The different rock units have a NE-SW trend or strike and they generally dip south-eastwards at a low angle. Two major fault sets are present — NE-SW and SE-NW. The joint pattern is likely to have similar orientations. The contact between Borrisokane Limestone and the Waulsortion limestone is a low-angled NE-SW trending thrust fault (Daly *et al*, 1998).

6.3 Subsoil (Quaternary) Geology

The subsoils comprise a mixture of coarse and fine grained materials, namely; alluvium, tills, sand & gravels and are directly influenced by the underlying bedrock, which is made up of the Borrisokane and Waulsortion limestones. The geological logs of the auger holes drilled are given in Appendix 1.

The characteristics of each category are described briefly below:

6.3.1 Peat & Bog

The peat is very thin and is located on the flat ground between the spring and the forestry. Thick blanket bog occurs further to the north.

6.3.2 Tills

'Till' is an unsorted mixture of coarse and fine materials laid down by ice. Angular to subrounded sandstone and limestone fragments are abundant in the tills. The tills are the dominant subsoil type to the south of the Silver River. The matrix of the tills are clayey SAND with silt; SILT, sandy CLAY all with occasional or frequent gravel size fragments.

6.3.3 Sand & Gravels

Extensive fluvioglacial sand and gravels are present in County Offaly and occur in the Kilcormac area in the form of eskers. The sands and gravels making up the eskers are (BS5930: sandy GRAVELS and GRAVELS). The boulders and cobbles are limestone in composition.

6.3.4 Depth to Bedrock

The depth to rock is known in certain localities from a drilling programme carried out by the GSI to ascertain the thickness and permeability of the subsoils. The locations of the auger holes are given in Figure 1 and the logs are given in Appendix 1. The depth to bedrock varies between 2 and 8 m.

7 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the Ballyboy source. The interpretations and conceptualisations of flow are used to delineate source protection zones around the source.

Hydrogeological and hydrochemical information for the study was obtained from the following sources:

- Offaly Groundwater Protection Scheme (Daly *et al* 1998).
- An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly, (Cronin *et al*, 1999).
- GSI files. Archival Offaly County Council data for the years 1977, 1989, 1991. C1–C2 type parameters.
- Offaly County Council annual drinking water returns 1992–1999 inclusive (C1, C2, C3 and C4 type parameters). Some raw water analyses were also carried out.
- Limited additional fieldwork.

7.2 Meteorology and 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 generally assumed to consist of input (i.e. annual rainfall) less water losses 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 in combination with abstraction rates it will dictate the size of the zone of contribution.

In areas where point recharge from sinking streams, etc., is discounted, the main parameters involved in recharge rate estimation are annual rainfall, and annual evapotranspiration, and are listed as follows:

- Annual rainfall: 850 mm. Rainfall data for the area are taken from Kilcormac and Mountbolus weather stations.
- Annual evapotranspiration losses: 432 mm. Potential evaporation (P.E.) is estimated to be 455 mm, from the average annual value at Birr Weather Station. Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.
- Potential recharge: 418 mm $yr.^{-1}$. This figure is a calculation based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater, or lateral soil quickflow and overland flow direct to surface water.
- Annual runoff losses: 42 mm. This estimation is based on the assumption that 10% of the potential recharge will be lost to overland flow and shallow soil quickflow prior to reaching the main groundwater system particularly during periods of heavy rainfall.

These calculations are summarised below:

Average annual rainfall (R)	850 mm
Estimated A.E.	432 mm
Potential Recharge (R – A.E.)	418 mm
Runoff losses	42 mm
Estimated Actual Recharge	376 mm

7.3 Groundwater Levels, Flow Directions and Gradients

At the source the water level is 2.4 m below ground level. The water level in the well is approximately the same level as the stream that flows past the well. The area around the wells is quite flat and low lying. The water table in the area is generally assumed to be a subdued reflection of topography; as the topography slopes westwards, the water table slopes westwards toward the well. The flow directions will be perpendicular to the contour lines. In simple terms, rainfall reaching the water table anywhere in the catchment of the well will flow in a westerly direction. The groundwater gradient is assumed to somewhat less than the topographic gradient, i.e. is estimated to be 0.01.

