

Establishment of Groundwater Zones of Contribution

Ballyaneen Rakerin Group Water Scheme

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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 Ballyaneen Rakerin 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 the 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 the aquifers are protected by overlying soil and subsoil; 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.

Ballyaneen Rakerin GWS is supplied by a single borehole by groundwater that flows through both fractures and conduits in a locally important bedrock aquifer (LI) which is moderately productive in local zones only. The current average abstraction rate is 73 m³/day.

¹ EPA/DELG/GSI, 1999.

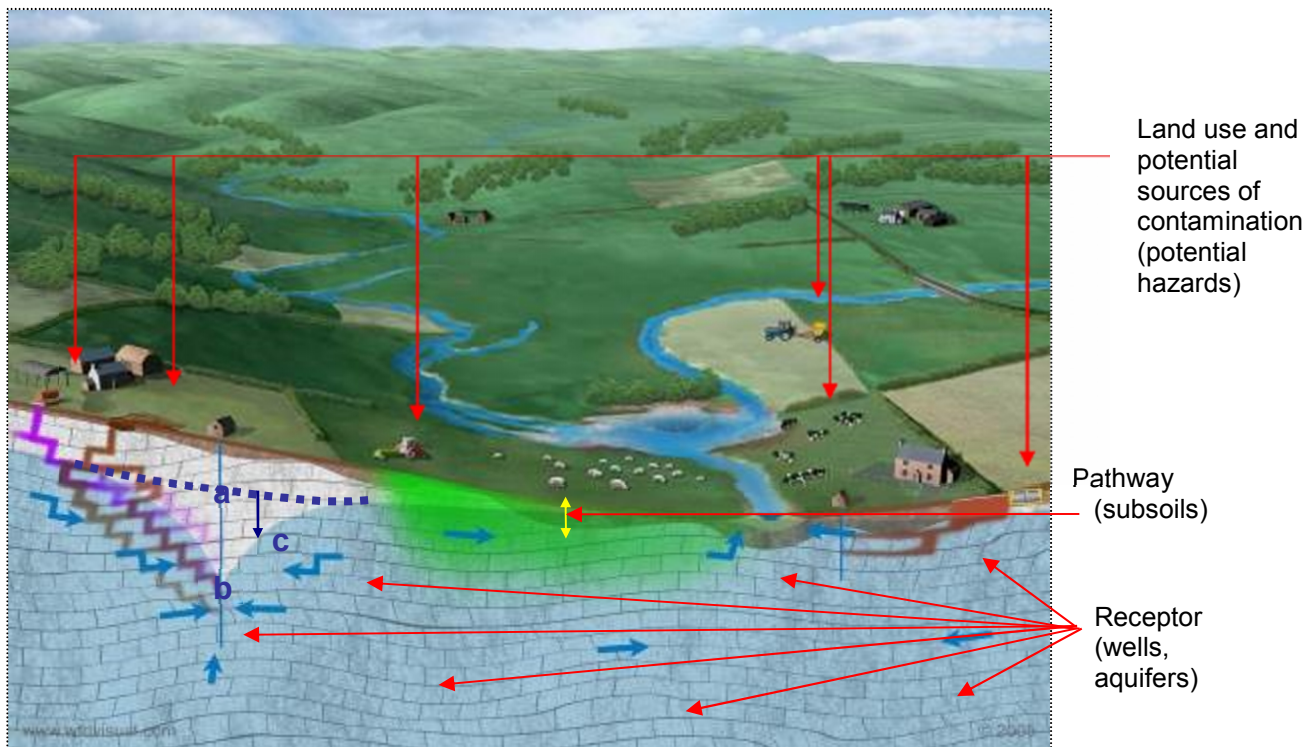


Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

2. Location, Site Description, Well Head Protection and Summary of Spring Source Details

The Ballyaneen Rakerin Group Water Scheme (GWS) is supplied from a single borehole in the townland of Rakerin, 2.75 km east-northeast of Gort, Co. Galway. The borehole is located within the GWS water treatment works (WTW) site, in agricultural land at the foot of the western side of the Sliabh Aughty Mountains, on the edge of the Gort lowlands (**Figure 1**). The current scheme demand is 73 m³/day. Typically the borehole is pumped for approximately 7 hours per day at a rate of 10 m³/hour. The borehole pumps to a small reservoir on the WTW site. The scheme is part of the Galway Group Water Scheme DBO Bundle No.2. The WTW is operated by Glan Aqua. Treatment at the WTW comprises a sand filter, and granular activated carbon (GAC) filter, followed by ultraviolet germicidal irradiation (UV), and finally chlorination disinfection. There is also a reverse osmosis unit prior to the UV unit which is used occasionally.

The current source borehole is located inside the wall of the WTW site, adjacent to the local road running east-northeast through Rakerin, between the wall and the WTW palisade fence (**Diagram 2**).

The borehole was drilled in July 2011. Headworks at the borehole comprise a concrete plinth constructed approximately at ground level, with a concrete ring sitting on the plinth². A small amount of leakage of rainfall into the chamber via the manhole rim was observed during the site visit on 30 July 2015; however the water was draining away to ground through a drainage point in the floor of the chamber, without ponding. The mouth of the borehole is capped by a steel plate.

The groundwater source for the GWS was from a historical borehole up to 2011. The borehole was located inside the northwest corner of the WTW palisade fence approximately 10 m from the current source borehole. The historical borehole was unable to meet the GWS demand without causing pump damage due to sediment mobilisation and was decommissioned by backfilling with grout in 2011.

² The chamber is a 1.7 m diameter by 0.82 m tall concrete ring chamber on top of the plinth. The chamber was capped by a 0.2 m thick concrete slab of 1.7 m diameter with a square manhole cover access point in the slab. The top rim of the manhole cover is 1.02 m above the chamber floor. The top of the borehole steel casing protrudes 0.085 m above the basal plinth inside the chamber. The borehole is provided with a dip-meter access tube, the top of which is positioned 0.365 m above the base of the chamber.

The current borehole yield of 10 m³/hr is below the design yield of 14 m³/hr. This is considered to be due to wear on the pump motor. The motor was previously in use in the historical borehole, where the pump was replaced twice due to clogging and damage from sediment. The motor and third pump were subsequently installed in the current source borehole when it was commissioned in 2011.

Photos of the current source borehole and WTW, plus the surrounding landscape can be seen in Photos 1 to 8 below. **Table 1** provides a summary of currently known information relating to the current and historical source boreholes. Borehole logs are shown in **Appendix 2**.

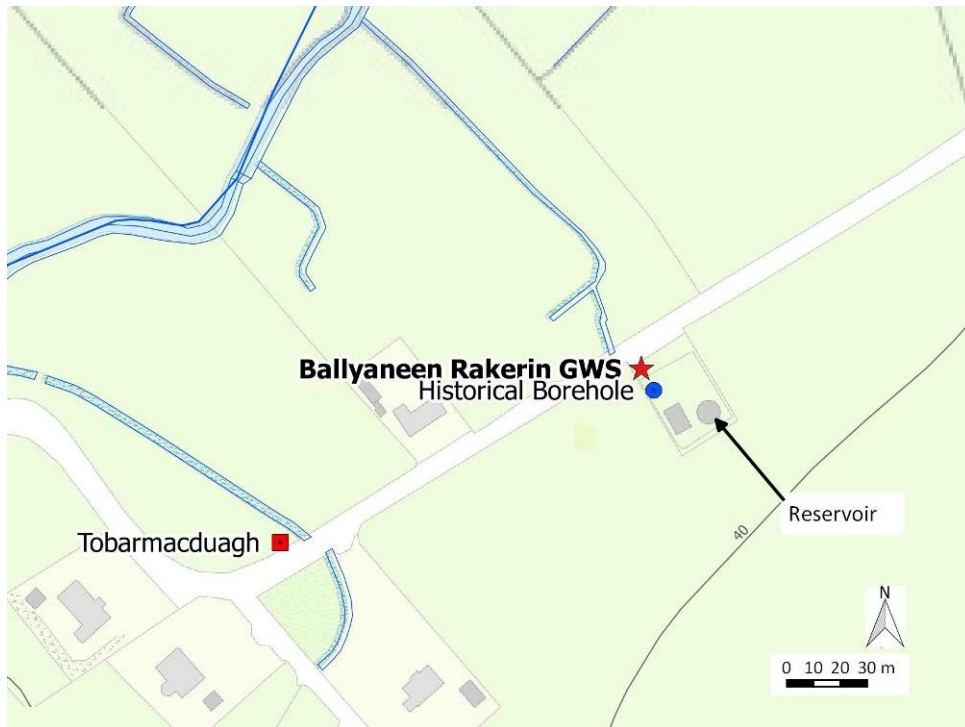


Diagram 2. Schematic Plan of the GWS Site

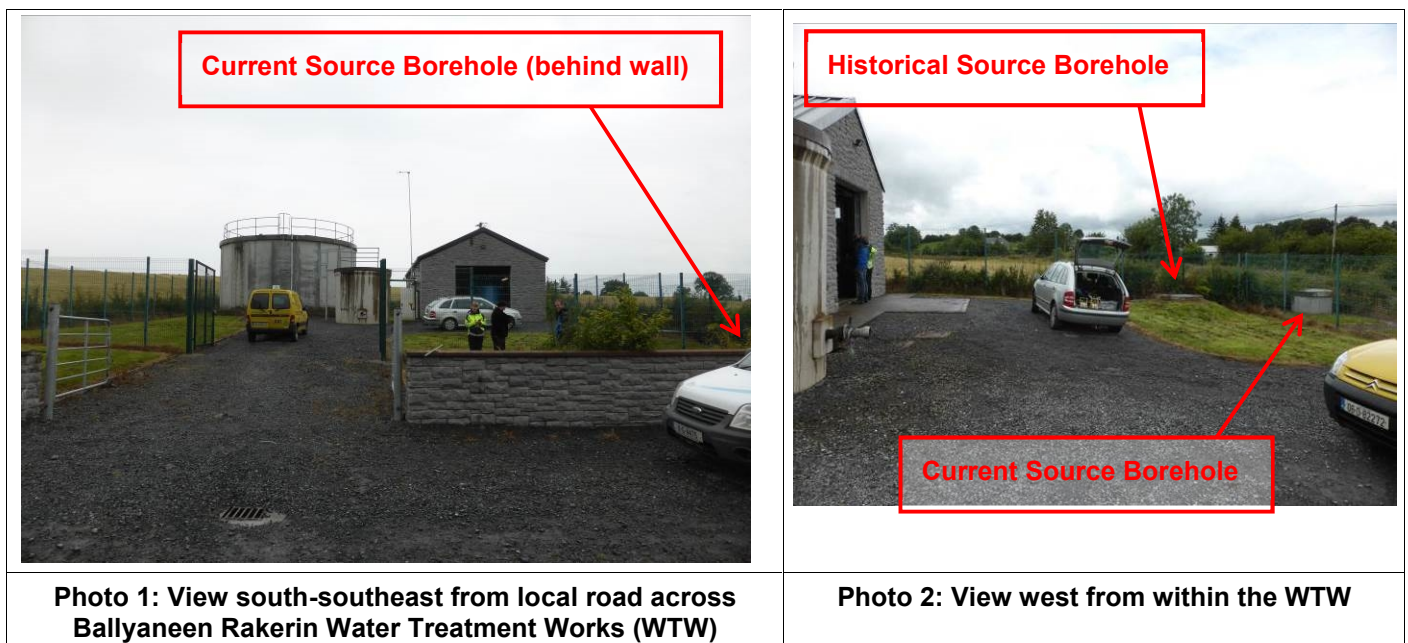




Photo 3: View East showing landscape around WTW



Photo 4: View WSW over Current Source Borehole



Photo 5: Current Source Borehole chamber access

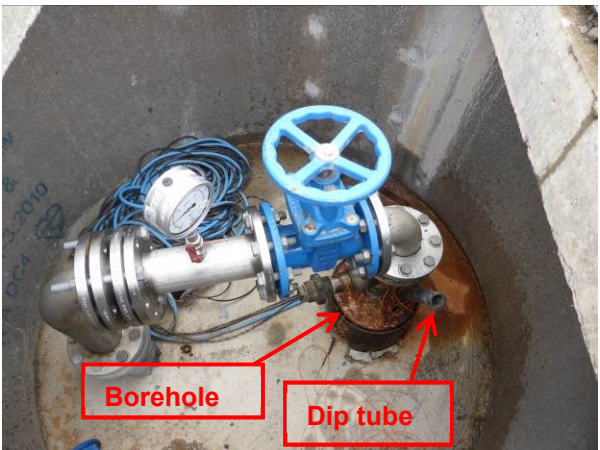


Photo 6: Current Source Borehole Well Head

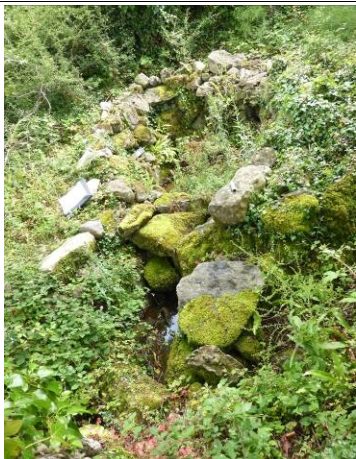


Photo 7: Tobarmacduagh



Photo 8: Tobarmacduagh overflow – rust staining (iron rich)

