

Establishment of Groundwater Zones of Contribution

Ballindoolin Group Water Scheme, Co. Kildare

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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 Ballindoolin 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 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 underground¹. 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.

Ballindoolin GWS is supplied by a well abstracting groundwater from limestone bedrock that is categorised as a Locally Important Aquifer that is moderately productive (Lm).

¹ Geological Survey of Ireland, 2000.

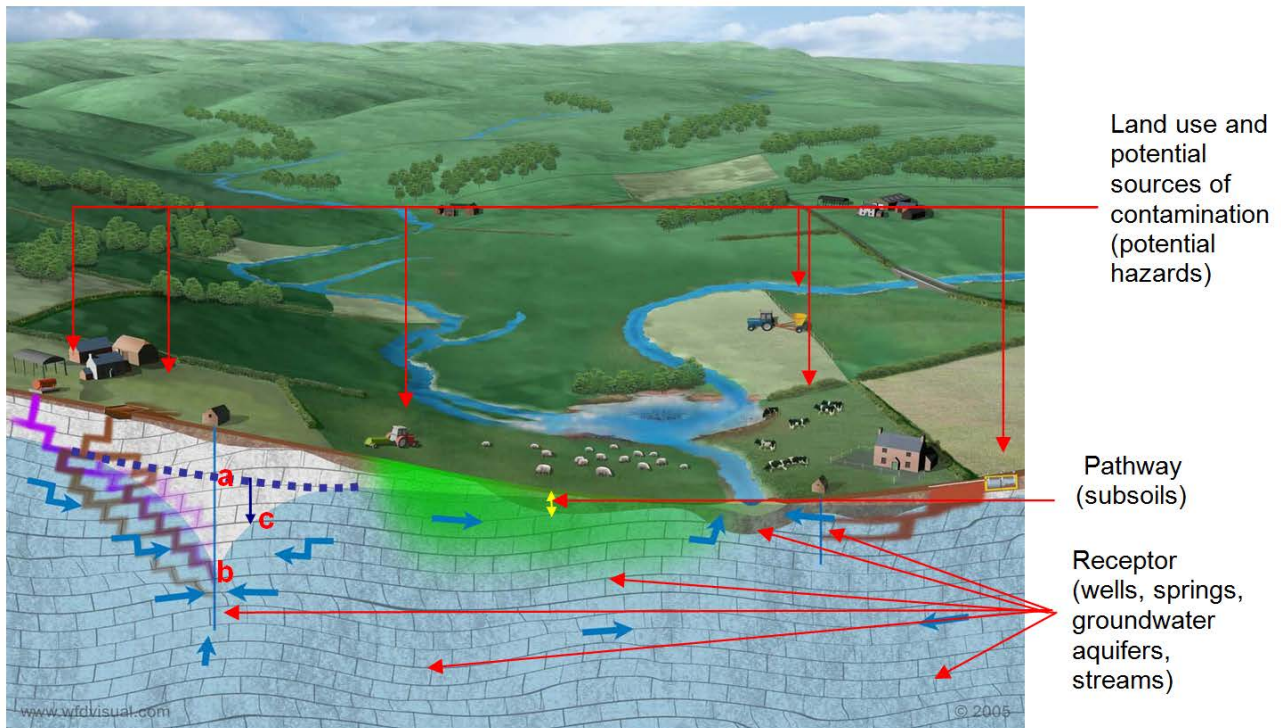


Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Ballindoolin Group Water Scheme (GWS) is currently supplied by one well in the townland of Ballindoolin, Co. Kildare. The site is located close to the border with Co. Offaly at Edenderry. The GWS was founded in 1976 and at that time was supplied by a shallow local authority well at the site. This shallow well had an unreliable supply and often ran dry in periods of dry weather and so a new well was commissioned in 2001.

The GWS is located on the western side of the R401 regional route that runs from Kinnegad in the north to Edenderry in the south (Figure 1). The pump house (Photo 1) is immediately adjacent to the road. The surrounding landscape is generally flat with large open fields used for grazing.



Photo 1 – Pump House at Ballindoolin GWS (note: drain cover in foreground represents position of old, shallow, local authority well)

The pump house contains the water treatment unit, which consists of chlorination (Photo 2) and filtration to remove iron and manganese (Photo 3). This filtration unit was replaced during late 2013 – early 2014. Information provided by the HSE² indicates that the chlorination unit may not be operating correctly as very low levels of free chlorine have been measured around the system.



Photo 2 – Chlorination unit



Photo 3 – Iron and manganese filtration unit

The scheme currently has 28 domestic connections which includes 7 non-domestic connections. At the time of writing this report a new house is currently being built which will increase the domestic connections to 29. Bulk meter readings recorded a total usage of 590 m³/d for the 21-day period from 01/07/2015 to 21/07/2015, indicating an average daily usage of 28 m³/d. The scheme does not have a storage reservoir.

The Ballindoolin GWS well is located in the front garden of a house belonging to a member of the scheme. A well drilling invoice from the drilling company, Dempseys Well Drilling Ltd., indicates that the well was finished at a 200 mm (8") diameter and is 45 m deep (Appendix 1). It states that 27.5 m of rock was encountered and that the well is lined with PVC. There are no details given on the depth of steel casing. The well head is housed with a plastic manhole lid that is flush with ground level (Photo 4). The space below the manhole lid and the top of the steel casing is filled in with broken polystyrene pieces and covered with plastic sheeting (Photo 5). Surplus electrical cable from the pump is rolled up inside the well head. It is understood that there are two septic tanks within 60 m of the well, servicing the two closest houses to the well.



Photo 4 – Well Head

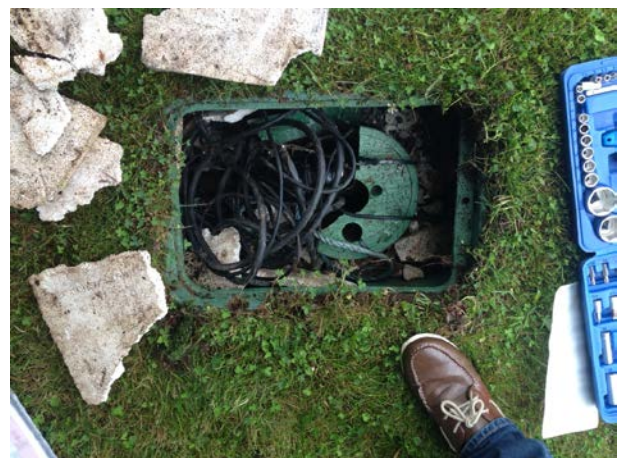


Photo 5 – Open Well Head

² Pers. Comm Ms. Eileen Loughmann, Principal Environmental Health Officer, HSE.

