Establishment of Groundwater Zones of Contribution

Errew Group Water Scheme

Errew GWS Spring

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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 Errew 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 underground[1]. Groundwater typically travels very fast in karst aquifers, which has a significant impact on the water quality; neither filtration nor pathogen die-off are associated with these aquifers.

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

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

Errew GWS is supplied by a locally productive sand and gravel aquifer (Lg) with intergranular flow. The supply is sourced from an abstraction point in a multiple spring discharge zone

[1] Geological Survey of Ireland, 2000.

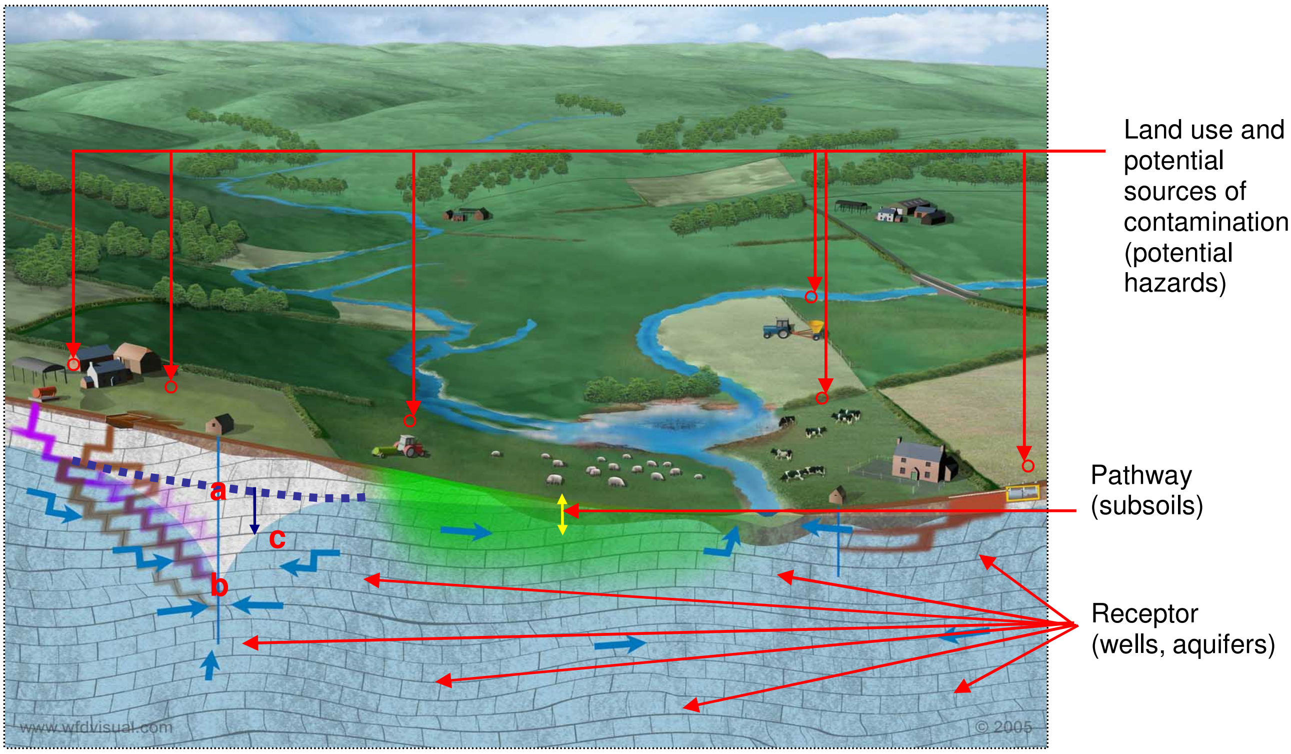

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Errew Group Water Scheme (GWS) is located in the townland of Sranalaghta North, approximately 5 km south of Crossmolina and 2 km west of Lough Conn. It is located in agricultural land, at a distance of approximately 150m from the R315 regional road, access is currently across fields. (See **Figure 1).**

The GWS supply is located in a spring discharge zone which includes Tobernagowna spring which is marked on mid 1800s 1:10,560 scale (six inch) Ordnance Survey topographic maps and the current abstraction point approximately 12 m east south-east of Tobernagowna, which was constructed, with the accompanying sump and pump house, in 1993. The spring discharge zone is located in very poorly drained agricultural land (See Photos 1 and 2) below a break in slope and is the source of a tributary of the Fiddaunglass River, which flows eastwards into Lough Conn at a distance of approximately 2.5 km.

The GWS abstraction point has a depth of approximately 3 m below ground level (b.g.l.), constructed of three stacked concrete o-rings, covered with a heavy concrete lid, which is probably vermin proof, but is not considered to be waterproof. There is no area of hardstanding around the o-rings, which are in direct contact with the subsoil and supported vegetation. The 100 mm outflow pipe located at approximately 1.4 m below the top of the o-rings (approximately 1.4 m b.g.l.) conveys water to a concrete sump beneath the pump house, which is located approximately 6m south east of the abstraction point (See Photo 4). There is access to the sump outside the pump house, with a heavy concrete lids which is probably not vermin proof or waterproof. The pump house has a cast concrete roof and a metal door, which is lockable. The pump sump is potentially open to vermin and potentially to surface water flooding, due to holes in the wall of the pump house. The two pumps were designed as a duty and stand-by system, but only one pump is currently operational.

The current average daily abstraction is estimated to be 194 m^3/day, based on continuous monitoring undertaken on behalf of the GWS between 14/7/2014 and 23/7/2014 (See Appendix 4). The scheme serves a total of approximately 108 connections, including approximately 12 farm connections. The daily abstraction volume is large for such a number of connections, indicating that there may be leakage in the distribution network. A large leak was recorded from 25/7/2014 to the end of the monitoring period on 27/7/2014, with daily abstraction peaking at 1,073 m^3/day.

The total discharge from the spring discharge zone, for which the Zone of Contribution is delineated, is estimated to be of the order of 2,500 m^3/day. (See Appendix 4).

Currently a low pressure UV system is operational, but potentially partially ineffective. There is a chlorine dosing system, which has been operational in the past but is not currently in use. **Table 1** below provides a summary of the spring with currently known information

Table 1. Supply Details

	PW01
Grid reference	112722, 313415
Townland	Sranalaghta
Source type	Spring Well
Drilled	Excavated 1993
Drilling Contractor	Unknown
Owner	Killeen GWS
Elevation (m OD) (Estimated from OSI 1:50,000 Scale	18
Total depth (m)	2.75 m
Construction details	Hole excavated to a depth of >2.75m, the base filled with stones and lined with two stacked 1m diameter o-rings; No grouting or cement pad surrounding the o-rings. Outflow pipe to sump in which pumps are located
Depth to rock (m bgl)	Unknown (Estimated >3 m based on H vulnerability classification and ranges of 10 - 23m depth estimated across the Moy sand and gravel groundwater body (Appendix 1))
Static water level (SWL) when drilled (m bgl)	Unknown
Pump intake depth (m bgl)	1m b.g.l. in pump sump (at a distance of c.6 m from spring location).
Current abstraction rate (GWS)	Average 194 m^3/d
Reported yield (m^3/d)	423 m^3/d (From pump sump, See Appendix 4) Combined discharge of 2,500 m3/d from spring discharge zone

Photographs of Errew GWS Infrastructure

Photo 1: Poorly drained land of spring discharge zone looking west towards pump house