Table 1. Supply Details

	Current Source Borehole	Historical Source Borehole
Grid reference	147806E; 202780N	147810E; 202771N
Townland	Rakerin	Rakerin
Source type	Borehole	Borehole (decommissioned)
Drilled	July 2011	Before 2007
Drilling Contractor	P. Briody & Sons Ltd.	Unknown
Owner	Ballyaneen Rakerin GWS	Ballyaneen Rakerin GWS
Elevation (m OD) (est. from 1:50,000 scale topographic map)	37	38
Total depth (mbgl)	139	55 m prior to decommissioning
Construction details	12" diameter hole 0 m to 3.5 m; 10" diameter steel casing (SC) 0 m to 3.5 m; 10" diameter hole 3.5 m to 42 m; 6" diameter uPVC blank casing 0 m to 16 m; Cement grout seal in annulus outside 6" & 10" casings from 0 m to 16 mbgl; 6" diameter open hole from 42 m to 139 m.	6" mild steel casing, estimated to be 3 m in length. Assume 6" open hole from 3 m to total depth. Borehole decommissioned in 2011 by backfilling with cement grout to ground level.
Depth to rock (m bgl)	3.5	unknown
Static water levels (SWL) and Pumping (PWL)	SWL = 2.5 mbgl (22/07/2011) PWL = 13.87 m below Datum (mbD) (30/07/2015) Datum = top of concrete slab roof of well chamber (0.96 m above ground level) Borehole becomes artesian during winter	SWL = 6 mbgl (02/03/2007) PWL = 42 mbgl (02/03/2007) Borehole became artesian in winter
Water strikes (mbgl)	5 mbgl in limestone, 26 m ³ /d, milky grey 17-18.5 mbgl, 57 m ³ /d 24-25 mbgl, main strike, max airlift discharge of 16 m ³ /hr achieved with rods at 25 mbgl. Inflow pressure enough to stall drill hammer action. Increasing inflow below 25 mbgl down to 85 mbgl, but no discernible strike below 25 m – increases possibly due to improving inflow at 25 mbgl as drilling progressed.	20 mbgl & 40 mbgl
Pump intake depth (m bgl)	15	approx. 40 to 45
Current abstraction rate	73 m ³ /day	0
Reported yield (m ³ /d)	393 m ³ /day max yield estimate from airlift development of borehole; On 30/07/2015, the borehole produced 128 m ³ at a rate of 10 m ³ /hr, during mains flushing	Abstraction rate = 13.5 m ³ /hr during Pat Kelly yield test (02/03/2007). Drawdown during Pat Kelly yield test = 36 m
Specific Capacity (Qs) (m ³ /d/m) (Abstraction rate divided by steady drawdown)	Discharge (Q) = 10 m ³ /hr (240 m ³ /d) est. drawdown (s) = 10.4 m Qs = 23 m ³ /d/m	Discharge (Q) = 13.5 m ³ /hr (324 m ³ /d) est. drawdown (s) = 36 m Qs = 9 m ³ /d/m
Transmissivity (T) (m ² /day)	28 (based on Logan approximation: T = 1.22*Qs)	11 (based on Logan approximation: T = 1.22*Qs)
Data Sources	Borehole Log (Hydro-G 2011)	DBO Tender Data Summary (Glan Agua 2010)
Other Information	At 09:30, 22/7/2011, SWL in current source borehole (during trial well drilling phase) = 2.5mbgl; PWL in historical source BH, pumping since approx. midnight = 35.6 mbgl at approx. 6 m ³ /hr. On 28/07/2011, in current source borehole (on completion of production well drilling phase) WL = 3.86 mb Casing at 16:45, and 3.14 mb Casing at 21:00; i.e. WL recovery in the current source borehole, even though the historical source BH was being pumped at 6 m ³ /hr from 16:00 to 21:00. Suggests poor connectivity between the boreholes.	

3. Physical Characteristics and Hydrogeological Considerations

3.1 Physical Characteristics of the Area

Table 2 summarises the physical characteristics of the study area.

Table 2. Physical Characteristics of the Area of Interest

Ballyaneen Rakerin Borehole		Description/Comments
Annual Rainfall (mm)	1034	Shanaglish G.S. rainfall station, 8.4 km to the SSW at 40 mOD (1961-1990)
Annual Evapotranspiration Losses (mm)	464	488 mm PE (avg. annual Potential Evapotranspiration data, Galway S.W.S: 1961-1990). 464 AE (Actual Evapotranspiration, assumed to be 95% of PE)
Annual Effective Rainfall (mm)	570	Annual rainfall minus the annual evapotranspiration losses
Topography (Figure 2)	Rakerin townland is situated at the foot of the western side of the Sliabh Aughty Mountains, on the edge of the Gort lowlands. The borehole is at an elevation of approx. 37 mOD in a hummocky landscape, dominated by drumlins rising up to 20 m above the surrounding the general ground level. The overall ground slopes west in the vicinity of the boreholes at a gradient of about 0.006.	
Land use	The borehole is located in an agricultural area, with the land predominantly used for grazing and for silage production. A small bog area is cut for turf 500 m east of the source borehole. There are numerous one off houses with onsite wastewater treatment systems in the area.	
Surface Hydrology (Figure 2)	The 1 km ² area surrounding the source borehole has no streams mapped at the 1:50,000 scale, which suggests a karst influence on the drainage system. The Turra River forms a large meander 170 m northwest of the source. It drains southwest opposite the source but 100 m downstream loops back to the northeast. The Carragh River drains southwest, 1.2 km southeast of the source borehole. Numerous drains feeding these streams are mapped at the 1:5,000 scale. Lough Nameil is mapped in the bog 400 m east of the source. Lough Aihileleen is located on the Carragh River 1.2 km southeast of the source. Areas identified as "Liable to Flood" in historical maps are mapped 675 m southwest and 850 m south of the source. The Tobarmacduagh holy well/spring is located 145 m WSW of the source.	
Topsoil ³	Soils in the area are mostly deep well drained basic mineral soils. Cut peat is mapped around Lough Nameil and in the vicinity of Turra River. Alluvial soils also occur at the latter location. Pockets of lacustrine, shallow and poorly drained soils also occur in places.	
Subsoil ² (Figure 3)	Subsoils mainly comprise till derived from limestone. Cut peat is mapped around Lough Nameil and in the vicinity of Turra River. Alluvial subsoils also occur at the latter location. Pockets of bedrock outcrop and lacustrine subsoils occur in places. The outcrop generally occurs in troughs between drumlins.	
Groundwater Vulnerability (Figure 4)	Moderate vulnerability is mapped in the vicinity of the source, with low vulnerability mapped at the peat areas to the northwest and southeast. Large areas of high vulnerability with pockets of extreme vulnerability occur to the south and south west. See Appendix 3 .	
Geology ⁴ Formation: Rock Unit Group (Figure 5)	Dinantian Pure Unbedded Limestone (DPUL).	DPUL (Massive, unbedded lime-mudstone) underlies the source borehole. This is underlain in turn by Dinantian Lower Impure Limestones (DLIL), Dinantian Early Sandstones and Shales and Devonian Old Red Sandstones, which outcrop in turn eastwards towards Sliabh Aughty, Bedrock layers dip to north west and southeast at 15° in the vicinity of the source, such that DLIL is present at shallow depths beneath much of the study area (Diagram 3). A NE to SW bedrock fault is mapped 770 m NW of the source borehole.
Aquifer (Figure 6)	The DPUL and DLIL bedrock is classified as a locally important aquifer (LI) which is moderately productive only in local zones. Karst caves are mapped 530 m SSW and 760 m SSE of the source borehole. Lough Nameil and the mapped "liable to flood" areas may also be karst influenced.	
Groundwater Body	Caherglassaun GWB	The LI aquifer is in the Caherglassaun GWB (part of Derrybrien GWB). http://www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions.htm
Recharge Coefficient (Appendix 4)	Capped	Well drained soils, moderate permeability subsoils, and moderate to extreme vulnerability suggest a moderate recharge coefficient in the range of 25% (142 mm) to 60% (342 mm). However recharge acceptance by LI aquifers is generally capped at 150 mm/yr to 200 mm/yr, with the excess reverting to surface runoff and/or interflow. 200 mm/yr is equivalent to 35% of available effective precipitation and does not account for point recharge at enclosed depressions or sinking streams.
Recharge (mm)	200	

³ Teagasc, 2006.

⁴ Gatley *et al.*, 2005

3.2 Hydrochemistry and water quality

One untreated water sample was collected and analysed by CLS Laboratories on behalf of the NFGWS on 25 August 2014; however the results were not available during the preparation of this report. Eleven untreated water samples were analysed for the GWS historical source borehole between November 2000 and November 2001 under a Department of the Environment initiative. Eleven routine, monthly raw water analyses carried out by City Analysts Laboratory on behalf of Glan Agua for the period August 2014 to June 2015 were made available for this report. In addition, a further five samples were collected on 24 July 2007 plus two more on 30 July 2007 in response to an elevated manganese incident associated with the untreated water. The seven additional samples were analysed by CLS Laboratory and City Analysts Laboratory on behalf of Glan Agua. 26 treated samples were collected and analysed between June 2008 and July 2015 by Galway County Council and Glan Agua. The analytical results for the current source borehole (i.e. post July 2011) are summarised in Table 3. The full data set is in **Appendix 5**.

The existing laboratory results have been compared to the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were adopted in Ireland under S.I. No. 9 of 2010, or with the drinking water standard (DWS) (SI 278 of 2007) where no environmental objective has been set.