7.4 Hydrochemistry and Water Quality

The hydrochemical analyses (12 samples) show that the water is a hard to a very hard water with total hardness values of 357-405 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 562-700 µS cm^{-1}, indicating that the groundwater has a hydrochemical signature of calcium bicarbonate type water. These values are typical of groundwater from limestone rocks.

Throughout the late 1980's and 90's nitrate concentrations range from 25-41 mg l^{-1} for 36 samples. The average concentration is 32.9 mg l^{-1}. This appears to somewhat higher than the general range of values in mid-County Offaly where there is grassland-dominated farming. Nitrate concentrations have never exceeded the EU Drinking Water Directive maximum admissible concentrations (MAC). Two trends appear in the current dataset; from 1989 to early 1997 there was a general increase in concentrations and since May 1997 there has been a decrease in concentrations.
Chloride concentrations range 24-30 mg l^{-1} with an average of 27 mg l^{-1} (12 samples; 1993-98). Chloride is a constituent of organic wastes and levels higher than 25 mg l^{-1} may indicate significant

contamination. Concentrations higher than the 30 mg l^{-1} usually indicates significant contamination. Out of the 12 samples all except 3 were above 25 mg l^{-1} and 2 samples recorded concentrations of 30 mg l^{-1}.

The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated along with other parameters and may indicate contamination if the ratio is > 0.4. Sodium levels range between 8-10.79 mg l^{-1}. Potassium levels range between 3.2-4.12 mg l^{-1}. The resulting ratios for 19 samples recorded between 1997 and 1999 have an average of 0.4 and are often above or at 0.4. The high ratios usually indicate contamination from farmyard wastes.

Bacteriological analyses (68 samples; 1993-99) record 21 occurrences of faecal coliforms (31%).

The water quality analyses show that the only parameter to have exceeded EU (MAC) is that of faecal coliforms. Other parameters (nitrates, chlorides, Na:K) including bacteria and coliforms indicate that there is significant (occasionally serious) contamination of the spring water, probably by farmyard wastes. All the drinking water returns analysed are for treated water.

7.5 Aquifer Characteristics

The Borrisokane Limestone is regarded as one of the best aquifers in Leinster, however, the data in County Offaly is limited in comparison to data for the Nore Basin area, thus may only indicate aquifer potential. Several large supplies draw water from this aquifer in County Offaly (Daly *et al*, 1998).

The data used in this section are based on test pumping undertaken by GSI at the Kilcormac source in May 2000 (Kelly, 2000). A constant discharge test was run at 545 m^3 d^{-1} for 10 hours, with a final drawdown of 11.19 m in the pumping well. This gives a specific capacity of about 40 m^3 d^{-1} m^{-1}. Comparable specific capacities are reported for boreholes at Tully and Hollimshill that are situated in the same aquifer (Cronin *et al*, 1998 and 1999). Analysis of the test pumping data from this specific 10 hour test gives transmissivity estimates of 20-40 m^2 d^{-1}. Estimates of the transmissivity for sources in the Borrisokane Formation at Tully and Hollimshill are 13 m^3 d^{-1} and 52-530 m^3 d^{-1} respectively (Cronin *et al;* 1998, 1999).

The porosity is taken to be approximately 2 %. The modelled permeability is derived to be about 1 m d^{-1}.

Vertical fissures and fractures are recorded in the borehole log for the new/upper borehole that indicate zones of higher permeability exist in the bedrock in the area. Occasional clay bands are located in the limestone. A small number of karst features are recorded in the Borrisokane Limestone but are infrequent, thus the degree of karstification would appear to be limited (Daly *et al*, 1998).