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

Table 1. Supply Details

	Well No. 1
Grid reference	264076 237904
Townland	Ballindoolin
Source type	Borehole
Constructed	2001
Constructed By	Dempsey Well Drilling Ltd., Clonbullogue, Co. Offaly
Owner	Ballindoolin GWS
Elevation (m aOD)	83
Total depth (m)	45 m
Construction details	200 mm diameter steel casing, depth of casing unknown
Depth to rock (metres below ground level, m bgl)	27.5 m
Pumped water level (m bgl)	21/07/2015 – 7.56 m bgl (Static water level unknown)
Pump intake depth	Unknown
Current abstraction rate (GWS)	28 m ³ /d
Reported yield (m ³ /d)	Unknown
Number of connections	29 domestic and 7 non-domestic
Estimated specific capacity (m ³ /d/m)	Unknown
Estimated transmissivity (m ² /d)	Unknown

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)	870	Met Eireann average annual rainfall data 2012 - 2015
Annual Evapotranspiration Losses (mm)	385	Met Eireann (www.met.ie)
Annual Effective Rainfall (mm)	485	National Groundwater Recharge Data (www.gsi.ie)
Topography	The Ballindoolin GWS well is at an elevation of 83 m above Ordnance Datum (m AOD). The surrounding area is largely flat with a gentle slope towards the Garr River in the north.	
Land use	Agricultural land surrounds the site with low intensity grazing and grassland the predominant activities. Landspeading in the general surrounding area takes place generally twice a year. All houses in the area have private septic tanks. There are two known septic tanks within 60 m of the well. A small quarry is marked on the 18 th Century 1:10,560 maps of the area, c.800 m to the southwest of the well.	
Surface Hydrology	The land appears to be reasonably well drained. The Garr River, a tributary of the River Boyne, drains the area and flows c.400 m to the north of the GWS site.	
Topsoil	Shallow well drained mineral soil.	
Subsoil (Figure 2)	Till derived from limestones (Teagasc 2006). Small area of bedrock outcrop or subcrop located approximately 1 km to the southwest.	
Groundwater Vulnerability (Figure 3)	High at the site of the Ballindoolin GWS (See Appendix 2). Small area of Extreme vulnerability approximately 1 km southwest (See Appendix 2).	
Geology (Figure 4)	The general bedrock type in this area is classified as Dinantian limestones of varying degrees of 'pureness' and bedding structure. The GWS at Ballindoolin is underlain by the Allenwood Formation Edenderry Oolite Member, limestone which is pure and bedded. A short distance to the south of the well, c.100 m, a body of Waulsortian Limestone is mapped, this limestone is less well bedded than the Edenderry Oolite. There are a number of small intrusions of volcanic rocks in the Lucan Formation limestones to the east. Karst features are known to occur within the rock unit underlying the GWS, such as springs at Toberhale near Edenderry, although none are mapped in the vicinity of the GWS. However a number of wells marked on the 18 th century 1:10,560 map of the area may in fact be springs; Scullys Well and Spout Well to the southwest and Beoghan's Well a short distance to the north.	
Aquifer (Figure 5)	Locally Important (Lm) – Bedrock which is moderately productive. The GWB description: the extremely heterogeneous nature of this aquifer makes it difficult to define general characteristics. The permeability of the bedrock will vary according to the degree of weathering, karstification and structural deformation.	
Groundwater Body	Trim GWB. Categorised as having a 'good' status. (www.epa.ie)	
Recharge Coefficient (Appendix 3)	60 %	Moderate permeability subsoil overlain by well drained soil, affording some protection to a Locally Important Aquifer (Lm) classified with High (H) vulnerability.
Average Recharge (mm/yr)	291	

3.2 Hydrochemistry and water quality

Three sources of water quality data was available for the Ballindoolin GWS:

- Historical raw water data from November 2000 to February 2001
- HSE compliance monitoring data from 2015
- HSE operational monitoring results 2015
- Raw water sample dating from July 2015 collected by the National Federation of group Water schemes as part of this project.

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. 278 of 2007), whichever is the lower.

The historical analytical data from untreated/raw water samples from Ballindoolin GWS are included in **Appendix 4** of this report, with summary data presented in **Table No. 3**. The data is from the period November 2000 to February 2001 and from May 2001 to November 2001.

Table 3. Summary Data of historical raw water quality analysis

Parameters	Units	Nov 2000	Aug 2001	Sept 2001	Oct 2001	Nov 2001	Drinking Water Limit (DWL) or Threshold
Colour	Hazens	10	<10	45	10	<10	No abnormal change
Turbidity	NTU	0	108.5	10.4	0.7	2.1	No abnormal change
Conductivity	µScm	827	678	695	802	683	800 (TV)
Aluminium	µg/l	23	377	72	<0.7	<20	150 (TV)
Manganese	µg/l	18	56	29	<0.03	10	<50 (DWL)
Total Coliforms	No./100ml	8	9	1	N.D	N.D	0
Faecal Coliforms	No./100ml	6	N.D	N.D	16	N.D	0

The historical raw water analysis shows that the water quality at that time was largely in compliance with the relevant standards, with a few notable exceptions. Colour, turbidity and conductivity were elevated on a number of occasions. Aluminum and manganese were both high in August 2001. There was evidence of bacteriological contamination in the raw water on a number of occasions with positive counts of both total and faecal coliforms recorded. The turbidity and bacteriological contamination are suggestive of the ingress of contaminated surface water through the well head and into the well itself.

The HSE compliance monitoring data consists of four monitoring rounds, in May, July, September and November 2015. The data is reproduced in **Appendix 4**, with a summary in **Table No. 4** below. The compliance monitoring reported an elevated count of total coliforms on one occasion in July 2015, with a positive count of 3 recorded.

Table 4. Summary Data of HSE compliance monitoring from 2015

Parameters	Units	May 2015	July 2015	Sept 2015	Nov 2015	Drinking Water Limit (DWL) or Threshold
Ammonium	mg/l NH ₄	<0.07	<0.07	<0.07	<0.07	0.3 (DWL)
Free chlorine	mg/l	0.68	0.03	0.87	0.87	
Hardness	mg/l Ca	398.8	423	359.8	386.5	
Odour	descriptive	Slightly chlorinous	None	Slightly chlorinous	Slightly chlorinous	No abnormal change
Conductivity	µS/cm	640	640	651	668	800 (TV)
Manganese	µg/l	<20	<20	<20	-	<50 (DWL)
Iron	µg/l	<100	<100	<100	<50	200 (DWL)
Nitrate	mg/l NO ₃	17.03	15.61	13.99	17.95	37.5 (TV)
Nitrite	mg/l NO ₂	<0.164	<0.164	<0.164	<0.164	0.5 (TV)
Total Coliforms	No./100 ml	-	3	0	-	0
Faecal Coliforms	No./100 ml	0	0	0	0	0

The HSE operational monitoring data from 2015 is presented below, in full, in **Table No. 5**.