Photo 2: Spring abstraction point and surrounding poorly drained land

Photo 3: GWS abstraction point o-rings with cover

Photo 4: Pump house over sump

Photo 5: External pump sump access

Photo 6: Pumps and holes in pump house wall beside open pump sump

3 Physical Characteristics and Hydrogeological Considerations

Table 2. Physical Characteristics of the Area of Interest

	Spring Location	Description/Comments
Annual Rainfall (mm)	1081	Met Eireann average annual rainfall data 1961-1990 Ballina Climatological Station
Annual Evapotranspiration and Run-off Losses (mm)	21	(Annual rainfall – Annual Effective rainfall)
Annual Effective Rainfall (mm)	1060	GSI Recharge mapping (GSI Website, 2013)
Topography	The spring discharge zone is located on a break in slope at an estimate height of 18m O.D., with a relatively flat area down gradient to the south and south east. The hummocky topography rises overall to the north and north west, to a maximum of 50m O.D. at a distance of 1 km. The surrounding landscape has a low gradient south east towards Lough Conn.	
Land use	The land is predominantly used for grazing and silage production. There is a very low density of dwellings, with one farmstead occurring at a distance of approximately 0.2km to the north north-west and a couple of domestic dwelling at c 0.7 km Two quarries, both currently inactive are located at a distance of 0.53km and 0.5km to the north west respectively.	
Surface Hydrology	The GWS supply is located in a spring discharge zone which includes Tobernagowna spring and the current abstraction point approximately 12m east south-east of Tobernagowna. The spring discharge zone and a number of small drainage channels in their vicinity are the source of a tributary which flows south south west into the Fiddaunglass River, which then flows eastwards into Lough Conn, which is at a distance of c. 2.5 km from the springs. The density of surface water drainage upgradient of that arising from the springs is extremely low.	
Topsoil	Shallow well drained basic mineral soils, interspersed with some shallow poorly drained basic mineral soils. (Teagasc/EPA, 2006).	
Subsoil (**Figure 3**)	Limestone sands and gravels, derived from Carboniferous rocks, dominate. . Cutover peat subsoils occur downgradient of the break in slope occurring at approximately 20m O.D. (Teagasc/EPA, 2006)	
Groundwater Vulnerability (**Figure 4**)	High on limestone sands and gravels; Moderate on cutover peats. See **Appendix 1**	
Geology (Long *et al*, 1992) and Rock Unit Group (**Figure 5**)	The spring discharge zone is located on the eastern edge of a large extent of limestone sand and gravels which overlies the Ballina Limestone Formation, comprising grey limestones and thin shale, classified as belonging to the Dinantian Pure Bedded Limestone Rock Group.	
Aquifer (Figure 6)	A locally productive limestone sand and gravel aquifer (**Lg**) overlies a regionally important karstified aquifer (**Rk**)	
Groundwater Body	Moy SG http://www.gsi.ie/NR/rdonlyres/B92E993A-0648-4079-BD63-8996B7938342/0/MoySG.pdf	Categorised as having 'good' status.
Recharge Coefficient (%) (**Appendix 2**)	4 on peat, 42.5 on wet soil over limestone sand and gravel, 85 on dry soil over limestone sand and gravel	Low recharge (42 mm/yr) occurs across c. approximately 2.4% of the ZOC on peat. Moderate recharge occurs on c. 24% on wet soils over lst. sand and gravel. High recharge occurs on c.74% on dry soils over lst. sand and gravel (GSI Recharge Mapping). The proportion of the ZOC receiving the high recharge rate is likely to be greater than that mapped (See Appendix 2) and the higher rate has therefore been assigned to a larger area.
Recharge (mm/yr) (**Appendix 2**)	42 on peat, 450 on wet soil over limestone sand and gravel, 901 on dry soil over limestone sand and gravel	

3.1 Hydrochemistry and water quality

Raw water samples have been compared to the drinking water standard (SI 122 of 2014) (Drinking Water Limits) and the European Communities Environmental Objectives (Groundwater) Regulations (SI No. 9 of 2010) (Threshold Values and Groundwater Quality Standards). These comprise analyses of 11 samples from November 2000 to November 2001 (NFGWS Raw Water Analysis Results) and 1 sample from 30/7/2014 collected and analysed on behalf of the GWS. (See Appendix 3)

Table 3 Summary of Raw Water Analysis

Parameter	Number of Values	Maximum	Minimum	Average	Parametric Value/Comment
Total Hardness (mg/l as $CaCO_3$)	1	321	321	n/a	-
Electrical Conductivity (µS/cm)	12	809	613	711	800 (TV-lower)
Total Coliforms (number/100ml)	12	372	0	37	0 (MAC)
E. coli (number/100ml)	12	2	0	1.5	0 (MAC)
Nitrate (mg/l NO_3)	12	5.49	0.2	2.8	37.5 (Groundwater Quality Standard)
Nitrite (µg/l NO_2)	12	50	3	21	375 (TV)
Ammonium (µg/l N)	11	200	0	100	65 (TV - lower)
Chloride (mg/l Cl)	1	23.19	23.19	n/a	24 (TV- lower)
Iron (µg/l Fe)	12	104	<5	18.2	200 (MAC)
Manganese (µg/l Mn)	11	6	<5	6	50 (MAC)
Turbidity (4 NTU)	11	0.71	<0.01	0.24	Acceptable to consumers and no abnormal change
Potassium:Sodium	1	0.33	0.33	n/a	-

Raw water electrical conductivity (E.C.) values are high and within the range of other measurements of E.C. (496 – 801 µS/cm) from within the Moy sand and gravel groundwater body. High E.C. is consistent with calcareous characteristics and source of the sands and gravels. Exceedences of the relevant raw water thresholds occur for Total Coliforms (6 exceedences), E. Coliforms (4 exceedences) and Ammonium (8 exceedences). The Potassium:Sodium ratio is at level which does not allow discrimination between sources of organic matter.

Exceedences of the Total Coliform, E. Coliform and Ammonium limits, while nitrate limits are not exceeded, for raw water indicate a localized source of pollution by animal or human wastes. This exceedences indicate that pollution most likely arises from direct access by livestock to the poorly drained area directly surrounding the spring source and pump sump, where surface and groundwater are in direct connectivity, combined with relatively poor well head protection. It could also result from pollution of up-gradient vulnerable groundwater by land spreading, farm yard or domestic dwelling waste close to the source or from pollution of surface waters immediately up-gradient of the springs by entrainment of animal wastes, which are transported by overland flow to the area surrounding the spring source, where surface and groundwater are in direct connectivity.

Treated water samples from 2008 to 2014, compiled by Mayo County Council have been compared to the drinking water standard (SI 122 of 2014) (Drinking Water Limits). The treated water samples comprise from 21 to 15 analysis of the individual parameters listed below.

Table 4 Summary of Treated Water Analysis

Parameter	Number of Values	Maximum	Minimum	Average	Parametric Value/Comment
Electrical Conductivity (µS/cm)	21	684	611	651	2,500 (MAC)
Turbidity (NTU)	21	0.60	<0.2	0.30	no abnormal change
Total Coliforms (number/100ml)	17	20	0	n/a	0 (MAC)
E. coli (number/100ml)	16	1	0	n/a	0 (MAC)
Clostridium Perfrinigens (including spores) (number/100ml)	15	0	0	0	0 (MAC)
Nitrate (mg/l)	21	12.50	6.00	9.38	50 (MAC)
Nitrite (mg/l)	21	0.03	<0.02	0.02	0.50 (MAC)
Chloride (mg/l)					250 (MAC)
Ammonium (mg/l as N)	21	0.07	<0.03	<0.03	0.30 (MAC)
Iron (µg/l)	21	<50	<25	n/a	200 (MAC)
Manganese (µg/l)	21	<20	<20	n/a	50 (MAC)
Aluminum (µg/l)	21	<20	<20	n/a	200 (MAC)

Exceedences of the relevant treated water quality over the period 2008 – 2014 occur for Total Coliforms (4 exceedences), E. Coliforms (2 exceedences).

The occurrence of occasional exceedences in the treated water, indicate that the single barrier UV disinfection approach to treatment is at least occasionally ineffective. The presence of bacteria (Total and E. Coliforms) in water treated by UV, which is relatively more effective at treating bacteria, indicates that the supply is potentially at risk from protozoans (such as Cryptosporidium) and viruses, which are less susceptible than bacteria to UV treatment. In addition, there is no output of UVT, UV intensity, no system validation certificate and no alarm to alert the GWS to potential UV disinfection inadequacy or failure. It is noted that there have been no raw water exceedences of the thresholds for Clostridium Perfrinigens, which is used as an indicator of Cryptosporidium risk. Treated water turbidity had 9 exceedences of the 0.2 NTU threshold, recommended in EPA (2009) where there is a risk of the presence of Cryptospiridium in the raw water.

The raw and treated water is of good quality for the other parameters measured, with these parameters values below detection limits or very low.

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is as follows.

Rain falling on the catchment reaches the groundwater aquifer by diffuse recharge, that is, recharge occurs across the whole land area, rather than at discrete locations. Recharge rates are predominantly very high, due to high permeability glacio-fluvial sand and gravels being overlain by dry soils (See Appendix 3), with 85% of effective rainfall percolating down to the groundwater table, Surface water run-off rates are correspondingly low in these areas. Run off rates are higher on small areas overlain by wet peat soils, where recharge is correspondingly reduced.

This sand and gravel aquifer in which the Zone of Contribution supplying the spring zone is located extends north, west and south of the spring discharge zone, having a total area of approximately 88 km^2. The limestone sands and gravels are hummocky, with varying depth, expected to have a thickness of generally greater than 10m, but with thicknesses of up to 23m recorded elsewhere in the Moy SG groundwater body. They have high to very high permeability. Groundwater flow through the sands and gravels is intergranular. The sand and gravel aquifer overlies a karstified bedrock aquifer of regional importance, but the characteristics of the sand and gravel and the spring sources indicate the sand and gravel, rather than the bedrock aquifer supplies the groundwater discharging at the spring zone.

The spring zone, which includes the GWS abstraction point, is estimated to discharge an annual average of 2,500 m3/day and is discharging from a break in slope on the eastern edge of a limestone sand and gravel where the unconfined water table in the sand and gravel aquifer intersects the topography at c. 18m O.D.. The occurrence of the spring discharge at this point may also be partially controlled by the abutment of the lower permeability limestone till subsoil against the edge of the higher permeability sand and gravel.