7.6 Conceptual Model

- The shallow large diameter well abstracts groundwater up to 176 m^3 d^{-1} and is located next to a sharp kink of a small perennial stream.

- The original spring appears to occurred in this location due a combination of bedrock close to the surface and very flat topography. Fractures in the rock probably allowed groundwater to come to the surface at this point.

- The Borrisokane aquifer (regionally important fissured aquifer) which underlies the source is assumed to feed groundwater to the well.

- There are few drains and surface streams apart from the stream flowing past the well, indicating the free draining nature of the subsoils and the relatively high permeabilities of the bedrock.

- Shallow groundwater with localised short flow paths (north west and west) probably contributes most of the wells water. Deeper groundwater is assumed to flow east to west on a regional scale, discharging mainly to the Silver River and also the stream flowing past the well.

- The water table is close to the surface in the vicinity of the well and is considered to have a relatively flat gradient.

- Groundwater flow is probably confined to fractures, fissures, joints, bedding planes and the uppermost part of the bedrock.

- Diffuse recharge occurs through the sands & gravels and the permeable tills up to 376 mm yr^{-1}.

- The eskers appear to sit above the water table thus acting as very free draining ridges of unsaturated subsoil that do not act as either surface or groundwater watersheds.

8 Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the areas around the spring that are believed to contribute groundwater to the well and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, as described in Section 7.6 and are presented in Figures 1 and 2.

Two source protection areas are delineated:

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

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), and is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by a) the total discharge, b) the groundwater flow direction and gradient, c) the rock permeability and d) the recharge in the area.

The ZOC for the Ballyboy source is delineated as follows:

1) An estimate of the area size is obtained by using the average recharge and the abstraction rate.
2) The shape of the area is then derived by both numerical modelling (using FLOWPATH) and hydrogeological mapping techniques.
3) To allow for errors in the estimation of groundwater flow direction and to allow for an increase in the ZOC in dry weather, a safety margin is incorporated by assuming a higher abstraction rate than the current rate.

The average abstraction is estimated to be 176 $m^3 d^{-1}$. For the purposes of modelling the source, the average yield is increased by 50% to 264 $m^3 d^{-1}$ for the following reasons:

- The higher yield allows for increased water demand (new houses are being added to the scheme each year).
- Numerical modelling assumes average conditions all year round, i.e., recharge is averaged out over winter and summer, therefore the model does not allow for an increase in the ZOC during dry weather. This is overcome by assuming a higher abstraction rate in the calculations.

Taking the recharge to be 376 mm, the area required to supply a pumping rate of 264 $m^3 d^{-1}$ is calculated to be 0.3 km^2. However, this area will increase in dry weather. A more accurate ZOC at

Ballyboy is derived from numerical modelling of the groundwater system together with hydrogeological mapping techniques.

The groundwater regime was modelled successfully for three scenarios; the non-pumping situation, a pumping situation using the current rate and a pumping situation using a rate at 50% greater than the current rate. The defining conditions for the numerical model are discharge, aquifer thickness, permeability and recharge. The source for Kilcormac Water Supply Scheme is within 2 km of the Ballyboy source, located within the same aquifer with similar hydrogeological conditions, thus it was appropriate to model the groundwater regime for both sources together.

The **southern, eastern and western boundaries** are groundwater divides that are derived from both the numerical modelling and the hydrogeological mapping.

The **northern boundary** is defined by the stream that passes the spring. It is assumed that the well does not pump any water from the other side of the river.

8.3 Inner Protection Area

According to the National Groundwater Protection Scheme (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100 day time of travel to the supply. Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling is also used and by using the aquifer parameters for permeability and hydraulic gradient 100 day ToT estimations are made. Using the parameters given in 7.5 groundwater would travel up to 120 m in 100 days. Thus the upgradient extent of the SI zone is 120 m.

