APPENDIX 9-5

GWS SOURCE PROTECTION REPORTS

Establishment of Groundwater Zones of Contribution

Anbally & District Group Water Scheme

June 2015

Prepared by:

Peter Conroy
and
Geological Survey of Ireland, Groundwater Programme

(Monica Lee, Caoimhe Hickey and Taly Hunter Williams)

And with assistance from:

Anbally & District GWS

The National Federation of Group Water Schemes

Acknowledgements:

Tom Goggins & Tommy Glynn (Anbally & District GWS)

Karen Carney (NFGWS)

Document control information

Revision	Date	Author	Checked	Approved
Draft	16/09/2014	Peter Conroy	CH	
Revised	03/12/2014	Peter Conroy	CH	
Final	11/06/2015	Peter Conroy	CH	CH

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 Anbally & District 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.

Anbally & District GWS is supplied by a single borehole located in a regionally important aquifer with karstified conduit flow (Rk_c). The current abstraction rate is estimated at 138 m^3/day.

[1] Geological Survey of Ireland, 1999.

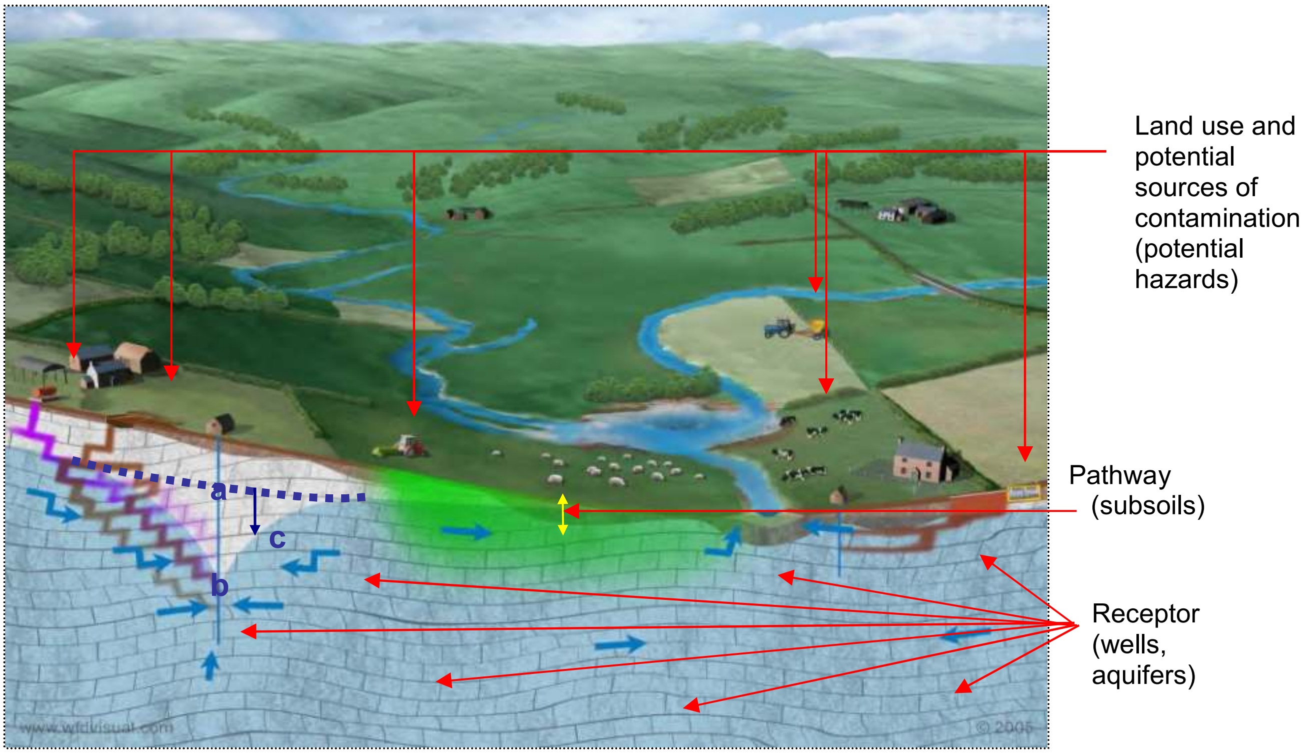

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Anbally & District Group Water Scheme (GWS) is supplied from a borehole in the townland of Tawnaghmore, Anbally, Corrofin, Co. Galway (Figure 1). The current scheme demand is approximately 69 m^3/day, estimated based on 115 connections with 3 PE per connection and a demand of 0.2 m^3/day per PE. The abstraction rate observed on site on 18 June 2014 was 63 m^3/day. Average daily usage between 18 June and 16 September was just 23.5 m^3/day. There are no borehole yield data available.

The GWS site is located 2.1 km southwest of Corrofin village centre, on the south side of a cul-de-sac local road heading east off the N17 Regional Road 800 m south of the N17 junction for Corrofin. The site comprises a short access road leading to a roughly 15 m by 15 m compound containing the pumphouse and borehole **(Diagram 2)**.

The borehole is located adjacent to the south wall of the pump house. The borehole chamber is set into the concrete plinth surrounding the pump house. The chamber is roofed by two concrete slabs but it is not water tight. It is block built and approximately 0.3 m deep with an earth floor. The borehole's 150 mm diameter, outer steel casing protrudes approximately 0.2 m above the floor. The chamber was dry during the site visit. The chamber is not sealed against pests and there is no cap on the mouth of the borehole. The pump rising main passes directly into the adjacent pumphouse from the chamber.

On the south side of the chamber the ground has subsided, creating a small trench which funnels runoff from the GWS compound towards the borehole. The subsidence is the result of remedial works on the borehole after the rising main broke at the well head in 2010. A 3 m deep trench was excavated through the subsoil adjacent to the steel casing. At this depth a window was cut through the steel casing to allow direct access to the top of the sheared rising main in order to attach a fishing tool which allowed the rising main and pump to be recovered. The window in the casing was patched with a split plastic pipe fitted around the casing and sealed with edge sealant. The trench was backfilled but has since settled, leading to the current condition. A downhole camera survey of the borehole was carried out during the works in 2010[2] (Appendix 1).

[2] Well Solutions, 2010

150 mm and 125 mm diameter steel casings are visible in the borehole well head. The GWS report that during drilling the 150 mm casing was seated in competent rock, but "soft soil" was encountered again at depth, which necessitated the use of the 125 mm casing to progress the borehole to greater depths.

The scheme has UV and chlorination treatment. Currently there is no pre-filter on the UV system. Diskin[3] recommends the installation of a basic sand filter and a granular activated carbon (GAC) filter to deal with excessive turbidity and colour in the abstracted water respectively, in order to ensure that the UV treatment operates correctly (Appendix 1). He also recommends the installation of flow proportional chlorine dosing. The GWS report that the supply can go brown when heavy rain occurs after a dry spell (e.g. February 2014).

There is a flow meter located inside the GWS pump house. The borehole pumps directly to the distribution mains via a pressure vessel in the pump house on a 24 hour basis.

Photos of the pump house and borehole can be seen in Photos 1 to 5 below. **Table 1** provides a summary of currently known information relating to the borehole.

Diagram 2. Schematic Plan of the GWS Site

3 Diskin, 2014.

Photo 1: Anbally & District GWS view south across GWS compound

Photo 2: Anbally & District GWS – Pump house and adjacent well chamber (view NE)

Photo 3: Borehole Chamber

Photo 4: Borehole Chamber – Note the Dip in ground level adjacent to chamber due to subsidence

Photo 6: Well head inside borehole chamber showing 150 mm steel casing and rising main

Photo 5: Pumphouse (Internal)

Photo 7: "Closh" wetland located 95 m southeast of the source borehole

Table 1. Supply Details

	Anbally & District GWS Borehole
Grid reference	140,387 E; 242228 N
Townland	Tawnaghmore
Source type	Borehole
Drilled	1987
Drilling Contractor	GWS think driller may have been Mulcairs
Owner	Anbally & District GWS
Elevation (m OD)	approximately 42
Total depth (m)	99
Construction details (Downhole Camera Survey in Appendix 1[4])	• 0 to 27.5 m below top of casing (mbtc): intact steel casing except for cutting at 2.0 to 2.2 mbtc made during fishing attempts for broken rising main. • 150 mm and 125 mm steel casing used to reach competent limestone at 27.5 mbtc. Depth of base of 150 mm steel casing is not known (no data), but the GWS report that it extends below the cutting made at 2.0 to 2.2 mbtc. • 27.5 to 99.1 mbtc: open hole • No grout seal • Cutting in outer steel casing sealed by covering with a split plastic pipe and sealing the plastic pipe edges to the steel casing with edge sealant.
Depth to rock (m bgl)	Greater than 3 m (The GWS report that the trench excavated adjacent to the borehole in 2010 encountered 3 m of subsoil and no bedrock)
Pumping (PWL) and Static water levels (SWL)	• Water level dipped on 18 June 2014 = 33.20 mbtc (pump off; ~ 8.8 mOD) • The GWS reports that the SWL is always around 32 m to 34 mbtc and that pumping drawdown is typically between 2 m and 3 m.
Pump intake depth (m bgl)	50
Current abstraction rate (GWS)	• 63 m^3/day observed on 18 June 2014 • Possibly up to 69 m^3/day based on 115 connections at 3 PE per connection & 0.2 m^3/day per PE • Average daily usage between 18 June and 16 September was 23.5 m^3/day
Reported yield (m^3/d)	No Data. GWS carried out a pumping test on the borehole when newly drilled and it generated only a few feet of drawdown. No data are available from the pumping test.
Transmissivity (m^2/day)	No Data
Other Information	Water can go brown when heavy rain occurs after a dry spell. The 2010 downhole camera survey recorded the following[4]: • 27.5 m – Inflow from base of casing (cascading) • 27.5 to 99.1 m – Predominantly solid rock. Regular circumferential indentations, interpreted as bedding planes and possibly some smaller fractures. Heavy calcite build up on borehole wall obscured minor features. • 32.7 m – cloudy water encountered • 51.1 m – water strike + borehole water becomes clear • 51.5 m – Probable water strike • 60.4 m – Probable water strike • 73.3 m – Probable water strike • 75.3 m – Probable water strike • 87.3 m – Probable water strike • 96.8 m – Very weathered fracture – possibly the main water strike • 99.1 m Old pump stuck at base of hole

[4] Well Solutions, 2010

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

	Anbally Borehole	Description/Comments
Annual Rainfall (mm)	1094	Corrofin Garda Station, 2.4 km East (1961-90)
Annual Evapotranspiration Losses (mm)	463	487.5 mm PE (Avg. annual potential evapotranspiration data, Galway SWS, 1961-1990). 463 AE (Actual Evapotranspiration, assumed to be 95% of PE)
Annual Effective Rainfall (mm)	631	Annual rainfall minus the annual evapotranspiration losses
Topography (**Figure 2**)		The highest point in the wider area is the SW to NE oriented Knockmaa-Knockacarrigeen ridge near Belclare (7 km NNW), which reaches 167 mOD. From the base of the ridge at approximately 60 mOD the ground generally slopes down to approximately 30 mOD in the vicinity of Corrofin. Frequent hummocks occur, with one such reaching 50 mOD 700 m NW of the source. The GWS site sits on the SE flank of the hummock at approximately 42 mOD, slightly elevated above the surrounding area.
Land use		Landuse is predominantly agricultural. Domestic residences with septic tank systems are located 250 m to the east and west of the source at either end of the cul-de-sac local road, as well as at greater distance. Clough-Cummer GWS is located 1.8 km NNW of the source.
Surface Hydrology (**Figure 2**)		The River Clare runs roughly N-S approx 1 km ESE of the source. The river has a bed elevation of 22.2 mOD at nearby Corrofin[5]. The Tonmace turlough is located 1.3 km ESE on the SE side of the Clare-Abbert river confluence. The modern Clare and Abbert River courses in the area are the result of arterial drainage. Historically the Clare River ended in the Turloughmore, which extended north to Corrofin and encompassed the Tonmace Turlough. The Abbert River sank at Ballyglunin 6 km east. A small wetland (noted as a well on the OSi 25" historical map) occurs 90 m SE of the source.
Topsoil[6]		Across most of study area soils are mainly deep, well drained basic mineral soils, becoming shallow on areas high ground and rock outcrop. Lacustrine soils at Tonmace Turlough. Alluvial soils and poorly drained peaty soils along original and modern Clare River courses.
Subsoil[6] (**Figure 3**)		Across most of study area subsoils are mainly made up of limestone till. Lacustrine subsoils are found at Tonmace Turlough. Pockets of karstified bedrock outcrop are widespread in the area. Alluvial subsoils are common along the modern Clare River course.
Groundwater Vulnerability (**Figure 4**)		Extreme (E) at the source and across most of the outlying area surrounding the source. Frequent pockets of extreme (X) occur within the extreme (E) areas, e.g. wetland area 90 m SE of source. Frequent pockets of high vulnerability often enclose areas of moderate vulnerability. See **Appendix 2.**
Geology[7] Formation: Rock Unit Group (**Figure 5**)	Dinantian Pure Bedded Limestone (DPBL).	DPBL (bedded limestone) underlies the study area. Beds generally dip SSE at 3^{O} to 3.5^{O}. No mapped faults in the area. GSI 6" Field sheets indicate dolomite in outcrop 2 km SSW at Corrandrum. Regionally N-S and E-W joint sets are expected to occur[8].
Aquifer (**Figure 6**)		The **DPBL** limestones are classified as a Regionally Important Aquifer – Karstified (Conduit) **(Rk_c)**. Known surface karst features in the vicinity of the GWS source are shown in Figure 6. GSI 6" Field sheets record 3 trial wells 500 m south in Anbally village failed due to clay infilling of karst solution features (GWS report that these were trial boreholes for the GWS)
Groundwater Body	Clare-Corrib GWB	The Rk_c aquifer is in the Clare-Corrib GWB. http://www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions.htm
Recharge Coefficient (**Appendix 3**)	80 %	Low drainage density, well drained soils, moderate permeability subsoils, and high to extreme vulnerability, plus point recharge via karst features suggest a high recharge coefficient.
Recharge (mm)	505	

[5] Ryan Hanley, 2010
[6] Teagasc, 2006.
[7] Gatley *et al.*, 2005
[8] Geological Survey of Ireland, 2004.

3.2 Hydrochemistry and water quality

Ten untreated water samples were collected and analysed for the Anbally & District GWS borehole between November 2000 and November 2001 under a DCENR initiative. 56 treated samples were collected and analysed between May 2002 and November 2011 by Galway County Council. In addition three samples each of untreated and treated water were analysed for Coliforms (Total, E Coli and VTEC) in August and September 2013 by NUI Galway. The analytical results are summarised in Table 3. The full data set is presented in Appendix 4.

The existing laboratory results have been compared to the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were recently 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	SP01 Untreated Water		SP01 Treated Water		Parametric Value/(Comment)
	Number of Values	Average	Number of Values	Average	
pH (Lab)	10	7.0	44	7.2	6.5 < pH < 9 / (untreated range 6.7 to 7.4) (treated range 6.6 to 7.9)
Electrical Conductivity (Lab) (uS/cm)	10	673	43	642	800 / (untreated range 639 to 701) (treated range 505 to 852)
Colour (PtCo Units)	10	16.3	44	12.1	(untreated range 2.5 to 40) (treated range 2.5 to 43.7)
Odour (Descriptive)			22	no odour	(treated samples had no odour)
Turbidity (NTU)	10	1.7	43	0.76	1 (untreated range 0.8 to 6.2) (treated range 0.01 to 2.2)
Nitrate (mg/l NO_3)	10	7.5	39	10.2	37.5 / (untreated range 0.4 to 15.5) (Treated range 0.1 to 25.3)
Nitrite (mg/l NO_2)	10	0.072	35	0.01	0.375 (Untreated range 0.01 to 0.164) (Treated range <0.02 to 0.05)
Ammonia (mg/l N)	10	0.42	26	0.02	0.175 / (untreated range <0.1 to 2) (treated range <0.02 to 0.07)
Chloride (mg/l)			7	18.3	0.24/ (treated range 15.3 to 21.3)
Coliform Bacteria (cfu/100ml)	13	153	53	25	0 / (untreated range <1 to 480) (treated range 0 to 816)
E. Coli (cfu/100ml)	13	2	52	7	0 / (untreated range <1 to 3) (treated range 0 to 144)
Clostridium Perfringens (cfu/100 ml)			26	0.4	0/ (treated range 0 to 3)
Potassium:Sodium Ratio					0.3

The field parameters pH, electrical conductivity (EC) and temperature were measured at the borehole during the site visit on 18 June 2014. The EC measured 722 uS/cm, pH measured 7.05 and temperature measured 12.9^{O}C.

The available water quality data suggest that the chemical water quality is good. Nitrate is well below the DWS and there appears to be an overall downwards trend in nitrate concentrations (see graph in Appendix 4). There are wide ranges for the parameters nitrate, turbidity, colour, electrical conductivity, total coliforms and E. coliforms. The data show evidence of flashy peaks in concentration for these parameters (see graph in Appendix 4). The peaks in nitrate correlate with turbidity and conductivity, while other peaks in conductivity and turbidity correlate well with the coliform peaks. The data suggest the borehole is influenced by intermittent slugs of contamination that have a short residence time in the aquifer. This could suggest interaction with a karst conduit system, nearby swallow hole or other influent karst features, which would be susceptible to contamination by point recharge at surface karst features and have high flow velocities/short groundwater residence time. The data also suggest that the nitrate and microbial contamination may derive from separate contaminant sources. The flashy turbidity data suggest that the conduit system is likely to be partially infilled, and that sediments are mobilised during extreme flow events in the conduit system.

Clostridium perfringens is an indicator for cryptosporidium and its detection in the treated water suggests a cryptosporidium risk. There are no cryptosporidium analysis data on record.

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)**.

A large proportion of the effective rainfall is assumed to infiltrate to groundwater as recharge (80%) either diffusely or via point recharge at surface karst features. The remainder of effective rainfall is expected to runoff to surface water.

Bedrock groundwater flow occurs in joints, fractures and conduits, and along bedding planes in the limestone bedrock. Two interconnected flow zones are envisaged, i.e. flow in the extensively karstified, epikarst zone in the top few metres of the bedrock, and flow in a network of interconnected fractures and karst beneath this. The epikarst can be visualised as a perched aquifer system channeling infiltrating water to points of entry into the deeper groundwater flow system.

Diffuse recharge is expected to recharge to the epikarst layer at the top of the bedrock. Point recharge may by-pass the epikarst layer and recharge directly to the deep conduit system.