The regional direction of groundwater flow is controlled by the discharge point which is Lough Conn, the presence of which creates a hydraulic gradient and therefore groundwater flow, towards the lake. Topography also exerts a control on groundwater gradients, with groundwater gradients and therefore flow directions generally mimicking the topographic gradient. Groundwater flow to the spring discharge zone is therefore predominantly from the north west, towards the south east and Lough Conn.

Groundwater gradients are low in sand and gravel aquifers, as a result of their high permeability. Flow path lengths in the sand and gravel aquifer can therefore potentially be long, extending up to several kilometres. Maximum flow path lengths in the catchment to the spring are estimated to be 1.5km.

The sand and gravel to the northwest and up-gradient of the spring zone, s is predominantly classified as high vulnerability. However, a combination of hummocky, variably low gradient topography and the estimated groundwater gradients in the area supplying the spring zone, indicate that the vulnerability of the area, classified as high, may be locally extreme where the water table is within 3m of the ground surface, close to the spring source.

4.2 Boundaries

The boundaries of the area contributing to the spring zone (which includes the GWS abstraction point), and which is estimated to discharge an annual average of 2,500 m3/day are considered to be as follows (See Figure 7):

The **northern western boundary** forms the upgradient boundary. The boundary is based on topography, on the water balance, such that the area is large enough to capture sufficient recharge to the spring zone (annual average 2,500 m^3/day) and on a maximum reasonable flow path length to the spring zone. The topography is hummocky and topographic gradients are low therefore the groundwater divide which defines the upgradient boundary is difficult to define and subject to some uncertainty. Groundwater flow is towards the south east and Lough Conn, being controlled by a combination of the regional hydraulic control of the groundwater gradient by Lough Conn and by the topographic gradient.

The **south western and north eastern boundaries** are delineated based on the water balance such that the area is large enough to capture sufficient recharge to the spring zone (annual average 2,500 m^3/day), on topography and on the groundwater flow lines resulting from the regional control on hydraulic gradient resulting from Lough Conn.

The south-**eastern** boundary, i.e. the down-gradient extent of the ZOC, is delineated as an arbitrary 20 m buffer zone around the spring to protect it from direct ingress of contaminants.

4.3 Recharge and water balance

The full discharge from the spring discharge zone (2,500 m^3/d) is the discharge volume for which the Zone of Contribution is delineated, since there is a single source area (Zone of Contribution) for all of the water discharging in this zone. Any pressures occurring in this Zone of Contribution will potentially equally affect all of the water discharging in this zone, including the GWS abstraction. The ZOC area therefore is defined such that it provides approximately the spring zone volume. The area required to provide this average annual daily spring discharge rate by diffuse recharge comprises approximately **1.055 km^2**.

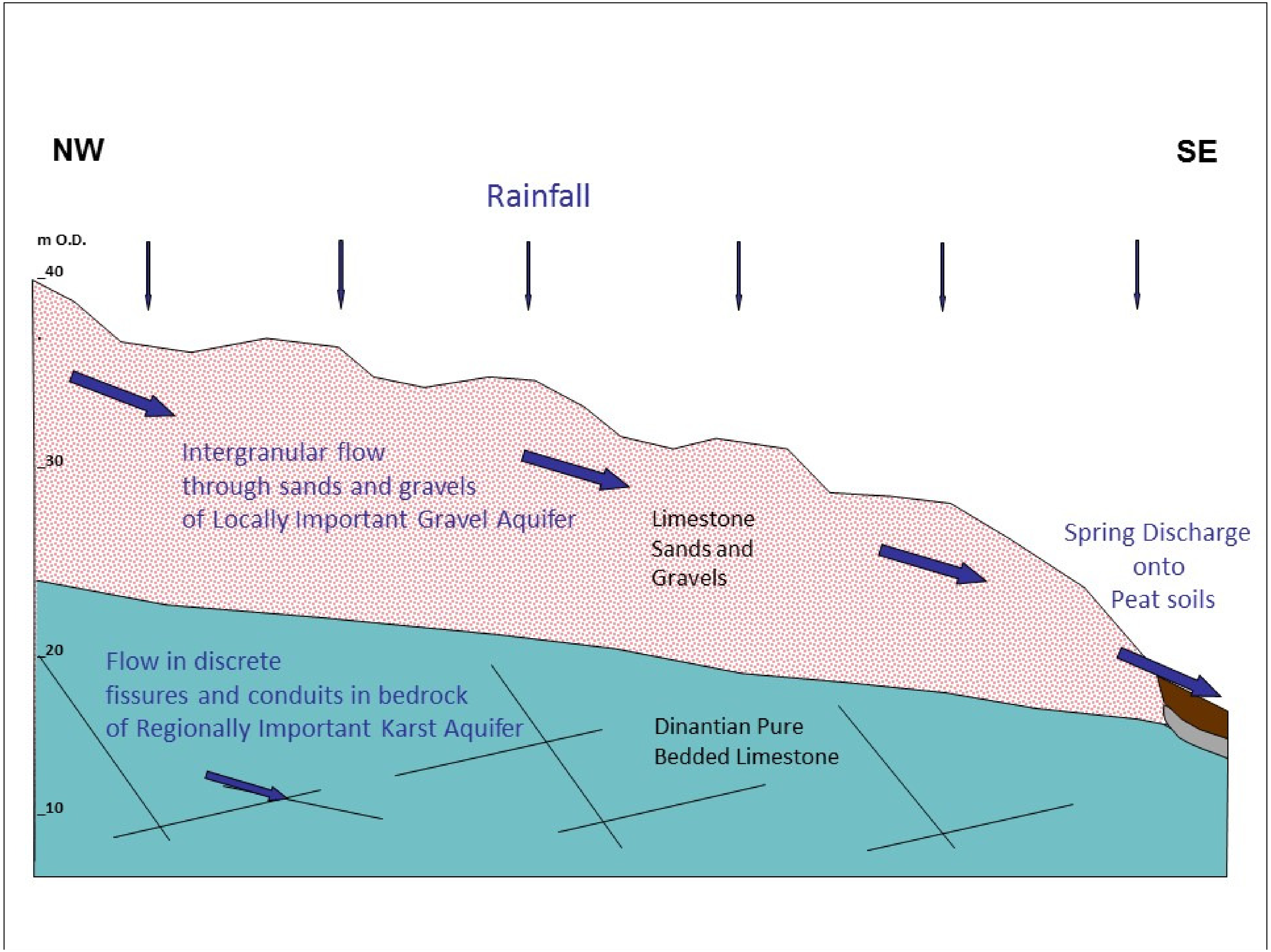

Diagram 3: Schematic Cross Section and Conceptual Model

5 Conclusions

The GWS currently abstracts an estimated 194 m^3/day from an abstraction point in a spring discharge zone which is estimated to discharge an annual average of 2,500 m^3/day. The spring zone discharges from a break in slope on the eastern edge of a limestone sand and gravel aquifer where the unconfined water table in the aquifer intersects the topography. This sand and gravel aquifer is a topographically hummocky, glacio-fluvial feature, expected to have a thickness of generally greater than 10m. The sand and gravel aquifer overlies a karstified bedrock aquifer of regional importance, but the characteristics of the sand and gravel and the spring sources indicate the sand and gravel, rather than the bedrock aquifer are the source of the spring discharge. Groundwater flow to the spring zone is from the north west.

A ZOC delineation was based on a combination of hydrogeological mapping, water balance calculation and topography. The area delineated as the ZOC comprises 1.055 km^2 and provides an annual average recharge of approximately 2,500 m^3/d to the spring discharge zone.

Exceedences of relevant thresholds has occurred in both raw and treated water samples. Exceedences of Total Coliform, E. Coliform and Ammonium limits for raw water indicate localized pollution sources and possibly also more distant sources of pollution by animal and/or human wastes. The very poorly drained spring discharge area has a high degree of connectivity between surface and groundwater and is open to livestock, waste from which pose a direct risk to the quality of water supply. The majority of the ZOC (98%) is delineated as having high vulnerability to groundwater pollution, with a small area (2%) delineated as having moderate vulnerability. It is likely that a proportion of the high vulnerability area close to the spring source, has in reality, extreme vulnerability, in areas and at times of the year where the water table level is less than three meters beneath ground surface. These extreme areas are at risk from land spreading and waste discharge activities.

The occurrence of occasional exceedences of relevant thresholds for Total and E. Coliforms in the treated water, indicate that the single barrier UV disinfection approach to treatment is at least occasionally ineffective and/or pollution is occurring in the distribution network. In addition there is no possibility for on-going monitoring or recording of UVT or any other verification or validation possible, in order to assess the operation of the UV system.

There is currently only one of the duty and stand-by pair of pumps operational, which leaves the scheme supply at risk.