9 Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 1. All of the land in the area is either highly or extremely vulnerable to contamination due to the general high permeability classification given to the subsoils and to the depth to bedrock generally being between 2 and 5 m. The area around the well has a depth to bedrock of less than 3 m and the subsoil type has a high permeability. This means that groundwater in this area is designated to be ‘extremely’ vulnerable to contamination. The rest of the area is designated to be ‘highly’ vulnerable as the depth to rock increases toward the main road to about 5 m. The eskers are considered to be ‘highly’ vulnerable as they are relatively thick (> 5 m) and the water table is assumed to lie below the base of the eskers.

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. In practice, the source protection zones are obtained by superimposing the vulnerability map 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. There are four groundwater protection zones present around the Ballyboy source as shown in Table 2. The final groundwater protection map is presented in Figure 2.

Table 2 Matrix of Source Protection Zones at Ballyboy

VULNERABILITY RATING	**SOURCE PROTECTION**	
	Inner	***Outer***
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)		
Low (L)		

11 Potential Pollution Sources

Land use in the area is described in Section 5. The land near the source is largely grassland-dominated and is primarily used for grazing. Agricultural activities, septic tanks and the main road are the principal hazards in the area. The main potential sources of pollution within the ZOC are farmyards, septic tank systems, runoff from the roads, leaky sewers and landspreading of organic fertilisers. The main potential pollutants are faecal bacteria, viruses, and cryptosporidium.

12 Conclusions and Recommendations

- The area around the supply is either extremely or highly vulnerable to contamination.

- Septic tanks, farmyards, landspreading and runoff from the roads pose a threat to the water quality in the well.

- It is recommended that:

1) a full raw water analysis should be carried out on a regular basis at the source.
2) particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well.
3) the potential hazards in the ZOC should be located and assessed.

- The protection zones delineated in the report is based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.

13 References

Cronin, C. and Daly, D., 1999. *An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly*. Geological Survey Report, 30 pp.

Daly, D., Cronin, C., Coxon, C. and Burns, S.J., 1998. *County Offaly Groundwater Protection Scheme*. Geological Survey Report for Offaly County Council, 60 pp.