Table 5. HSE Operational Monitoring Data, 2015

Parameter	Units	23 rd March 2015	30 th March 2015	Drinking Water Limit (DWL) or Threshold Value (TV)
Coliform bacteria	No./100ml	45	25	0
E. Coli	No./100ml	0	0	0
Free Chlorine	mg/l	0	0	

A raw water sample was collected by the National Federation of Group Water Schemes (NFGWS) on 22/07/2015. This sample represents the most up-to-date raw water analysis for the GWS. **Table No. 6** presents a summary of this raw water analysis with the full analytical report in **Appendix 4**. The recent raw water sample indicates that the chemical parameters were within the acceptable limits at the time of sampling, August 2015. The bacteriological analysis indicates a positive count for total coliforms, 7.5 cfu/100ml. This may be due to the ingress of contaminated surface water through the well head and into the well itself.

Table 6. Summary Raw Water Quality Data

Parameter	Ballindoolin GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
Conductivity @ 20C	675	µS/cm	800 (TV)
Sodium	6.39	mg/l	150 (TV)
Chloride	15.91	mg/l	24
Ammonia NH ₃	0.26	mg/l NH ₃	
Nitrate as NO ₃	14.74	mg/l	37.5 (TV)
Nitrite as NO ₂	0.36	mg/l	0.5 (TV)
Potassium, total	0.85	mg/l	
Total Hardness (Kone)	388.3	mg/l CaCO ₃	
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
E Coli	<1.0	cfu/100ml	0
Total Coliforms	7.5	cfu/100ml	0

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**).

The groundwater is replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. The subsoils are considered to have a moderate permeability thus allowing a good proportion of rainfall to percolate downwards. Once the downward percolating rainfall reaches the top of the bedrock, the majority of it will move along the top of the bedrock, which is likely to be more weathered and therefore have interconnected fractures and fissures (i.e. more flow paths), until it reaches a point of discharge such as a stream or spring.

The Ballindoolin GWS is currently supplied by one well that abstracts groundwater from the underlying rock unit which is classified as a Locally Important Aquifer (Lm), bedrock which is moderately productive.

Groundwater will flow in a northerly direction towards the Garr River. The groundwater that is not intercepted by the GWS well will continue downgradient and discharge into the river. The area supplying groundwater to the GWS well (the ZOC) will extend upgradient from the well in a southerly direction. The vulnerability of the aquifer (which describes the ease at which the aquifer may become contaminated) in the region of the well rated as High (H). It is also rated High (H) across the ZOC, with some areas of Extreme (E) on the higher ground to the south and southeast of the ZOC where bedrock is close to or at the surface.

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.

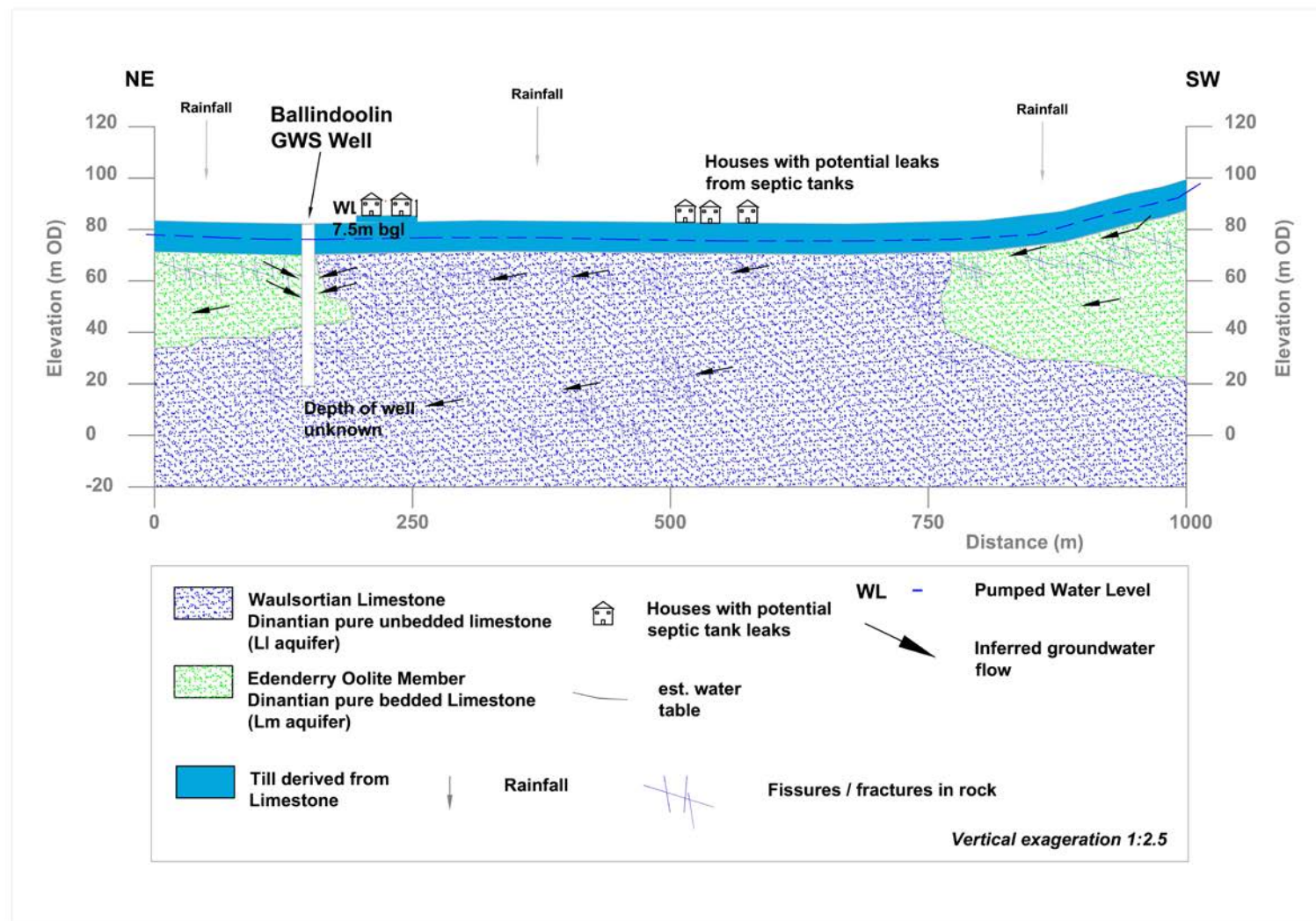


Diagram 2: Schematic Cross Section and Conceptual Model

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 (**Appendix 5**).

The **North-Eastern boundary**, is the 'downgradient' limit', beyond which groundwater will not be drawn back upgradient under the influence of the pump. It is estimated using the uniform-flow equation (Todd 1980) as 18 m. This figure is increased to c. 50 m in order to be conservative and allow for uncertainties in the estimates of transmissivity and gradient.

The **South-Western Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the water balance for the site and on the local topography. 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. This boundary extends to incorporate the houses along the roadway to the south-west of the well in order to be conservative.