The epikarst hydraulic gradient is likely to reflect the local topography and groundwater flow directions in the epikarst will therefore be directed downslope towards points of vertical infiltration to the deeper conduit system, or to surface water courses in hydraulic continuity with the epikarst (e.g. the Clare River). Boreholes will also capture flow through the epikarst where they intersect and are open to it. Groundwater flow in the deeper conduit system is expected to be directed southwest towards Lough Corrib, as shown by tracer testing (**Appendix 5**).

Water inflow to the borehole at the base of the steel casing was observed in the camera survey and suggests the GWS borehole receives water from the epikarst. The camera survey suggests the presence of numerous small water strikes below 51 mbtc with the main inflow in a very weathered zone at 96.8 mbtc. The borehole may be connected to a karst conduit system via the deep water strike.

The water quality data suggest the borehole is influenced by intermittent slugs of microbial contamination that have a short residence time in the aquifer. This suggests interaction with surface karst landforms, such as swallow holes. The flashy turbidity data suggest that the conduit system is likely to be partially infilled, and that sediments are mobilised during extreme flow events in the conduit system. The chemical water quality appears to be good, with an overall downward trend in nitrate concentrations.

Overall, it is considered that the borehole is mainly supplied from the deep water strike which is likely to derive from the regional scale conduit network. There also appears to be some epikarst inflow from the base of the casing and other minor fracture inflows. Nearby surface karst features which could be linked to the source are shown in **Figure 7**.

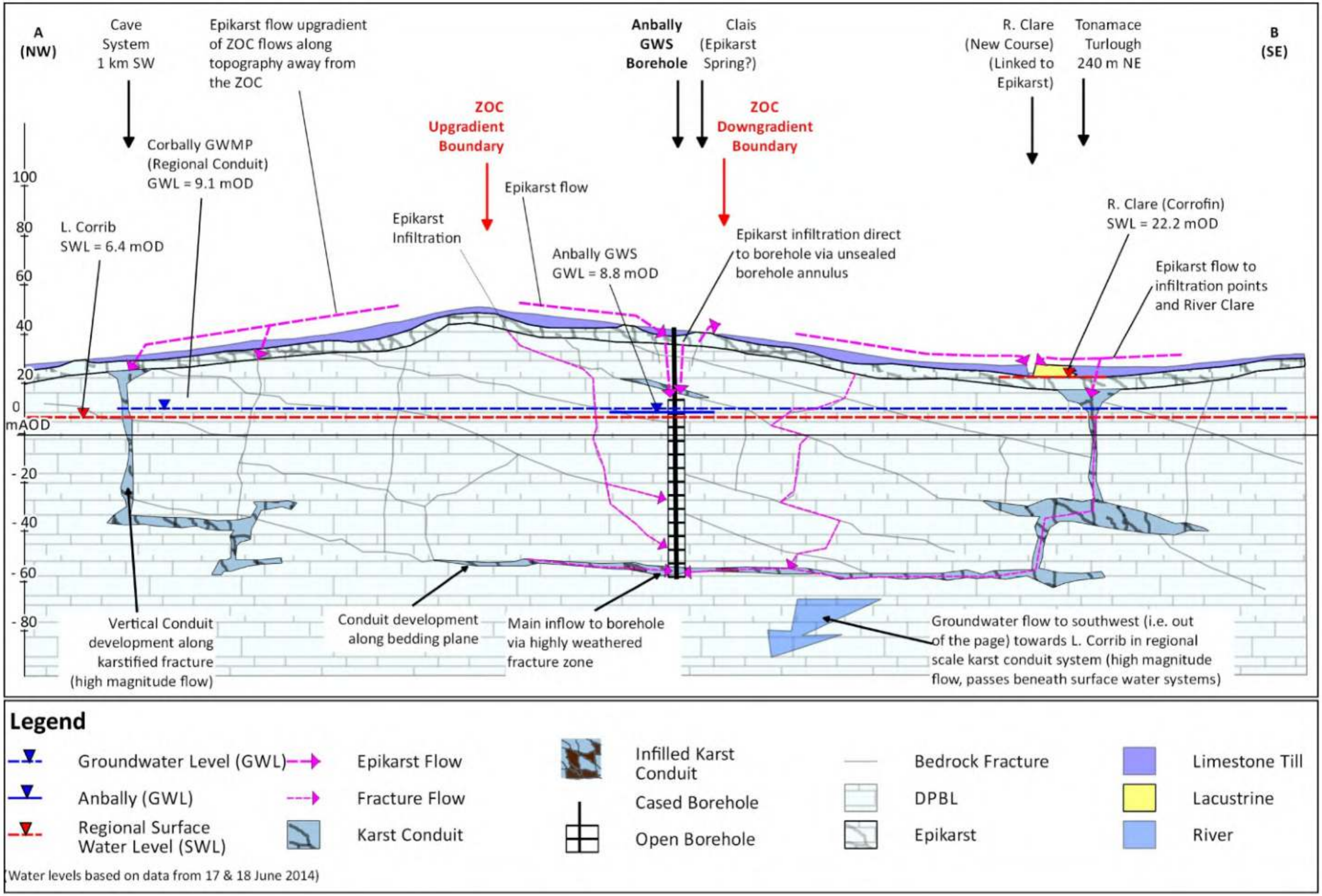

Diagram 3: Schematic Cross Section and Conceptual Model

4.2 Boundaries

The conceptual model envisages that the groundwater supply to the borehole has two components, i.e. a contribution from the regional conduit system and a contribution from the perched epikarst system.

4.2.1 Regional Component of ZOC

The GWS source is located in a large Rk_c limestone aquifer which is known to have flow paths from east to west extending across straight line distances of up to 11 km. The flow lines are known to pass under the River Clare from east to west and the River Clare is known to leak surface water down into the groundwater system. In this context and on the basis of the available dataset it is not possible to delineate boundaries for the regional component of the ZOC that are 100 percent justified in terms of hydraulics.

In this kind of setting a basic risk management approach is considered to be appropriate for delineating a prioritised zone of contribution, whereby by appropriate landuse management within that area is hoped to protect the water quality of the regional component of the GWS abstraction. It cannot be guaranteed that the delineated area is the principal zone contributing recharge to the regional component of the abstraction; however it is considered that this approach is preferable to either delineating no zone for the regional component or delineating an ultra conservative zone which is unmanageable from a practical viewpoint. If evidence comes to light in future which suggests that the boundaries of the zone should be revised then this can be done as required.

The justification for the delineation of the ZOC for the regional component of the abstraction as shown in **Figure 7** is as follows:

- The regional groundwater flow direction is approximately east-west to northeast-southwest. The regional component of the abstraction is assumed to derive from the regionally upgradient side of the borehole, i.e. east to northeast.

- In the area to the east and northeast of the borehole the most likely locations to contribute recharge to the regional flow system, which might subsequently be abstracted by the GWS borehole are point recharge locations such as swallow holes and turloughs. As such, the regional ZOC component has been delineated to encompass the known swallow holes and turloughs in the vicinity east and northeast of the borehole. As seen in **Figure 7**, the delineated area includes:

    - the Turloughour, Turloughcartron, Turloughmartin and Tonamace turloughs, and the clais spring mapped to the southeast of the borehole during the site visit.

    - a northeast trending zone of potential enclosed depressions identified from the 25-inch historical map of 1913 and the OSi Orthophotos 2005 collection. There appears to be a concentration of these features between the borehole and Turloughour/Corofin to the northeast, compared to the areas to the north and west.

    - a significant piece of the former Turloughmore footprint from prior to arterial drainage (Appendix 5).

- The boundaries are delineated to enclose the karst features listed in the previous bullet point, maintaining a distance of at least 100m from all of the features.

- The River Clare is not considered to be a hydraulic boundary with respect to the Rk_c bedrock limestone bedrock aquifer (Appendix 5). The boundary of the regional ZOC component extends east of the river to encompass the Turloughcartron, Turloughmartin and Tonamace turloughs due to their proximity to the source.

- The western boundary of the regional ZOC component has been set 100 m west of the GWS borehole.

4.2.2 Epikarst Component of ZOC

The delineation of the epikarst ZOC component assumes that lateral groundwater flow occurs in the perched epikarst layer. This lateral flow is assumed to infiltrate vertically at points where vertical and sub-vertical fractures in the underlying bedrock intersect the base of the epikarst. When these fractures are intersected by the borehole the infiltrating water could potentially be captured by the GWS abstraction. Where there is enough vertically permeability the epikarst groundwater may infiltrate vertically without significant lateral flow. Delineation of this ZOC component conservatively assumes that some lateral epikarst flow might be occurring in the vicinity of the borehole.

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

The **Western Boundary** is the upgradient boundary. It is located on the, extreme (E) vulnerability ridgeline of a small hummock northwest of the source. Epikarst groundwater flow off the hummock ridge is expected to radiate outwards. Flowlines radiating to the east-northeast and south are considered to flow towards the Clare River or points of entry to the deep conduit system, and thereby stay outside the localised, epikarst ZOC for the GWS source borehole. The boundary is the point of origin of the northern and southern boundaries and its location is based on the water balance calculation (Section 4.3).

The **Northern and Southern Boundaries** are flow line boundaries. The orientation of the flow lines is based on the groundwater flow direction in the epikarst, which is assumed to follow the local topography. The separation distance between the two boundaries is based on the water balance calculation (Section 4.3).

The **Eastern Boundary** is the downgradient boundary with respect to localised, lateral groundwater flow in the epikarst, and is the point of intersection of the flow line boundaries coming from the north and south. It is estimated to be located 265 m east of the Anbally & District GWS borehole.

Inside the boundaries groundwater flow in the epikarst is expected to infiltrate directly to the borehole annulus in the epikarst and via fractures providing minor inflows to the borehole. Outside the boundaries groundwater flow in the epikarst is expected to flow to points of vertical recharge to the deep conduit system or to the Clare River.

4.3 Recharge and water balance

The pumping rate observed on site on 18 June 2014 was 68 m^3/day. The average daily usage between 18 June and 16 September was 23.5 m^3/day. The current demand for the Anbally & District GWS is estimated at 69 m^3/day based on the number of scheme connections (Section 2). Due to the lack of long term records to confirm the scheme demand, the estimated demand has been doubled to 138 m^3/day to give a conservative value to use in the water balance calculations.

Recharge to the ZOC is estimated as 505 mm/year (see **Table 2**). At a recharge rate of 505 mm/yr the 138 m^3/day abstraction rate requires a ZOC of 0.1 km^2 to capture the required volume of diffuse recharge to balance the abstraction. Due to the high level nature of the assessment, the overlap between the regional and epikarst ZOC component water balance calculations has been ignored.

4.3.1 Regional ZOC Component Water Balance

The area of the delineated regional ZOC component is 4.1 km^2. This area could potentially contribute 5,670 m^3/day of recharge to the regional groundwater flow system from diffuse infiltration. This could be topped up by inflow of surface water at point recharge locations. The borehole is not considered to be capable sustaining an abstraction of this magnitude. Rather the regional ZOC component reflects a likely potential area from which the actual abstraction might derive.

4.3.2 Epikarst ZOC Component Water Balance

The delineated epikarst ZOC has an area of 0.1 km^2 and receives a diffuse recharge contribution equal to 138 m^3/day. If there were an epikarst component to the abstraction it is considered likely that it would derive from within the delineated area.

5 Conclusions

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 current abstraction for the Anbally & District GWS is conservatively estimated at 138 m^3/day.

The ZOC delineation was based on a combination of hydrogeological mapping and the topographical catchment of the borehole. The delineated ZOC has a regional component deriving from the deep conduit flow system, and a localised component deriving from the perched epikarst system.

- A 4.1 km^2 area to the east and northeast of the source has been delineated within the regional scale flow system. This regional ZOC component reflects a likely potential area from which the actual abstraction might derive, and which has been prioritised for risk management.

- An area of 0.1 km^2 ZOC to the west-northwest of the source has been delineated within the localised epikarst flow system. The delineated area conservatively encompasses a recharge area equivalent to 138 m^3/day. If there were an epikarst component to the abstraction it is considered likely that it would derive from within the delineated area.

The groundwater vulnerability within the overall ZOC (i.e. combined regional and epikarst component areas) is mapped as Extreme (X) (6%), Extreme (E) (56%), High (33%) and Moderate (5%). 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 suggest the borehole is influenced by intermittent slugs of microbial contamination that have a short residence time in the aquifer. The flashy turbidity data suggest that the conduit system is likely to be partially infilled, and that sediments are mobilised during extreme flow events in the conduit system. The chemical water quality appears to be good, with an overall downward trend in nitrate concentrations.

6 Recommendations

Essential

A close fitting cap with openings for the rising main, cables and a dip meter should be fitted to the borehole mouth. A water-tight, lockable lid should be fitted to the top of the borehole chamber. The trench/area of ground subsidence adjacent to the borehole chamber should be reinstated and the ground contoured to slope away from the borehole chamber.

The cumulative flow reading on the meter should be recorded along with the time and date of the reading on a weekly basis.

Routine analysis of the untreated or raw water along with the existing analysis of treated water around the distribution network should be undertaken. It is recommended that this is carried out on a monthly or quarterly basis for a period of 12 months, and at least once after a rainfall event. If the water quality appears generally stable during this period then the monitoring could be reduced.

The following water quality parameters are considered essential:

- 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 4**).

- A correctly functioning treatment and disinfection system that is fully effective at removing pathogens in the treated water needs to be installed. Currently there is no pre-filter on the UV system. Diskin[9] recommends the installation of a basic sand filter and a granular activated carbon (GAC) filter to deal with excessive turbidity and colour in the abstracted water respectively, in order to ensure that the UV treatment operates correctly.

Desirable

The GWS should seek advice with respect to undertaking a cryptosporidium risk assessment for this supply.

Tracer testing at surface karst features in the vicinity of the source (**Figure 7**) would be worthwhile as a precaution to investigate if there is interaction between the borehole and local point recharge inputs to the regional scale karst conduit system. If tracing shows the borehole to be connected to these locations, this will reinforce the need for landuse management if the delineated regional ZOC component. If tracer tests are to be carried out it may be economical to collaborate with the nearby **Clough-Cummer GWS** in the planning and execution of the tests.

Comprehensive hazard mapping within the delineated ZOC should be undertaken. 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**).

If there are any septic tank systems located within 60 m of the source they should be decommissioned and replaced with an appropriate new system located at least 60 m from the source and preferably outside the delineated ZOC. Any new, replacement system should comply with the EPA Code of Practice on Wastewater Treatment and Disposal Systems for Single houses.

The untreated water rising main should be fitted with a turbidity and associated supply shut-off threshold and alarm.

The following EPA guidelines may serve as future useful reference documents for the Anbally & District 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] .

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

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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

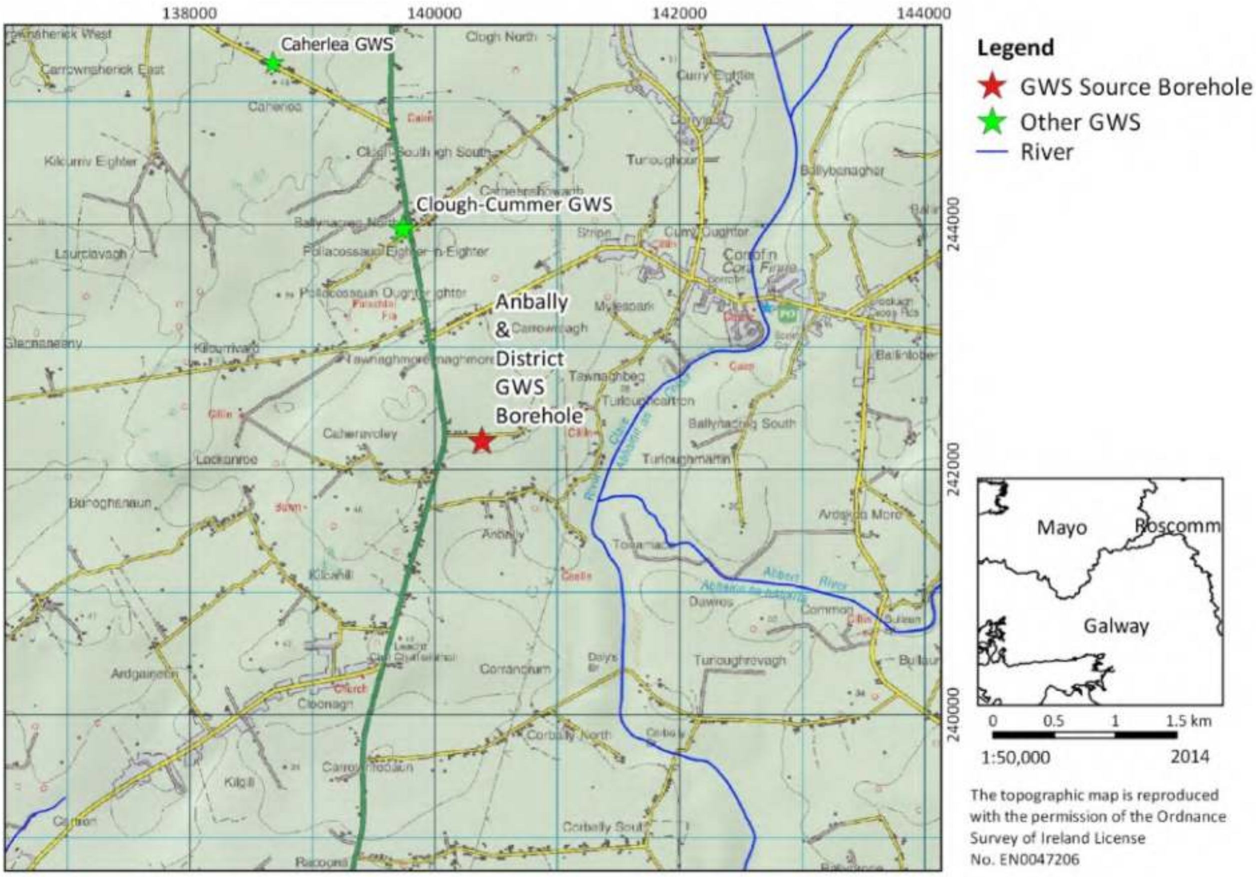


Figure 1: Location Map (OSi Discovery Series Map. 1:50,000 Scale)