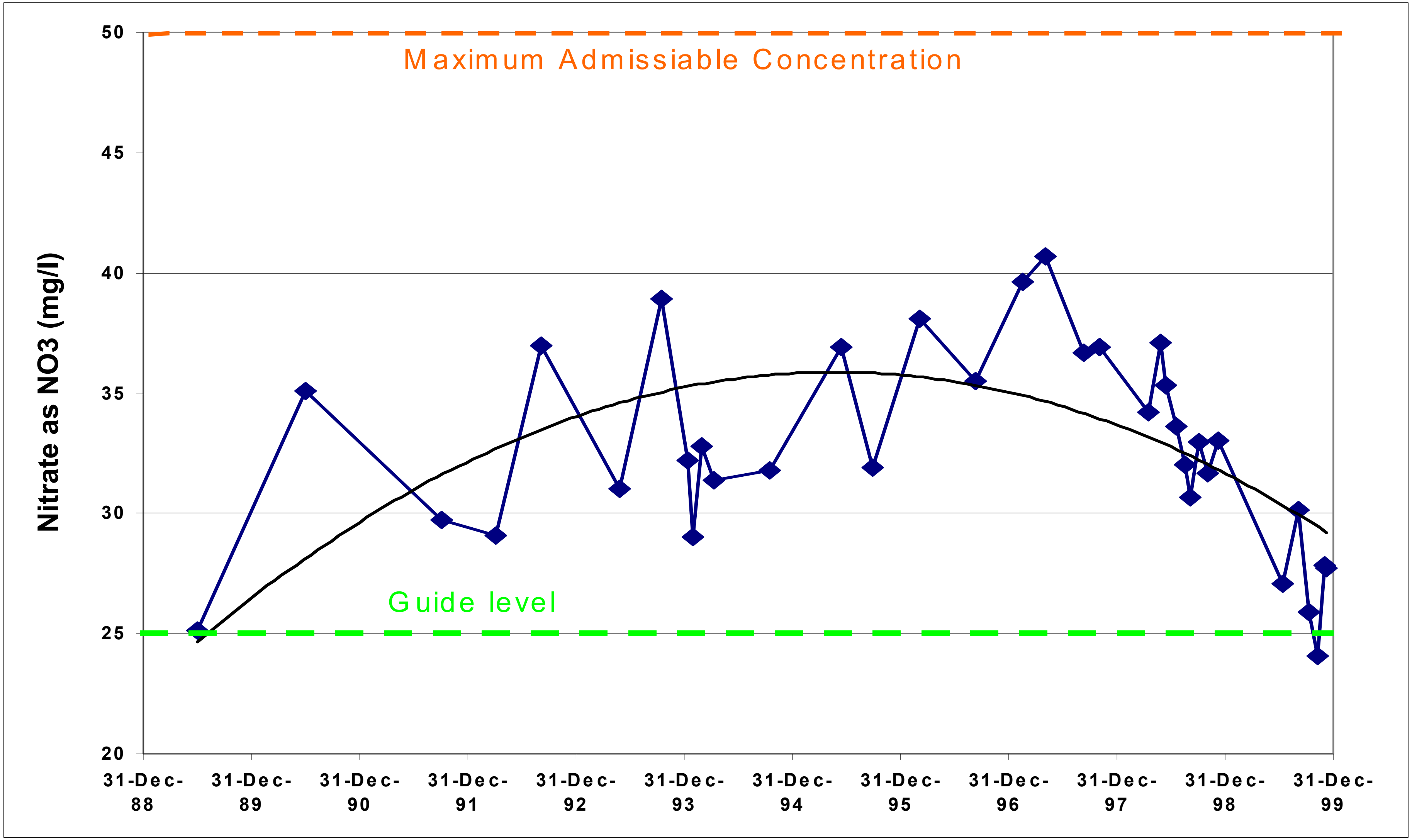
Kelly, C., 2000. *Kilcormac Water Supply Scheme. Groundwater Source Protection Zones*. Geological Survey Report for Offaly County Council, 15 pp.

Appendix 1 Geological Logs of the Auger Boreholes.

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It assumed that the auger has reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Borehole No.	GSI No.	Grid Ref.	Depth	BS5930	Permeability
Kilcormac 1	17	N1905 1500	0-6.0	Sandy SILT with clay	Moderate
Kilcormac 2	18	N1905 1450	0-2.0	Silty SAND	High
			2.0-7.30	GRAVEL with sand and silt	High
Kilcormac 3	19	N1950 1520	0-6.5	Sandy SILT with clay	Moderate
Kilcormac 4	20	N1980 1565	0-1.0	Sandy CLAY with silt	Low
			1.0-2.0	Silty SAND with Gravel	High
Kilcormac 5	21	N2010 1520	0-4.0	Silty SAND with Gravel	High
			4.0-5.0	Sandy SILT with clay	Moderate
Kilcormac 6	22	N2040 1480	0-1.5	SILT with clay	Moderate
			1.5-2.60	Clayey SAND with gravel	High
Kilcormac 7	23	N1920 1370	0-4.0	Clayey SAND with frequent small stones	High
			4.0-6.0	SILT with gravel (small angular stone)	High