The **North-Western and South-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 uniform flow equation (Todd 1980) was used to estimate the width of the ZOC at its downgradient extent as 56 m. It is assumed that this is an unrealistically small figure and so is expanded to take account of the topography and the recharge characteristics. The two boundaries meet on the downgradient side of the boreholes at the 'downgradient 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 abstraction rate from the Ballindoolin GWS well is 28 m³/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 42 m³/d i.e. 150% of the known current abstraction rate.

The available recharge is estimated at 291 mm/yr (see Table 2). The minimum geographical area required to sustain an abstraction of 42 m³/d (or 15,330 m³/yr) based on the available recharge of 291 mm/yr (or 0.29 m/yr) is 0.05 km² (52,680 m²). The delineated ZOC measures 365,693 m² (36.6 hectares).

5 Conclusions

The Ballindoolin GWS currently abstracts 28 m³/d from one well located in the front garden of one of its members. The well is abstracting groundwater from limestone bedrock that is classified as a Locally Important Aquifer that is moderately productive (Lm). The scheme currently has 7 non-domestic connections and 28 domestic connections. The domestic connections will soon rise to 29 as a new house is being built and will join the scheme.

The vulnerability of the groundwater supplying the well is considered High (H). There are small areas of Extreme (E) vulnerability to the site of the well and its ZOC where the land rises. The ZOC is occupied by agricultural land 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. There is grazing in the area and landspreading takes place within the area once or twice a year. The houses immediately adjacent to the well are understood to both have septic tanks which are estimated to be less than 60 m away from the well. The integrity of the well is unknown and therefore the well is considered at high risk of contamination from these nearby septic tanks. The well head protection is poor and requires improvement.

Recent raw water analysis demonstrated that chemical parameters were within acceptable limits. There was however evidence of bacteriological contamination in the well, which may be a reflection of the poor well head protection.

Any land use 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.
- The proximity of two septic tanks to the well is a cause of concern. It is recommended that the scheme engage someone to assess the age, integrity and efficiency of the septic tanks. The owners of the septic tanks are members of the scheme and therefore have a vested interest in protecting their groundwater quality. If agreeable, the owners could commit to a maintenance schedule for the septic tanks whereby the tanks would be emptied on an annual basis. It is recommended that the scheme with the support of the NFGWS provide all local homeowners with EPA literature on managing septic tanks.
- The chlorine dosing system appears to be in need of attention to optimise its performance. Consideration should be given to the installation of a contact tank to assist with chlorine dosing.
- The integrity of the well is unknown and information on the depth of casing in the well was not available. The drilling company should be contacted to obtain borehole logs (this was done as part of this report but data was not received at the time of report issue). If the borehole construction is inadequate, consideration should be given to replacing it with a modern borehole, drilled in accordance with the best available technical standards (IGI 2007, EPA 2014).
- The well head protection is considered inadequate and in need of attention. Ideally the well head should be finished above ground and housed within a raised concrete chamber that is watertight and vermin proof.
- 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.
- The old county council well at the site should be properly decommissioned as, in its current state, it may act as a pathway for contaminants to gain access to the aquifer.

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

Other:

- The following EPA guidelines may serve as future useful reference documents for the Ballindoolin GWS:
 - o 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 Mapping³.
 - o 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 ZOC⁴.
 - o EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

³http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno7.html#.UpNP_eJ9KEp

⁴<http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno8.html#.UpNQf-J9KEo>