Table 3. Water Quality Data

Parameter	Current Source Untreated Water		Current Source Treated Water		Parametric Value/(Comment)
	Number of Values	Average	Number of Values	Average	
pH (Lab)	15	7.3	17	7.29	6.5 < pH < 9 / (untreated range 7.1 to 7.6) (treated range 7.1 to 7.5)
Electrical Conductivity (Lab) (uS/cm)	0 (Historical source average 764)		7	558	800 / (treated range 497 to 703)
Colour (PtCo Units)	25	22.9	14	14.3	(untreated <5 to 72.5) (treated range 9.8 to 23)
Turbidity (NTU)	26	2.9	16	0.81	(untreated range <0.5 to 7.4) (treated 0.2 to 1.33)
Nitrate (mg/l NO ₃)	15	7	11	0.97	37.5 / (untreated 1 to 18) (Treated 0.97 to <8.9)
Nitrite (mg/l NO ₂)	15	0.08	10	0.03	0.375 / (untreated <0.016 to 0.2) (Treated <0.016 to 0.03)
Ammonia (mg/l NH ₃)	15	0.47	14	0.06	0.175 / (untreated 0.13 to 1.2) (treated <0.013 to 0.25)
Chloride (mg/l)	0		2	9.16	24 / (treated range 0.02 to 18.3)
Iron (Total) (mg/l)	15	206	14	118	200 /(untreated range <10 to 590) (treated range <7.2 to 253)
Manganese (Total) (mg/l)	16	291	13	169	50 /(untreated range 6 to 1492) (treated range 1.8 to 2018)
Coliform Bacteria (cfu/100ml)	1	201	18	0	0 / (treated all 0)
E. Coli (cfu/100ml)	1	18	18	0	0 / (treated all 0)
Clostridium Perfringens (cfu/100 ml)	1	2	18	0	0 / (treated all 0)
Potassium:Sodium Ratio	0		0		0.3

The field parameters pH, electrical conductivity (EC) and temperature were measured at the borehole during the site visit on 30 July 2014. They measured: EC 662 uS/cm, pH 7.33, and temperature 12.1°C.

The moderate to high EC and slightly alkaline pH is typical of highly mineralised limestone groundwater. The single microbiological sample from 24 July 2015 for the current borehole suggests the raw water quality is poor, with total and fecal coliforms and clostridia detected. Coliforms were also detected in the historical borehole in the period August to November 2001. Ammonia has been detected in every sample from the historical and current boreholes since November 2000, with 19 out of 26 results above the SI 9 of 2010

threshold of 0.175 mg/l N. These data suggest a persistent source of organic matter, possibly sewage-related, groundwater pollution in the area.

During the manganese incident of 24 to 30 July 2015 coliforms and clostridia were detected, plus ammonia concentrations up to 0.41 mg/l N, and turbidity of up to 7.4 NTU. During the incident, manganese persistently exceeded its SI 9 of 2010 threshold while iron oscillated above and below its threshold. In addition, over repeated samples on 24 July 2015, iron was lowest when manganese was highest and *vice versa*. This suggests that a plume of fluctuating anoxic (oxygen poor), organic matter-contaminated groundwater was migrating through the bedrock aquifer groundwater system, with highly anoxic dissolved-iron rich groundwater, and slightly less anoxic dissolved-manganese rich groundwater. The manganese and iron are likely to originate in the impure (shaley) limestones, and are mobilised in dissolved form by low-oxygen polluted waters.

Given that persistent groundwater contamination occurs in the area without resulting in frequent manganese incidents, it is likely that the July 2015 incident was the result of a specific, significant pollution event within the ZOC. Given the presence of cave systems in the area and the large water strike at 25 mbgl in the current source borehole, it is possible that the pollution event may be related to point source pollution at a surface karst feature.

Septic tank discharges and farmyard runoff are potential persistent sources. It is noted that a school and other buildings have been built over the cave mapped 530 m SSW of the source, while numerous residences occur in the Kilbeacanty area in the vicinity of both mapped caves in the area and the mapped “liable to flood” areas.

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 3**).

Diffuse recharge to locally important (LI) bedrock aquifers generally does not exceed 200 mm/yr due to the inability of the bedrock to allow more water to infiltrate into the rock. This is equivalent to 35% of the available effective precipitation (EP). The remainder of the rainfall is expected to become surface runoff or interflow. Some of it may enter the groundwater system at points, such as enclosed depressions or sinking streams, increasing the total amount of rainfall becoming groundwater.

Once the infiltrating water reaches the bedrock aquifer, flow occurs in joints and fractures, and along bedding planes and major faults in the bedrock. Some of the fissures may be extensively karstified. There may also be a thin, highly weathered and dissolved “epikarst” layer present at the top of the limestone bedrock, which could facilitate groundwater flow. The majority of groundwater flow is likely to take place in the epikarst and weathered zone in the top few metres of rock and in fractures in the underlying 10 m to 15 m of the bedrock aquifer. Below this depth fractures become less frequent. Significant deeper flow may be associated with bedrock faults or significant karstified fractures.

The borehole log indicates that a large water strike occurred at 25 mbgl in the current source borehole, with enough water pressure and flow to stifle the air-hammer drill bit. In addition geological mapping by the GSI shows a minor bedrock fold crest under Kilbeacanty, where impure limestone (DLIL) bedrock forms rockhead. To the north and south of Kilbeacanty the impure limestone is overlain by unbedded pure limestone (**Figure 5**). GSI data suggests the rock layers dip northwest and southeast away from Kilbeacanty at 15° tilts. The boundary between the impure limestone and overlying pure limestone is likely to have the same orientations.

In **Diagram 3**, the geological boundary between different limestone layers is shown dipping northwest at 15° away from Kilbeacanty. The diagram shows that the interpreted position of the boundary correlates well with the location of the mapped cave at the ground surface and the logged water strike at 25 mbgl in the source borehole. Overall, this suggests that there is a karst conduit present along the bedding plane that is connected to cave systems at the ground surface, that it is intersected by the source borehole, and that provides the main groundwater inflow to the source borehole.

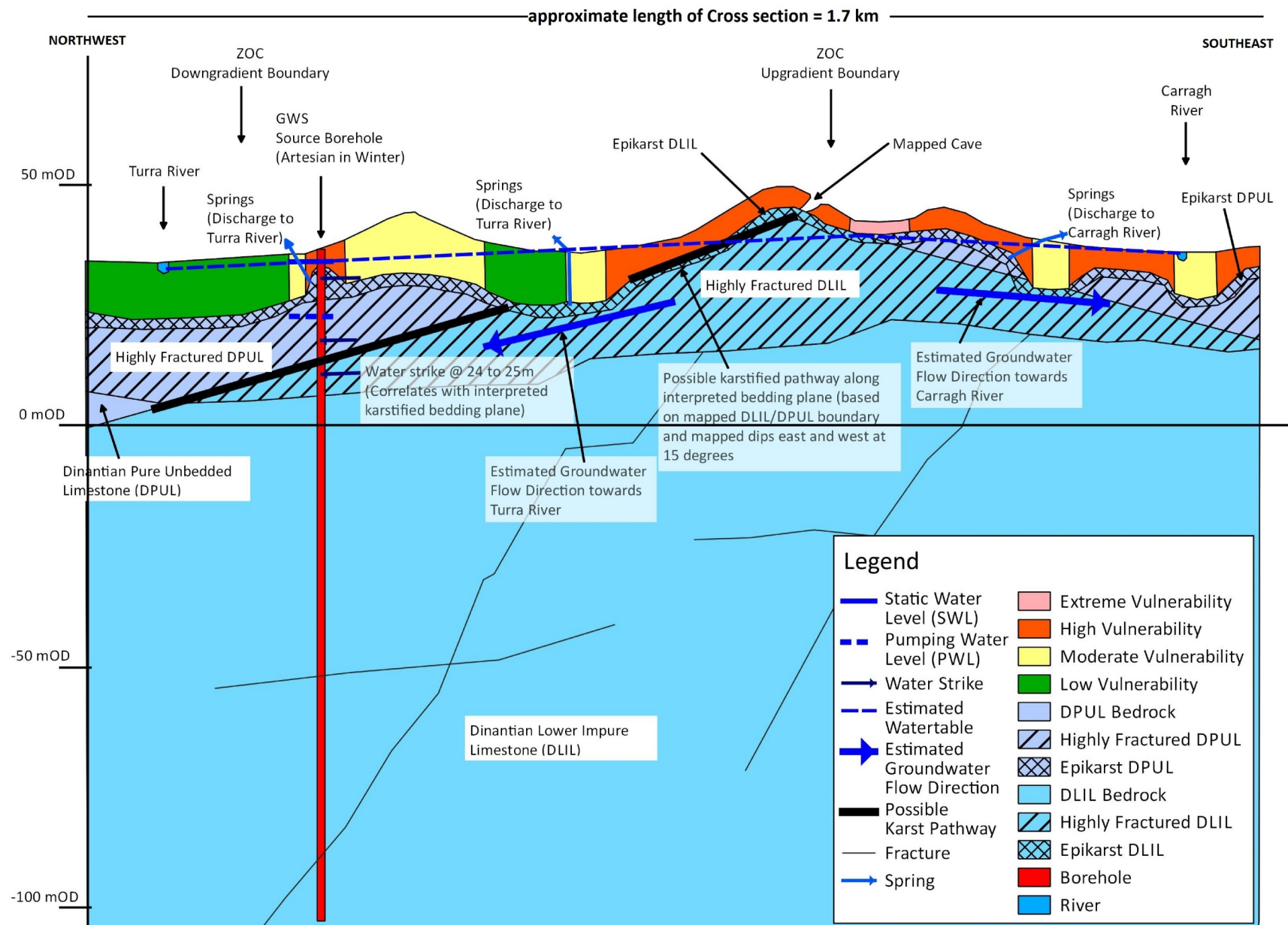


Diagram 3: Schematic vertical cross section through the subsurface and conceptual model of groundwater flow

The local groundwater flow direction is assumed to follow the topographic slope to the west or northwest. There is uncertainty in this regard however. It is possible that there could be a stronger northerly trend, or that regional scale influences could override the local factors and induce groundwater to flow southwest towards Gort, or south towards the Beagh River and Lough Cutra.

The static water level data indicate that the watertable is close to the ground surface and that artesian conditions can occur in winter. Flow paths in the locally important aquifer are likely to be short and of the order of 300 m or less, although if a very extensive cave system is present longer flow paths could occur.

With the high/artesian groundwater levels, groundwater is likely to discharge at springs and as baseflow to the Turra/Bolyneendorrish stream, which is one of three main streams draining the western side of Sliabh Aughty onto the Gort Lowlands.

The apparently lower yield of the historical source borehole compared to the current source borehole and the lack of hydraulic continuity between the two boreholes observed during drilling of the current source borehole, suggests that the historical borehole did not intersect the main karst pathway/water strike encountered in the current borehole.

4.2 Boundaries

The boundaries of the area contributing to the source are considered to be as follows (**Figure 7**):

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

The **north-western boundary** is the downgradient boundary. The position of the boundary was calculated to be approximately 100 m northwest of the GWS source borehole. This was calculated using the Uniform Flow Equation (Todd 1980) based on an abstraction rate of 110 m³/day, a transmissivity of 28 m²/day and a hydraulic gradient of 0.006.

The **south-eastern boundary** is the upgradient boundary and was drawn along a drumlin ridge just southeast of the south-easterly mapped cave in Kilbeacanty. The ridge is underlain by the DLIL/DPUL bedrock fold crest, and has pockets of shallow rock and a mapped cave. These factors suggest it is likely to be an area of relatively high recharge with potential to create a localised recharge mound. The recharge mound could result in a groundwater divide running along the ridge axis. Groundwater is thought to flow outwards from the ridge roughly to the northwest and southeast towards the Turra and Carragh Rivers respectively. Groundwater is likely to flow along the karstified contact between the impure limestone (DLIL) and the overlying pure unbedded limestone (DPUL). The ZOC upgradient boundary is delineated along this potential groundwater divide.

The **south-western and north-eastern eastern boundaries** were delineated taking into account the known and potential karst features in the area, the topography and the water balance (**Section 4.3**). The boundaries were extended from the upgradient boundary to encompass three main potential karst features, i.e. the mapped caves located 530 m south-southwest and 850 m south-southeast of the source borehole, and Lough Nameil located 400 m east of the source borehole. They also encompassed the two mapped “Liable to Flood” areas. The boundaries then converge at the upgradient boundary 100 m north of the source borehole.