Appendix 2 Graph of Nitrate concentrations at Ballyboy



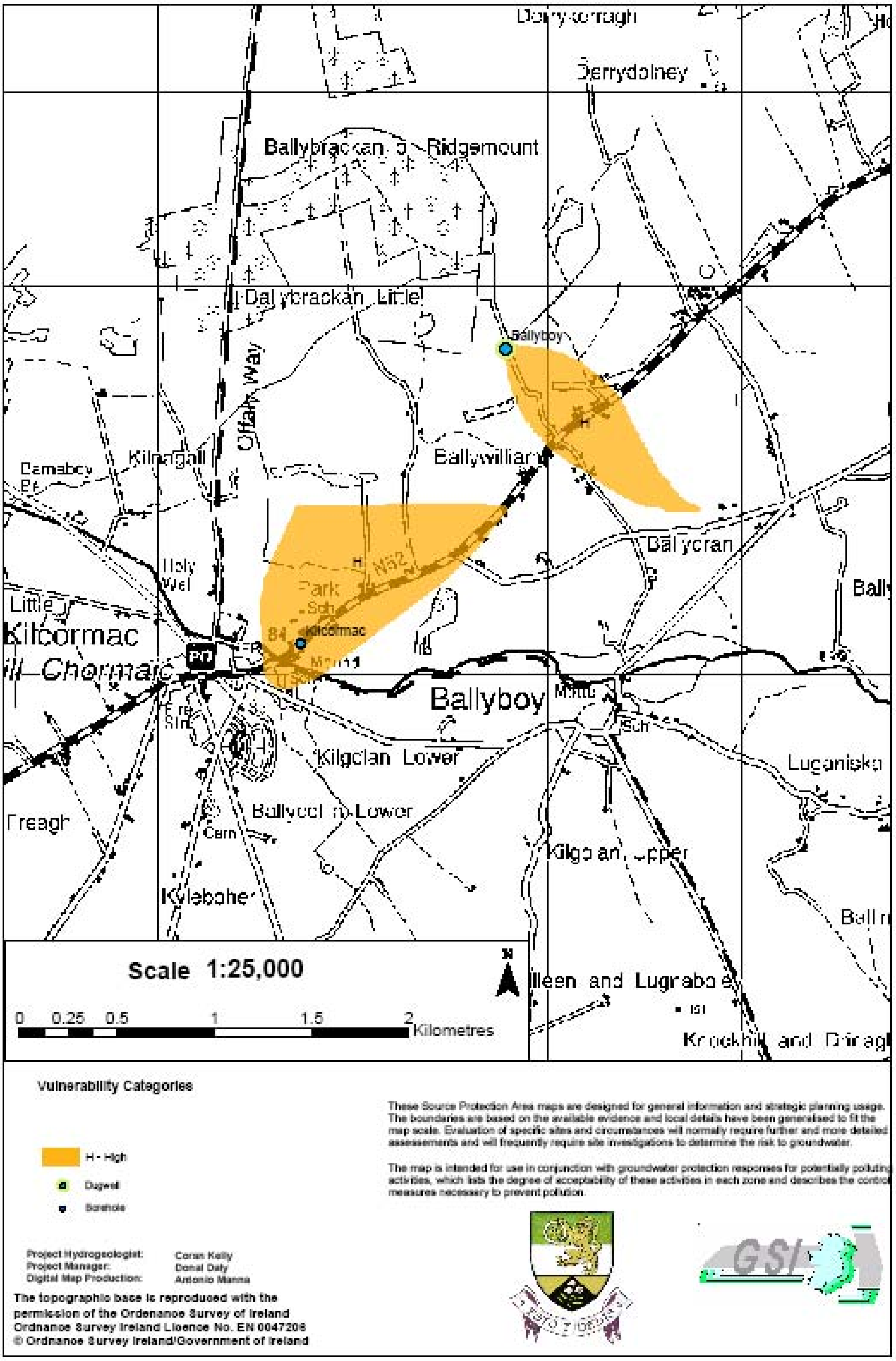


Figure 1 **Groundwater