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

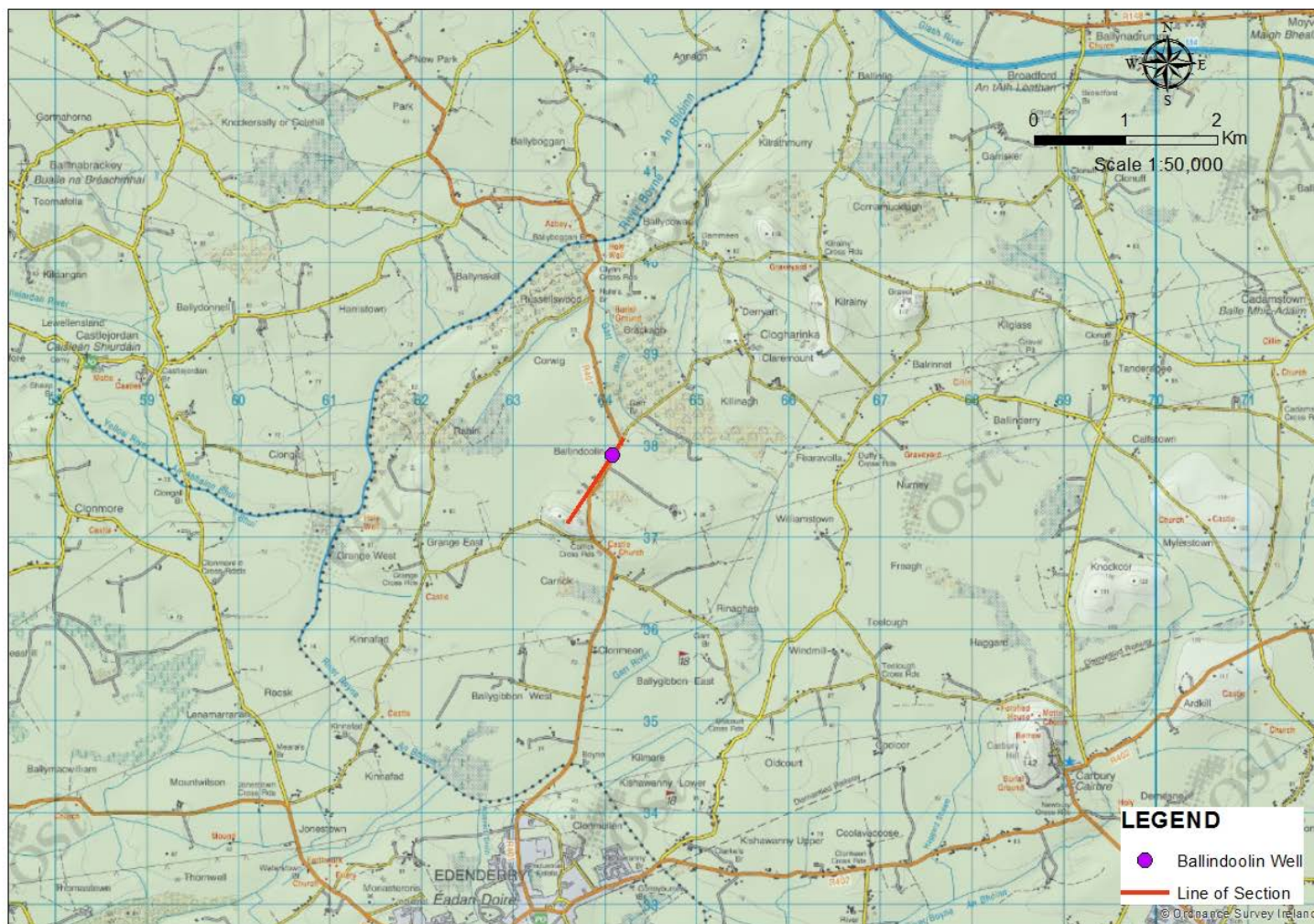


Figure 1. Location Map

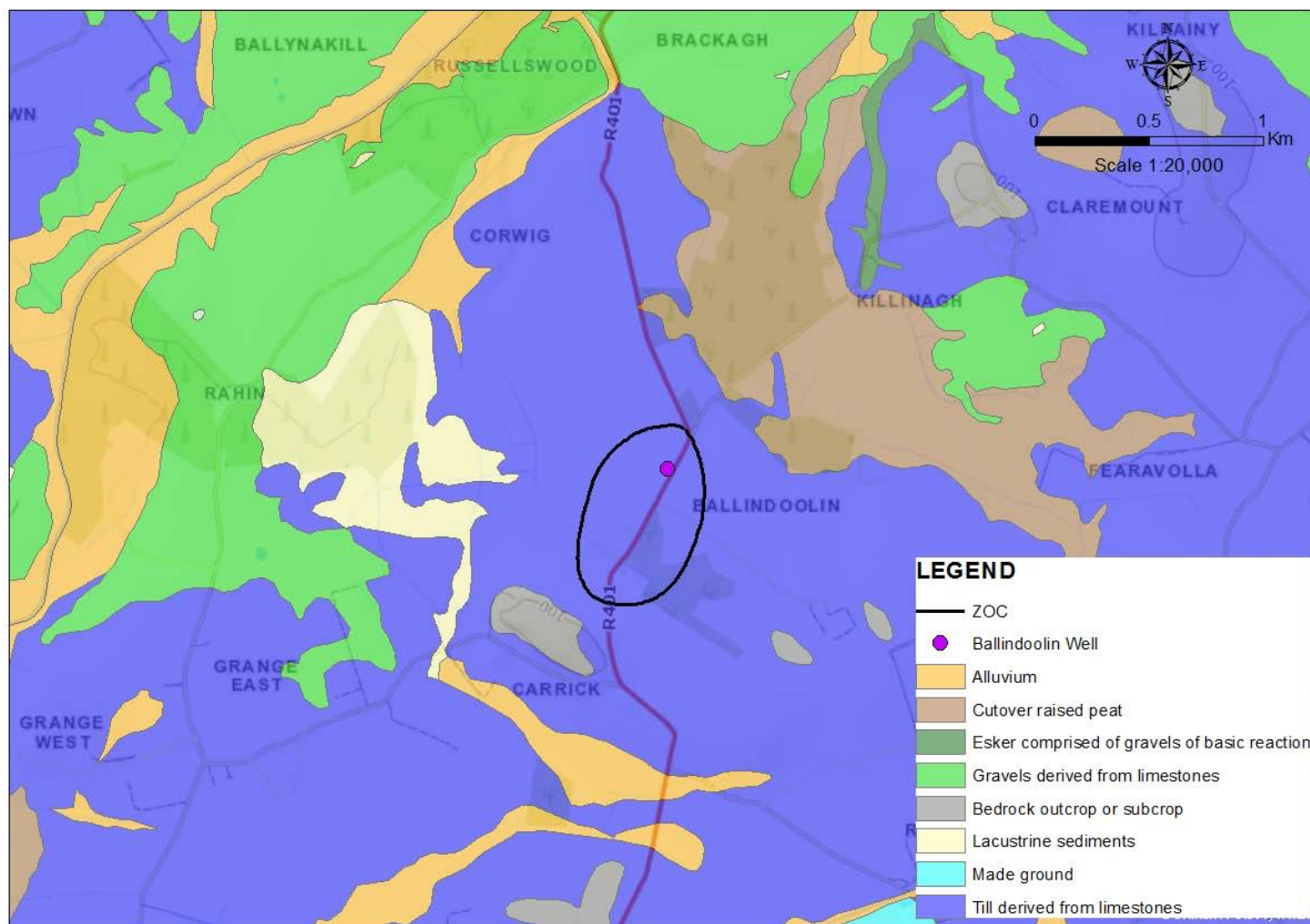


Figure 2. Subsoils Map