There is some uncertainty in the location of the southern end of the ZOC. The southern part of the boundaries could be extended further south if the groundwater flow direction has a stronger northwards component than anticipated.

Furthermore, there are likely to be other karst features present beyond the delineated boundary, however the area captured in the delineated ZOC exceeds the required water balance (**Section 4.3**) by 250%. Groundwater flowing along other karstic conduits outside the ZOC is considered to discharge to the Carragh stream or to the Bolyneendorrish Stream.

4.3 Recharge and water balance

The GWS currently abstracts 73 m³/d at a pumping rate of approx. 10 m³/hr over about a 7 hour pumping period each day. In order to delineate a conservative ZOC, the current abstraction rate of 73 m³/day is increased by 50% to 110 m³/day. This should allow for any variation in the size or shape of the ZOC due to groundwater flow direction fluctuations or reductions in recharge during droughts.

The recharge is conservatively estimated as 200 mm/year (see **Table 2**). The area described above and shown in **Figure 7** is 0.71 km², and is sufficient for 350% of the current scheme demand (i.e. 390 m³/d). Therefore the ZOC can adequately sustain the current daily 7 hours of abstraction at a rate of 10 m³/hour, giving a daily abstracted volume of 73 m³.

5. Conclusions

Ballyaneen Rakerin GWS is supplied by a single borehole in a locally important (LI) bedrock aquifer which is moderately productive only in local zones. The bedrock aquifer is locally highly karstified. Groundwater is thought to flow into the borehole from shallow pure limestones via a conduit, and from deeper fractures within the underlying impure (shaley) limestone. The current abstraction rate is 73 m³/day.

The ZOC is delineated based on a combination of hydrogeological mapping and the topography in the vicinity of the current source borehole. For a daily abstraction rate of 110 m³/d (i.e. current abstraction rate plus 50%), the estimated ZOC covers an area of 0.2 km². In order to encompass surface karst features which could potentially interact with the source borehole, a conservative ZOC area of 0.71 km² was delineated.

The upgradient ZOC boundary has a degree of uncertainty associated with its position as it is based on an interpretation indicating that there may be a groundwater divide present beneath the boundary, rather than on direct observation of the groundwater divide. It is considered that there is good evidence in support of the interpretation and that it is consistent with the conceptual model.

The south-western and north-eastern ZOC boundaries have a degree of uncertainty associated with their positions as drawn, since their location is based on encompassing nearby mapped surface karst features, while taking account of the water balance and topography. Given that the delineated area greatly exceeds the water balance requirement, the boundaries are considered to be conservative.

Overall, the delineated ZOC gives a good basis for assessing and mitigating groundwater quality and quantity issues at the source.

The groundwater vulnerability within the ZOC is mapped as Extreme (X) (0.4%), Extreme (E) (0.5%), High (40.2%), Moderate (42.8%) and Low (16.1%). This categorisation will enable the GWS to prioritise areas of risk when auditing or mapping potential hazards, or areas to investigate if a pollution incident does occur.

The water quality data for the current source borehole suggest persistent groundwater pollution by an organic matter source. The untreated water manganese incident in July 2015 is likely to have been the result of a specific, significant pollution event within the ZOC. Given the presence of cave systems and the interpreted karstified bedding plane pathway intersected at 25 mbgl in the current source borehole, it is likely that the pollution event may be related to point source pollution at surface karst feature(s) within the ZOC that allow rapid inflows to the aquifer.

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.

6. Recommendations

Essential

- Routine analysis of the untreated or raw water along with the existing analysis of treated water around the distribution network should continue at the current monthly frequency. It is recommended that for a period of 12 months, and at least once after a rainfall event the laboratory analysis parameter suite should be expanded to include the following essential water quality parameters:
 - total and faecal coliforms, pH, alkalinity, turbidity, hardness, electrical conductivity, nitrate, nitrite, ammonia, iron, manganese, chloride, sodium and potassium.
- It is also recommended to analyse for the following parameters:
 - clostridium perfringens (cryptosporidium indicator)
 - The basic untreated groundwater analytical suite used by the NFGWS in Summer 2014 should be used for monitoring untreated water quality where more detailed assessments of water quality are required (see **Appendix 5**).
- If the water quality appears generally stable during this period then the monitoring frequency for the expanded suite could be reduced to quarterly, with the current suite used on the intervening monthly events.
- The GWS should consider carrying out tracer testing between known surface karst features (e.g. caves) within the ZOC and the source borehole, to confirm the proposed karst pathway intersected by the borehole. This confirmation would support any management decisions relating to any potential sources of pollution which may be discharging to the karst pathway. Tracer testing should also include any karst features in the ZOC uncertainty area indicated in Figure 7.
- Comprehensive hazard mapping within the delineated ZOC should be undertaken, particularly in relation to the location of karst features and extreme groundwater vulnerability areas. The location of some land use activities within the local area has already been determined. Any risks of contamination to the supply can be assessed by comparing these to the delineated ZOC and groundwater vulnerability map (**Figure 4**).

Desirable

- The GWS should seek advice with respect to undertaking a cryptosporidium risk assessment for this supply.
- The following EPA guidelines may serve as future useful reference documents for the Ballyaneen Rakerin 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^[1].
 - 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^[2].

^[1]http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno7.html#.UpNP_eJ9KEp

^[2] <http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno8.html#.UpNQf-J9KEo>

7. References

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Teagasc, 2006. Soils and Subsoils map of County Galway. Map produced as part of EPA Soils and Subsoils Mapping Project. Teagasc, Kinsealy, Dublin.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edition New York: John Wiley & Sons.

Figures

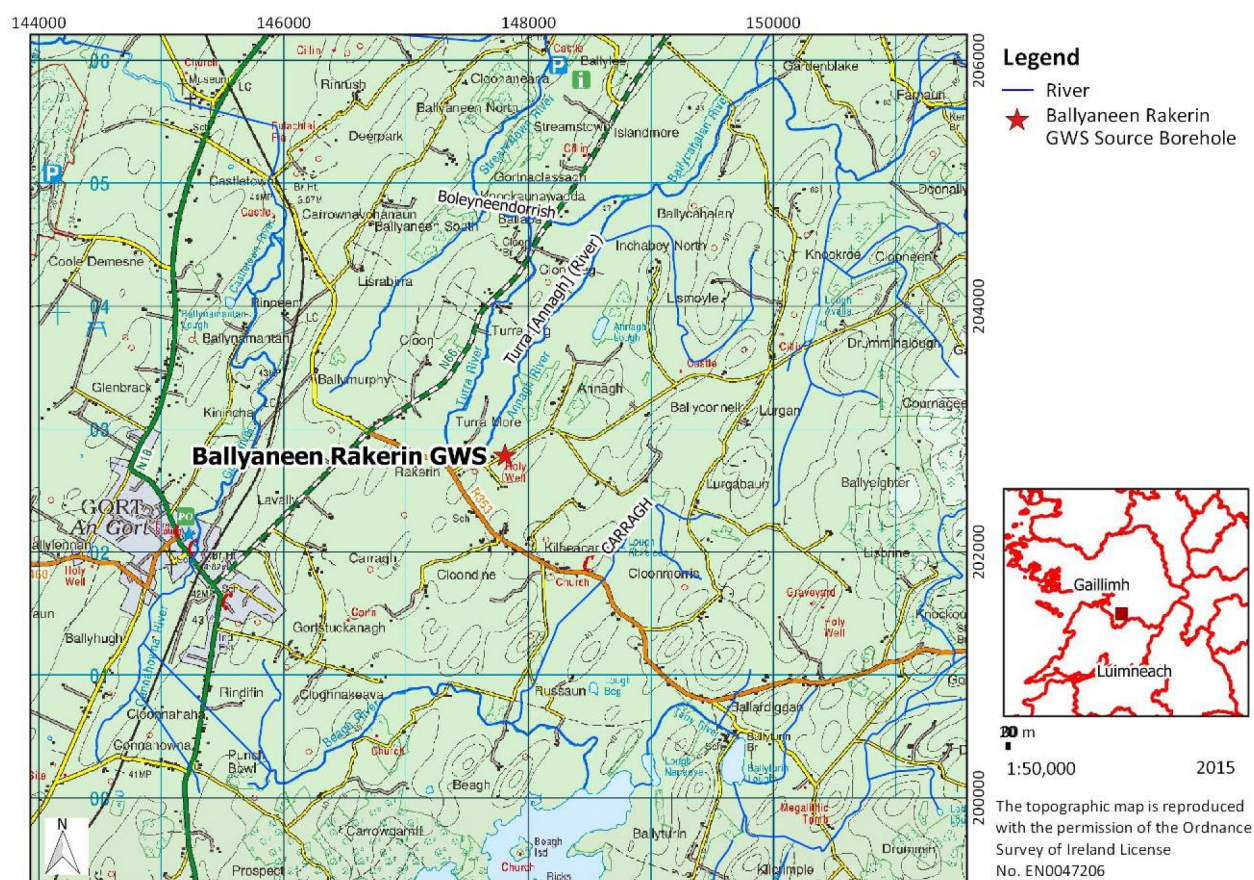


Figure 1: Location Map (OSi Discovery Series Map. 1:50,000 Scale)