6 Recommendations

6.1 Essential

- Routine untreated groundwater monitoring should commence for the GWS abstraction point and afull audit suite analysis plus any additional parameters from the basic suite should be carried out at least once every 2 to 3 years on the untreated groundwater;

- The spring discharge area and immediately surrounding up-gradient land should be fenced to permanently exclude livestock. The fenced area should include an area within an approximately 25m radius of the GWS pump house laterally from and upgradient of it and 20m downgradient. This should include no less than the area west of the pump house to the watercourse, north to the boundary hedge and north east and east to the crest of the poorly drained/rushy area. Interception drainage should be put in place along the fenced boundary to divert surface water drainage away from the enclosed area;

- Upgrading or replacement of the UV disinfection system in accordance with EPA (2011) guidance on specification and design. The upgraded or new system to include the monitoring and controls necessary for verification that the UV system is operating within the specified parameters, consistent with the validation certificate, to ensure the UV dose necessary for the required pathogen inactivation is delivered at all times. A appropriate schedule of monitoring and maintenance will be required. This approach is consistent with the Drinking Water Safety Plan approach, where the natural catchment vulnerability is such that there is a risk to raw water quality, then the approach is to ensure that appropriate water treatment is in place.

- Use of a secondary disinfection system (usually chlorine) should be considered, in order to provide a multi-barrier approach to disinfection;

- Replacement of the spring abstraction point and external sump access point covers with easily openable, lockable, waterproof and vermin proof covers;

- Close off holes in pump house or otherwise make the pump house waterproof, vermin proof and lockable. Subsequently, remove bags from around pump entrance points into sump;

- Fixing or replacement of the stand-by pump.

6.2 Desirable

- Improvement of access to the abstraction point and pump house. Any constructed access way should include suitable interception drainage to divert surface water run-off from it's surface away from the spring abstraction point and pump sump area;

- Based on available raw water results, the highest risk of pollution results from access of livestock to the area of the spring discharge zone. However, hazard mapping within the delineated ZOC would be useful, in particular to identify those areas close to the spring discharge zone which may be subject to land spreading;

- Further investigations to verify whether the current conceptual model is correct would assist in the definition of the ZOC and therefore ensure that pollutant pressures within the ZOC could be correctly identified.

- Enforcement of the European Communities (Good Agricultural Practise for Protection of Waters) S.I> No. 610 of 2010 regulations, concerning the spreading of organic fertilizer or soiled water, should be considered. Organic fertilizer or soiled water should not be spread within 200 m of the up-gradient side of the abstraction point.

6.3 Other

- The following EPA guidelines may serve as future useful reference documents for the 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. See http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html

- 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. See http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html

- EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection. See http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html

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8 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

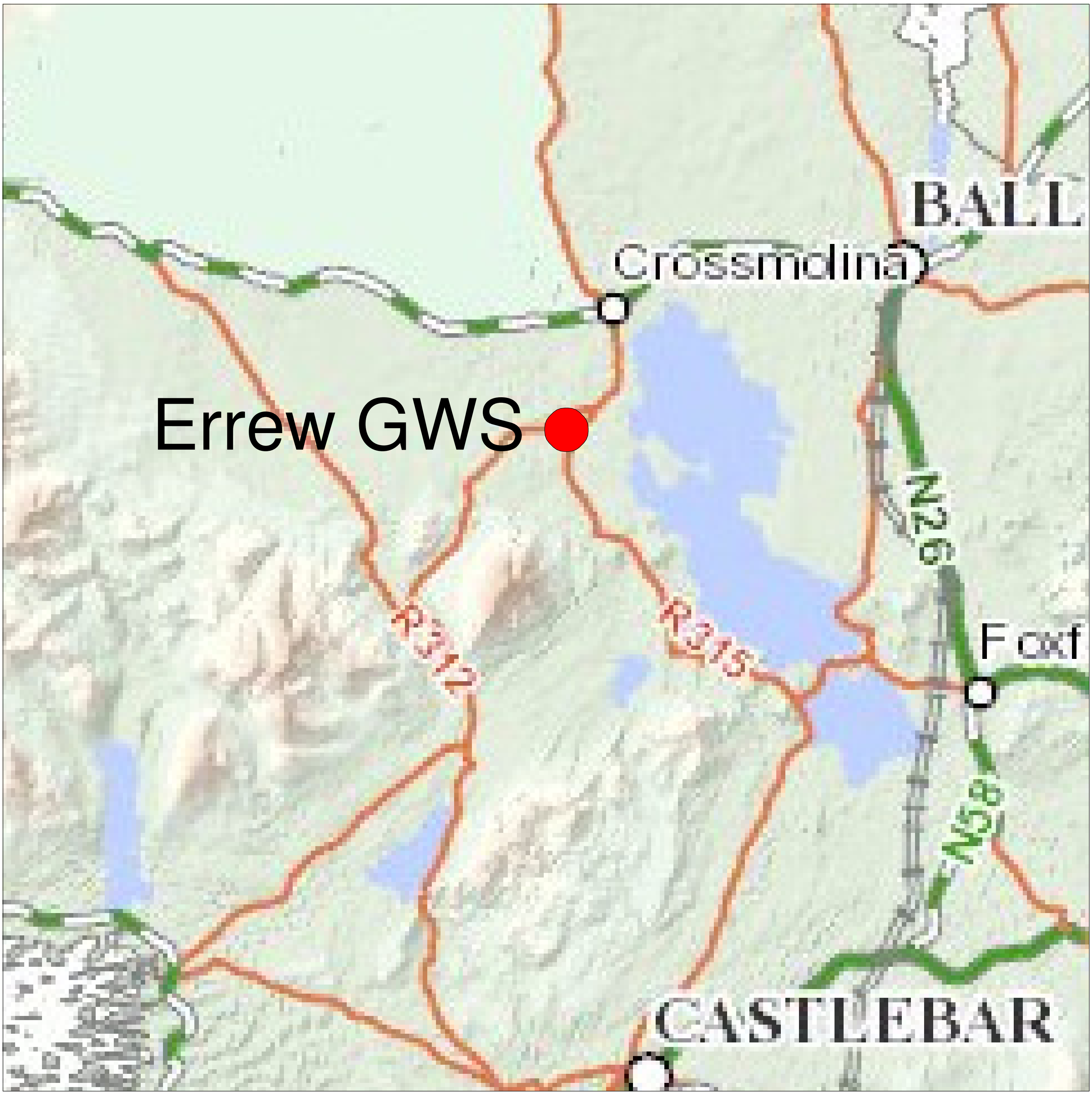
The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

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

Figures



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Drawn By: ST	Checked By: ST	Drawing No: 124_1

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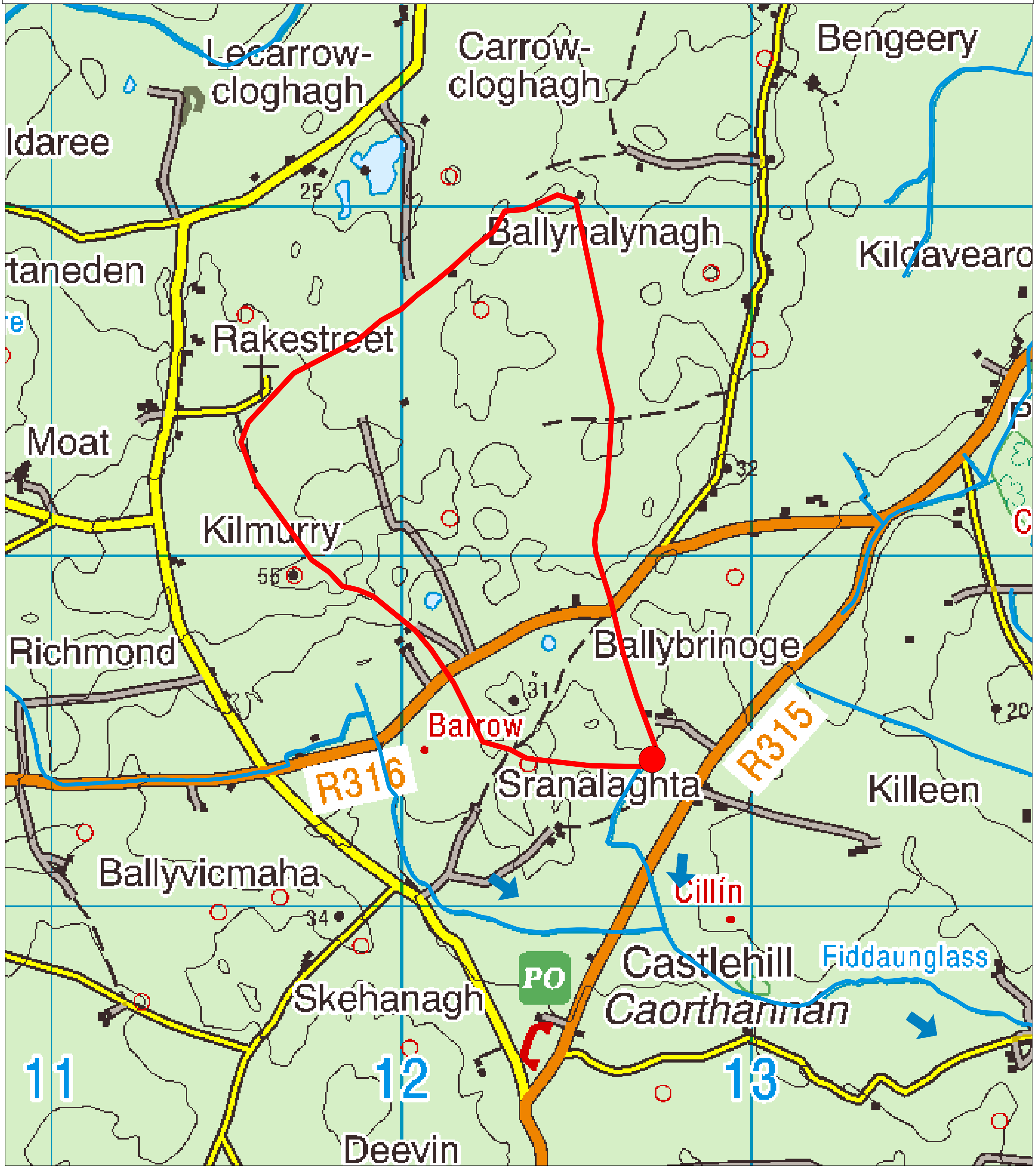
Group Water Scheme