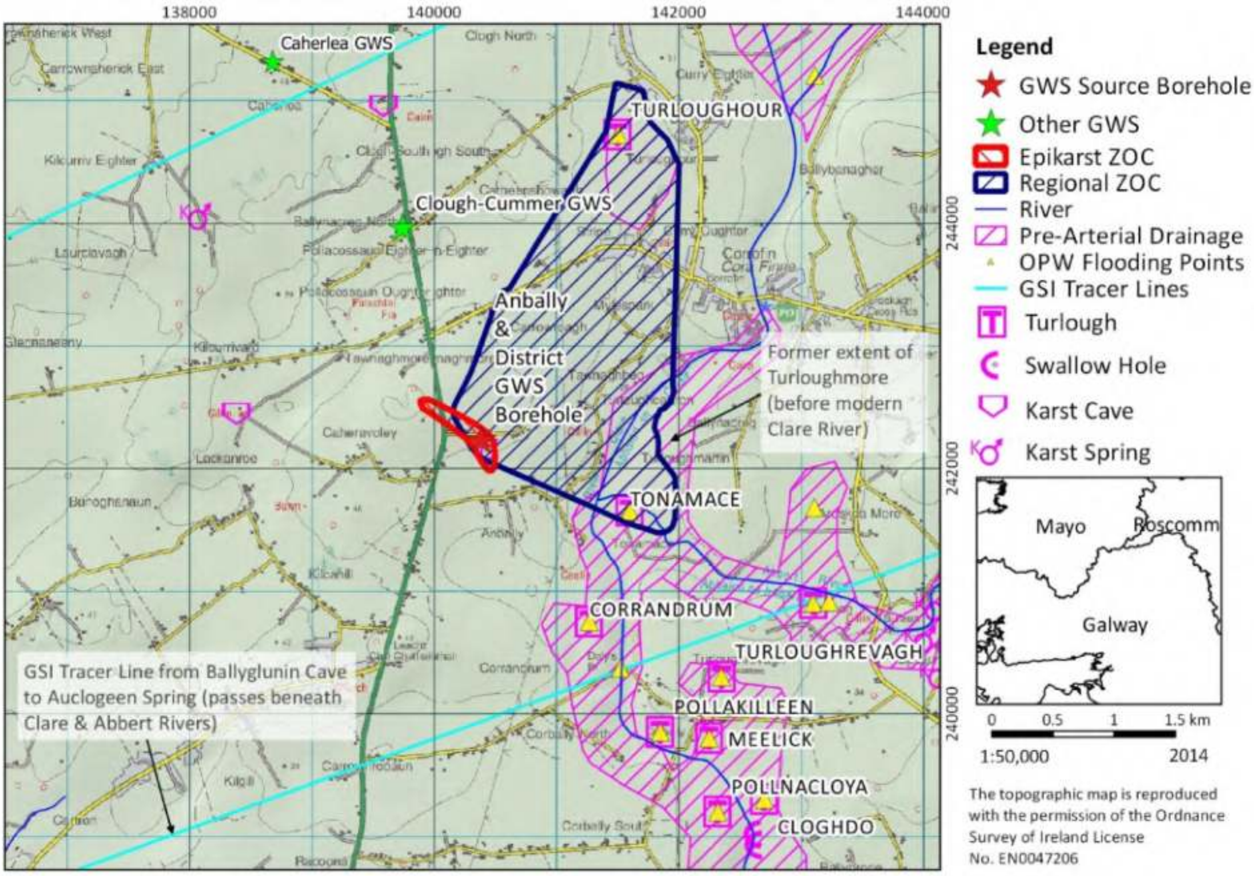


Figure 2: Topography and Drainage

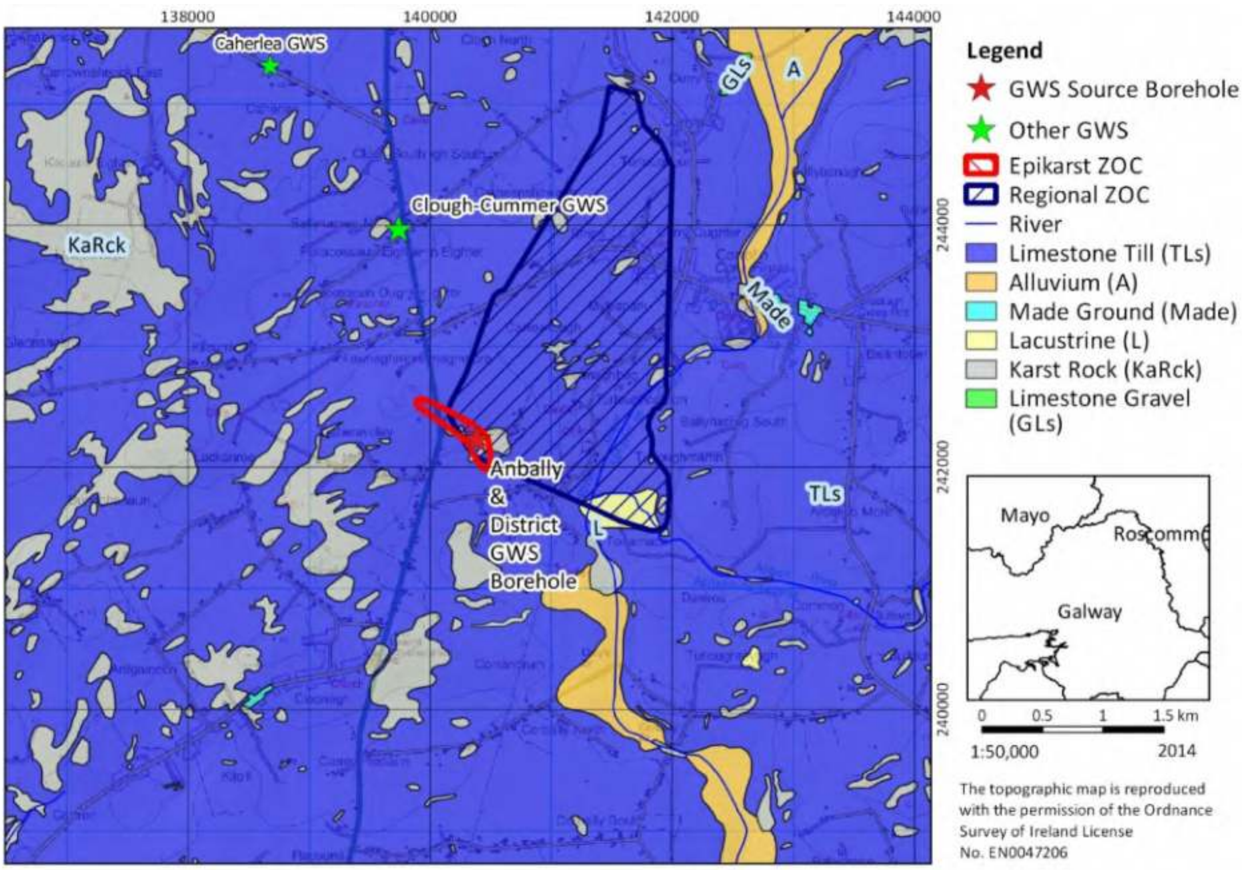


Figure 3: Subsoil Map

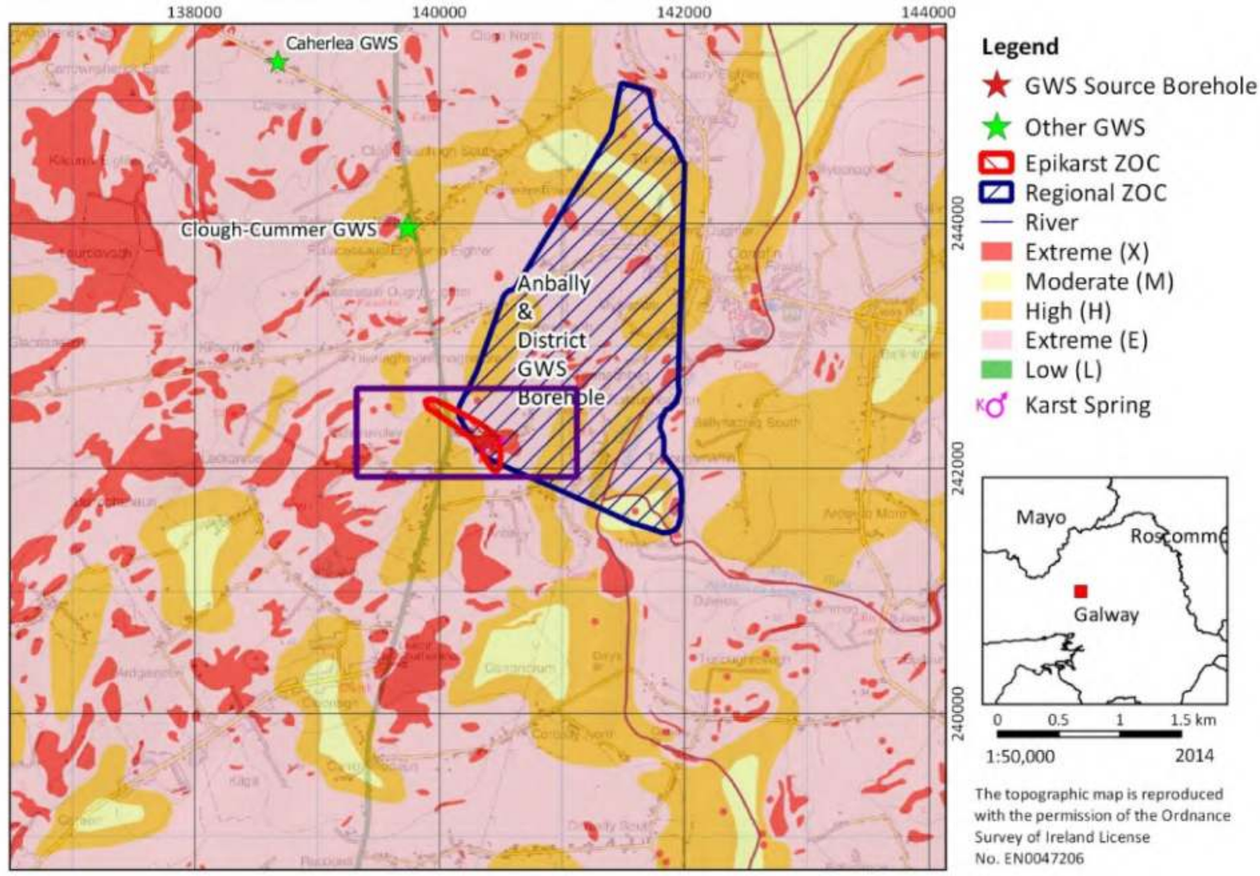


Figure 4: Groundwater Vulnerability Map

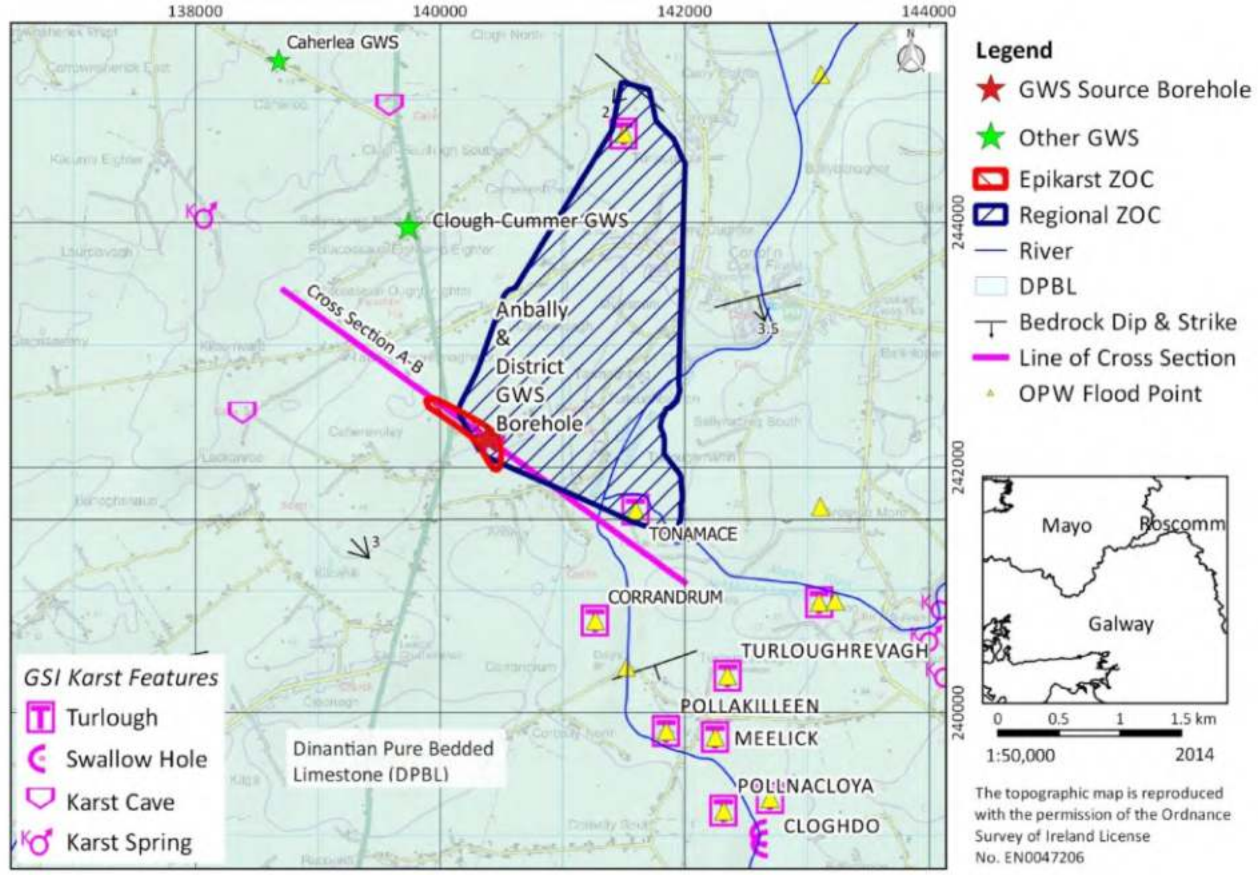


Figure 5: Rock Unit Group Map

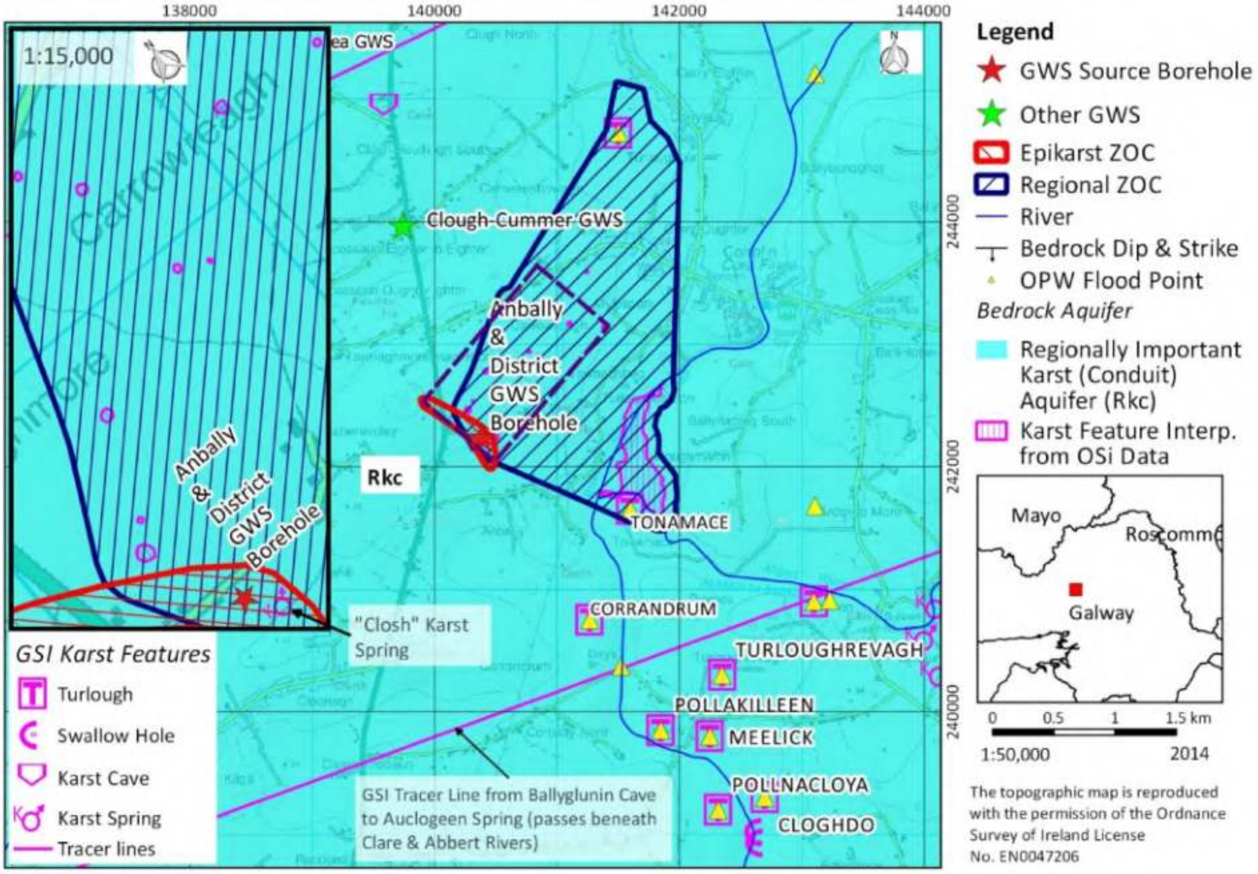


Figure 6: Aquifer Map

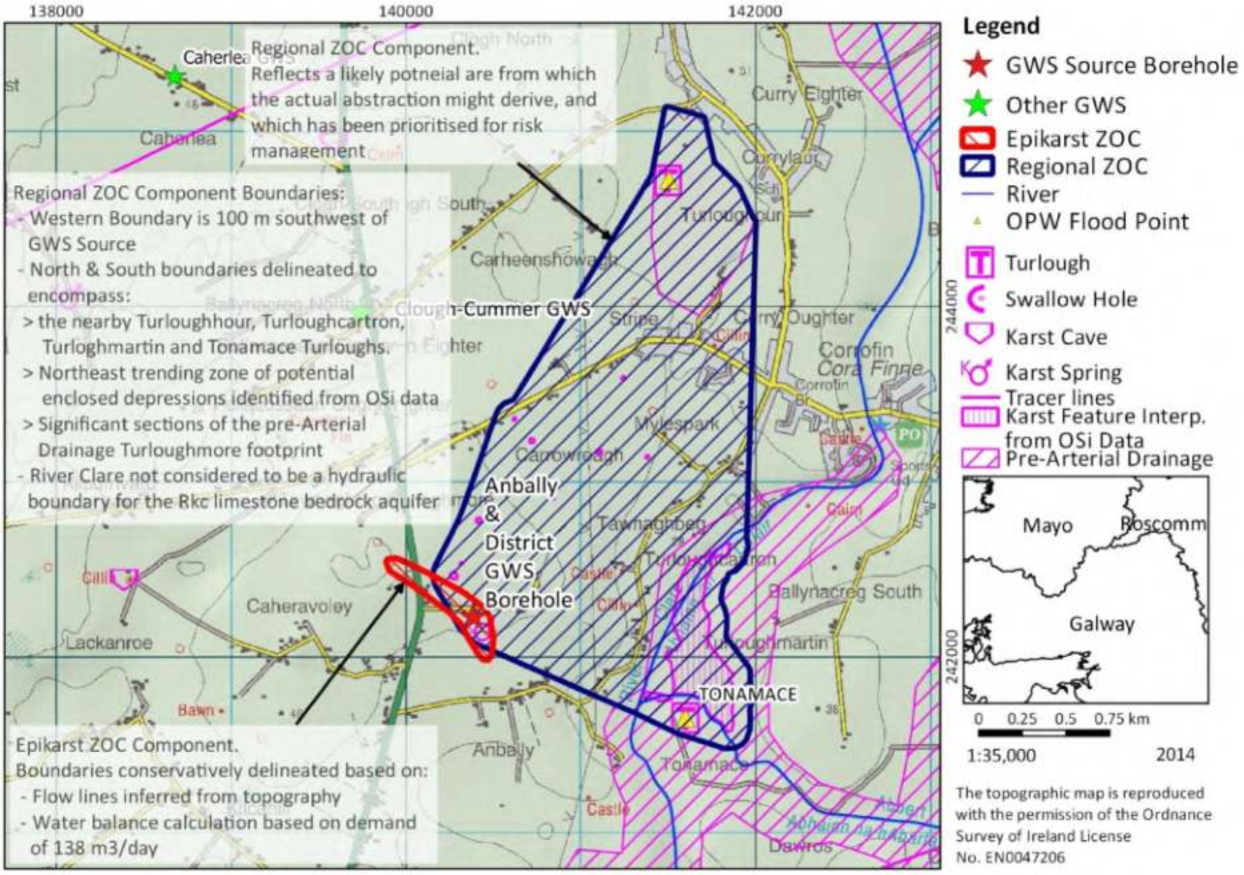


Figure 7: ZOC Boundaries

APPENDIX 1

- Diskin, J., 2014. Anbally and District Group Water Scheme Infrastructure Report, March 2014. John Diskin & Assoc. Consulting Engineers, Clarinbridge, Co. Galway.
- Well Solutions, 2010. Well Camera Survey Anbally and District, Group Water Scheme, Co. Galway. Well Solutions, Thomastown, Co. Kilkenny.