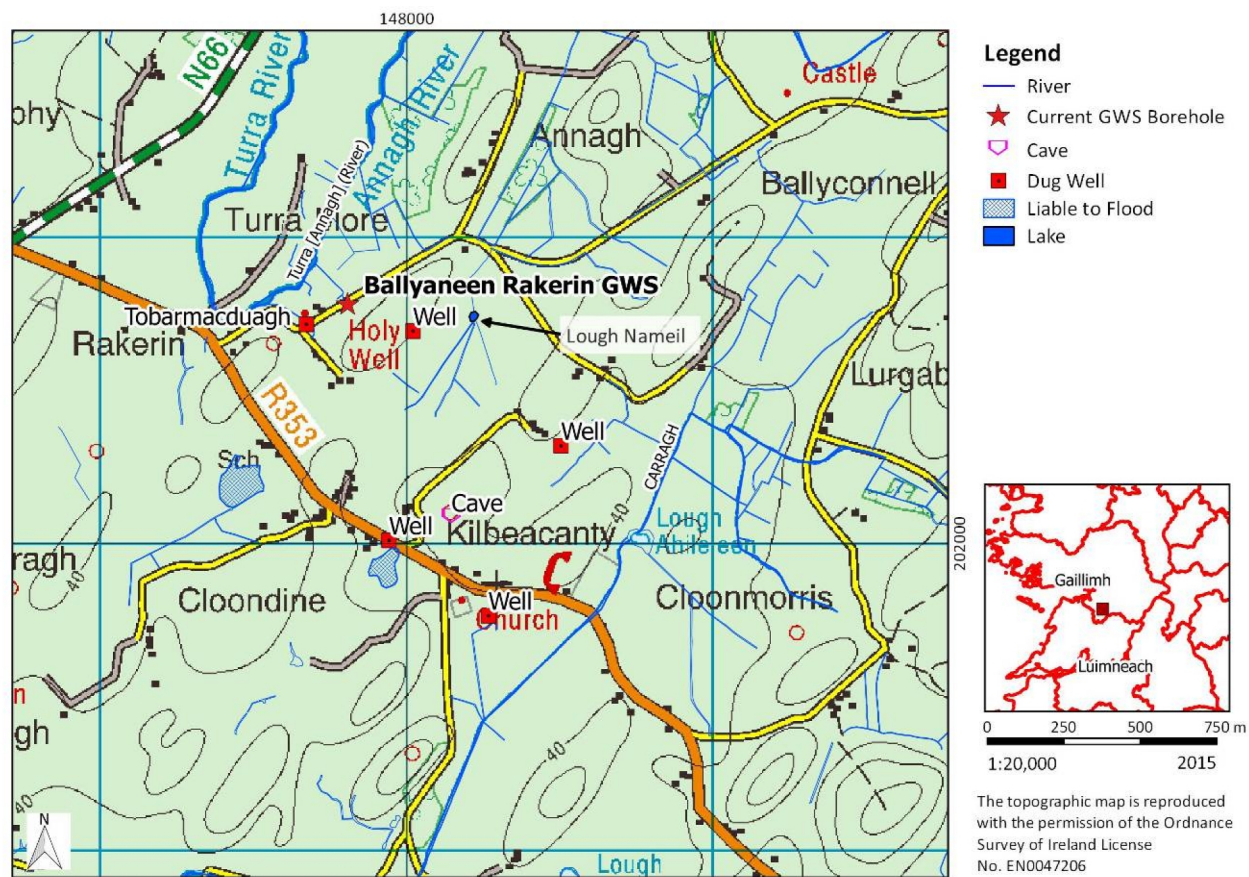


Figure 2: Topography and Drainage

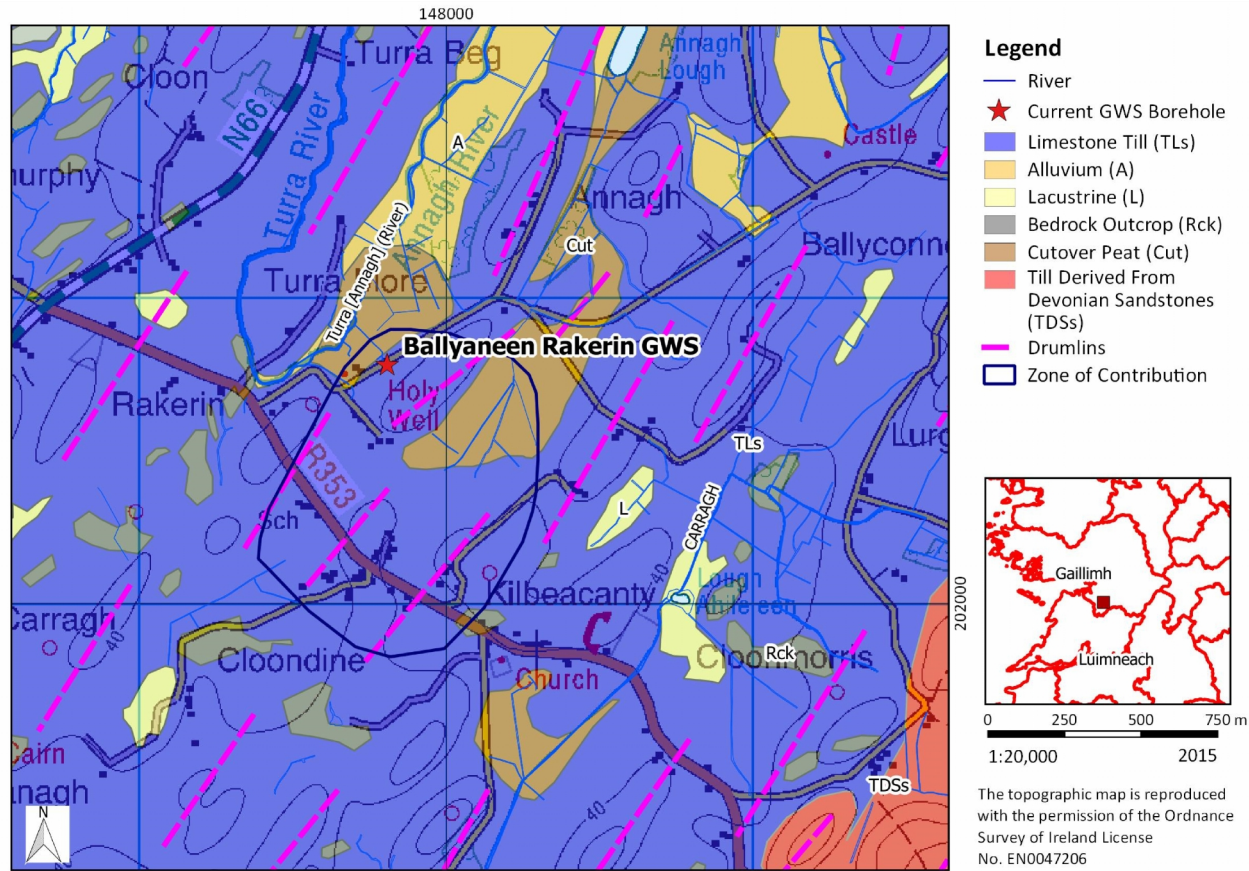


Figure 3: Subsoil Map

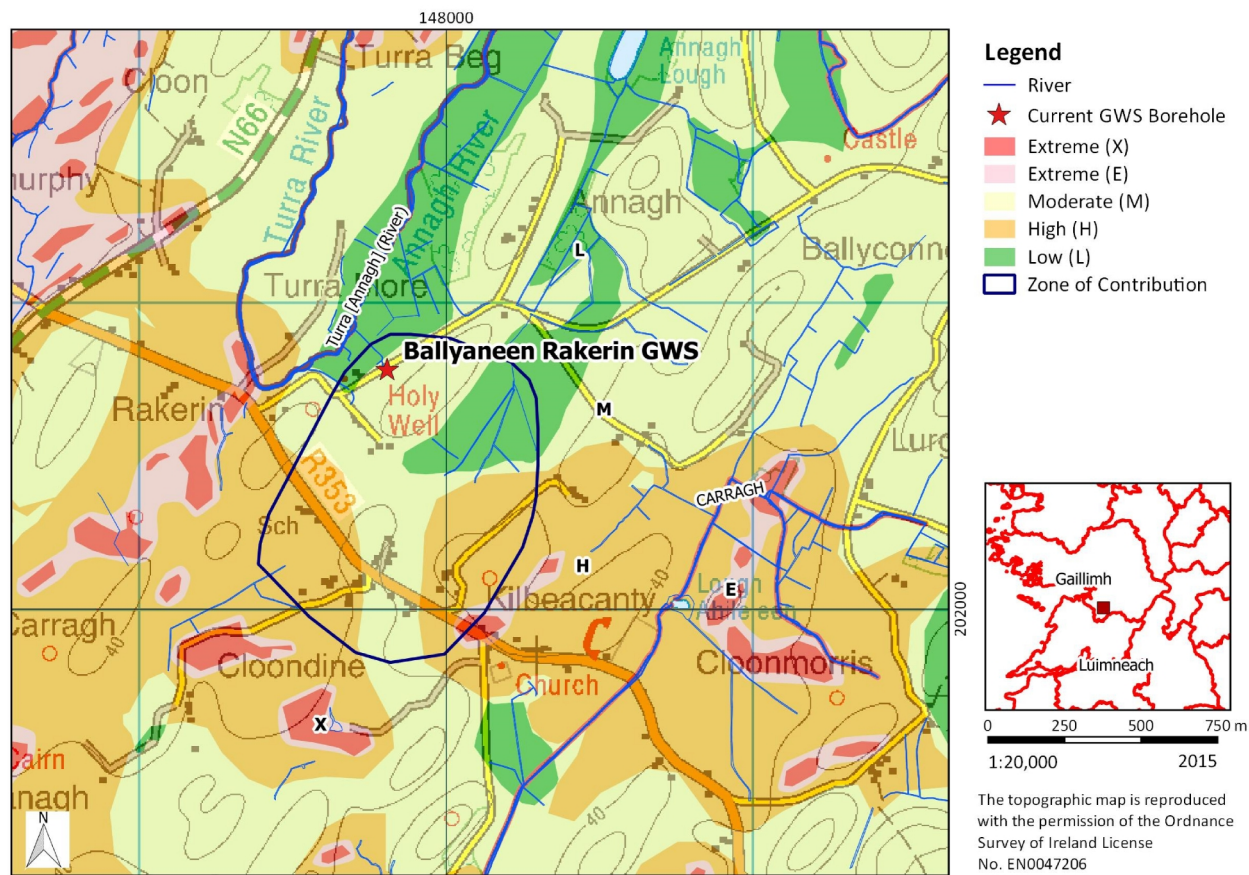


Figure 4: Groundwater Vulnerability Map

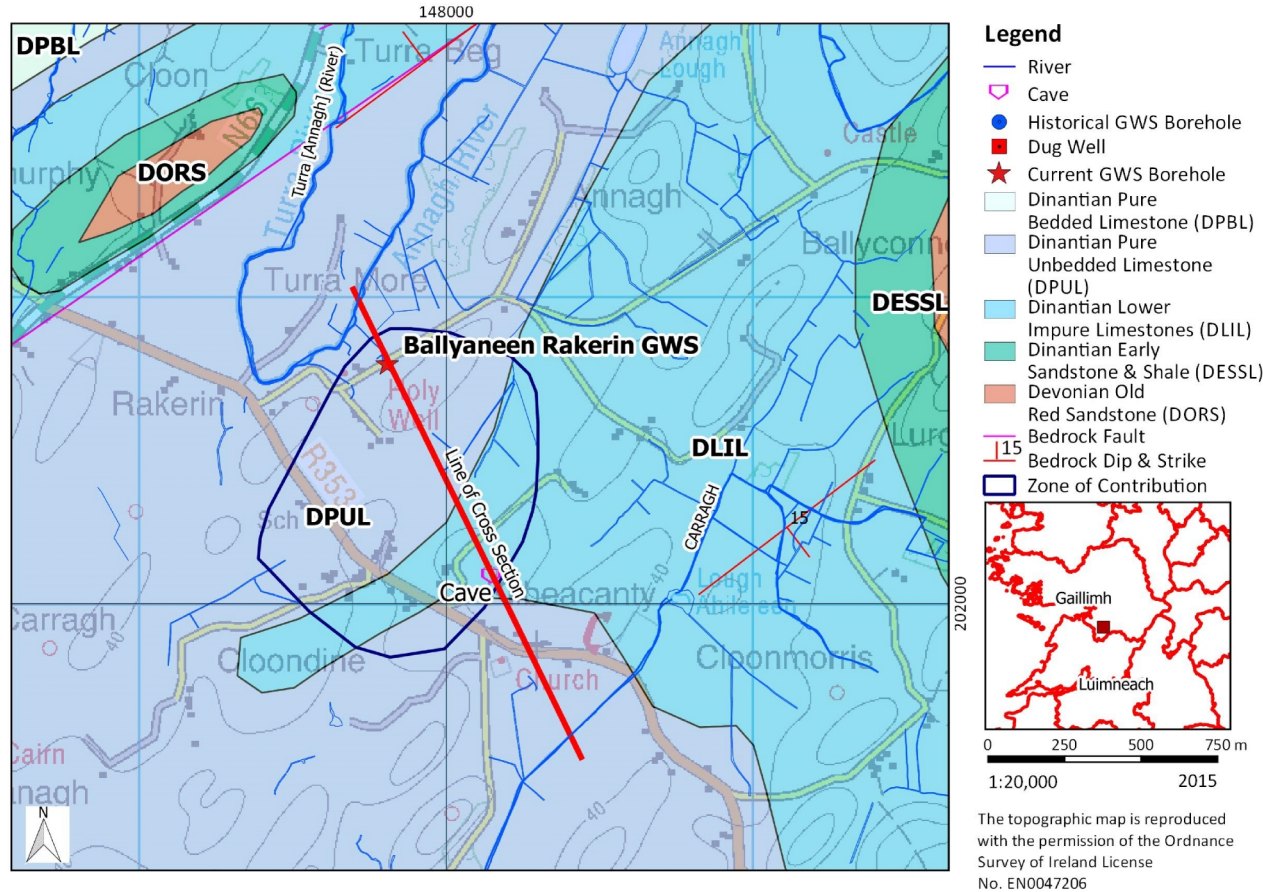


Figure 5: Rock Unit Group Map

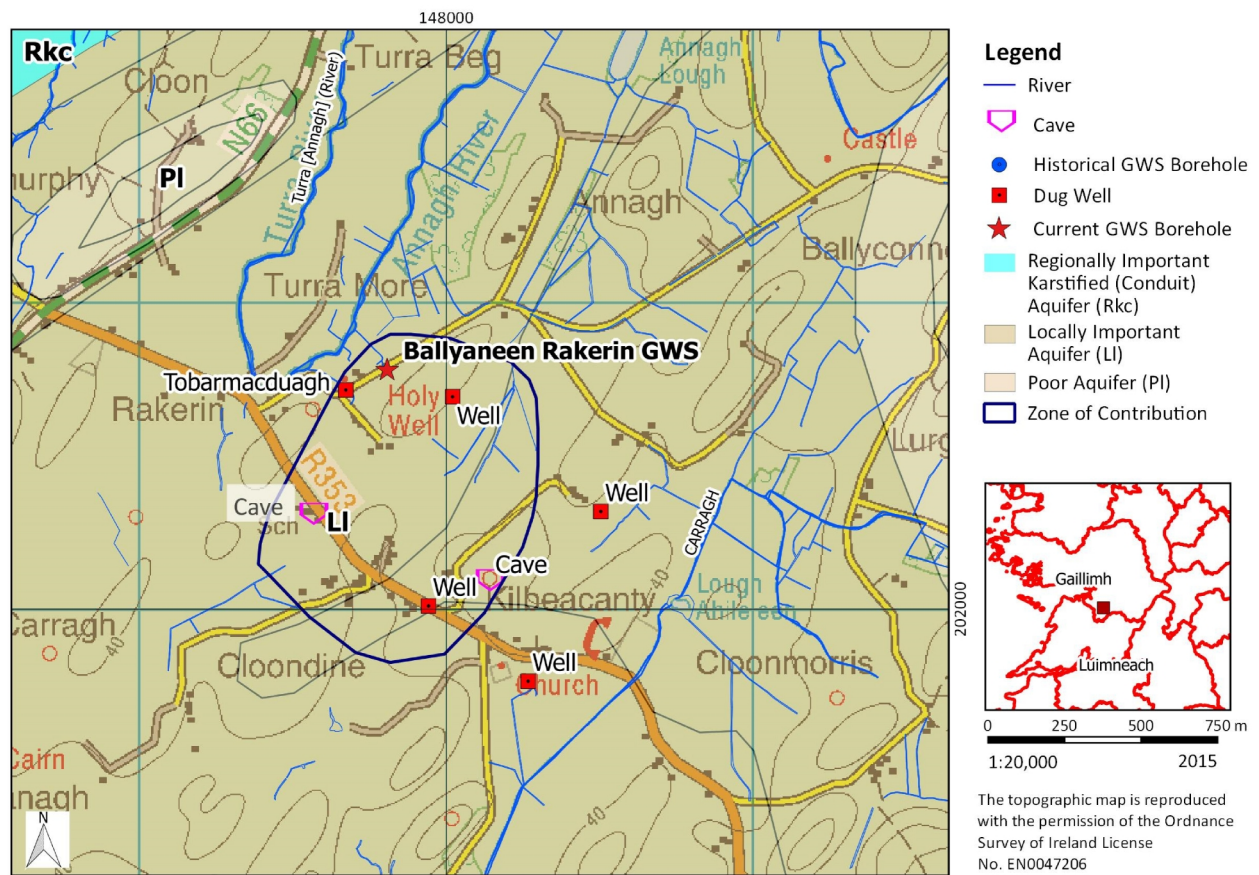


Figure 6: Aquifer Map

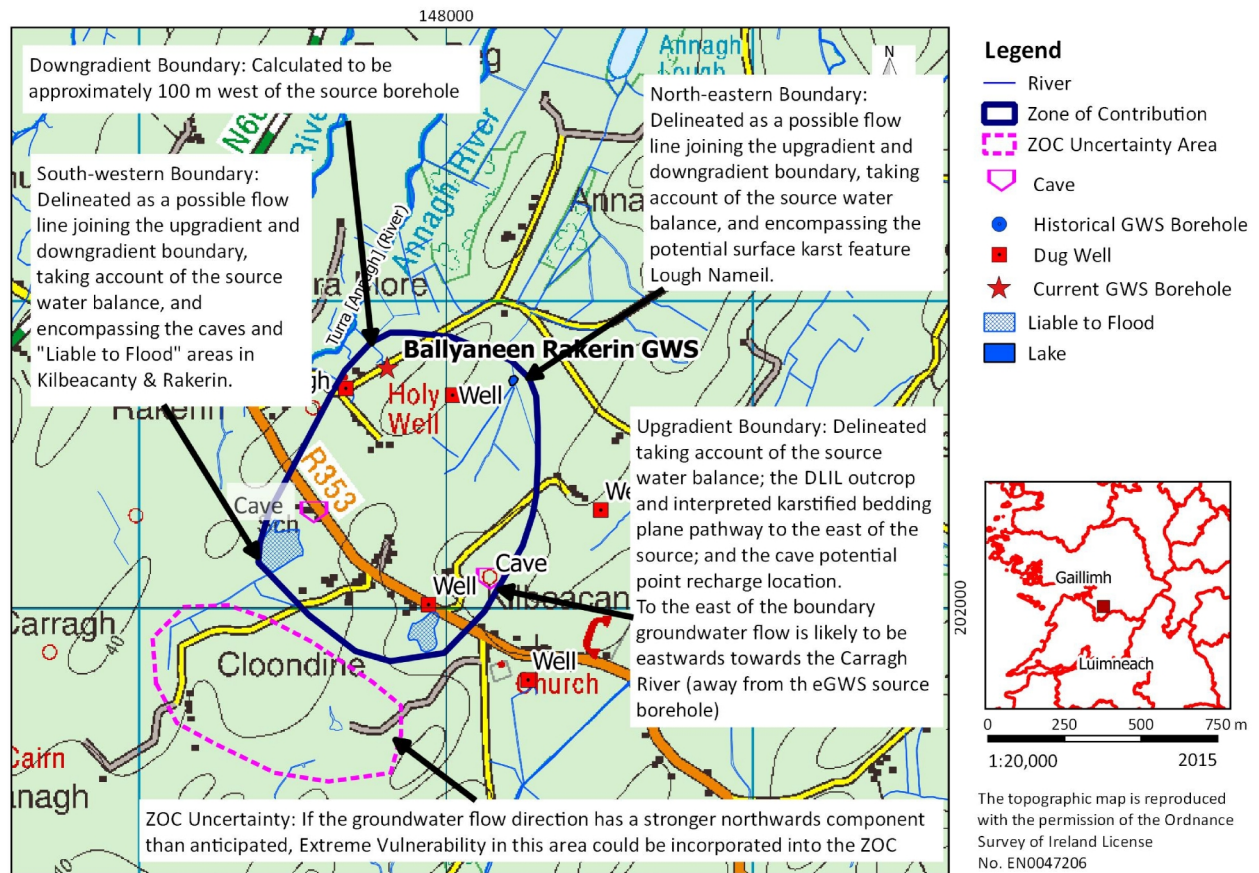


Figure 7: ZOC Boundaries

APPENDIX 1

Acronyms and Glossary of Terms

Acronyms

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 spring 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 2

Borehole Logs



Hydro-G

Drilling Purpose: Trial Borehole				Site: Ballyneen Rathlieman GMS DB02	
Location: Tow nland = Annagh, ~3 km North East of Gort, Co. Galway				Hydro-G Project Ref: 09229 RH, Ballyneen Drilling	
National Grid Co-ordinates: 147810 202776				Site Particulars: Existing Well has turbidity & draw down issues, tight site, little room left to drill, Water Treatment Plant up and running off 30 yr. old BH on site. 2027 Design Demand for this Source = 250 m3/d	
Client: Galway County Council/Ryan Hanley				Date Drilled: 20th, 21st, 22nd July 2011	
Drilled By: P Bricody & Sons Ltd. (Aikman Drilling)				Method: DTH Hammer & Compressed Air Flush	
Logged By: Pamela Bartley				Notes	
Depth* (m bgl)	Description	Colour	LOG	Drill Diameter (inches)	Installation Details
0	Ground Level			8"	
0.3	Topsoil	Brown		8"	8" Diameter Steel casing in Overburden to Top of Rock
0.3	overburden subsoil: clayey brown GRAVEL (angular chipped returns = ? Made ground from site construction period)	Brown		8"	
3	overburden subsoil: CLAY & GRAVEL (equal constituents, wet and rounded gravels 30-40mm diam GRAVELS)	Grey		8"	
3.5	Top of rock, mucky, weathered			8"	
4	Solid ROCK LIMESTONE, Black, DRY			8"	
5	Water Strike in limestone, no discernable weathered zone: dirty milky grey water returned			8"	
	Solid ROCK LIMESTONE, Black, DRY			8"	
	likely to be 'LUCAN FORMATION' Dark limestone and Shale (calp)			8"	
17.5	small anomaly in limestone			8"	
18.5	small anomaly in limestone, calcite chips, discharge turns clayey coloured			8"	
	Solid ROCK LIMESTONE, Black, DRY			8"	
	likely to be 'LUCAN FORMATION' Dark limestone and Shale (calp)			8"	
24	anomaly, resistance to hammer, calcite chips returned, very milky grey			8"	
25	water returned, increase in volumes of water returned			8"	
32	Solid, HARD, Limestone: Black, no change, just end of days drilling			8"	
	likely to be 'LUCAN FORMATION' Dark limestone and Shale (calp)			8"	