River and Flow Direction



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Drawn By: ST / Checked By: ST	Drawing No: 124_2 RevB

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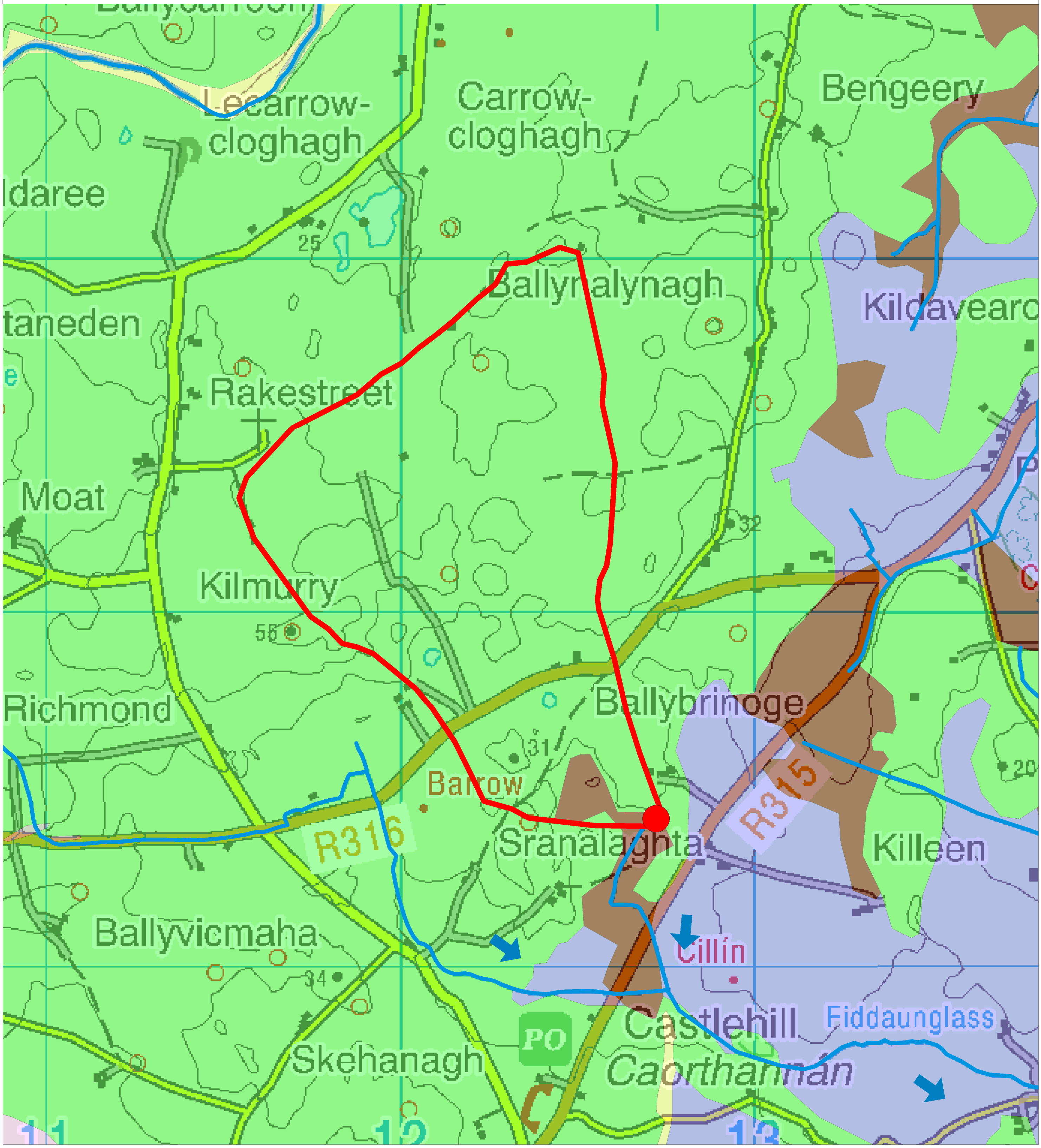
Group Water Scheme
Zone of Contribution
River and Flow Direction

Subsoils (Teagasc/EPA)
- Peat
- Limestone Sands and Gravels
- Limestone Till

N



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Drawn By: ST Checked By: ST	Drawing No: 124_3 RevB

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Group Water Scheme

Zone of Contribution

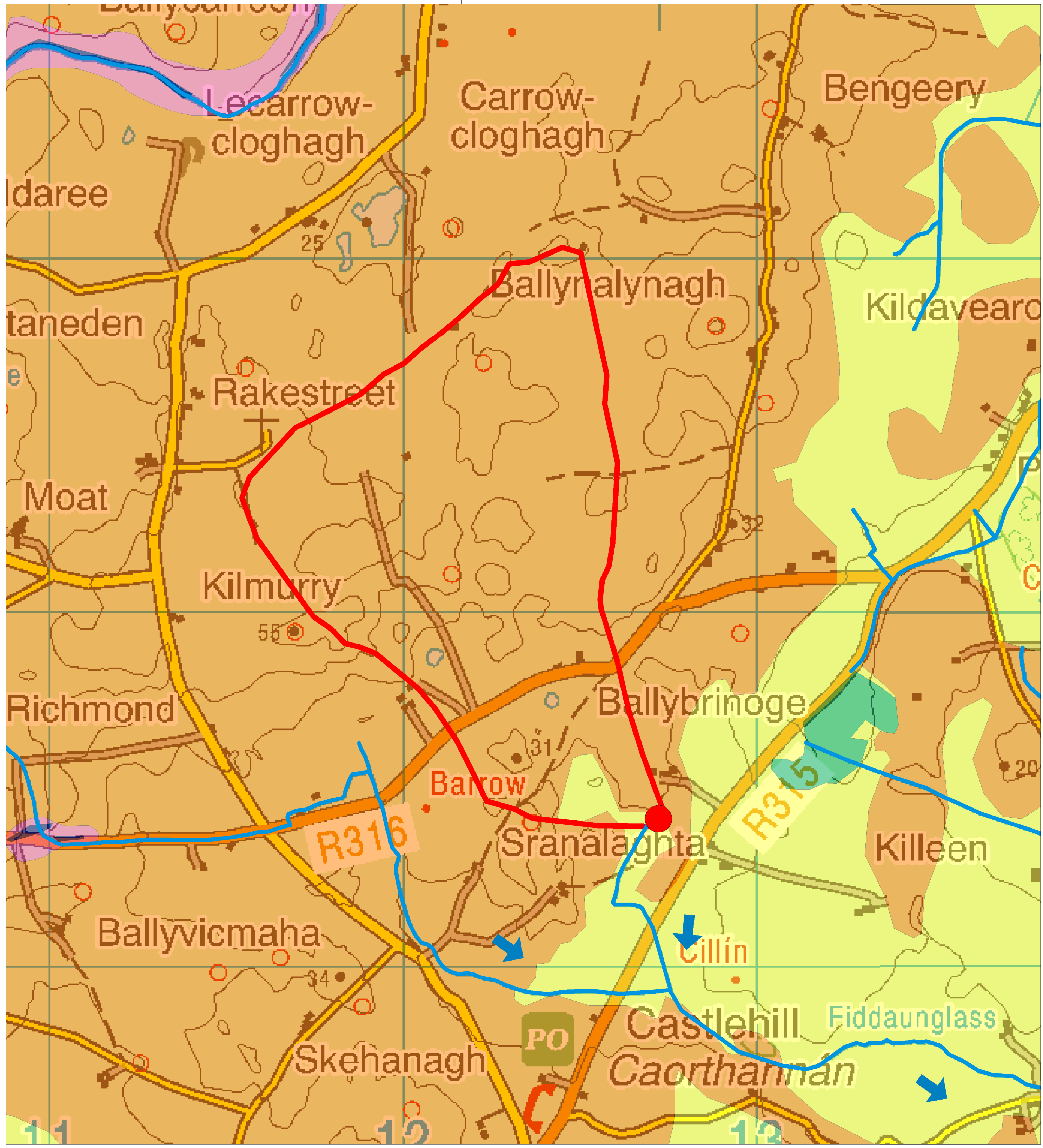
Rivers (EPA) and Flow Direction

Groundwater Vulnerability

High

Moderate

N



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Scale: 1:15,000 @ A4	Project No: 124
Drawn By: ST Checked By: ST	Drawing No: 124_4 RevB