JOHN DISKIN & ASSOCIATES, CONSULTING ENGINEERS

Stradbally Nth Clarinbridge Co Glaway

Telephone: 087 2257118, 091 796071.
Email: johndiskin@eircom.net

Anbally And District Group Water Scheme Infrastructure Report - March 2014

1) Executive Summary

The Anbally and District Group Water Scheme is located approx. 13km south of Tuam town. The area supplied by the Group Scheme is outlined in heavy red line on attached Discovery series type map *" Anbally and District No1"* in Appendix A. The Group Scheme supplies water to approx 95 houses and the agricultural demand within its area. The source of water for the Group Scheme is a borehole, which was drilled in 1987

There have been frequent failures of the Group Scheme's water to comply with the drinking water regulations in the past. As such the Group Scheme is on the Dept of Environment's Annex 14 list of Group Schemes. Chemically the Anbally and District Group Water Scheme's water has failed to meet the Drinking Water Regulations due to high turbidity levels, high colour levels and high Total Organic carbon Levels. There has been exceedences in E Coli and Total Coliforms. More worryingly there has been 4 exceedences in Clostridia Pergringes in 6 consecutive months in 2003 with a further two failures one in 2011 and one in 2013

A Treatment system with itemised costs for the Group Water Scheme's water is proposed. A water Safety Plan is also proposed for the Group Water Scheme. That will enable the Group Water Scheme to be taken off the Annex 14 list of Group Water Scheme's and should mean that the water will be safe to drink for the foreseeable future.

2) Existing Group Water Scheme Statistics

The length of pipe lines in the Group Scheme is approx 10km. There are 95 houses presently serviced by this Group Water Scheme with extra connections serving lands only. The total number of connections to the Anbally and District Group Water Scheme pipe is 115 approx. There are no consumer meter boxes or meters on the various connections.

The water itself comes from a borehole located on the Anbally and District Group Water Scheme`s property, approx. 70 meters away from the public road. A submersible pump in this borehole pumps the water directly to the consumers. There is no treated water reservoir. The water is presently treated with Chlorine only.

The level, to Malin Head Datum, of the area served by the Anbally and District Group Water Scheme varies from 27.00m Malin Head Datum to 45.00m Malin Head Datum.

3) Survey of the Group Water Scheme's Pipe Lines

A complete survey of the Anbally and District pipe lines will require the purchase of the most up to date 1/5000 Roster maps, for the Group Water Scheme's catchment area, from the Ordnance Survey of Ireland

4) Leakage Levels in the Group Water Scheme

A full assessment of the existing leakage levels in the Anbally and District Group Water Scheme will require the installation of a new Bulk Meter at the pumphouse and strategic sluice valve on the network. The leakage survey could be carried out then.

Galway County Council's standard for a leakage level that could trigger pipe line replacement is a flow of 0.10 cubic meters per kilometre of pipe line per hour or greater, with all the connections on the said pipe line turned off. In addition the history of leak repairs on the existing pipes needs to be catalogued and recorded before any submission for funding of pipe replacement could be made.

5) Details of the Existing Borehole

The source of water for the Anbally and District Group Water Scheme is a borehole, which was drilled in 1987. The bore hole is 99m deep. The borehole is lined with a steel liner down as far as 27.2 m below ground level. Below that level it is unlined. Polluted shallow surface water can enter the borehole, as there is a slot in this liner 2.5m below ground level. The borehole was surveyed by a company called Well Solutions from County Kilkenny. Well Solutions produced a very relevant and informative report on this borehole. Based on the camera survey of the borehole water strikes were encountered at the following depths below the top of the existing steel casing {=ground level at pump house}:

32.70m	cloudy water is encountered
51.10m	water strike and borehole water clear
51.50m	probable water strike
60.40m	probable water strike
73.30m	probable water strike
75.30m	probable water strike
87.30m	probable water strike
96.80m	weathered rock possibly the main water strike
99.10m	Old pump that had fallen into bore hole some time in the past

The borehole head presently is not sealed. The head of the steel liner would need to be extended upwards and then sealed up by an appropriate cap which would allow for removal of the pump in the borehole for maintenance purposes. The possible option of sealing the borehole down as far as 50m below ground level should be examined as that would allow better ground water to be extracted from the lower level in the borehole. Care would need to be taken that the current Water demand by the Water Scheme from the lower 49m of the borehole is satisfactorily maintained after sealing the top 50m.

6) **Geological Survey of Ireland data relevant to the Aquifer from which the Group Water Scheme's water is taken.**

As mentioned already, the source for the Anbally and District Group Water Scheme is the local ground water which is abstracted via a borehole. The Aquifer itself is located in the water body known as the Western River Basin. I attach, in Appendix C, a copy of the following six Geological Survey of Ireland maps:

A ".Aquifer Type at Annbally_District GWS Source", scale 1:47211. The Aquifer is designated as "Rkc" which is Regionally Important Aquifer- Karstfied"

B *"National Draft Bedrock map near Anbally and District GWS borehole".* You will see from same that the bedrock around the borehole source is described as DPBL, namely "Dinantian Pure Bedded Limestone"

C *Karst features and Tracer Lines near Anbally and Dist GWS Borehole"* You will see from this map that there is a Turlough within 1.4km, 1.7km and 2.6km from the source. There is a swallow hole within 4.6km north east of the source. There are also other under ground features, contiguous to the borehole, which may help the direct ingress of surface water to the ground water body from which Anbally and District gws get their water. As can be seen from the green tracer lines on the aforesaid map the ground water flows in a south westerly direction. Any pollution event north east of the group water scheme`s borehole should be of concern to the Group Water Scheme.

D *"Aquifer Vulnerability Contiguous to the Anbally and District Group Water Scheme", scale 1:42,788*
You will see from same that the Aquifer contiguous to the borehole is designated as subject to extreme vulnerability to pollution.

E *"Aquifer Vulnerability at the Anbally and Dist gws borehole"*, Scale 1:5,135
You can see from this graph that ground at the Anbally and District Group Water Scheme borehole is subject to extreme vulnerability or worse still it was originally exposed rock with no barrier at all to prevent surface pollution entering the ground water body.

F *"Teagasc Subsoil Map near Annbally_District Borehole"*
You can see that the soil in the general area of the borehole is "Till derived chiefly from limestone" and that beside the borehole there is no soil at all as it is "Bedrock outcrop and subcrop"

7) **Quality of the Existing Raw Water Source**

I set out in Appendix D details of all tests results on Galway Co Council`s files for the period 1992 to date. I set out below, in Table 3, a brief summary of the parameters that need to be addressed by the Group Water Scheme so that their water complies with the Drinking Water Regulations.

Table 1 – test results between 13/05/1992 and 08/10/27 08/2013

Parameter	Max. Acceptable Level	Units	No of Test Results on Co Co files	No of test failures	Average Value	Maximum recorded Value
Turbidy	0.2	NTU	38	29	0.64	2.1
Total Organic Carbon	2.0	mg/lt	6	6	3.37	4.4
Colour (Ha)		Degrees Hazen	38	4	11.13	43.70
General Coliforms	0	Number/ 100ml	39	18	41	816
Ecoli	0	Number/ 100ml	38	14	11	143
Clostridia Perfringes	0	Number/ 100ml	12	5	2	3

On looking at the test results spreadsheet in Appendix D you can see that there is roughly a three month gap in the dates between which the various tests samples were taken. There are no test results on file for the period during the serious flooding in Co Galway at end November and early December 2009. This was an exceptional flood with a likely return period of at least 100 years. One would really need continuous monitoring of the Group Scheme`s raw water for at least 12 months to be sure that most of the spikes in the various parameters were captured.

On looking at the map entitled "*Karst Features contiguous to Anbally and District Group Water Scheme borehole*" you will see that the area around the Anbally and District Group Water Scheme borehole has three Turloughs and one Swallow hole within a 4.6km radius of the borehole. The tracer lines on the GSI map indicate that the flow of the ground water is from the North East towards the south west. For that reason the existing Anbally and District borehole could get contaminated with contaminated surface water falling on the lands north east of the borehole. Similarilly any septic tanks, silage pits, dung steads and fields on which slurry has been spread north east of the borehole should be of concern to the Group Scheme. As the existing borehole is in a Karst area there is no guarantee that surface water will not mix with the ground water given the appropriate weather conditions. If the surface water picks up contaminants before it joins the ground water then it will pollute the ground water. In the absence of continuous monitoring, I will take the measured test result levels summarised on the table above as representative of the likely water to be treated when designing a treatment plant for the Anbally and District Group Water Scheme

8) Recommended Treatment Plant

The average levels of *Total Organic Carbon* in the water is 3.37mg/lt, over 6 tests with a peak of 4.40mg/ltr. At that concentration there is a possibility of forming THMs when that water is dosed with chlorine. If a validated UV reactor is provided to disinfect the treated water against a likely cryptosporidium risk, that level of TOC will make it difficult for any UV system to fully disinfect the water

The recorded levels of *Turbidity*, as per the table above, exceeds the EPA requirement of a maximum level of turbidity of 0.20 NTU for water going to disinfection by UV on 29 of the 38 test results on file. High turbidity renders a UV system inefficient and also makes it difficult to maintain a free chlorine residual of 0.2mg/ltr at the end of the pipe lines. Turbidity levels can be significantly reduced using a basic sand filter.

The recorded levels of *Colour*, as per table above is an average of 11.13 degrees Hazen with a peak of 43.7 degrees Hazen. A water with high Colour and high Total Organic Carbon would require treatment before the water could go forward for disinfection by UV and Chlorine. A Granular Activated Carbon filter could lower the Colour and Total Organic Carbon levels. It will also take care of the Turbidity. Before one could say for certain that the GAC filter would work efficiently, it would be necessary to test a small pilot GAC filter on site. A budget cost for such a pilot GAC filter would be €900.00 to €1,000.00

There are 39 *General Coliforms* and 38 *Ecoli* tests results on the Galway County Council file for the Anbally and District Group water Scheme. A large number of these tests failed. This should not have happened as an appropriate chlorine dose should have killed that bacteria in the water. The possible reasons for the failure could be:

The chlorination equipment at the pump house was working or

The equipment was working but the appropriate chlorine dose was not applied for the character of the water to be treated on the day.

There was 5 occasions when live *Clostridia Perfringes* was detected in the water, three of the failures occurred over a continuous period of 6 months. One needs a strong dose of chlorine to kill the Clostridia Perfringes bacteria. The Clostridia bacteria is an indicator organism for the cryptosporidium parasite. Presently there is no barrier to deal with the cryptosporidium risk in the Anbally Group Water Scheme. A validated UV reactor disinfection system , duty and standby, would be required, provided the water gets the treatment outlined above before the UV and chlorination is applied. As there is no treated water reservoir in the group scheme, the flow pumps are going 24 hours a day. These pumps supply the peak demand and the minimum night flow demand. Any validated UV system would have to be able to cope with that flow regime. As a UV reactor is not as effective as a pump in dealing with fluctuations in flow, there will be inefficiences in any UV reactor provided in the absence of a treated water reservoir. A combined UV and Chlorination system applied to the water which is pre-treated as outlined above, will make the water comply with the Drinking Water Regulations and safe to drink.

9 Water Safety Plan for the and District GWS management

The Anbally and District Group Water Scheme management will need to prepare a Safety Plan for the proper running of their Water Scheme into the future. This plan is also necessary to guarantee the safety of their water. The following is a list of tasks that the Group Water Scheme needs to carry out going forward. It should be reviewed at the end of each year and updated as necessary

1) Seal the top 50m of the borehole or pre-treat the water and install the Validated UV Reactor disinfection system as outlined at item 8 above and maintain same as per manufactures instructions.

2) Replace existing Chloros disinfection system. Make it flow proportional and bund the chloros tanks

3) Provide a sealed container with a volume equivalent to 20 minutes flow during peak flow to act as contact tank so that the Chlorine has had sufficient contact time to fully disinfect the water before it reaches the first consumer.

4) Clean out the pump house, dispose of any defunct items, Tile the floor and walls (up to 1.1m high above floor level) of pump house and paint the rest of the interior. Provide a frost thermostat and appropriate heater controlled by the frost thermostat.

5) Define the zone of contribution for the borehole source. As the source is located in a Karst area with Turloughs and Swallow Holes it will be difficult to establish this area exactly on the ground. The area itself is probably quite large. It could extend at least a kilometre north east of the bore hole source. Based on the GSI maps, detailed at item 6 above, the ground water seems to flow from North East to the South West. That should mean the the Anbally and District Group Water Scheme should take particular note of any activity taking place North East of their borehole source. All point sources of possible pollution, e.g. septic tank, farmyards, within this area should be inspected and brought up to best practice standard in terms of their maintenance. The Group Water Scheme should also take note of any land owners spreading agricultural slurry within 500 meters of the borehole. The caretaker would need to be informed of same so that he can be extra vigilant during the days after the slurry spreading. The Group Water Scheme management should adopt a protocol for dealing with that type of threat to their water and make sure their caretaker is aware of it.

6) Adopt a programme for flushing out the scour valves. Target to aim for should be once per 4 weeks in summer and once per 6 to 7 weeks for the rest of year.

7) All connections to the Group Water Scheme pipe should be checked so that no backflow into the Group Water Scheme's water main is possible.

8) The Group Scheme should consider sealing off shallow water strikes in the borehole. The first water strike in the borehole seems to be at a depth 51 metres below ground level. However, the major strike occurs at 96.8m below ground level. There is water entering the borehole at 27m below ground level which may be contaminated with surface water. The existing ope on the 6 inch steel liner at approx depth of 2.5m below ground level should be sealed. Quotations from specialist drill companies should be sought as to how best to seal the top 50m of the bore hole without reducing the yield from the borehole. The existing borehole head should be sealed to

prevent insects, slugs, frogs and polluted matter entering the borehole while at the same time allowing for the electric cable and water pipe.

9) Keep a daily log of the levels of Chlorine dosing at the pump house and of the free Chlorine residual at the end of the pipe lines. Print out and keep a graphical record of the continuously monitored Turbidity levels and UVI levels produced at item b1 of Section 10 below. Other significant events like pump failure, leak repairs, slurry spreading within 500m of the pump house etc. should also be noted.

10 Budget Cost of suggested Upgrade Works to Anbally and District GWS

a Exhaust the possibility of sealing off the borehole from 0.00m below ground level to 50m below ground level so that water consumed by the Group Scheme comes from a lower level. Approx. Est. Cost.....................€12,000.00 incl VAT

b1 Provide pressurised sand filter, duty and stand-by with controls.......................................€15,000.00 incl VAT

b2 Validated UV Reactor, Turbidity and UVI monitor, Alarm system, cleaning system for UV tube and a Turbidity and UVI logger. Est. Cost ....€35,000.00 incl. VAT

b3 Extend existing pumphouse to accommodate items at point b1 and b2 above and b4 and e below. Est Cost...€20,000.00 incl VAT

b4 Fit flow proportional, including one new bulk meter to measure all water leaving pumphouse, Chloros dosing system, duty and stand-by, and bunded. Est Cost....................................€ 6,000.00 incl. VAT

c Provide a sealed galvanised steel container, with capacity of 20 minutes peak flow, that will ensure a chlorine contact time of 20 minutes. Est.Cost..........€3,000.00 incl. VAT

d Provide frost thermostat and appropriate heater-controlled by frost thermostat in pumphouse. Est Cost..€200.00 incl. VAT

e Based on the continuously logged turbidity and Ultra violet intensity data recorded over 12 to 18 months at item b1 and depending on the success of item a above, provide two GAC filters, duty and standby, complete

with pump controls, back washing
facility. Est. Cost………………………………….....€36,000.00incl VAT

f Build new treated water reservoir…………………....€40,000.00 incl VAT

g Install ?? No additional scour valves in the
Group Water Scheme = € ????? incl VAT

h Install ??? No extra air valve and ??? extra
sluice valves = € ??????? incl VAT

i Install water control boxes cum meters on
each of the ??? connections ………………………….€ ??????? incl VAT

j Seal the top existing bore head
Est. Cost…………………………………………….. €300.00 incl. VAT

k Provide a free chlorine monitor and alarm at the
end of the group water scheme`s pipe line which
will alarm the caretaker when the free chlorine
residual drops below 0.1mg/ltr……………………..€5,000.00 incl. VAT

11 Phasing of the Recommended Works

Phase 1

Provide items a, b1, b2, b3, b4, c, d, g, h, I, j and k at Section 10 of the report above.
Cost as detailed above for each item.