Vulnerability around Ballyboy**

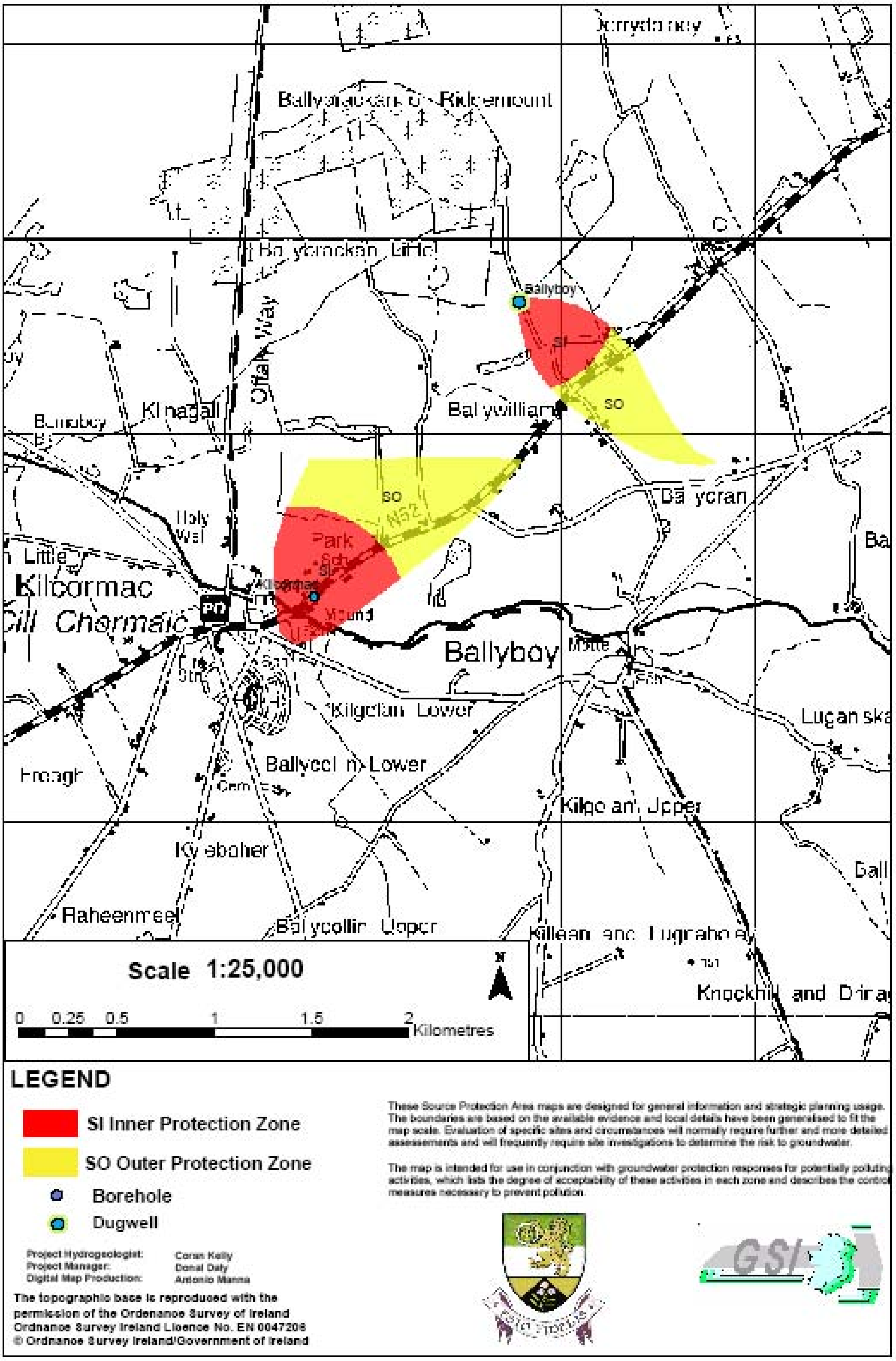


Figure 2 **Groundwater Source Protection Areas for Ballyboy**