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Group Water Scheme

Zone of Contribution

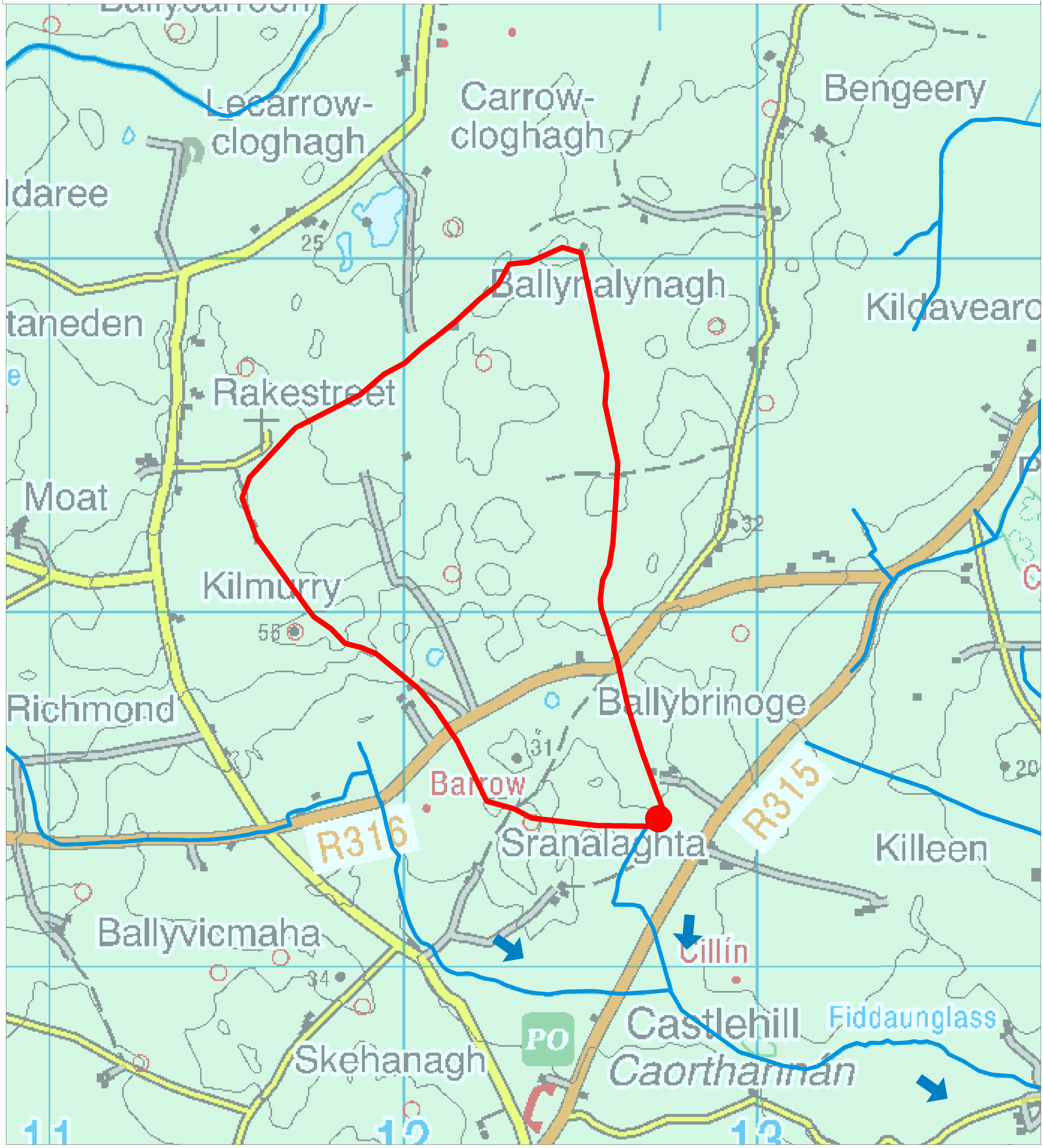
Rivers

Geological Rock Units

Dinantian Pure Bedded Limestones

Geological Fault

N



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Group Water Scheme

Zone of Contribution

Rivers

Bedrock Aquifer

Regionally Important Aquifer - Karstified

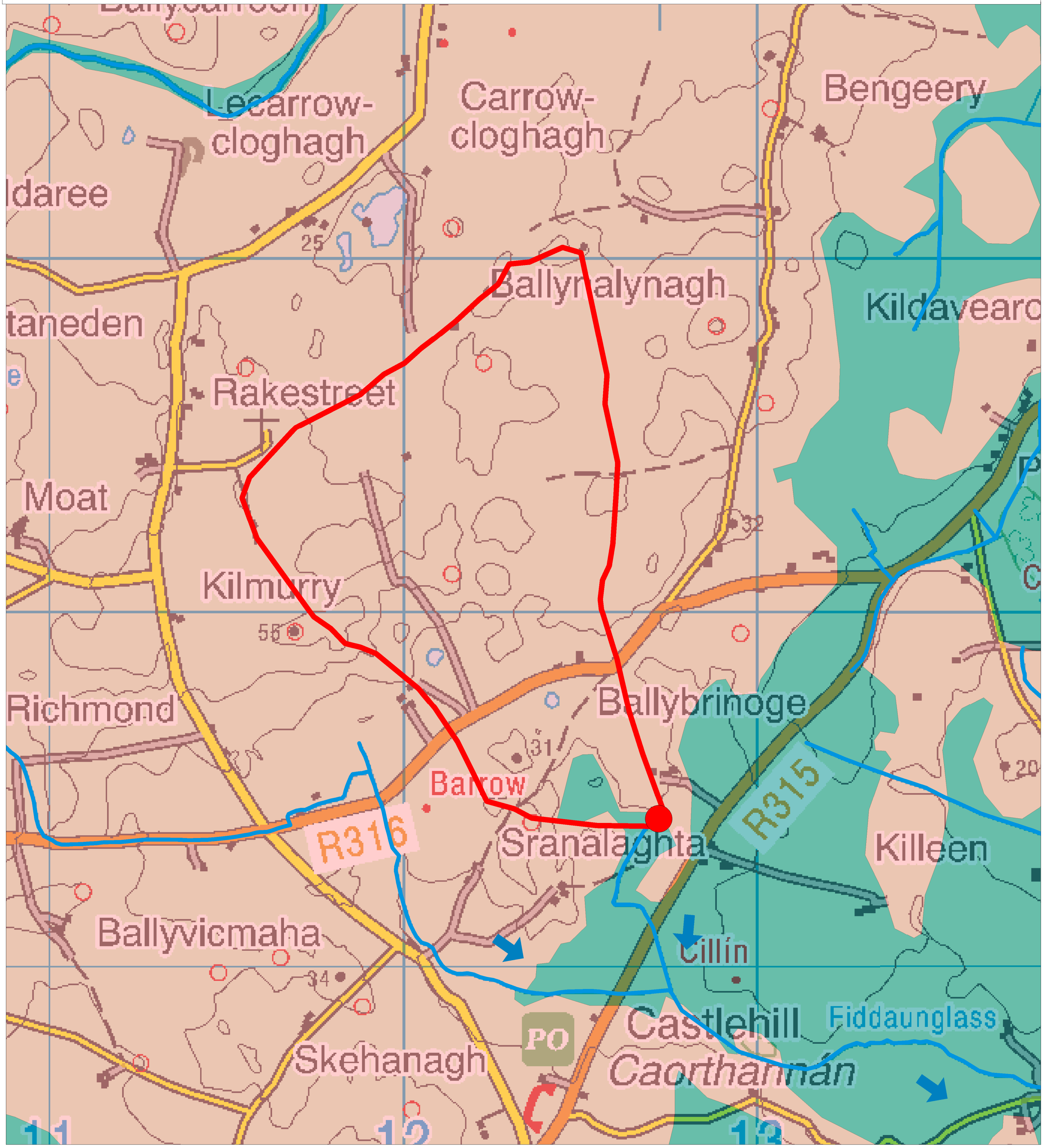
Gravel Aquifers

Locally Important Aquifer

Regionally Important Aquifer

Geological Fault

N



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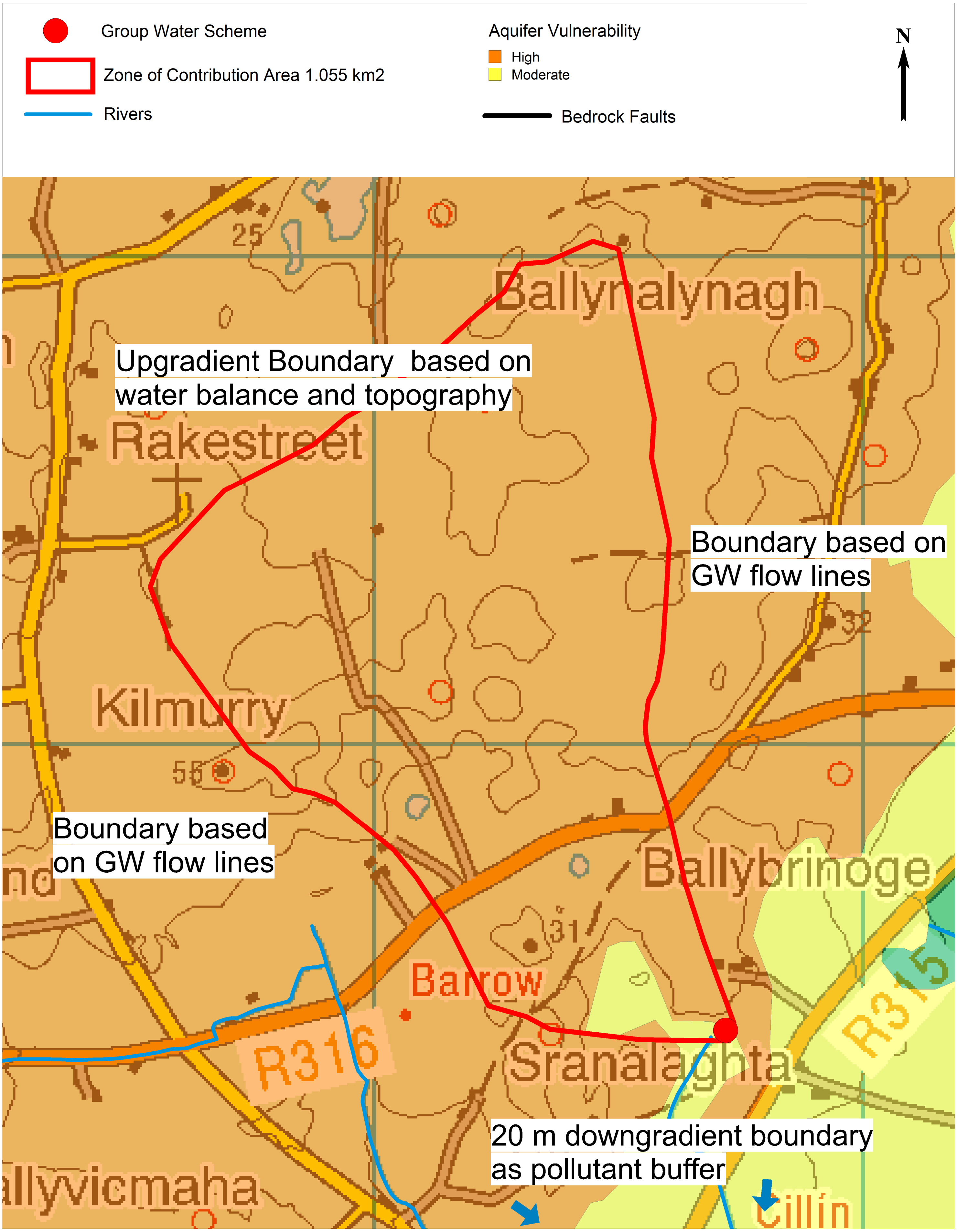

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APPENDIX 1

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

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

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

<table>
<tr><td rowspan="3">Thickness of Overlying Subsoils</td><td colspan="5">Hydrogeological Requirements for Vulnerability Categories</td></tr>
<tr><td colspan="3">Diffuse Recharge</td><td rowspan="2">Point Recharge</td><td rowspan="2">Unsaturated Zone</td></tr>
<tr><td colspan="3">Subsoil permeability and type</td></tr>
<tr><td></td><td>High permeability (sand/gravel)</td><td>moderate permeability (sandy subsoil)</td><td>low permeability (clayey subsoil, clay, peat)</td><td>(swallow holes, losing streams)</td><td>(sand & gravel aquifers <u>only</u>)</td></tr>
<tr><td>0–3 m</td><td>Extreme</td><td>Extreme</td><td>Extreme</td><td>Extreme
(30 m radius)</td><td>Extreme</td></tr>
<tr><td>3–5 m</td><td>High</td><td>High</td><td>High</td><td>N/A</td><td>High</td></tr>
<tr><td>5–10 m</td><td>High</td><td>High</td><td>Moderate</td><td>N/A</td><td>High</td></tr>
<tr><td>>10 m</td><td>High</td><td>Moderate</td><td>Low</td><td>N/A</td><td>High</td></tr>
<tr><td colspan="6">Notes: (i) N/A = not applicable.
(ii) Release point of contaminants is assumed to be 1–2 m below ground surface.
(iii) Permeability classifications relate to the engineering behaviour as described by BS5930.
(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability
(amended from Deakin and Daly (1999) and DELG/EPA/GSIa (1999))</td></tr>
</table>

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 2

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 (2013), which is based on Guidance Document GW5 (Groundwater Working Group 2005).

Table 1. Recharge coefficients for different hydrogeological settings.

Groundwater vulnerability category	Hydrogeological setting		Recharge coefficient (RC)		
			Min (%)	*Inner Range*	*Max (%)*
Extreme	1.i	Areas where rock is at ground surface	30	80-90	100
(X or E)	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	2.i	Sand/gravel aquifer, overlain by 'well drained' soil	50	80-90	100
(H)	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	3.i	Moderate permeability subsoil and overlain by 'well drained' soil	35	50-70	80
(M)	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	4.i	Low permeability subsoil	1	5-10	20
(L)	4.ii	Basin peat	1	3-5	10