Sub Total 1 = € ??????? incl VAT

Phase 2

Provide items e and f above

Sub Total 2 = € ??????? incl VAT

Phase 3

Following a water audit on the section of pipe deemed
to be leaking excessively and following an appropriate
leak repair history data being located replace the said ???
of pipe………………………………………………………….**€ ??????? incl VAT**

Overall Total =   €????????? incl.VAT

……………………………..End of report……………………………………………..

John Diskin B.E.
21st March 2014

Annabally & District Group Water Scheme

Parameter	Coliforms Bacteria	E Coli	Aluminum (Al 3)	Ammonium (NH4)	Chlostridia Perfringes	Colour	Conductivity	Iron	Nitrite	Hard ness	PH	Turbidy	Manganese	Nitrate	Total Organic Carbon	THM's	Cl (2)	Sulphate
Unit	No/100ml	No/100 ml	µg/l(Al)	mg/l(NH4)	No/100ml	mg/l Pt.Co Hazen	µs/cm @ 20°c	µg/l(Fe)	mg/lt(NO2)	mg/l	PH Units	NTU	µg/l(Mn)	mg/lt(NO3)	mg/l	µg/l	mg/l	mg/lSO4
Acceptable Levels DATE of Test	Zero	Zero	200	0.30	Zero		2500	200	0.50		6.5 - 9.5	1 NTU	50	50		100	250	250
13/05/1992	13	12																
06/02/1995	1	1																
23/04/1996	132	120																
11/06/1996	120	70																
25/06/1996	6	1																
06/08/1996																		
03/03/1997	0	0																
10/03/1997	1	1																
24/03/1997	1	1																
11/05/1998	0	0		0.025		10.1	680	<50	0.02		7.2	0.62	<50	13.40				
06/07/1998	0	0																
03/02/1999	0	0		<0.025		3.7	694	<50	< 0.02		7.1	1.1	<20	11.40				
19/04/1999				0.094		<2.0	778	<50	< 0.02		7.5	0.5	<20	15.00				
25/01/2000				<0.025		5.4	698	<50	< 0.02		7.3	0.45	<20	12.20				
05/09/2000	0	0		0.036		19.5	628	67	< 0.02		7.3	0.84	<20	4.30				
12/01/2001	0	0		<0.025		6.5	659	<50	< 0.02		7.3	2.1	<20	12.90				
20/11/2001	0	0		<0.025		8.7	695	57	< 0.02		7.3	0.7	<20	11.00				
08/05/2002	0	0		<0.025		10.7	678	<50	< 0.02		7.5	0.6	<20	11.30				
24/07/2002	1	0		<0.025		14.9	707	<50	< 0.02		7.3	0.6	<20	8.20				
04/09/2002	9	5		<0.025		18.2	681	84	< 0.02		7.2	1.83	24	7.40				
22/01/2003	0	0	6	0.01	0	7.5	603	7	0.004		6.99	0.01	2	4.40				
07/04/2003	0	0	17	0.01	2	10	577	57	0.004		7.01	0.97	3	1.50				
17/07/2003	0	0	11	0.01	3	15	665	75	0.01		7.26	0.01	11	3.40				
17/10/2003	0	0	8	0.01	2	20	636	33	0.007		7.1	0.37	3	7.20				
21/01/2004	0	0	10	0.01	0	2.5	620	15	0.008		7.33	2.01	2	20.60				
19/04/2004	0	0	6	0.01	0	10	599	14	0.012		6.92	0.01	2	14.60				
13/07/2004	2	0	12	0.01	0	40	602	85	0.001		7.17	0.01	6	6.50				
18/10/2004	0	0	23	0.02	0	2.5	640	55	0.001		7.08	0.01	3	0.10				
13/01/2005	0	0	10	0.01	0	2.5	604	25	0.001		6.93	0.01	2	16.40				
17/10/2005	1	1																
06/11/2006	1	0																
18/02/2008			<20	<0.03		4.7	625	<50	<0.02		7.1	0.7	<20	14.10		7		
03/07/2008			<20	0.06		5.8	630	<50	<0.02		7.1	0.9	<20	11.30		19		
23/07/2008			7.5	0.083		11.3	640		<0.04	367	7.4	1.66	2.4	8.34	4.4	<5	19.3	<1

Parameter	Coliforms Bacteria	E Coli	Aluminum (Al 3)	Ammonium (NH4)	Chlostridia Perfringes	Colour	Conductivity	Iron	Nitrite	Hardness	PH	Turbidy	Manganese	Nitrate	Total Organic Carbon	THM's	Cl (2)	Sulphate
Unit	No/100ml	No/100 ml	µg/l(Al)	mg/l(NH4)	No/100ml	mg/l Pt.Co Hazen	µs/cm @ 20°c	µg/l(Fe)	mg/lt(NO2)	mg/l	PH Units	NTU	µg/l(Mn)	mg/lt(NO3)	mg/l	µg/l	mg/l	mg/lSO4
09/10/2008			64	<0.03		4.4	647		<0.02		7.1	0.4	<20	15.00		<10		
21/04/2009			12.13	0.042		11.9	635		0.05		7.3	0.37	<1	9.56	3.1	<5	20	9.73
07/05/2009	201	12	<20	<0.03		7.9	691	<50	<0.02		7.3	0.5	<20	9.30				
12/05/2009	0	0				4		10	0.021	387	6.6	0.01	<5	8.94			0.25	10.56
12/06/2009	0	0																
26/06/2009	0	0																
02/11/2009			28	0.03		5.9	638	52	<0.02		7	0.9	<20	8.80				
01/03/2010			12.74	0.042		16.9	621		<0.04		7.3	<0.11	2.47	7.28	3.5	30.6	15.3	12.3
13/04/2010	0	0	<20	0.03	0	3.7	623	<20	< 0.02		7.2	0.5	<20	11.10			0.07	
07/10/2010			<20	<0.03		9.8	595	33	<0.02		7.1	1.1	<20	10.20				
13/01/2011			24.61	<0.009		6.3	555		<0.043		7.2	0.49	1.036	7.13	3.4	15.9	16.7	7.1
26/05/2011	6	3	18	0.032	1	43.7	545	77	<0.017		7	1.4						
10/11/2011			9	<0.01		7	628	44	<0.017		7.1	0.9						
10/02/2012			5	<0.01		10.1	593	35	<0.017		7.4	0.5						
14/03/2012			12.2	0.011		10.4	505		<0.043		7.9	0.46	1.2	6.09	3.59	19.85	17.6	7.5
17/09/2012	1		8	0.01		17.4	762	58	<0.017		7.2	0.2						
25/04/2013			8.7	0.01		<2.5	620		<0.043		7.1	0.4	<1.0	7.59	2.24	26.68	18	5.1
09/07/2013			37	0.031	2	34.1	852	49	<0.017		7.1	0.3						
21/08/2013	816	143.9																
21/08/2013 RW	187.2	35.9																
26/08/2013 RW	79.4	14.6																
27/08/2013	1	0																
TOTALS	1580	421			10	423						24.44			20.23			
No of Tests	39	38			5 failed	38						38			6			
average count per test	**41**	**11**			**2 per failed test**	**11.13**						**0.64**			**3.37**			

A cell shaded in yellow means a failed test result	xxx

Well Camera Survey
Anbally and District,
Group Water Scheme,
Co. Galway

Anbally and District GWS

24th March 2010

Well Solutions

Well Surveys and Rehabilitation

Email:wellsolutions@jsdrilling.ie
Tel: 0871776966 / 0877433451
Fax: 0567793887
Website: www.wellsolutions.ie

Contents

Introduction

Well Solutions is pleased to present this report summarising the camera survey of the group water scheme supply well for Anbally and District Group Water Scheme in Galway. The survey was carried out on the 24th March 2010 during a pump retrieval exercise carried out by Well Solutions and the group water scheme.

The objectives of the camera survey were to determine the internal conditions of the well and identify any notable features in the well.

Methodology

One of the most difficult aspects of determining the source of a particular problem in a well is the inability to see into the well. Well Solutions has a specially adapted camera system (see figure 1 below) which can be lowered into wells giving a full 360º view of the well wall in addition to the ability to look down and back up the well. This enables us to determine the quality of well construction and locate any damage caused to the casing during or since installation. This is the first step to ascertaining the reason for water contamination, yield decrease or pump problems in a well.

An added difficulty was encountered in this well, the ropes holding the pump had broken and the pump was suspended from the electrical cable. The riser pipe was removed and the camera system was used to guide the removal of the pump which had become stuck at approximately 30 m below ground level (bgl). Once the pump was removed the camera survey was carried out. The pump was then suspended from stainless steel wire rope and lowered into the well with a new riser pipe and now sits at approximately 50m bgl. A recording of the camera inspection of the wells is provided to the client with the written report.

Figure 1 Specially adapted camera system

Results of Camera Survey

Anabally and District Supply well was installed with 6 inch steel casing however due to drilling difficulties 5 inch steel casing was driven inside this. The well cover was located approximately 0.6m from the pump house wall with the casing approximately 0.2m above ground level, no plug was present in the internal casing due to the difficulties with pump removal therefore water ingress was potentially possible from the surface.

The camera survey showed steel casing running from 0 m btoc (below top of casing) i.e. ground level to 27.5 m btoc. The casing was intact with the exception of between 2.0m btoc and 2.2m btoc where a section of casing has been cut during previous attempts to remove the pump. At 27.5m btoc water ingress can be seen into the well from outside the casing. From 27.5 m btoc to 99.1 m btoc (the total depth of survey) the well was cored limestone. The well was predominantly solid cored wall with the exception of regular indentations around the circumference of the core, over 50 of these were noted down the length of the core and these are most probably bedding planes in the limestone. Some may have been smaller fractures and hence, potential minor water feeds however heavy build up of calcite on the well wall makes them hard to definitively identify. The following features recorded during the survey were thought to indicate the location of the main water feeds for this well;

- 32.7m btoc water was encountered. Water is very cloudy and suspended solids visible in the water column
- 51.1 m btoc water clears possibly due to proximity of water feed
- 51.5 m btoc weathered fracture around circumference of core - probable water feed
- 60.4 m btoc fracture around circumference of core - probable water feed
- 64.4 m btoc fracture around circumference of core - probable water feed
- 73.3 m btoc fracture around circumference of core – probable water feed
- 75.3 m btoc fracture around circumference of core – probable water feed
- 87.3 m btoc fracture around circumference of core – probable water feed
- 96.8 m btoc very weathered fracture around circumference of core – probable main water feed

At 95 m btoc the top of an old electric cable was encountered this was followed to 99.1m where rope, electric cable and electrical tape is thought to possibly obscure an old pump which was left to sink to the bottom of the well. The camera could not progress beyond 99.1m btoc.

Discussion and Recommendations

According to Anbally and District GWS members the well was drilled in 1987 and the pump has been replaced twice in this time. It appears that one of the pumps was not removed but allowed to fall to the bottom of the borehole this may have been due to difficulty in removing the pump. A clear picture could not be achieved of what was at the base of the well however the presence of the electric cable and rope suggest that the pump is also at the bottom of the well. At present this does not pose a problem for the well, however if another pump were to fall to the bottom there is a strong possibility that the main water feed to the well at 96.8m btoc would become obstructed.

It is recommended that in future when removing pumps all possible efforts are made to retrieve old pumps, electric cables and ropes so as to ensure the free flow of water from the main feed at 96.8 m btoc.

The water appears to have a high suspended solid content particularly in the upper 20m of the water column. A possible explanation for the high suspended solid content is the age of the well and the fact that it is drilled in limestone. The walls of the well are coated in what appears to be a calcite deposit which is loosened during pumping and suspended in the water. The water clarity shows improvement from 51.1m btoc to the bottom of the borehole. This is thought to be because the main water feed is at 96.8m btoc and other water feeds from 96.8 m btoc up to 51.5m btoc provide clearer water. The significant calcite build up on the well walls would be unlikely to completely block water feeds to the well however it is likely that it is reducing yield and plugging the smaller fractures feeding the well. This is further supported by the cavitation which occurred in the well in the summer of 2009. The cause of this drop in water level is suspected to be that the well is producing water at or near capacity.

Well Solutions recommends that when the pump is next being removed or changed that the inside of the well is cleaned using mechanical means such as jetting to remove the calcite build up from the wall of the well in particular from the fracture zones feeding the well. The encrustation which is removed from the walls of the well should then be lifted from the base of the well. Initially it is recommended that the entire well is cleaned. This should help to reduce the suspended solid concentration in the water in addition to increasing the yield of the well. A methodology for jetting the well has been attached as appendix 1. A complete jetting of the well should not be necessary for several years after the initial cleaning, however, a regular jetting of the fracture zones every 2 years in conjunction with a camera survey of the well to check the overall condition is recommended to prevent a fall off in yield.

Water ingress was noted at 27.5m btoc from the outside of the steel casing. This is a potential contamination issue as it increases the risk of faecal coliform and e coli entry into groundwater.

The water ingress from the outside of the steel casing may become an issue, particularly if bacteria counts in the water start to increase as this is the most likely entry point for bacteria from surface waters. It is recommended that the well head area is reworked to include a concrete plinth around the top of the well, a new upright cover that is at least 0.5 m above the surrounding ground level, a winch and wire tautening system be included to aid in the removal of the pump when required and a water proof cover on the well which allows the riser pipe, electric cable and suspension wires and nothing else to pass into the well.

A pump upgrade will be required for this scheme in the future. Information is provided on a variable speed pump, which is the recommended upgrade for the Anbally and District Group Water Scheme. The correct pump size was investigated for the scheme at its current usage and factoring in the addition of future members over the coming years. A 3-phase, 7.5 horse power Grundfos, variable speed pump is thought to be the best option for the scheme. This has been successfully installed in a scheme supplying 140 households where it is working efficiently and is recommended as the best option in this case. The price for this pump and accessories is included as appendix 2 (note this is for information only and is not intended as an immediate recommendation). The replacement of the pump will not be necessary until problems are encountered with the pump in place or demand exceeds capabilities of the pump currently in place.

It is recommended that a schedule of works be organised for the next 12- 24 months to complete this work.

Limitations

Well Solutions prepared this report for the sole use of Anbally and District Group Water Scheme. This report is intended to assist Anbally and District Group Water Scheme in understanding the issues identified in relation to the water supply well on site. Field investigations carried out by Well Solutions were restricted to a level of detail appropriate to the presented assessment. It is important that these limitations be clearly recognised when the findings of this report are being interpreted.

To the best of our knowledge information contained in this report is accurate at the time of issue. Subsurface conditions may vary with time. This should be borne in mind if the report is used without further confirmatory testing after significant delay.

APPENDIX 1

Jetting methodology

Mobile: 0877433451
Fax: 0567793887
E-mail: jim@jsdrilling.ie
Website: www.jsdrilling.ie
Vat. No: IE6431197F

J S DRILLING
Geological & Environmental Drilling Contractors
Well Solutions
Water well rehabilitation services
Mobile: 0871776966
Email: wellsolutions@jsdrilling.ie
Website: www.wellsolutions.ie

JS Drilling Ltd,
20, The Belfry,
Chapel Lane,
Thomastown,
Co. Kilkenny.

Methodology for Jetting Wells

The winch system for lowering the jetting tools into the well is set up over the well. Jetting relies on the erosional effects of thin but fast flowing water jets. High-pressure jetting features a tool with an adjustable, multi-head, water-powered jet that is rotated as it is lowered into the well and injects water at a high pressure, dislodging debris from the well. The well is cleaned section by section as the jetting nozzle is lowered into the well.

Once the sediment has been dislodged the jetting equipment is removed from the well and a Venturi apparatus is used to lift the heavy sediment out of the well. The well will then be developed and suspended solids will be pumped from the well.

When the jetting is completed the well will be inspected using the underwater borehole viewing camera system to ensure that all sections of the well have been adequately cleaned.

APPENDIX 2

Pump information

Supply and install;

Size: 7.5 HP

Power: 3 phase

Make: Grundfos

Type: Variable speed pump

Diameter: 4 inch

This price includes removal of existing pressure tank and fittings and installation of new pressure system, electrical cable and pipe.

Propose to install at 75m below ground level.

Price €7,500

5HP pump not considered suitable for this scheme not quoted

APPENDIX 2

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

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

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 3

Groundwater Recharge

Introduction

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using 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
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear (in press).