65	stop to measure flow, no change in the Limestone: HARD, black, solid			8"	
	likely to be 'LUCAN FORMATION' Dark limestone and Shale (calp)			8"	
	no discernable strikes??? Groundwater discharge from rig increases, could be enhanced development higher up in the borehole?			8"	
85	stop to measure flow, no change in the Limestone: HARD, black, solid			8"	
97	softer limestone but no change of colour, no change in texture of rock			8"	
	returned at surface, no evidence of fossils (the mapped 'Ballysteen formation' for this area would be 'fossiliferous', dark grey). No evidence of lime-mudstone, no evidence of powder returns and no pale grey returns of bedrock spoil (which would be expected of the 'Whalsortian Limestones also mapped for this area).			8"	
102				8"	
119	serious calcite returns in the limestone chippings			8"	
121	green chips returned			8"	
124	red/dark brown returns... silty, chippy			8"	
	likely start of Upper Devonian 'Ayle River Formation' (mudstone, siltstone conglomerate)			8"	
128	green, slaty, chippy			8"	
	avacado coloured discharge waters			8"	
130	calcite returns in Black limestone chippings			8"	
130	green marble coloured chips in the Black coarse grained limestone returns, mossy colour to some of the calcite returns			8"	
130	return to the slaty green chipped returns			8"	
130	END BORE			8"	
*DEPTHS NOT TO VERTICAL SCALE					

Notes:

LOG legend	
	Topsoil
	Sand
	Clay
	Gravel
	Limestone
	Upper Devonian Period mudstones, siltstones, sandstones, conglomerates

Development Notes:

Did some air bailing on the way down as we drilled: on encountering zones at 17m, 18m, 25m, and just clearing out just due to depth at 85m. On the way back up (i.e. during afternoon of Rod Removals): measured discharge from 6" discharge pipe connected to sealed rig head at the following depths (FRIDAY 22/07/2011):

12 noon	at 130 m bgl	: 2 gal/3 secs = 11 m3/hr approx (260 m3/d, approx) = total discharge from total depth of 130 m Borehole
3.40 pm	at 25 m bgl	: 2 gal/2 secs = 16 m3/hr approx (approx 393 m3/d) = total discharge: most promising zone*
3.50 pm	at 18 m bgl	: 2 gal/3 secs = 11 m3/hr approx (260 m3/d, approx) = total discharge from total depth of 130 m Borehole
3.55 pm	at 15 m bgl	: 2 gal/3 secs = 11 m3/hr approx (260 m3/d, approx) = total discharge from total depth of 130 m Borehole
4.15 pm	at 25 magain	: 2 gal/2 secs = 16 m3/hr approx (approx 393 m3/d) = total discharge: most promising zone*

* Why should we observe a higher discharge volume here = not losing water back into this weathered zone.