The recharge coefficients in this table are summarised in a paper by Hunter Williams *et al.* (2013) in the Quarterly Journal of Engineering Geology and Hydrogeology. Aquifer recharge acceptance capacity is generally limited in LI aquifers (200 mm/yr) and PI and PuI aquifers (100 mm/yr). Made ground has recharge coefficient of 20%.

Where the sand and gravel aquifer occurs beneath dry soils, the recharge co-efficient is estimated to be 85% of effective rainfall, resulting in an estimated annual average recharge of 901 mm in the area of the ZOC. This high recharge is mapped as occurring on c.74% (GSI Recharge Map). Where wet soils overly the sand and gravel aquifer a moderate recharge co-efficient of 42.5% of effective rainfall has been assigned, resulting in an estimated annual average recharge rate of 450mm. The proportion of the ZOC receiving the high recharge rate (901 mm) is considered likely to include a significant area of that currently mapped at the moderate rate (450 mm). This is based on a number of factors including examination of aerial photographs, which show no minimal evidence of wet soils or vegetation and descriptions of sands and gravels from quarries identified as location numbers 1149 and 1213 (Geological Survey of Ireland mineral localities database, www.gsi.ie) located to the north of the spring discharge zone. Sediments in a quarry 0.57 km to the north for example, are described as coarse cobbles/boulders in a matrix of gravel and sand. As a result there is significant intergranular porosity, through which significant groundwater flow occurs. Estimated groundwater gradients in the area suggest that small wetland and lake areas within the ZOC are likely to be an expression of the unconfined groundwater table, where the groundwater level is locally higher than the topography in depressions which have no outflow route and which occur in the hummocky surface of the sand and gravel aquifer, rather than resulting from ponding of surface water run-off in areas of low permeability soils. In addition the water balance for the discharge at the spring discharge zone is only balanced, if the higher recharge rate occurs across a greater proportion of the area than the current mapping indicates.

APPENDIX 3

Water Analysis Results

Summary Report on Samples of Raw Untreated Water, November 2000 to November 2001

Source : **MO102**, Errew/Castlhill/Killeen
Martin Mulhearn
Killeen
Castlehill
Co Mayo

The experimental results for the samples collected during November 2000 to February 2001 and for May 2001 to November 2001 from the source of the raw water for the group water scheme **MO102**, Errew/Castlhill/Killeen, are presented in the table below. (Samples were not collected for March and April 2001 due to F&M precautions). These results must be interpreted having regard to the national limit values for each parameter specified in the Quality of Drinking Water Regulations 1988 (S.I. No. 81 of 1988). This is the standard required at the consumers tap and will normally require treatment and disinfection of the raw water to achieve these values. A brief description of these chemical and bacteriological parameters and their associated limit values is provided in the explanatory leaflet that accompanies this report.