APPENDIX 4

Anbally & District GWS Borehole Untreated Water Quality Data

Anbally & District GWS Borehole Treated Water Quality Data

Anbally & District Treated Water Quality Graph

Untreated Groundwater Quality Monitoring Parameter Suite

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliform	Faecal Coliform	BOD
Units	Hazen	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	0.23	11.3	0.15	200	200	50	0/100ml	0/100ml	
Nov-00	10	1.04	660	6.76	**2**	2	0.05	28	26	<6	**480**	<1	
Dec-00	2.5	1.3	653	6.85	0.1	0.1	0.05	8	10	<6	<1	<1	
Jan-01	5	0.79	639	6.94	0.1	2	0.05	<4	14	<6	**310**	<1	
Feb-01	7.5	0.83	694	6.74	0.2	3.5	0.05	<4	8	<6	<1	<1	
May-01	**30**	1.07	666	6.84	0.15	1.4	0.003	16	8	<6	**2**	**1**	
Jun-01													
Jul-01	**25**	1.78	694	7.37	0.15	1.4	0.003	15	69	<6	<1	<1	
Aug-01	**40**	**6.24**	663	7.15	<0.1	0.7	0.003	50	167	22	**6**	**3**	
Sep-01	**25**	1.35	667	7.35	<0.1	1.5	0.004	12	62	6	<1	<1	
Oct-01	7.5	1.48	701	7.2	<0.1	2.4	0.003	20	19	<6	<1	<1	
Nov-01	10	0.98	688	7.21	**0.25**	2	0.003	8	27	<6	**1**	**1**	
21-Aug-13											**187**	**36**	
27-Aug-13											**79**	**15**	
02-Sep-13											**162**	**9.8**	
Count	10	10	10	10	10	10	10	10	10	10	13	13	0
Average	16.3	1.7	673	7.0	0.42	1.7	0.02	19.6	41	14	153	11	#DIV/0!
Max	40.0	6.2	701	7.4	2.00	3.5	0.05	50.0	167	22	480	36	0.0
Min	2.5	0.8	639	6.7	<0.1	0.1	0.003	8.0	8	6	<1	<1	0.0

Parameter	COD	Alkalinity	Sodium	Chloride	Dissolved O2	Potassium, Total	Hardness, Total	Magnesium Total	Silica	Sulphate	Orthophosphate	Calcium, Total	Copper, Dissolved
Units	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	mg/l	ug/l
SI278of 2007 - DWS			200	250						250			2000
Nov-00													
Dec-00													
Jan-01													
Feb-01													
May-01													
Jun-01													
Jul-01													
Aug-01													
Sep-01													
Oct-01													
Nov-01													
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
Min	0.0	0	0	0.0	0.0	0.0	0	0	0.0	0.0	0	0	0

Parameter	Lead, Dissolved	Chromium, Dissolved	Nickel, Dissolved	Cadmium, Dissolved	Arsenic, Dissolved	Zinc, Dissolved	Barium, Dissolved	TOC	Clostridium Perfringens	Strontium	Fluoride	Potassium: Sodium
Units	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	cfu/100ml	ug/l	mg/l	Ratio
SI278of 2007 - DWS	10	50	20	5	10			NAC			0.8	
Nov-00												
Dec-00												
Jan-01												
Feb-01												
May-01												
Jun-01												
Jul-01												
Aug-01												
Sep-01												
Oct-01												
Nov-01												
Count	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!
Max	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.00
Min	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0.00

Date							13/05/1992	06/02/1995	23/04/1996	11/06/1996	25/06/1996	03/03/1997	10/03/1997	24/03/1997	11/05/1998	06/07/1998	03/02/1999
Location	Units (Assumed)	SI278of 2007 - DWS	Count	Average	Max	Min											
1,2-dichloroethane	ug/l	3	3	0.10	0.10	<0.1											
Acrylamide			0														
Aluminium	ug/l	200	26	15.37	64.00	<0.006											
Ammonium	mg/l	0.3	40	0.03	0.09	<0.025									0.03		<0.025
Antimony	ug/l	5	3	0.10	0.10	0.10											
Arsenic	ug/l	10	5	0.43	0.51	0.40											
Benzene	ug/l	1	3	0.10	0.10	<0.1											
Benzo(a)pyrene	ug/l	0.01	3	0.003	0.003	<0.003											
Boron	mg/l	1	3	0.02	0.02	<0.02											
Bromate	ug/l	10	4	2.63	5.00	1.00											
Cadmium	ug/l	5	3	0.10	0.10	<0.1											
Chloride	mg/l	250	7	18.31	21.30	15.30											
Chromium	ug/l	50	3	1.00	1.00	<1.0											
Clostridium Perfringens	no/100 ml	0	26	0.38	**3.00**	0.00											
Coliform Bacteria	no/100 ml	0	53	25.13	**816.00**	0.00	**13.00**	**1.00**	**132.00**	**120.00**	**6.00**	0.00	**1.00**	**1.00**	0.00	0.00	0.00
Colony Count @ 22°C	no/100 ml		1	0.00	0.00	0.00											
Colour	Hazen	AC & NAC	44	12.06	**43.70**	2.50									**10.10**		3.70
Conductivity	uS/cm	2500	43	642	852	505									680		694
Copper	mg/l	2	5	0.03	0.07	5E-05											
Cryptosporidium			16														
Cyanide	ug/l	50	3	5.00	5.00	<5.0											
E. coli	no/100 ml	0	52	7.15	**144.00**	0.00	**12.00**	**1.00**	**120.00**	**70.00**	**1.00**	0.00	**1.00**	**1.00**	0.00	0.00	0.00
Enterococci	no/100 ml	0	5	0.00	0.00	0.00											
Epichlorohydrin			16														
Fluoride	mg/l	0.8	5	0.14	0.20	0.10											
Free Chlorine	mg/l		6	0.11	0.28	0.01											
Giardia			16														
Hardness	mg/l as CaCO3		3	385.00	401.00	367.00											
Iron	ug/l	200	41	51.19	109.20	7.00									<50		<50
Lead	ug/l	10	5	0.90	1.66	0.38											
Manganese	ug/l	50	37	8.30	24.00	1.00									<50		<20
Mercury	ug/l	1	3	0.02	0.02	<0.02											
Nickel	ug/l	20	5	2.07	2.92	<0.5											
Nitrate	mg/l	50	39	10.17	25.30	0.10									13.40		11.40
Nitrite (at tap)	mg/l	0.5	35	0.01	0.05	<0.02									0.0200		<0.02
Nitrites (at WTW)			16														
Odour		AC & NAC	22	0.00	0.00	0.00											
Oxidisability			16														
PAH	ug/l	0.1	3	0.01	0.01	<0.01											
Pesticides - Total	ug/l	0.5	3	0.01	0.01	<0.01											
pH	[-]	6.5-9.5	44	8.69	73.00	6.60									7.20		7.10
Selenium	ug/l	10	5	1.00	1.68	0.57											
Sodium	mg/l	200	5	11.46	12.78	10.52											
Sulphate	mg/l	250	8	8.40	13.90	1.00											
Taste		AC & NAC	6	0.00	0.00	0.00											
Tetrachloroethene & Trichloroethene	ug/l	10	6	3.06	5.00	0.10											
Total Chlorine			16														
Total Indicative Dose			16														
Total Organic Carbon	mg/l	NAC	7	3.48	4.40	2.24											
Trihalomethanes(Total)	ug/l	100	10	16.28	30.60	5.00											
Tritium			16														
Turbidity (at tap)	NTU	AC & NAC	43	0.76	2.20	0.01									0.62		1.10
Turbidity (at WTW)			16														
Vinyl Chloride			16														

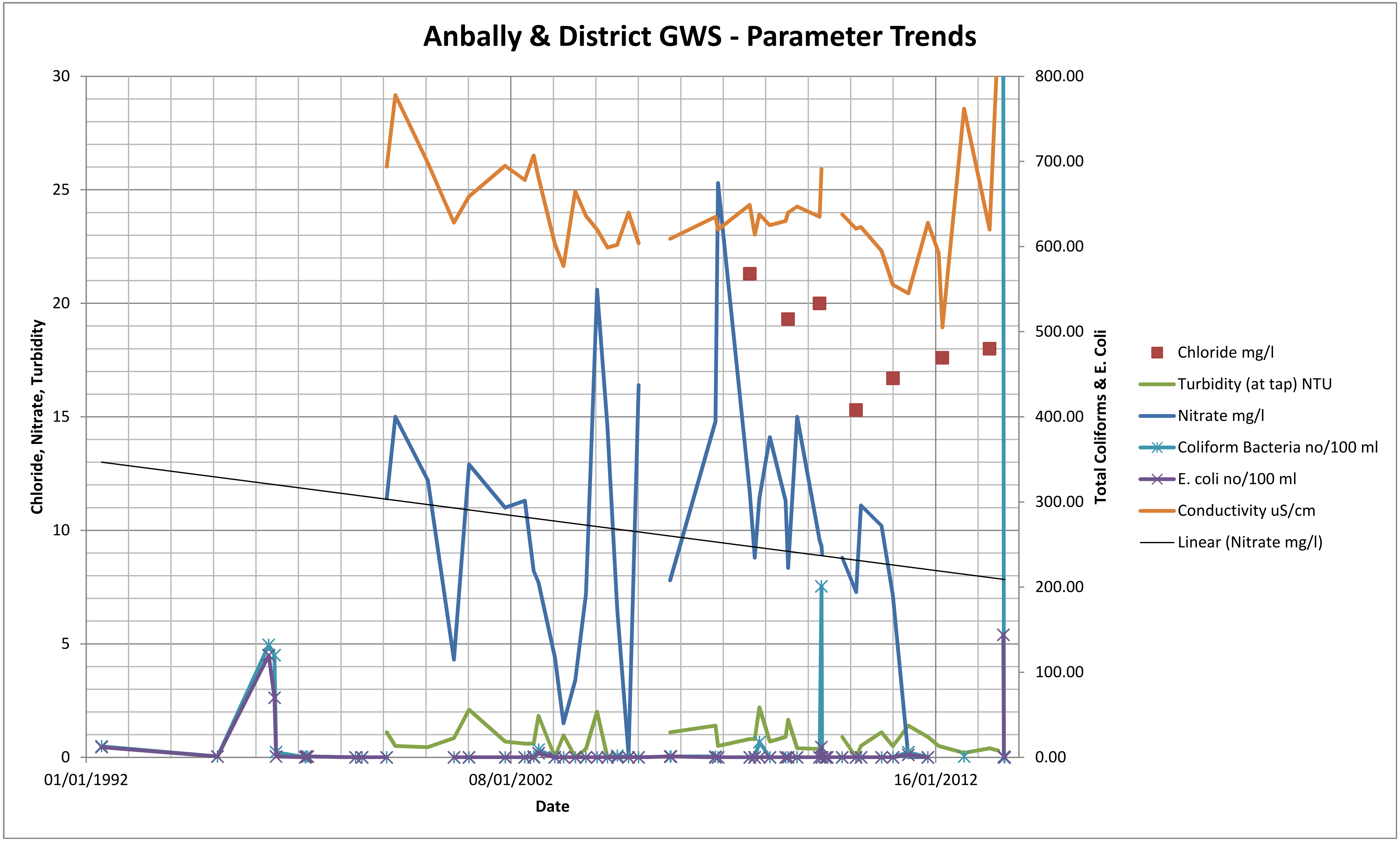
Anbally GWS Drinking Water Quality - Treated Water Quality 2002 to 2014

19/04/1999	25/01/2000	05/09/2000	12/01/2000	20/11/2001	08/05/2002	24/07/2002	04/09/2002	22/01/2003	07/04/2003	17/07/2003	17/10/2003	21/01/2004	19/04/2004	13/07/2004	18/10/2004	13/01/2005
					Goaley -external tap	Goaley-ext tap	Goaley, private dwelling, Ext Tap									
								6	17	11	8	10	<0.006	0.012	0.023	10
0.09	<0.025	0.04	<0.025	<0.025	<0.025	<0.025	<0.025	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	0.02	0.01
								0	2	3	2	0	0	0	0	0
		0.00	0.00	0.00	0	1	9	0	0	0	0	0	0	2	0	0
<2.0	5.40	19.50	6.50	8.70	10.7	14.9	18.2	7.5	10	15	20	2.5	10	40	2.5	2.5
778	698	628	659	695	678	707	681	603	577	665	636	620	599	602	640	604
		0.00	0.00	0.00	0	0	5	0	0	0	0	0	0	0	0	0
<50	<50	67.00	<50	57.00	<50	<50	84	7	57	75	33	15	14	85	55	25
<20	<20	<20	<20	<20	<20	<20	24	2	3	11	3	2	<2	6	3	2
15.00	12.20	4.30	12.90	11.00	11.3	8.2	7.7	4.4	1.5	3.4	7.2	20.6	14.6	6.5	0.1	16.4
<0.02	<0.02	<0.02	<0.02	<0.02	<0.020	<0.020	<0.020	0.004	0.004	0.01	0.007	0.008	0.012	0.001	0.001	0.001
					None	None	None									
7.50	7.30	7.30	7.30	73.00	7.5	7.3	7.2	6.99	7.01	7.26	7.1	7.33	6.92	7.17	7.08	6.93
0.50	0.45	0.84	2.10	0.70	0.6	0.6	1.83	0.01	0.97	0.01	0.37	2.01	<0.01	<0.01	0.01	0.01

Anbally GWS Drinking Water Quality - Treated Water Quality 2002 to 2014

17/10/2005	12/10/2005	06/11/2006	28/11/2006	28/08/2007	09/10/2007	19/11/2007	18/02/2008	03/07/2008	23/07/2008	09/10/2008	21/04/2009	07/05/2009	12/05/2009	12/06/2009	26/06/2009	02/11/2009
	Goaley	Goaley	Mullins	Mary Ann Fergh's House	Morans House	Morans private house	Kearneys House	Morans Private House	ANNIE COENS HOUSE	Jason Woods House	ANNIE COENS HOUSE	Jason Woods House				Jason Woods House
				<0.1					0.1		0.1					
				<5.0			20	20	7.5	64	12.13	20				28
	<0.025	<0.03	<0.03	0.08	<0.03	<0.03	0.03	0.06	0.083	0.03	0.042	0.03				0.03
				0.1					0.1		0.1					
				0.4					0.4		0.507					
				<0.1					0.1		0.1					
				<0.003					0.003		0.003					
				<0.02					0.02		0.02					
				3.5					1		1					
				<0.1					0.1		0.1					
				21.3					19.3		20					
				<1.0					1		1					
				0	0	0	0	0	0	0	0	0				0
1	**1**	**1**	0	0	0	**18**	0	0	0	0	0	**201**	**0**	**0**	**0**	0
				0												
	22.6	5	4.2	**11.1**	**23.7**	**16.9**	4.7	5.8	**11.3**	4.4	**11.9**	7.9	4			5.9
	609	635	620	649	614	638	625	630	640	647	635	691				638
				0.050					0.000047		0.068					
				<5.0					5		5					
1	**1**	0	0	0	0	0	0	0	0	0	0	**12**	**0**	**0**	**0**	0
				0					0		0					
				0.12					0.12		0.1					
										0.02		0.03	0.25			0.28
		401						367					387			
	100	<50	<50	30.0	83	98	50	50	36.4	50	37.38	50	10			52
				1.7					1.3		0.677					
	<20	<20	<20	1.9	<20	<20	20	20	2.4	20	1	20	<5			20
				<0.02					0.02		0.02					
				<0.5					2.2		1.733					
	7.8	14.8	25.3	11.71	8.8	11.4	14.1	11.3	8.34	15	9.56	9.3	8.94			8.8
	<0.020	<0.02	0.04	<0.043	<0.02	<0.02			0.000043		0.046	0.02	0.021			0.02
	None	0	0	None	None	None	0	0	0	0	0	0				0
				<0.01					0.01		0.01					
				<0.01					0.01		0.01					
	7.5	7	7.2	7.1	7.1	7.3	7.1	7.1	7.4	7.1	7.3	7.3	6.6			7
				0.6					0.6		1.679					
				12.3					10.7		12.78					
				13.9					1		9.73		10.56			
									0		0					
				<0.2			5	5	0.2	5	0.1					
				4.1					4.4		3.1					
				23.8			7	19	5	10	5					
	1.1	1.4	0.5	0.81	0.8	2.2	0.7	0.9	1.66	0.4	0.37	0.5	0.01			0.9

01/03/2010	13/04/2010	07/10/2010	13/01/2011	26/05/2011	10/11/2011	10/02/2012	14/03/2012	17/09/2012	25/04/2013	09/07/2013	21/08/2013	27/08/2013	02/09/2013
Majella Coen s House	Jason Woods House	Jason Woods House	Lawless Residence	Jason Woods House	Jason Woods House						Treated (NUIG)	Treated (NUIG)	Treated (NUIG)
12.74			24.61	18	9	5	12.2	8	8.7	37			
0.042	0.03			0.032		<0.01	0.011	0.01	0.01	0.031			
0.421			0.421										
5													
15.3			16.7				17.6		18				
0	0	0	0	**1**	0					**2**			
0	0	0	0	**6**	0			**1**			**816**	**1**	0
16.9	3.7	9.8	6.3	**43.7**	7	**10.1**	**10.4**	**17.4**	<2.5	**34.1**			
621	623	595	555	545	628	593	505	762	620	852			
0.012			0.023										
0	0	0	0	**3**	0						**144**	0	0
0			0										
0.2			0.18										
	0.07	0.01											
109.2		33	12.23	77	44	35		58		49			
0.475			0.376										
2.47			1.036				1.2		<1.0				
2.916			1.432										
7.28	11.1	10.2	7.13				6.09		7.59				
						<0.017	<0.043	<0.017	<0.043	<0.017			
0	0	0	0	0	0								
7.3	7.2	7.1	7.2	7	7.1	7.4	7.9	7.2	7.1	7.1			
0.939			1.195										
10.52			10.99										
12.3			7.1				7.5		5.1				
0			0	0	0								
3.5			3.4				3.59		2.24				
30.6			15.9				19.85		26.68				
	0.5	1.1	0.49	1.4	0.9	0.5	0.46	0.2	0.4	0.3			



Anbally & District GWS - Parameter Trends
Chloride, Nitrate, Turbidity
30
25
20
15
10
5
0
01/01/1992
08/01/2002
16/01/2012
Date
Total Coliforms & E. Coli
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Chloride mg/l
Turbidity (at tap) NTU
Nitrate mg/l
Coliform Bacteria no/100 ml
E. coli no/100 ml
Conductivity uS/cm
Linear (Nitrate mg/l)

Raw Water Analysis Parameters Required for ZOC Delineation
Turbidity
pH
Conductivity @20C
Alkalinity, total
Sodium, total
Chloride
Ammonium as NH4
Nitrate as NO3
Dissolved Oxygen (%)
Iron, total
Potassium, total
Total Hardness (Kone)
Magnesium, total
Colour, apparent
Sulphate
Orthophosphate as PO4-P
Manganese, total
Calcium, total
TOC
E coli (Filtration) (Environmental Waters)
Total Coliforms (Filtration) (Environmental Waters)
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),
Clostridium perfringens
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.

APPENDIX 5

Regional Hydrogeology Summary

1 The Study Area

The group water schemes (GWS) at Claretuam, Belclare, Rusheens, Anbally and Carheenlea are under consideration for this study. They are located in central Galway between Tuam and Claregalway (Figure A).

2 Historical Drainage and Regional Scale Groundwater Flow

The present day drainage system within the study area has been greatly altered by artificial drainage works over the last 150 years. The original, natural, drainage system that existed in the area in the late 1700s is shown in Figure B (Coxon and Drew, 1983), which shows the entire Clare River sinking to groundwater. The current altered state of the drainage system in comparison to the condition in the late 1700s is shown in Figure C. Handwritten notes on the GSI 6" historical field sheets for the area indicate that the Clonkeen Lake area is "rarely flooded since Board of Works Operations in 1848".

The artificial drainage was intensified by an OPW arterial drainage scheme in the 1950s and 1960s, which was designed to provide basic conditions for increased crop production and improvement of stock by drainage of 135,000 km^2 of wetlands for agricultural use (Ryan Hanley, 2010). The scheme involved continuous channel excavation along the whole length of the Clare River involving deepening and widening or both, and creating the deep rock cuts at Lackagh, Corofin and Conagher (above Milltown) (Ryan Hanley, 2010).

In large river catchments groundwater within the river catchment is expected to flow towards the river and discharge to it as baseflow. This may be only partly true for the Clare River within the study area due to the strong interaction that evolved between the original drainage system and the underlying karstified limestone bedrock aquifer (Box 1). The following paragraphs elucidate this point.