Friday 22/07/2011 WL in this newly trial well (9.30am) is 2.5 m bgl. WL in existing on-site pumping well = 35.6 m bgl (indicates poor connectivity between the two wells - the existing pumping well has been pumping at ~6m3/hr for at least 9 hrs previous).



Depth* (m bgl)	Description FROM TRIAL WELL DRILLING	Colour	LOG	Diameter (inches)	Installation Details	ADDITIONAL NOTES FROM PRODUCTION WELL DRILLING
0	Ground Level					
-0.3	Topsoil	Brown Brown		12"		
--	overburden subsoil: clayey brown GRAVEL (angular chipped returns = ? Made ground from site construction period)					
-3	overburden subsoil: CLAY & GRAVEL (equal constituents, wet and rounded gravels 30-40mm diam GRAVELS)	Grey				
-3.5	Top of rock, mucky, weathered					
-4	Solid ROCK: LIMESTONE, Black, DRY			10"		
-5	Water Strike in limestone, no discernable weathered zone: dirty milky grey water returned					confirmed with Gian Agua that the pump at this site's existing well will fit in a 6" casing. Therefore, plan to install 6" BOODE solid walled pump chamber casing to a depth of 15-16m bgl cement grouted annulus to 16-16m bgl to seal off the 4.5 to 5m waqter ingress zone. clayey returns
	Solid ROCK: LIMESTONE, Black, DRY likely to be LUCAN FORMATION: Dark limestone and Shale (calp')				10" Diameter Steel casing in Overburden to Top of Rock	
16					6" Diameter BOODE Pump Chamber: Ground Level to 16m bgl	
17.5	small anomaly in limestone				pumped (tromie pipe) Cement Grout from 16m bgl to overflow observance at GL Filling annulus between 10" drilled diameter and 6" BOODE Pump Chamber.	calcite returns in chippings Brown discharge waters reutmed: clayey
18.5	small anomaly in limestone, calcite chips, discharge turns clayey coloured Solid ROCK: LIMESTONE, Black, DRY likely to be LUCAN FORMATION: Dark limestone and Shale (calp')					QUITE WEATHERED AND BROKEN at 18m bgl
24	anomaly, resistance to hammer, calcite chips returned, very milky grey water returned, increase in volumes of water returned					Drilling Hammer and rod stop in reaction to formation or water entry force at this level. Pressure build up. 2 major shocks applied after rest periods. Development with air pressure, very milky white groundwater returns (2.50 pm to 3.15 pm 29th July, Monday, 2011)
33	Solid, HARD, Limestone: Black, no change, just end of days drilling likely to be LUCAN FORMATION: Dark limestone and Shale (calp')				10" Diameter OPEN BOREHOLE drilled to 42 m bgl	
38	VERY VERY VERY HARD					
42	end 10" Diameter DRILLING			6 "		42 m bgl = end 10" Diameter DRILLING, this is the depth of the current pump set level. It is envisaged that the drawdown characteristic of this new Production Well will allow for the pump to be set within the BOODE Pump Chamber. However, if the operational drawdown characteristic dictates that it be at a greater depth then there is no reduction/restriction in bore diameter until 42m. Even at that level of 42m, the 6" open home diameter to 139m depth will accomodate the pump.
65	likely to be LUCAN FORMATION: Dark limestone and Shale (calp'):					
85						
97	softer limestone but no change of colour, no change in texture of rock returned at surface, no evidence of fossils (the mapped 'Ballysteen formation' for this area would be 'fossiliferous', dark grey). No evidence of lime-mudstone, no evidence of powder returns and no pale grey returns of bedrock spoil (which would be expected of the Waulsortian Limestones also mapped for this area).				6" Diameter OPEN BOREHOLE to 139m bgl	
102						
119	serious clacite returns in the limestone chippings					
121	green chips returned					
124	red/dark brown returns... silty, chippy likely start of Upper Devonian 'Ayle River Formation' (mudstone, siltstone conglomerate)					
128	gren, slakey, chippy					
	avacado coloured discharge waters					
130	clacite returns in Black limestone chippings					
136	green marble coloured chips in the Black coarse grained limestone returns, mossy colour to some of the calcite returns					
138	return to the slatey green chipped returns					
139	END BORE					
*DEPTHS NOT TO VERTICAL SCALE						
Notes:-						

LOG legend

	Topsoil
	Sand
	Clay
	Gravel
	Limestone
	Upper Devonian to Permian mudstones, siltstones, sandstones, conglomerates.

PRODUCTION WELL Notes:
 Did some air bumping on the way down as we drilled: on encountering zones at 17m, 18m, 25m, and just clearing out just due to depth at 85m. the BOODE PUMP CHAMBER was installed by siting on a column of pea gravel, which we extracted after the cement grouting of the BOODE had set off (Calcium Chloride was used to enhance setting). The entire borehole depth to 139 m bgl was therefore cleaned out and developed on retrieval of rods.

DEVELOPMENT DETAIL
 2/17/2011: gravel fully retrieved and full depth penetrated to 139m bgl by 5pm
 28/7/2011: start development at 10.10 am, development at 27m, 26 m, 25m, 24m, 23m: multiple shocks and rests.
 Water samples from 12 noon to 4pm Physicochemical only: range from 62m to 537 uS/cm, 12 to 12.8 oC, 8 pH, 288 to 302 tds
 28/7/2011: Final blast at 25m zone at 2.05 pm, retrieve rods to 18m bgl, develop until 4pm gently, clear water returned by 3pm, develop for one more hour. CLEAR

Water Level = 3.86 m bed at 4.45 pm, 3.44 m bed at 9pm (water level recovery in new production well even though existing well was being pumped at ~6m3/hr from 4am to 9pm continuous)

APPENDIX 3

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 DfE G/EPA/GSla (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 4

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 Guidance Document GW5 (Groundwater Working Group 2005).

Table 2: Recharge coefficients for different hydrogeological settings.

Vulnerability category		Hydrogeological setting	Recharge coefficient (rc)		
			Min (%)	Inner Range	Max (%)*
Extreme	1.i	Areas where rock is at ground surface	60	80-90	100
	1.ii	Sand/gravel overlain by 'well drained' soil	60	80-90	100
		Sand/gravel overlain by 'poorly drained' (gley) soil			
	1.iii	Till overlain by 'well drained' soil	45	50-70	80
	1.iv	Till overlain by 'poorly drained' (gley) soil	15	25-40	50
	1.v	Sand/ gravel aquifer where the water table is ≤ 3 m below surface	70	80-90	100
	1.vi	Peat	15	25-40	50
High	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	60	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by 'well drained' soil	60	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil			
	2.iv	Moderate permeability subsoil overlain by 'well drained' soil	35	50-70	80
	2.v	Moderate permeability subsoil overlain by 'poorly drained' (gley) soil	15	25-40	50
	2.vi	Low permeability subsoil	10	23-30	40
	2.vii	Peat	0	5-15	20
Moderate	3.i	Moderate permeability subsoil and overlain by 'well drained' soil	25	30-40	60
	3.ii	Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil	10	20-40	50
	3.iii	Low permeability subsoil	5	10-20	30
	3. iv	Basin peat	0	3-5	10
Low	4.i	Low permeability subsoil	2	5-15	20
	4.ii	Basin peat	0	3-5	10

APPENDIX 5

Ballyaneen Rakerin GWS Borehole Untreated Water Quality Data

Ballyaneen Rakerin GWS Borehole Treated Water Quality Data

Untreated Groundwater Quality Monitoring Parameter Suite

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliform	Fecal Coliform	TOC
Units	mg/l PtCo	NTU	uS/cm	6 to 9	mgN/l	mgN/l	mgN/l	ug/l	ug/l	ug/l	cfu/100ml	cfu/100ml	mg/l
SI278of 2007 - DWS	(20 Hazen)	4	1500	6 to 9	0.175	11.3	0.15	200	200	50	0/100ml	0/100ml	NAC
01/11/2000	7.5	0.75	705	6.74	0.30	0.4	0.05	<4	130	46	<1	<1	
01/12/2000	15	0.78	712	6.86	0.30	0.8	0.05	4	600	270	<1	<1	
01/01/2001	5	9.45	695	6.75	0.30	0.6	0.05	58	220	161	<1	<1	
01/02/2001	7.5	5.37	746	6.67	0.20	0.6	<0.05	<4	120	41	<1	<1	
01/05/2001	10	7.23	771	6.63	0.10	<0.1	0.012	19	450	181	<1	<1	
01/06/2001	7.5	1.24	807	6.85	0.15	0.9	0.01	9	59	91	<1	<1	
01/07/2001	7.5	1.56	849	7.46	0.10	0.9	0.005	11	18	41	<1	<1	
01/09/2001	15	1.04	755	7.15	0.45	<0.1	0.007	<4	365	504	60	13	
01/08/2001	15	0.3	798	7.13	0.25	1	0.003	4	122	266	28	1	
01/10/2001	20	4.38	822	7.39	0.15	1.3	0.002	<4	462	402	164	33	
01/11/2001	10	1.75	747	7.37	0.10	1.1	0.008	<4	269	234	2	1	
14/08/2014	<5	0.52		7.07	0.28	<2	0.03	<5	68	13			<3
11/09/2014	<5	<0.5		7.071	0.30	<2	0.03	<5	82	14			0.54
16/10/2014													
13/11/2014	<5	<0.5		7.49	0.53	4.1	<0.016	<5	99	10			0.53
11/12/2014	<5	<0.5		7.35	0.34	<2	0.03	<5	88	10			1.3
15/01/2015	<5	<0.5		7.31	0.30	<2	<0.016	<5	41	9			0.94
12/02/2015	<5	0.77		7.41	0.33	<2	0.07	7	439	30			0.62
12/03/2015	<5	0.61		7.32	0.91	<2	0.03	5	104	31			0.7
09/04/2015	11	3.38		7.34	0.34	3.1	0.2	11	251	19			0.77
15/05/2015	<5	<0.5		7.24	0.32	<2	<0.016	5	59	12			<3
11/06/2015	<5	<0.5		7.06	0.10	2.6	0.03	8	33	6			2.68
09/07/2015													
24/07/2015											>201	18	
24/07/2015	72.5	7.4		7.4	0.167	0.32	<0.005	<2	<10	1241			
24/07/2015	45.9	4.6		7.3	0.41	0.39	0.02	<2	481	102			
24/07/2015	53.9	4.3		7.4	0.41	0.34	0.02	<2	523	89			
24/07/2015	62.9	1.1		7.6	0.30	0.34	<0.005	<2	28	1492			
30/07/2015										880			
30/07/2015		2.35		7.24	0.41	<2	0.07	10	590	700			1.2
Count	25	26	11	26	26	26	26	26	26	27	12	12	11
Average	22.9	2.9	764	7.2	0.3	1.2	0.0	12.6	228.0	255	64	13	1.0
Max	72.5	9.5	849	7.6	0.9	4.1	0.2	58	600.0	1492	>201	33	2.7
Min	<5	<0.5	695	6.6	0.1	<0.1	<0.005	<2	<10	6.0	<1	<1	0.5

Parameter	TOC	BOD	COD	Alkalinity	Sodium, Total	Chloride	Dissolved O2	Potassium, Total	Hardness, Total	Magnesium Total	Silica	Sulphate	Orthophosphate
Units	mg/l	mg/l	mg/l	mg/l as CaCO3	mg/l	mg/l	% Sat	mg/l	mg/l as CaCO3	mg/l	mg/l as SiO2	mg/l	mg/l as PO4-P
SI278of 2007 - DWS	NAC				200	250						250	
Count	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Max	0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	0.0	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Parameter	Calcium, Total	Copper, Dissolved	Lead, Dissolved	Chromium, Dissolved	Nickel, Dissolved	Cadmium, Dissolved	Arsenic, Dissolved	Zinc, Dissolved	Barium, Dissolved	Clostridium Perfringens	Strontium	Fluoride	Potassium: Sodium
Units	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	cfu/100ml	ug/l	mg/l	Ratio
SI278of 2007 - DWS		2000	10	50	20	5	10					0.8	
24/07/2015										2			#DIV/0!
24/07/2015		<1	<0.5										
24/07/2015		<1	3										
24/07/2015		<1	<0.5										
24/07/2015		2	<0.5										
Count	0	4	4	0	0	0	0	0	0	1	0	0	1
Average	#DIV/0!	2.0	3.0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	2.0	#DIV/0!	#DIV/0!	#DIV/0!
Max	0.0	2.0	3.0	0.0	0.0	0.0	0.0	0.0	0	2.0	0	0.0	#DIV/0!
Min	0.0	<1	<0.5	0.0	0.0	0.0	0.0	0.0	0	2.0	0	0.0	#DIV/0!