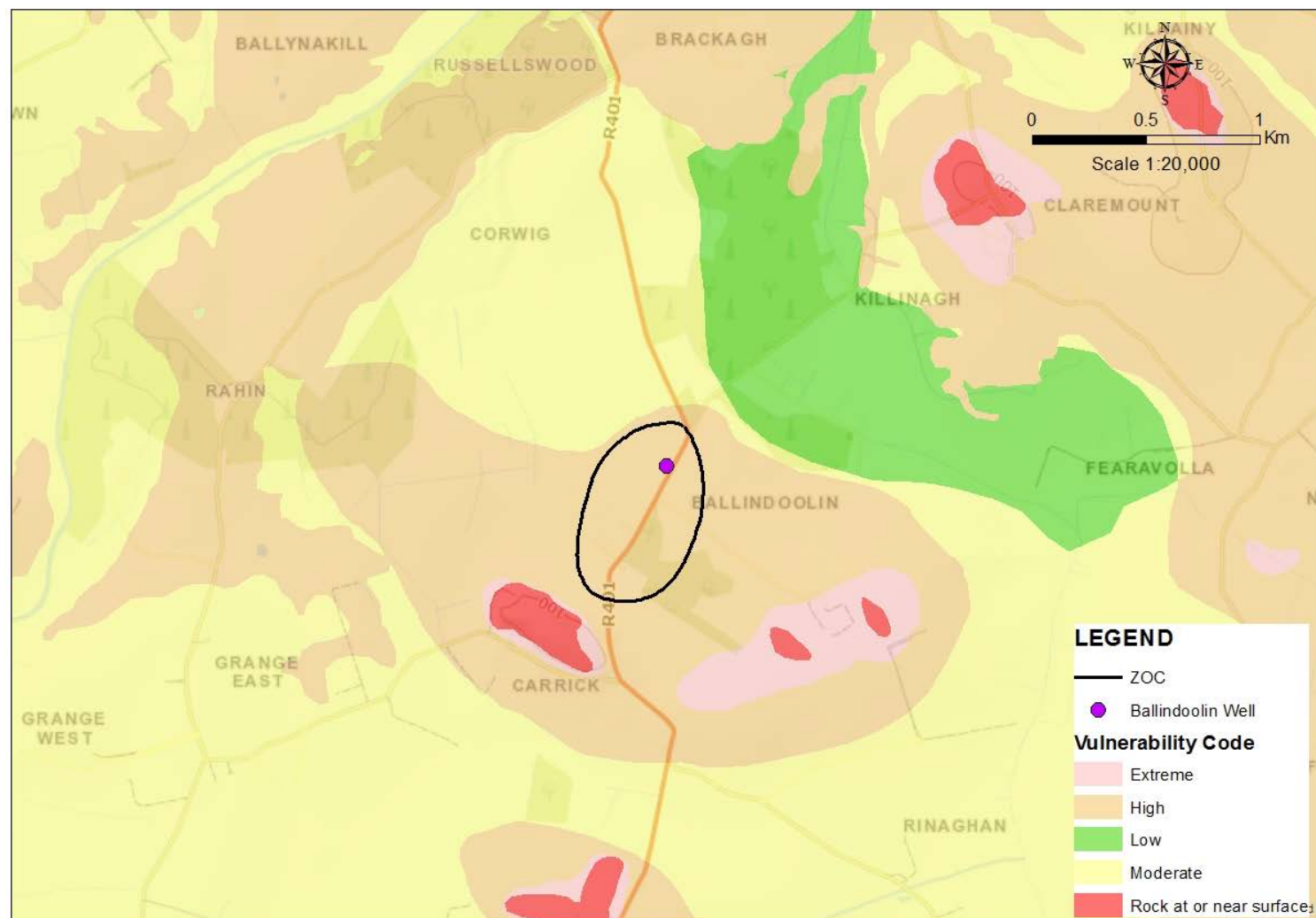


Figure 3. Groundwater Vulnerability Map

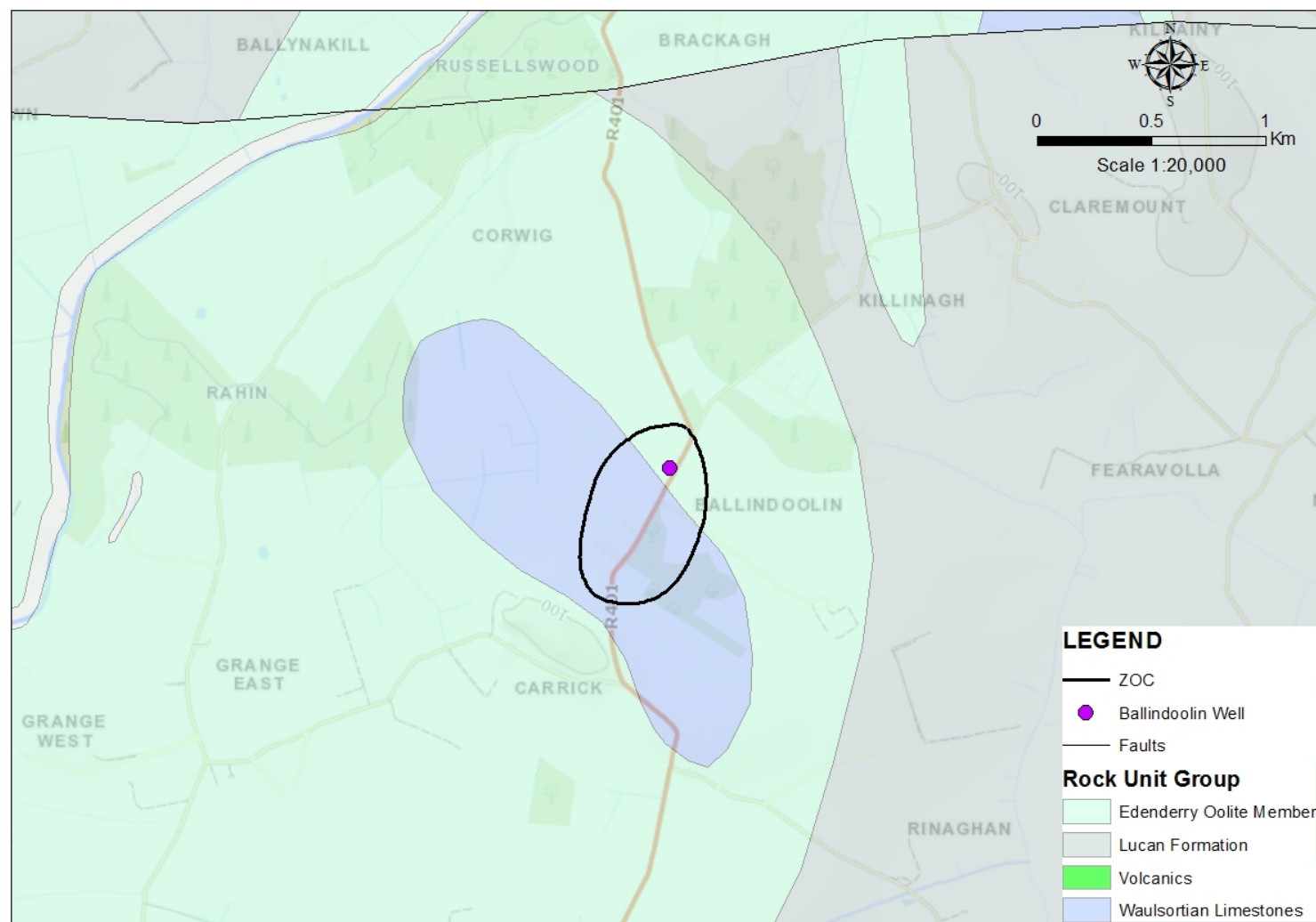


Figure 4. Rock Unit Group Map

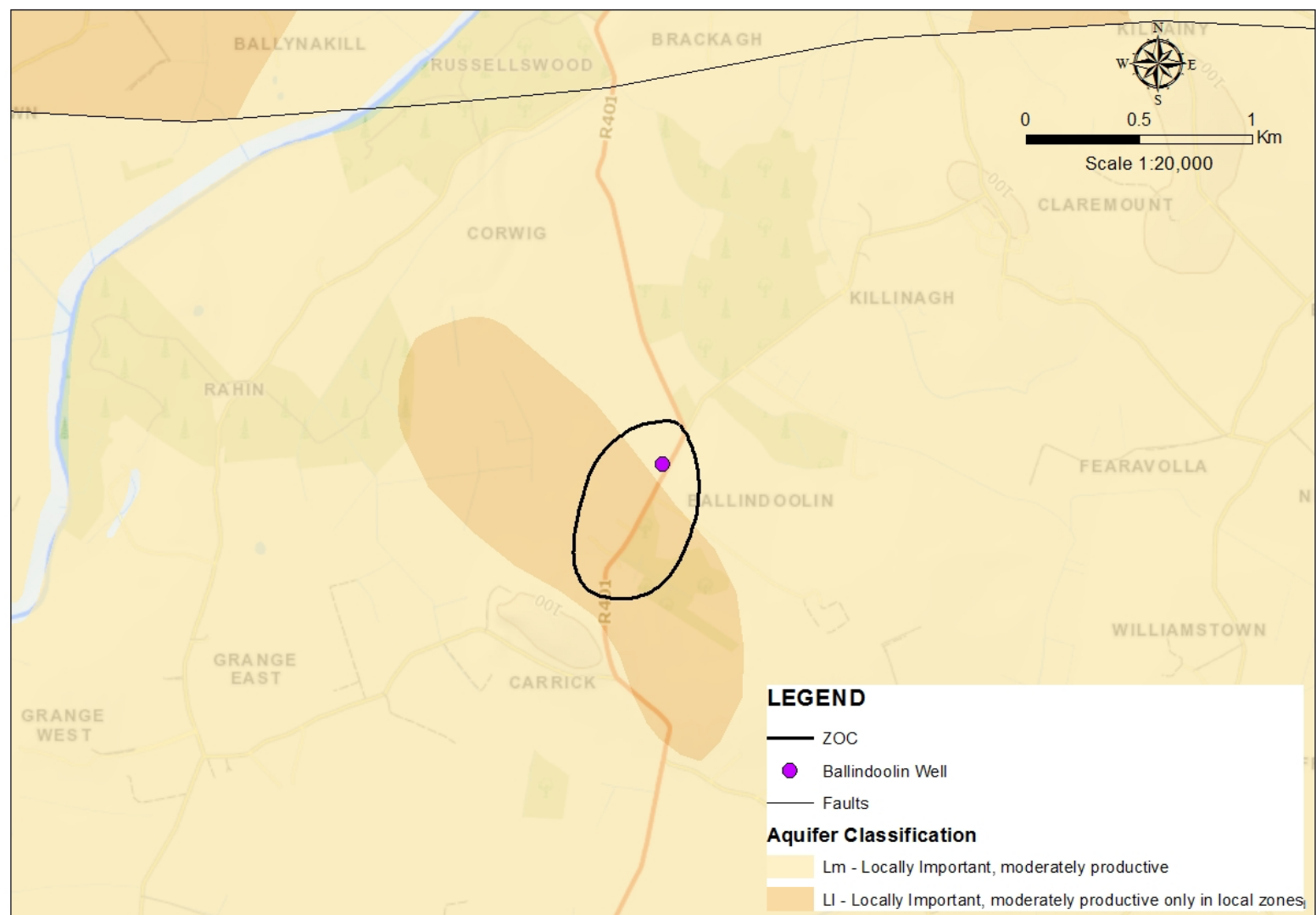