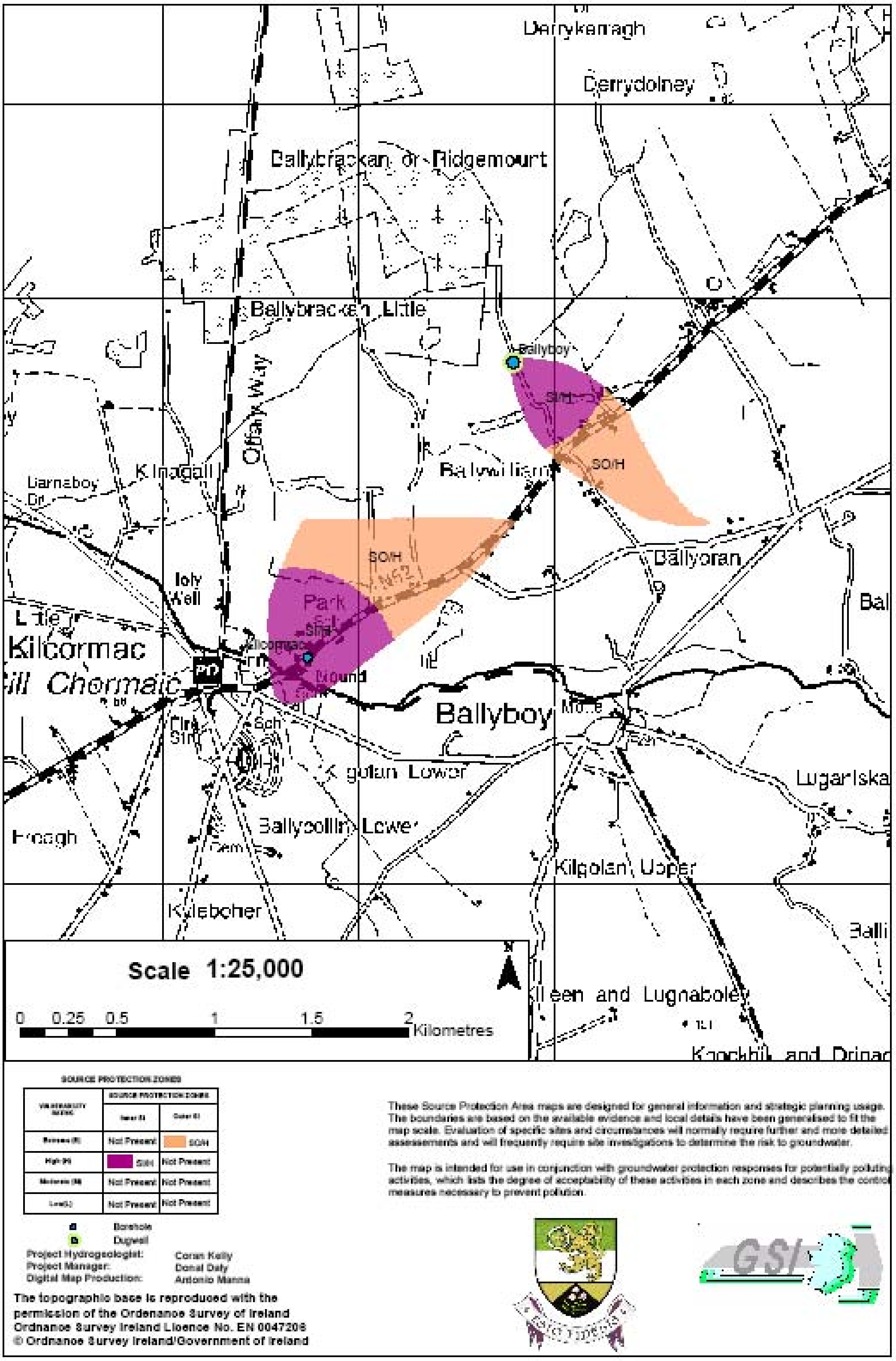


Figure 3 **Groundwater Source Protection Zones for Ballyboy**