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliform	Faecal Coliform
Limit Value	**20 Hazen**	**4 NTU**	**1500 µS/cm**	**6.0 to 9.0**	**0.23 mgN/l**	**11.3 mgN/l**	**0.03 mgN/l**	**200 µg/l**	**200 µg/l**	**50 µg/l**	**0 per 100 ml**	**0 per 100 ml**
NOV2000	2.5	<0.01	717	6.79	0.2	0.2	0.05	5	9	<6	1	<1
DEC2000	2.5	<0.01	715	6.87	0.2	2	0.05	<4	7	<6	4	1
JAN2001	2.5	<0.01	677	6.83	0.1	1.4	0.05	<4	<5	<6	<1	<1
FEB2001	2.5	<0.01	727	6.64	0.1	2	0.05	<4	<5	<6	<1	<1
MAY2001	2.5	0.09	747	6.53	0.2	1.5	0.006	<4	10	<6	<1	<1
JUN2001	2.5	0.71	718	6.47	0.15	1.6	0.008	5	39	<6	22	2
JUL2001	2.5	0.01	731	7.2	0.1	1.7	0.008	10	<5	<6	6	<1
AUG2001	2.5	0.37	735	6.9	<0.1	1.6	0.004	<4	104	<6	4	1
SEP2001	2.5	<0.01	742	6.84	0.15	2.3	0.005	4	31	6	<1	<1
OCT2001	<2.5	<0.01	809	7.08	<0.1	1.5	0.008	4	<5	<6	372	2
NOV2001	<2.5	0.01	792	7.14	<0.1	1.6	0.003	<4	<5	<6	<1	<1

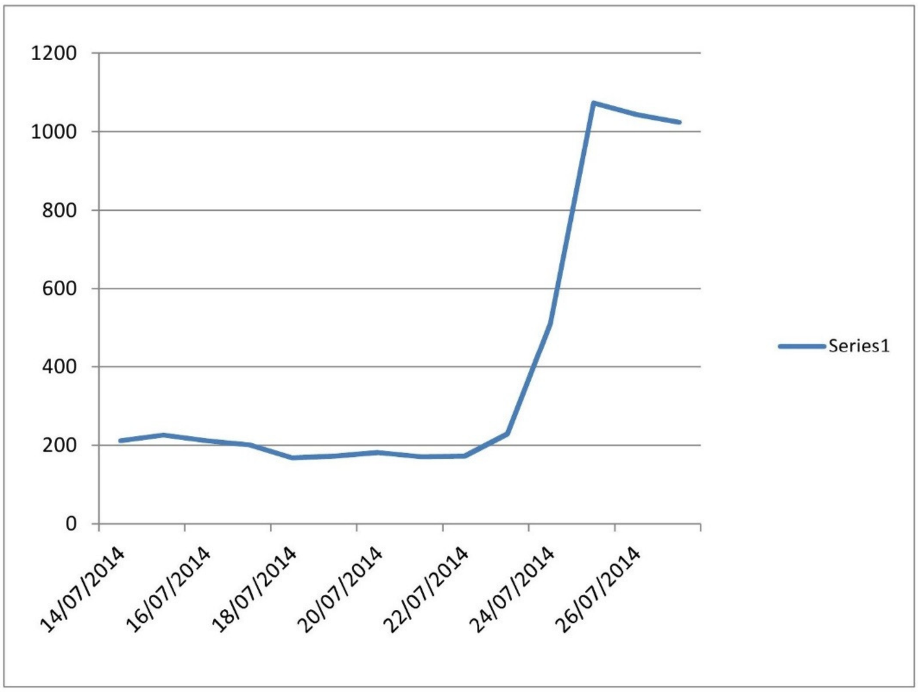
Sample No.	Report No.	Receipt Date	Sample ID	BOD	COD	Turbidity	pH	Conductivity @20C	Alkalinity, total	Sodium, total	Chloride	Ammonium as NH4	Nitrate as NO3	Nitrite as NO2	Dissolved Oxygen (%)	Potassium, total	Total Hardness (Kone)	Magnesium, total	Colour, apparent	Sulphate	Orthophosphate as PO4-P	Calcium, total	Aluminium, dissolved	Iron, dissolved	Manganese, dissolved	Copper, dissolved	Lead, dissolved	Chromium, dissolved	Nickel, dissolved	Cadmium, dissolved	Arsenic, dissolved	Zinc, dissolved	Silica	Barium, dissolved	TOC	Clostridium Perfringens in Water	Strontium, dissolved	E coli (Filtration) (Environmental Waters)	Total Coliforms (Filtration) (Environmental Waters)	Fluoride by ISE
				mg/l	mg/l	N.T.U.	pH Units	uS/cm	ng/l CaCO:	mg/l	mg/l	mg/l	mg/l	mg/l	%Sat	mg/l	ng/l CaCO:	mg/l	mg/l Pt Co	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	ug/l	mg/L	cfu/100ml	ug/l	cfu/100ml	cfu/100ml	mg/l
533431	235076	31/07/14	Killeen Errew F	<1	<10	<0.2	6.9	613	347	169	23.9	0.038	5.49	<0.017	71	57	321	14	<4	7.57	<0.01	104	<2	58	<5	2	<0.5	0.6	2	<0.5	<0.5	<5	1.31	44	1.2	0	683	0	0	0.5

APPENDIX 4

Abstraction Monitoring and Spring Discharge Zone Total Discharge

Abstraction Monitoring

Continuous abstraction Monitoring was carried out on behalf of the GWS from 14/7/2014 to 27/7/2014. The results were tabulated by the recorder as below.



Date	M^3 PER DAY
27/07/2014	1024.059
26/07/2014	1043.852
25/07/2014	1073.652
24/07/2014	511.79
23/07/2014	229.273
22/07/2014	172.721
21/07/2014	171.315
20/07/2014	181.902
19/07/2014	172.357
18/07/2014	168.277
17/07/2014	201.841
16/07/2014	212.193
15/07/2014	226.585
14/07/2014	212.482

Discharge from Spring Discharge Zone

The full discharge from the spring discharge zone is the discharge volume for which the Zone of Contribution will be delineated, since there is a single source area (Zone of Contribution) for all of the water discharging in this zone. Any pressures occurring in this Zone of Contribution will potentially equally effect all of the water discharging in this zone, including the GWS abstraction.An assessment of the sustainable yield of the GWS abstraction was carried out by O'Neill Groundwater Engineering in 2001 (O'Neill Groundwater Engineering, 2001). Step testing of the GWS abstraction was carried out over a period of 4.5 hours, at 4 pumping rates. This was accompanied by measurement of the overflow volume and hydrochemistry from the GWS abstraction at the sump and measurement of flow and hydrochemistry downstream of Tobernagowna Spring during the step testing. It is not clear whether the measurement of flow from Tobernagowna spring includes some surface water inputs from surface water drainageDuring the 2001 pump testing, the sustainable yield from the GWS abstraction point, such that the water level does not drop below the outflow pipe, was calculated to be 4.91 l/s, corresponding to 423 m3/day. This abstraction rate was accompanied by an overflow rate of 12.1 l/s, corresponding to 1,045 m3/day. During the pump testing the average flow from the GWS abstraction point and it's overflow at the sump was 18.1 l/s, corresponding to 1,563 m3/day. This raises the question of whether part of the measured overflow is water sourced from either the base of, or around, the sump, rather than direct overflow from the GWS abstraction point, regardless, it is still part of the total spring discharge. It is not clear whether this sump is closed or open to the subsoil at it's base, but it shows evidence of leakage between the top of the sump and the base of the shed. During the period of monitoring in 2014, a leak occurred in the system from 24/7/2014 and the abstraction volume from the abstraction point increased to a peak of 1074 m3/day on 25/7/2014, being in excess of 1000 m3/day until the end of the monitoring period on 27/7/2014. This indicates that a larger volume of water is potentially available from the abstraction point over the short term, than indicated by the pump testing, possibly because the spring overflow can be recruited over longer periods of pumping, but this would need to be validated by long-run yield testing. The overflow volume was not measured over this period. It is noted that pump testing was restricted to rates slightly in excess of, and less than, that which the pump and distribution network set-up was capable of conveying to the furthest extent of the distribution network

The flow measured downstream of Tobernagowna spring during the 2001 pump testing did not change, ranging from 24.6 l/s, corresponding to 2,125 m3/day to 26.8 l/s, corresponding to 2,401 m3/day. However it is not clear whether this volume includes some surface water inputs from adjacent drains, one of which flows from a small lake.

The maximum possible spring catchment area was estimated for the spring discharge zone, based on an assessment of topography, available groundwater gradients, reasonable flow path lengths and annual average groundwater recharge to the sand and gravel aquifer. The largest recharge area possible taking into account all of these constraints, can support an average annual daily discharge at the spring of approximately 2,500 m3/day.

For the purposes of delineation of the ZOC, a total spring discharge zone volume of 2,500 m3/day has therefore been assumed.