Figure 5. Aquifer Map

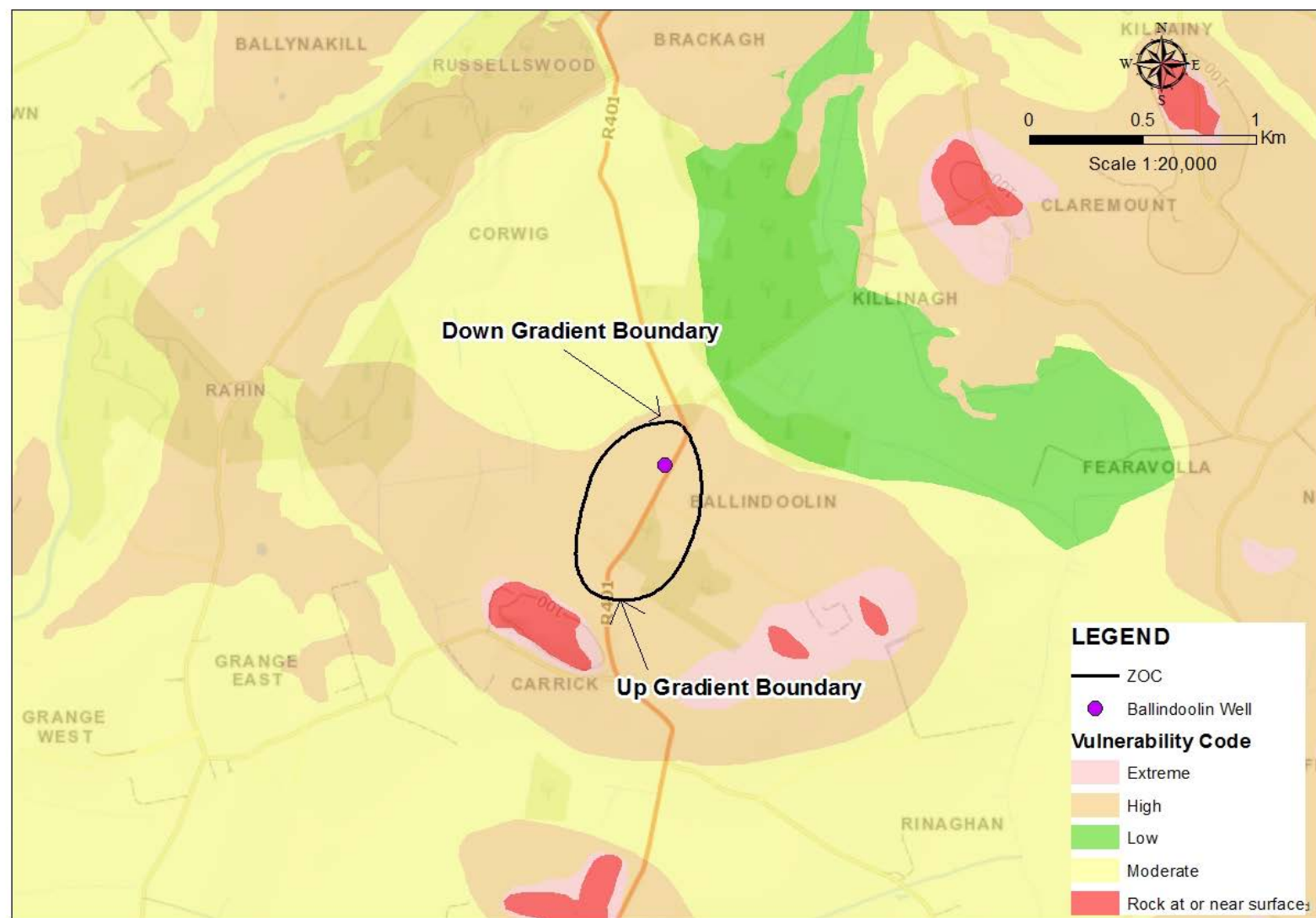


Figure 6. ZOC Boundary Map

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

Well Drilling Invoice

INVOICE

DEMPSEY WELL DRILLING LTD.