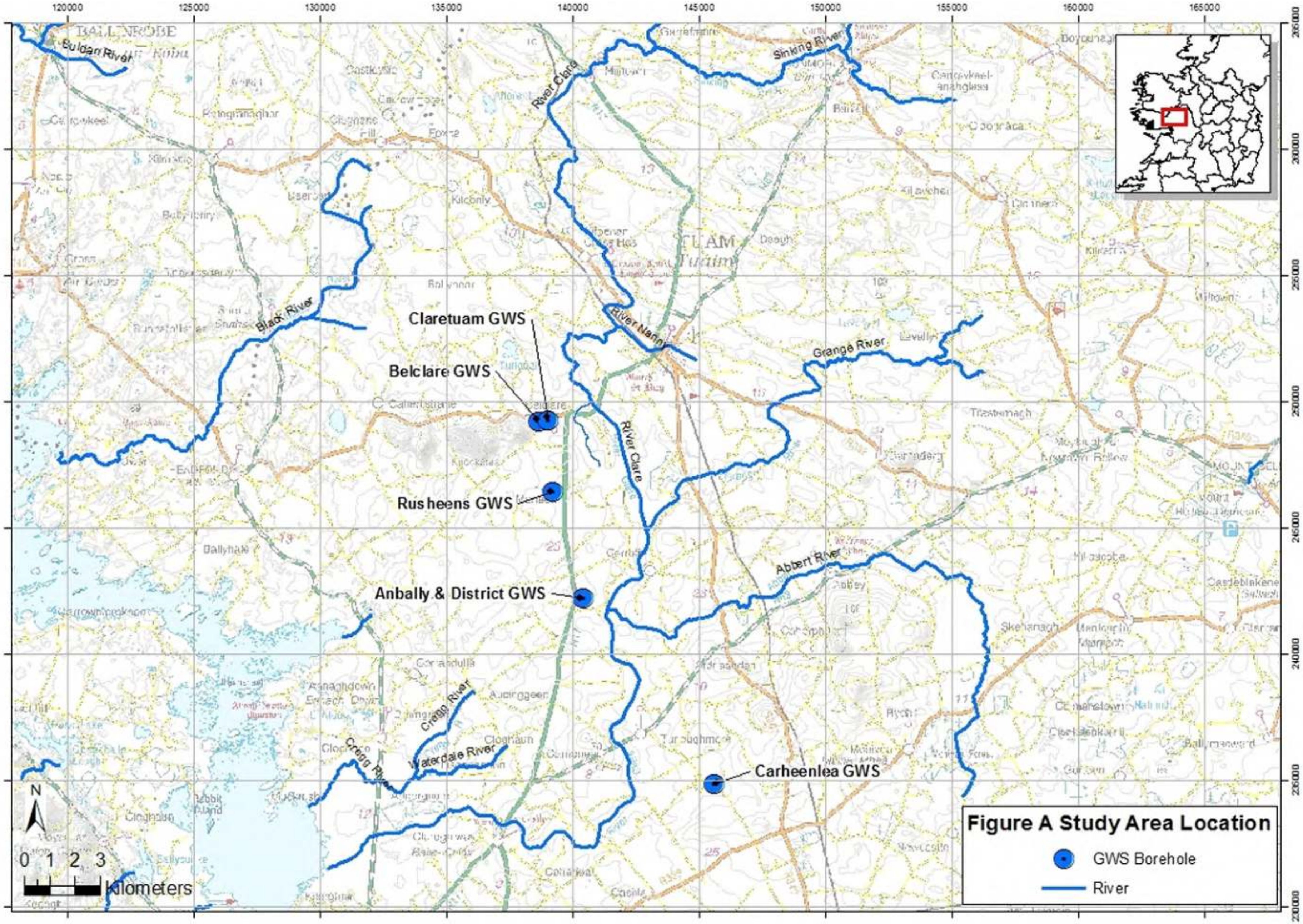
Box 1. Bedrock Aquifer

The limestone bedrock aquifer in the study area is classified as a Regionally Important Karstified Aquifer dominated by Conduit Flow (Rk_c). These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In the pure bedded limestones which occur in the study area these openings are enlarged by karstification *(i.e. . rock gets dissolved by the flowing groundwater)* which significantly enhances the permeability of the rock. Most groundwater flows in a highly permeable epikarst **(Box 2)** layer a couple of metres thick at the top of the rock, and in a zone of interconnected karstification-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation (i.e. magnesium limestone) (GSI, 2004).

Box 2. Epikarst

Epikarst is likely to form at the top of the limestone aquifer wherever rock is close to surface or where permeable subsoils occur, such that rainfall infiltrates freely. The epikarst can be visualised as a perched aquifer system channelling infiltrating water to points of entry into the deeper groundwater flow system (CDM, 2012). The water penetrates vertically where vertical fissures occur. The water flow enlarges the fissures in a positive feedback loop which creates preferential vertical flow paths. Deeper Underground, the waters from the preferential vertical pathways and any networks of smaller fissures unite to form small streams and in turn these join and excavate correspondingly large conduits and even cave systems.

Extensive karst conduit systems exist in the limestone bedrock in the study area, as exemplified


Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
Black River
River Clare
River Nanny
Grange River
Abbert River
Sinking River
Clegg River
Waterdale River
Figure A Study Area Location
GWS Borehole
River
0 1 2 3
Kilometers
N

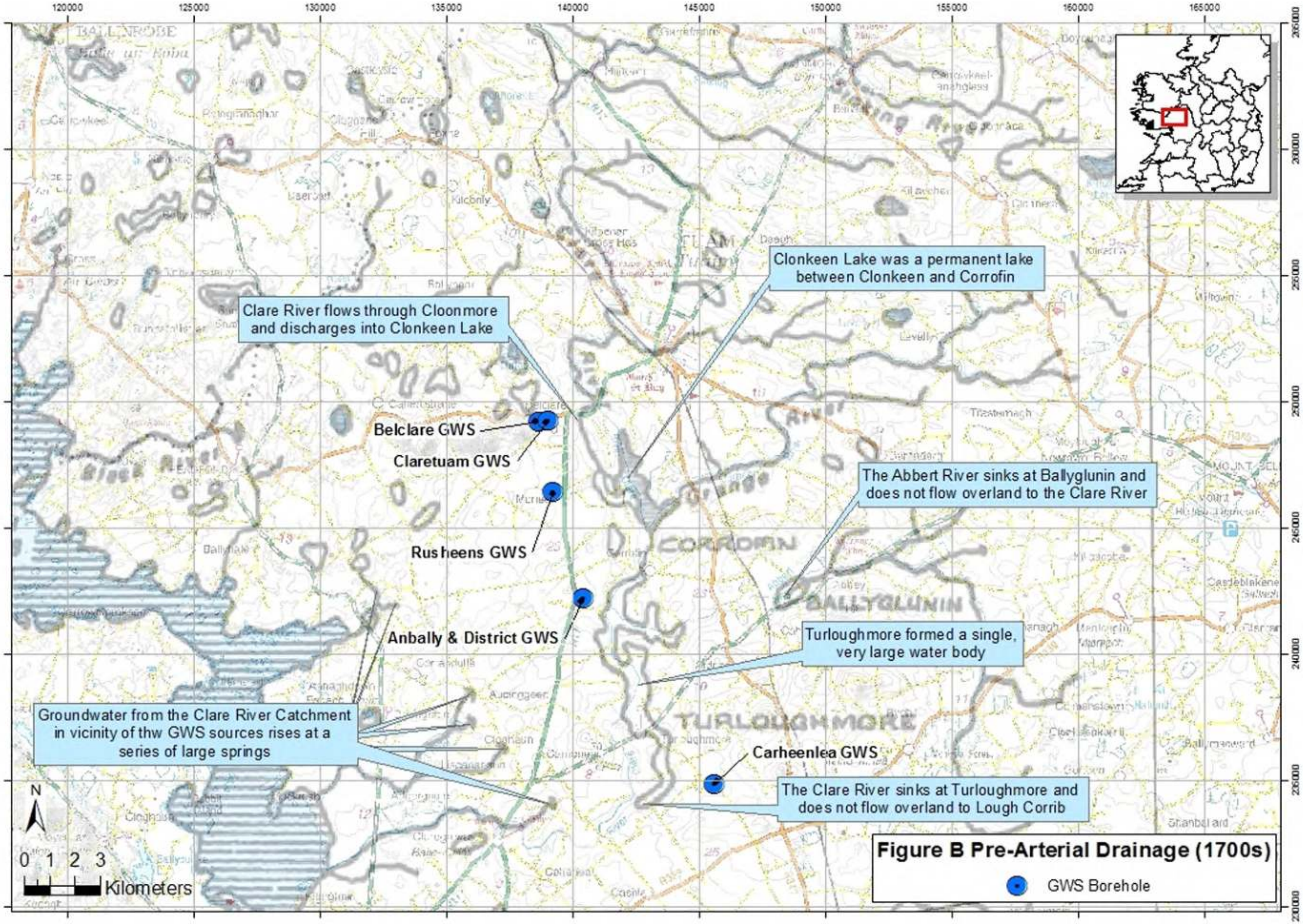


Figure B Pre-Arterial Drainage (1700s)

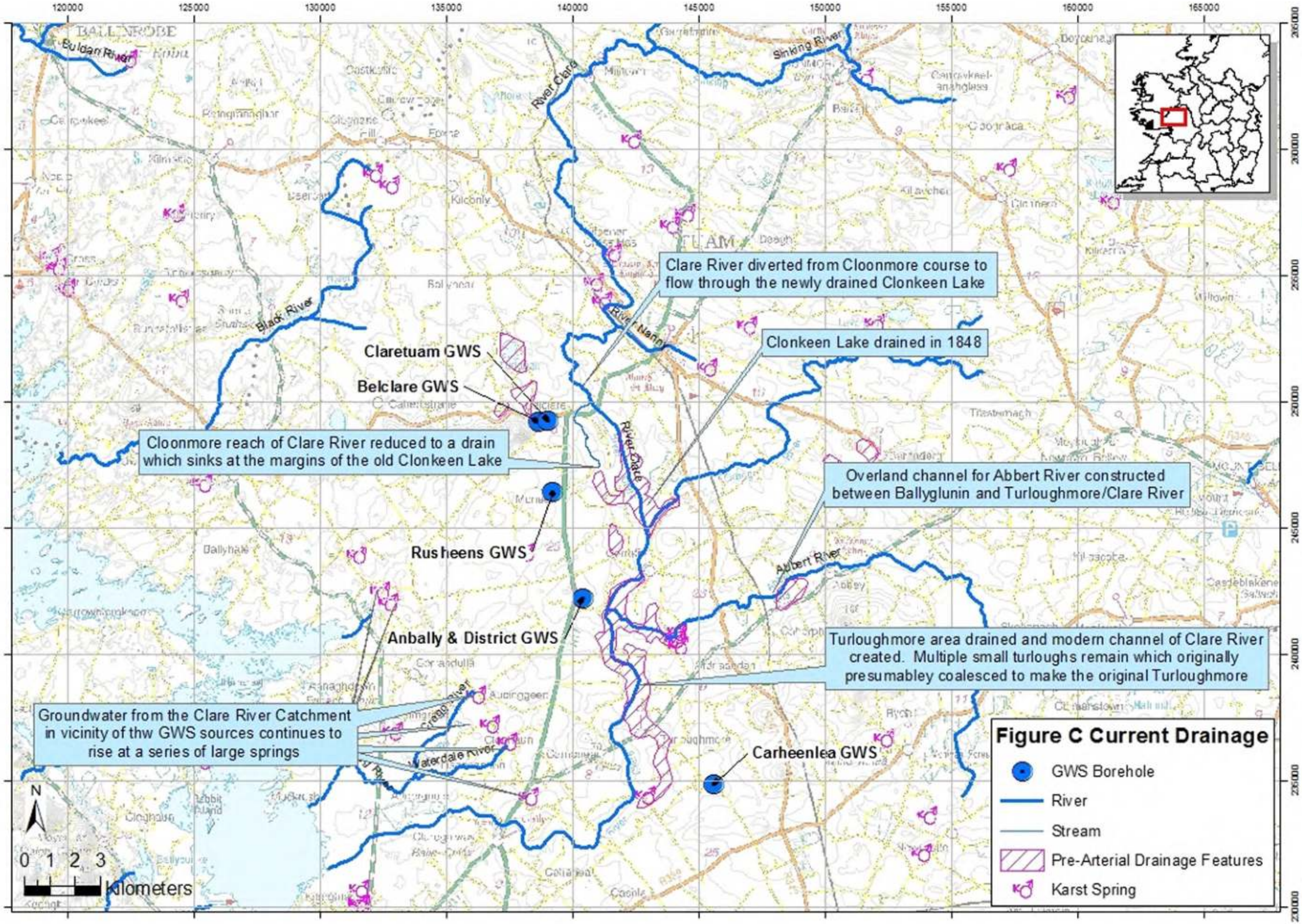


Figure C Current Drainage
GWS Borehole
River
Stream
Pre-Arterial Drainage Features
Karst Spring
Clare River diverted from Cloonmore course to flow through the newly drained Clonkeen Lake
Clonkeen Lake drained in 1848
Cloonmore reach of Clare River reduced to a drain which sinks at the margins of the old Clonkeen Lake
Overland channel for Abbert River constructed between Ballyglunin and Turloughmore/Clare River
Turloughmore area drained and modern channel of Clare River created. Multiple small turloughs remain which originally presumabley coalesced to make the original Turloughmore
Groundwater from the Clare River Catchment in vicinity of thw GWS sources continues to rise at a series of large springs
Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
River Clare
River Nanny
Black River
Abbert River
Sinking River
Buldan River
Grange River
Waterdale River
N
0 1 2 3
Kilometers
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000

by the Ballyglunin Cave system. The mapping of this system indicates conduit development along north to south and west to east joint sets, with an overall dip to the west (Drew and Daly, 1993).

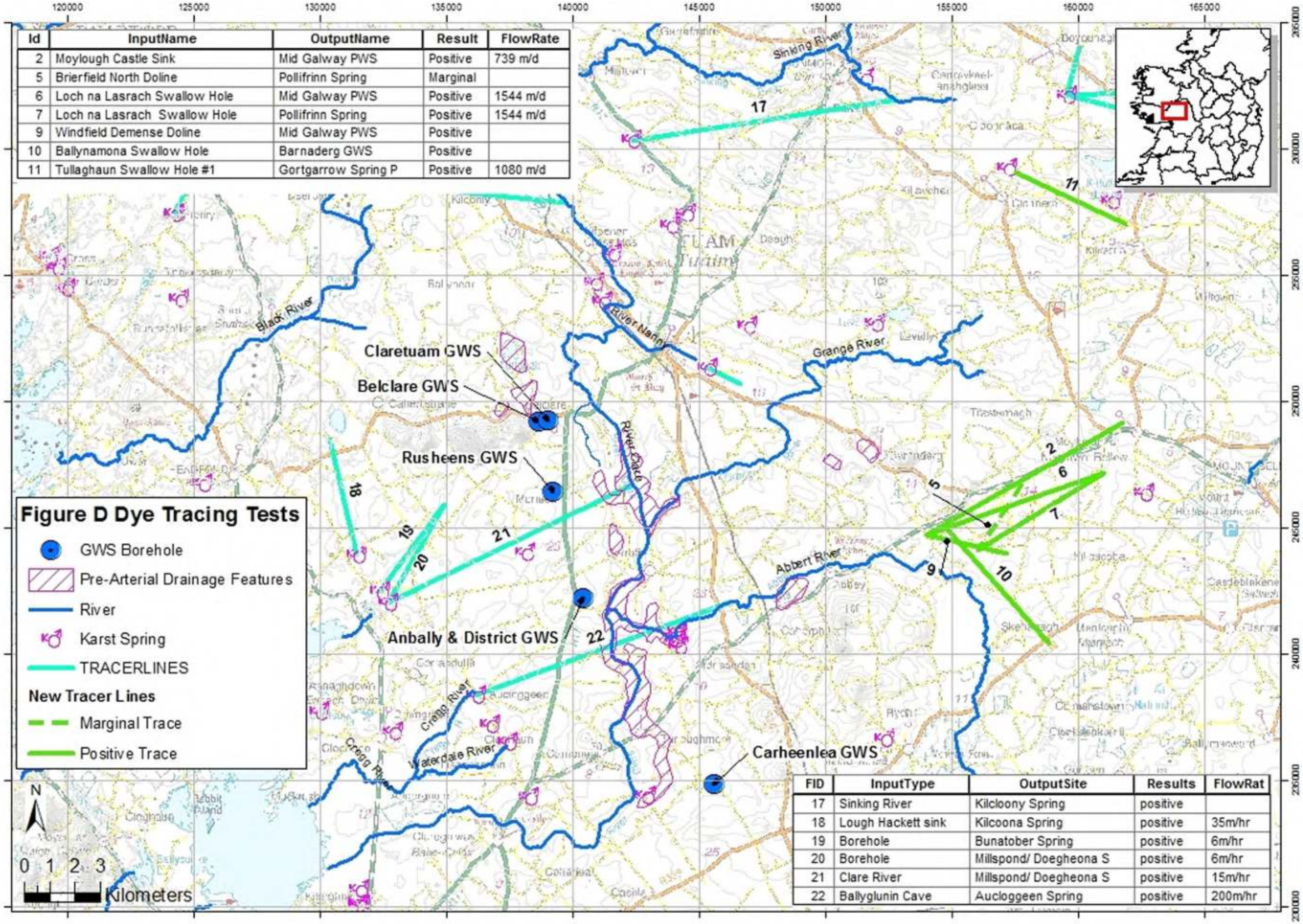
Overall, groundwater flow will be westwards towards the River Clare and L. Corrib, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable (GSI, 2004). Dye tracing tests between swallow holes and springs within the study area show that groundwater can flow across the surface water divides and beneath surface water channels, e.g. the traced groundwater connection between Ballyglunin Cave and Aucloggeen Spring, which passes underneath both the Abbert and Clare Rivers (Drew & Daly, 1993). Connections proven by dye traces between swallow holes and springs in the study area are shown in Figure D. Details of the individual "tracer-tests" are also shown on Figure D. The flow paths exemplified by these tests are regional in scale, e.g. Ballyglunin to Aucloggeen is a straight line distance of 9.6 km. High groundwater flow velocities occur along the corresponding karst conduits. The data provided on Figure D indicates that groundwater velocity from traces bearing north to south range from 6 m/hr to 35 m/hr (144 to 840 m/d) whereas traces bearing east to west have velocities ranging from 15 m/hr to 200 m/hr (360 to 4800 m/d). Regionally the data suggest that velocities are larger in the east to west direction compared to the north south direction (GSI, 2004). By inference, conduit sizes follow the same trend.

Figure D shows a strong correlation between the tracer-tests proving east to west connections, and areas where the current Clare River did not exist under the original drainage system, i.e. Clonkeen Lake and Turloughmore. In these areas, in line with the tracer-test results, it seems likely that the original drainage system had evolved underground drainage pathways which allowed water to drain westwards along preferential karst conduit pathways from Clonkeen and Turloughmore/Ballyglunin to Lough Corrib. The fact that these pathways have been proven by tracer-tests under the modern drainage regime shows that the pathways are still active in the present day.