Date							11/06/2008	20/10/2008	28/10/2008	28/10/2010	14/12/2010	04/07/2011	22/08/2011
Location	Units (Assumed)	51278 of 2007 - DWS	Count	Average	Max	Min	BALDWIN'S HOUSE CONTACT	Patrick Baldwins, Dwellling House, Outside Tap	Fordes House, Ballyaneen, Gort	BALDWIN'S HOUSE CONTACT	BALDWIN'S HOUSE CONTACT	Patrick Baldwins, Dwellling House, Outside Tap	Donohues
1,2-dichloroethane	ug/l	3	1	0.10	0.10	0.10	0.1						
Aluminium	ug/l	200	19	10.96	26.00	<5	16.5	26	20				6
Ammonium	mg/l	0.3	17	0.06	0.25	<0.013	0.104	0.03	0.03			0.01	0.254
Antimony	ug/l	5	1	0.10	0.10	0.10	0.1						
Arsenic	ug/l	10	4	0.78	2.30	0.20	0.2				0.323	2.3	
Benzene	ug/l	1	1	0.10	0.10	0.10	0.1						
Benzo(a)pyrene	ug/l	0.01	1	0.003	0.003	0.003	0.003						
Boron	mg/l	1	3	0.05	0.10	0.02	0.02					0.02	
Bromate	ug/l	10	1	1.00	1.00	1.00	1						
Cadmium	ug/l	5	2	0.10	0.10	0.10	0.1						
Chloride	mg/l	250	3	16.11	30.00	0.02	30					0.02	
Chromium	ug/l	50	1	1.00	1.00	1.00	1						
Clostridium Perfringens	no/100 ml	0	22	0.2	1	0	0	1	0	1		0	0
Coliform Bacteria	no/100 ml	0	22	17	201	0	201	0	0	2		0	0
Colour		AC & NAC	18	11.09	23.30	6.30	7.94	6.3	9.4	7.9		13.5	9.8
Conductivity	uS/cm	2500	11	618	753	497	724	745	753	669		703	591
Copper	mg/l	2	3	0.004	0.008	0.0001	0.0001					0.008	
Cyanide	ug/l	50	1	5.00	5.00	5.00	5						
E. coli	no/100 ml	0	22	3	36	0	36	0	0	0		0	0
Enterococci	no/100 ml	0	3	6	17	0	17					0	
Fluoride	mg/l	0.8	3	0.14	0.22	0.10	0.1					0.1	
Free Chlorine	mg/l		4	0.06	0.12	0.02		0.04	0.02	0.04	0.12		
Hardness (as CaCO3)	mg/l as CaCO3		0										
Iron	ug/l	200	18	99.45	253.00	<7.2	48.3	146	50	76		190.3	253
Lead	ug/l	25 (10)	2	1.05	1.30	0.80	0.8					1.3	
Manganese	ug/l	50	16	141	2018	1.80	4.5	29	20			2018	
Mercury	ug/l	1	1	0.02	0.02	0.02	0.02						
Nickel	ug/l	20	3	2.70	6.30	0.70	1.1					6.3	
Nitrate	mg/l	50	15	6.57	12.80	0.97	12.8	5.4	6.8	6.9			
Nitrite (at tap)	mg/l	0.5	11	0.02	0.03	0.00004	0.00004						
Odour		AC & NAC	11	0	0	0	0	0	0	0		0	0
PAH	ug/l	0.1	1	0.01	0.01	0.01	0.01						
Pesticides - Total	ug/l	0.5	1	0.01	0.01	0.01	0.01						
pH	[-]	6.5-9.5	21	7.32	7.60	7.09	7.6	7.5	7.3	7.4		7.1	7.2
Selenium	ug/l	10	2	0.40	0.60	0.20	0.2					0.6	
Sodium	mg/l	200	3	23.40	40.10	14.30	14.3					15.8	
Sulphate	mg/l	250	3	14.63	15.90	12.80	12.8					15.2	
Taste		AC & NAC	8	0	0	0	0					0	0
Tetrachloroethene & Trichloroethene	ug/l	10	3	3.40	5.00	0.20	0.2	5	5				
Total Chlorine			0										
Total Organic Carbon	mg/l	NAC	13	1.77	4.66	0.60	3.11					4.66	
Trihalomethanes(Total)	ug/l	100	5	31.78	59.00	5.00	5	45	59			41.86	
Turbidity (at tap)	NTU	AC & NAC	20	0.90	2.70	0.20	0.46	2.7	0.6	0.5		1.33	0.7

Date		23/01/2012	13/02/2012	15/05/2012	08/08/2012	08/10/2012	14/08/2014	11/09/2014	16/10/2014	13/11/2014	11/12/2014	15/01/2015
Location	Units (Assumed)	Thomas O Donaghue	Sean Boylan, Rakerin, Gort.	Connollys house	Connollys house	Connollys house	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW
1,2-dichloroethane	ug/l											
Aluminium	ug/l	16	5	17	5	6	<5	<5		<5	<5	<5
Ammonium	mg/l		0.011			0.034	<0.013	0.05		0.08	<0.013	<0.013
Antimony	ug/l											
Arsenic	ug/l	0.3										
Benzene	ug/l											
Benzo(a)pyrene	ug/l											
Boron	mg/l	0.1										
Bromate	ug/l											
Cadmium	ug/l	0.1										
Chloride	mg/l	18.3										
Chromium	ug/l											
Clostridium Perfringens	no/100 ml	0	0	0	0	0	<1	<1		<1	<1	<1
Coliform Bacteria	no/100 ml	0	0	0	0	0	<1	<1		<1	<1	<1
Colour				10.6	23.3		<5	<5		<5	<5	<5
Conductivity	uS/cm	530	497	517	526	539						
Copper	mg/l	0.003										
Cyanide	ug/l											
E. coli	no/100 ml	0	0	0	0	0	<1	<1		<1	<1	<1
Enterococci	no/100 ml	0										
Fluoride	mg/l	0.22										
Free Chlorine	mg/l											
Hardness (as CaCO3)	mg/l as CaCO3											
Iron	ug/l			22		10	<7.2	<7.2		<7.2	<7.2	<7.2
Lead	ug/l											
Manganese	ug/l	1.8					20	21		10	6	2
Mercury	ug/l											
Nickel	ug/l	0.7										
Nitrate	mg/l	0.97					<8.9	<8.9		<8.9	<8.9	<8.9
Nitrite (at tap)	mg/l						<0.016	<0.016		<0.016	<0.016	<0.016
Odour		0	0	0	0	0						
PAH	ug/l											
Pesticides - Total	ug/l											
pH	[-]	7.5	7.1	7.5	7.3	7.4	7.11	7.176		7.088	7.31	7.31
Selenium	ug/l											
Sodium	mg/l	40.1										
Sulphate	mg/l	15.9										
Taste		0	0	0	0	0						
Tetrachloroethene & Trichloroethene	ug/l											
Total Chlorine												
Total Organic Carbon	mg/l	0.94					<0.5	<0.5		0.71	1.09	<0.5
Trihalomethanes(Total)	ug/l	8.02										
Turbidity (at tap)	NTU	1.19		0.8	0.7	0.2	<0.5	<0.5		<0.5	<0.5	<0.5

Date		12/02/2015	12/03/2015	09/04/2015	15/05/2015	11/06/2015	09/07/2015	24/07/2015	30/07/2015
Location	Units (Assumed)	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	GlanAgua WTW	Ballyaneen Treated	Ballyaneen Treated
1,2-dichloroethane	ug/l								
Aluminium	ug/l	7	7	8	5	9			
Ammonium	mg/l	0.05	0.03	0.05	<0.013	<0.013			
Antimony	ug/l								
Arsenic	ug/l								
Benzene	ug/l								
Benzo(a)pyrene	ug/l								
Boron	mg/l								
Bromate	ug/l								
Cadmium	ug/l								
Chloride	mg/l								
Chromium	ug/l								
Clostridium Perfringens	no/100 ml	<1	<1	<1	<1	<1		0	
Coliform Bacteria	no/100 ml	<1	<1	<1	<1	<1		0	
Colour		<5	<5	<5	<5	<5			
Conductivity	uS/cm								
Copper	mg/l								
Cyanide	ug/l								
E. coli	no/100 ml	<1	<1	<1	<1	<1		0	
Enterococci	no/100 ml								
Fluoride	mg/l								
Free Chlorine	mg/l								
Hardness (as CaCO3)	mg/l as CaCO3								
Iron	ug/l	<7.2	<7.2	<7.2	<7.2	<7.2			
Lead	ug/l								
Manganese	ug/l	6	4	11	39	17			41
Mercury	ug/l								
Nickel	ug/l								
Nitrate	mg/l	<8.9	<8.9	<8.9	<8.9	<8.9			
Nitrite (at tap)	mg/l	0.03	<0.016	<0.016	<0.016	<0.016			
Odour									
PAH	ug/l								
Pesticides - Total	ug/l								
pH	[-]	7.4	7.37	7.35	7.23	7.43			
Selenium	ug/l								
Sodium	mg/l								
Sulphate	mg/l								
Taste									
Tetrachloroethene & Trichloroethene	ug/l								
Total Chlorine									
Total Organic Carbon	mg/l	<0.5	<0.5	0.6	<3	1.31			
Trihalomethanes(Total)	ug/l								
Turbidity (at tap)	NTU	<0.5	<0.5	<0.5	<0.5	0.73			

Raw Water Analysis Parameters Required for ZOC Delineation
Turbidity
pH
Conductivity @20C
Alkalinity, total
Sodium, total
Chloride
Ammonium as NH ₄
Nitrate as NO ₃
Dissolved Oxygen (%)
Iron, total
Potassium, total
Total Hardness (Kone)
Magnesium, total
Colour, apparent
Sulphate
Orthophosphate as PO ₄ -P
Manganese, total
Calcium, total
TOC
<i>E coli (Filtration) (Environmental Waters)</i>
<i>Total Coliforms (Filtration) (Environmental Waters)</i>
Optional Extras:
Additional metals: Al, As, Cd, Cr, Cu, Pb, Ni, Zn, Ba, Sr
Fluoride (by Ion Selective Electrode)
Nitrite as N
Silica
BOD (incl. separate COD analysis prior to BOD),
<i>Clostridium perfringens</i>
Onsite filtration kit is required for additional metals consisting of ziplock bag containing luer/lock syringe for trace metals, 0.45um syringe filter, 50ml sample tube) Note: Sampler needs to wear clean pair of powder free gloves before touching any of the items in the bag to prevent cross contamination.