CLONBULLOGUE, CO. OFFALY. 0330

TEL: 0405 524301 / 0405 30134. MOBILE: 087 445685 / 088 2755630

V.A.T. NO. IE 95236490

Ballindoolin Group Water scheme

Date: 14-5-2001

8" Bore 150ft. deep		
Drill to 60ft.	£400	
90 ft. of rock drilling at £11. per ft.	£490	
150 ft. of plastic		
Liner at £2.00 per ft.	£300	
V.A.T. at 12.5%	£273.75	
Total.	£2,637.50	

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: **Extreme**, **High**, **Moderate** and **Low**, 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 <u>only</u>)
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/GS1a (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 of Raw Water

Raw Water Data, Ballindoolin GWS, July 2015

Parameter	Ballindoolin GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	<1	mg/l	
COD	<1	mg/l	
Turbidity	0.09	N.T.U.	No abnormal change
pH	7.1	pH units	6.5 – 9.5
Conductivity @ 20C	675	µS/cm	800 (TV)
Alkalinity	367.77	mg/l CaCO ₃	
Sodium	6.39	mg/l	150 (TV)
Chloride	15.91	mg/l	24
Ammonia NH ₃	0.26	mg/l NH ₃	
Nitrate as NO ₃	14.74	mg/l	37.5 (TV)
Nitrite as NO ₂	0.36	mg/l	0.5 (TV)
Dissolved Oxygen (%)	5.80	%Sat	
Potassium, total	0.85	mg/l	
Total Hardness (Kone)	388.3	mg/l CaCO ₃	
Magnesium, total	7.27	mg/l	50 (DWL)
Colour, apparent	1.2	mg/l Pt Co	No abnormal change
Silica as SiO ₂	7.86	mg/l	
Sulphate	10.04	mg/l	187.5 (TV)
Orthophosphate as PO ₄ -P	0.18	mg/l	
Calcium, total	143.5	mg/l	
Aluminium, dissolved	<20	µg/l	150 (TV)
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
Copper, dissolved	<20	µg/l	1500 (TV)
Lead, dissolved	<20	µg/l	18.75 (TV)
Chromium, dissolved	<20	µg/l	37.5 (TV)
Nickel, dissolved	<20	µg/l	15 (TV)
Cadmium, dissolved	<20	µg/l	3.75 (TV)
Arsenic, dissolved	<10	µg/l	7.5 (TV)
Zinc, dissolved	113	µg/l	
Barium, dissolved	0.04	µg/l	
Total Organic Carbon	5.8	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	252	µg/l	
E Coli	<1.0	cfu/100ml	0
Total Coliforms	7.5	cfu/100ml	0
Fluoride	0.17	mg/l	0.8 (DWL)

Summary of Raw Water Data, November 2000 – February 2001 and May 2001 – November 2001

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliforms	Faecal Coliforms
Unit	Hazen	NTU	µScm	pH units	mg/l N	mg/l N	mg/l N	µg/l	µg/l	µg/l	No./100ml	No./100ml
Nov 2000	10	0	827	7.9	<0.01	6.77	<0.005	23	63	18	8	6
Dec 2000	<10	0.1	786	7.1	<0.01	6.77	<0.005	<0.7	4	<0.03	N.D	N.D
Jan 2001	<10	0.8	780	7.1	<0.01	11.04	<0.005	<0.7	5	<0.03	N.D	N.D
Feb 2001	20	1.3	765	7.3	<0.01	7.09	0.007	<0.7	0	7	N.D	N.D
May 2001	10	0.6	769	7.4	0.013	7.02	<0.005	<0.7	<0.09	0	N.D	N.D
June 2001	<10	1.2	758	7.1	0.02	7.32	<0.005	<0.7	1	5	N.D	N.D
July 2001	<10	<1	742	7.1	<0.01	3.89	<0.002	64	0	32	N.D	N.D
Aug 2001	<10	108.5	678	7.1	0.2	2.68	0.014	377	124	56	9	N.D
Sept 2001	45	10.4	695	7.3	<0.01	2.77	<0.005	72	47	29	1	N.D
Oct 2001	10	0.7	802	7.3	<0.01	5.95	<0.005	<0.7	<0.09	<0.03	174	16
Nov 2001	<10	2.1	683	7.5	<0.01	2.8	<0.005	<20	11	10	N.D	N.D
Drinking Water Limit (DWL) or Threshold Value (TV)	No abnormal change	No abnormal change	800 (TV)	6.5 – 9.5	-	37.5 (TV)	0.5 (TV)	150 (TV)	200 (DWL)	<50 (DWL)	0	0

HSE Compliance Monitoring Data 2015

Parameters	Units	May 2015	July 2015	Sept 2015	Nov 2015	Drinking Water Limit (DWL) or Threshold
Ammonium	mg/l NH ₄	<0.07	<0.07	<0.07	<0.07	0.3 (DWL)
Free chlorine	mg/l	0.68	0.03	0.87	0.87	
Hardness	mg/l Ca	398.8	423	359.8	386.5	
Odour	descriptive	Slightly chlorinous	None	Slightly chlorinous	Slightly chlorinous	No abnormal change
Conductivity	µS/cm	640	640	651	668	800 (TV)
Manganese	µg/l	<20	<20	<20	-	<50 (DWL)
Iron	µg/l	<100	<100	<100	<50	200 (DWL)
Nitrate	mg/l NO ₃	17.03	15.61	13.99	17.95	37.5 (TV)
Nitrite	mg/l NO ₂	<0.164	<0.164	<0.164	<0.164	0.5 (TV)
Total Coliforms	No./100ml	-	3	0	-	0
Faecal Coliforms	No./100ml	0	0	0	0	0
Aluminium	µg/l	<50	<50	<50	<50	150 (TV)
Chloride	mg/l	-	-	17.1	-	24
Colour (true)	Pt-Co	<10	<10	<10	<10	No abnormal change
Fluoride	mg/l	-	<0.1	-	-	0.8 (DWL)
pH	pH units	7.2	7.2	7.2	7.2	6.5 – 9.5
Sodium	mg/l	-	-	-	9	150 (TV)
Taste	descriptive	None	None	None	None	Acceptable to consumers and no abnormal change
Temperature	degC	10.9	10.6	12.2	7.5	
Turbidity	NTU	<0.5	<0.5	1.27	<0.5	No abnormal change

APPENDIX 5

ZOC Boundaries

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 **North-Eastern boundary**, is the 'downgradient' limit', beyond which groundwater will not be drawn back upgradient under the influence of the pump. It is estimated using the uniform-flow equation (Todd 1980), which is;

$$\text{Down-gradient distance} = Q / 2\pi Ti,$$

Where;

Q = the daily discharge rate (28 m³/d)

$$\pi = 3.14$$

T = the transmissivity (25 m²/d) - estimate

i = the non-pumping groundwater gradient (assuming the groundwater gradient is parallel to the topographic gradient), 0.01

The 'down-gradient limit' is therefore estimated as 18 m. This figure is increased slightly in order to be conservative and allow for uncertainties in the estimates of transmissivity and gradient.

The **South-Western Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the water balance for the site and on the local topography. 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 boundary is extended to incorporate the houses along the road to the south-west of the well in order to be conservative.

The **North-Western and South-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 uniform flow equation (Todd 1980) was used to estimate the width of the ZOC at its downgradient extent, as follows;

$$y_L = Q/2Ti,$$

Where;

Q = the daily discharge rate (28 m³/d)

T = the transmissivity (25 m²/d)

i = the non-pumping groundwater gradient (assuming the groundwater gradient is parallel to the topographic gradient), 0.01

This estimates the downgradient width of the ZOC as 56 m. It is assumed that this is an unrealistically small figure and so is expanded to take account of the topography, recharge characteristics and to incorporate the Extreme (E) vulnerability areas to the south of the well. The two boundaries meet on the downgradient side of the boreholes at the 'downgradient 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.