In terms of the hydraulic connectivity of the modern Clare River system and the underlying bedrock aquifer therefore, the conventional model of discharge of groundwater as baseflow to the river is unlikely to provide the full picture.

It is expected that with the OPW arterial drainage works, extensive hydraulic continuity may have been established between the Clare River and the underlying limestone bedrock aquifer, particularly where deep rock cuts were made. It is likely that this hydraulic continuity is chiefly between the river and the epikarst layer at the top of the bedrock. As such, it is likely that the Clare River may act as a drain for the epikarst layer, with the epikarst saturated to at least the elevation of the river. The saturated epikarst will still be connected to the underlying deep karst conduit system by preferential vertical infiltration points (Box 2).

When the water pressure in the conduit system is lower than in the epikarst, the shallow groundwater will drain down to the deeper system, while (presumably) simultaneously draining laterally to the Clare River. Where the Clare River bed intersects a swallow hole from the original Clonkeen Lake or Turloughmore systems, some river water is also likely to sink down to the deep conduit system. When the pressures are reversed the deep conduit system is likely to discharge some groundwater to the epikarst and river via the same pathways, in reverse. In both scenarios, the deep conduit system is likely to continue discharging westwards at depth towards the lowest head in the system at Lough Corrib, irrespective of the type of interaction with the overlying shallow groundwater and river catchments.



Id	InputName	OutputName	Result	FlowRate
2	Moylough Castle Sink	Mid Galway PWS	Positive	739 m/d
5	Brierfield North Doline	Pollifrinn Spring	Marginal	
6	Loch na Lasrach Swallow Hole	Mid Galway PWS	Positive	1544 m/d
7	Loch na Lasrach Swallow Hole	Pollifrinn Spring	Positive	1544 m/d
9	Windfield Demense Doline	Mid Galway PWS	Positive	
10	Ballynamona Swallow Hole	Barnaderg GWS	Positive	
11	Tullaghaun Swallow Hole #1	Gortgarrow Spring P	Positive	1080 m/d

FID	InputType	OutputSite	Results	FlowRat
17	Sinking River	Kilcloony Spring	positive	
18	Lough Hackett sink	Kilcoona Spring	positive	35m/hr
19	Borehole	Bunatober Spring	positive	6m/hr
20	Borehole	Millspond/ Doegheona S	positive	6m/hr
21	Clare River	Millspond/ Doegheona S	positive	15m/hr
22	Ballyglunin Cave	Aucloggeen Spring	positive	200m/hr

The implications of the system described above for GWS borehole sources in the study area are outlined in Box 3.

Box 3. Implications for GWS Borehole Sources

Based on the system of surface water/groundwater interactions occurring in the Clare-Corrib Catchment, the following scenarios may be relevant where a GWS borehole source has been drilled into the system:

- Borehole only intersects a shallow epikarst water strike:
  - Borehole distant from Clare River – Borehole yield is likely to be moderate to good. Pumping drawdown likely to induce localised inflow from the epikarst. Drawdown likely to dewater the strike before abstraction can increase sufficiently to establish a gradient generating leakage from the river to the borehole. ZOC likely to be localised.
  - Borehole close to the Clare River – Borehole yield may be good. Pumping drawdown likely to induce localised inflow from the epikarst. Drawdown might establish a gradient generating leakage from the river to the borehole which would allow increased abstraction. ZOC likely to be localised but partial contribution from surface water catchment is possible.
- Borehole only intersects a deep water strike (epikarst sealed off by grout):
  - Borehole intersects a small fissure – may result in a moderate yield. Abstraction drawdown will increase the downwards vertical gradient from the overlying epikarst. Drawdown might reverse the gradient between the fissure and conduits in the same area, with some potential for a minor partial contribution by leakage from the conduits back along the fissure to the borehole, depending on the proximity of the conduit. ZOC likely to be localised and fed by downward leakage from the epikarst through the fissure, but a partial contribution from the conduit system is possible.
  - Borehole intersects a conduit – may result in a good to excellent well. Abstraction will mainly derive from the regional scale conduit system upgradient of the borehole. The zone of contribution may extend beyond the immediate surface water catchment. There may also be partial contributions from losing reaches of local and distant surface water courses that contribute to the regional conduit flow. Localised, indirect epikarst input is also likely to occur via natural vertical pathways that contribute to the conduit.
- Borehole intersects a deep water strike and epikarst not sealed off:
  - This situation is likely to result in a mix of the previous scenarios.

3 Data Relevant to Groundwater Flow Conceptualisation at each GWS

3.1 Geological Data from GSI 6" Field Sheets

Table 1 summarises the most relevant site specific annotations on the 6" Field sheets in the vicinity of Claretuam, Belclare, Rusheens, Anbally and Carheenlea.

3.2 Groundwater Elevation Data

EPA groundwater monitoring locations are shown on Figure E. Three of the locations shown within the study area are boreholes with long term groundwater level monitoring records available, i.e. Tuam, Lackagh and Corbally. There are no borehole construction data available for the boreholes, except for Corbally which is noted to be 80 m deep in the relevant EPA groundwater monitoring point site (GWMP) folder.

The available groundwater level data for the three EPA boreholes and the five GWS boreholes are shown in Graph 01, along with the elevation of the Clare River bed at Corofin and the high water elevation for Lough Corrib.

Table 1. Summary of relevant data from GSI 6" field sheets

Dataset	Claretuam & Belclare	Rusheens	Anbally	Carheenlea
GSI 6" Hist	Well exposed dark grey to black limestone (Lst) Crags and outcrop to south, dips flat to 3 degrees to SSE; weathered and much-jointed in places; in some places joints noted oriented NNW; Outcrop to east of old course in Cloonmore dips flat to west at 3 to 5 degrees, beds approx 18" thick, "this band of exposed rock stretches for nearly 100 yds w/o a single crack or joint and is perfectly smooth – Glacial action?"; Clonkeen Lough callow semi drained – noted to be peat and chiefly shell marl, old course of Clare R. has peat and marl. Large bog to north & NE of the sources to north of Polldarragh.	Outcrop to SE flat to dipping W and NW (6^{O}?). To the SE at Turloughour = well bedded dark grey Lst, dip SSW	Outcrop at Turloughcartron to ENE = dark grey thin bedded Lst, full of calcite infilled cells about potato sized. Just SE of source modern note says "3 bores failed here due to clay in Lst solution fissures". Dark grey beds to SE at Tonmace; white bed , dips east to ESE at 3 to 5^{O}. Bore at Dawros 83', WL 18.5m. Large outcrop to W at Cahernavoley most dips SSE at 3 to 10^{O}; dip of 3^{O} NE at south end of outcrop. Dolomite Lst at Corrandrum 2km SSW	Map for immediate area not available to download. NW at Lackaghbeg, large outcrop shows dark blue Lst, dip 3^{O} to SE, joints N60W, cross joints, irregular. Faults & calcite spar veins noted nearby to NE at Clare R. in Lackaghmore. Just E Kilskea dip NNW at 3 to 5^{O}, angular cross joints N15E, and nearby joints N80E & N10E, N70W & N20E To the N at Laraghmore outcrop dip 3^{O}W and full of irregular cross joints N10W and N75E

The Tuam groundwater level (GWL) data are significantly higher than all of the other level data. The Tuam borehole is on the east side of the Clare River, i.e. upgradient in terms of the nominal regional hydraulic gradient. On the basis of Section 2, it is considered that the Tuam borehole probably intersects the epikarst only. The GWL in this layer is likely to be controlled by the head in the Clare River, with the head in the epikarst reflecting the gradient needed to drive groundwater through the epikarst to discharge to the river. The GWL range in the Tuam borehole is not particularly flashy, which suggests GWL buffering by storage in the epikarst and a high permeability.

The Lackagh and Corbally boreholes are on the west side of the Clare River, i.e. nominally downgradient. The two boreholes have a GWL range of approximately 16 m. They follow very similar flashy trends suggesting they are part of the same groundwater system. The high GWL range and flashy water level response suggests the boreholes may be in hydraulic continuity with a karst conduit system with low storage capacity and influenced by point recharge[1]. The GWLs are much lower than at the Tuam borehole. In line with Section 2 this further suggests interaction with a deep conduit system (as opposed to the perched epikarst system).

The Clare River bed level at Corofin is 22.2mOD (Ryan Hanley,2010). This bed level (halfway between Lackagh and Corbally) exceeds all but the peak flashy water levels at Lackagh and Corbally. This suggests that the deeper karst system generally operates at a lower pressure head than the epikarst-Clare River

[1] Point recharge means rapid transmission of surface water into the groundwater system, e.g. by a stream sinking at a swallow hole.

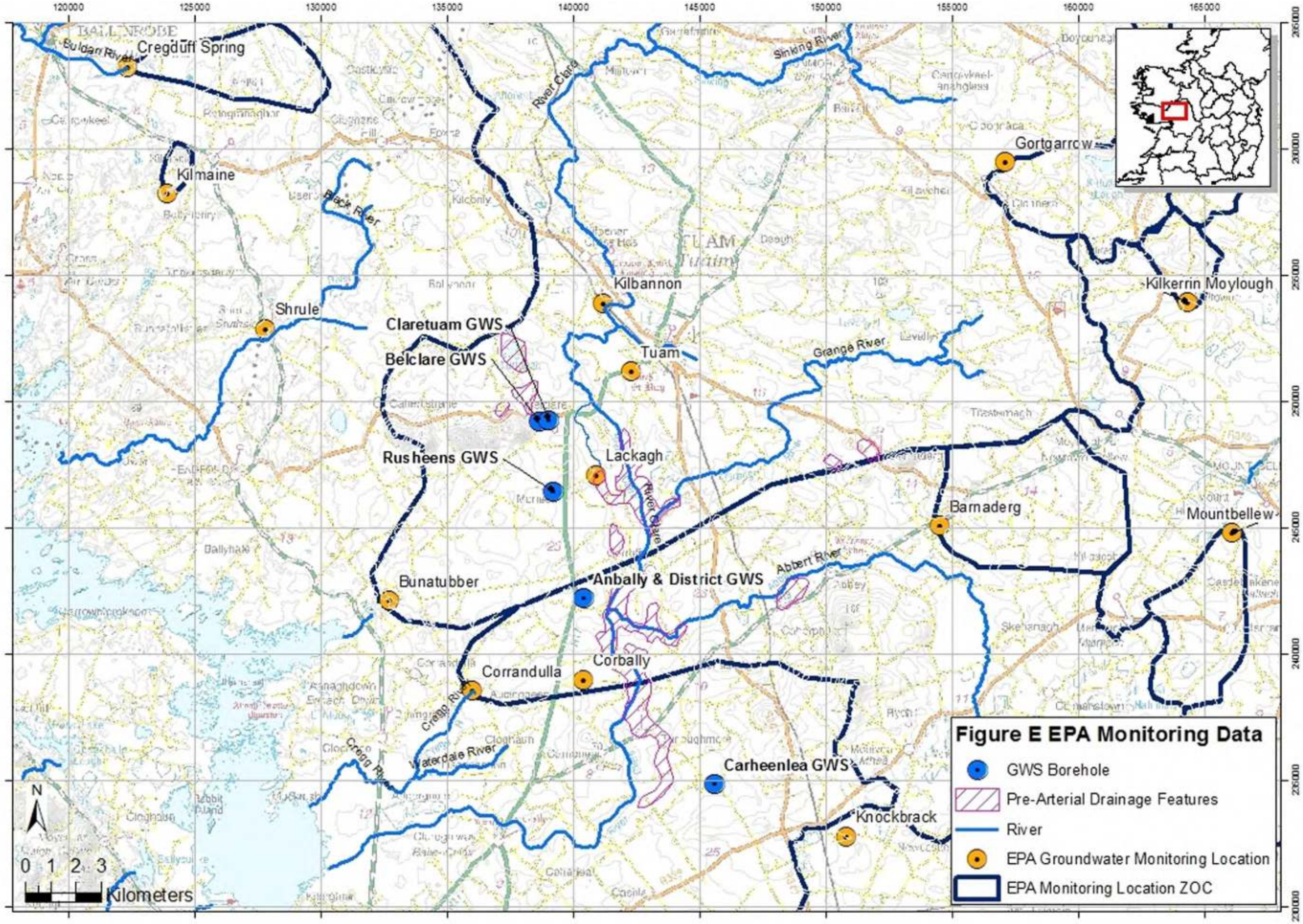
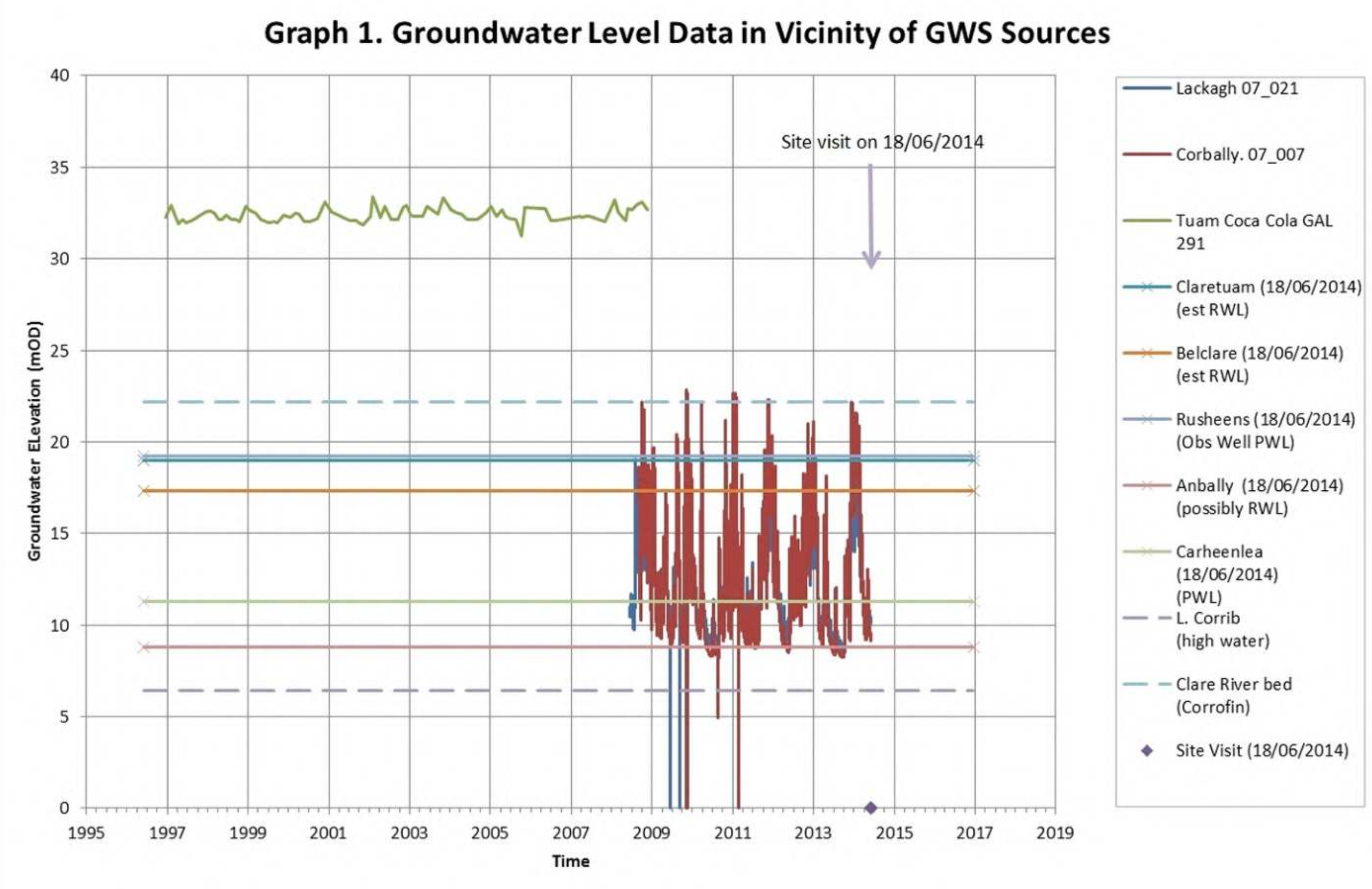


Figure E EPA Monitoring Data
GWS Borehole
Pre-Arterial Drainage Features
River
EPA Groundwater Monitoring Location
EPA Monitoring Location ZOC
Cregduff Spring
Kilmaine
Shrule
Claretuam GWS
Belclare GWS
Rusheens GWS
Kilbannon
Tuam
Lackagh
Gortgarrow
Kilkerrin Moylough
Barnaderg
Mountbellew
Anbally & District GWS
Bunatubber
Corrandulla
Corbally
Carheenlea GWS
Knockbrack
Grange River
Abbert River
Sinking River
River Clare
Black River
Cregg River
Waterdale River
Kilometers
0 1 2 3
N


Graph 1. Groundwater Level Data in Vicinity of GWS Sources
Groundwater ELevation (mOD)
40
35
30
25
20
15
10
5
0
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
Time
Site visit on 18/06/2014
Lackagh 07_021
Corbally. 07_007
Tuam Coca Cola GAL 291
Claretuam (18/06/2014) (est RWL)
Belclare (18/06/2014) (est RWL)
Rusheens (18/06/2014) (Obs Well PWL)
Anbally (18/06/2014) (possibly RWL)
Carheenlea (18/06/2014) (PWL)
L. Corrib (high water)
Clare River bed (Corrofin)
Site Visit (18/06/2014)

system and therefore would generally receive leakage from any vertical pathways connecting the two systems. The leakage direction would only be reversed during times of peak GWL in the conduit system. The generally lower head in the conduit system compared to the river also means that hydraulically it should be more favourable for deep groundwater in conduits east of the Clare River to flow on westwards in conduits beneath the river, rather than to discharge upwards to the river. The maximum water elevation at Lough Corrib of 6.44 mOD is the lowest in the system, and therefore also favours this scenario. This is in agreement with the indications from tracer tests as discussed in Section 2.

3.2.1 Groundwater Levels at the GWS Source Boreholes

The spot GWL measurements at the five GWS sources are also shown on Graph 01. Some inferences have been drawn from these data; however one measurement per source is insufficient to draw any firm conclusions with respect to any or all of the sources.

Furthermore the GWLs depicted for Claretuam and Belclare are estimated rest GWLs based on short recovery periods monitored at each source; the GWL for Rusheens is the water level in an observation well 30 m from the GWS source borehole, while source well was pumping; the GWL for Anbally was taken when the pump was off and may be close to the rest GWL; and the GWL for Carheenlea is a pumping GWL.

The time series data for the Lackagh and Corbally boreholes runs to 17 June 2014 and shows that the GWLs in the boreholes (and therefore the conduit system) were in the basal reach of the known GWL range. The site visit measurements were taken on 18 June 2014 (i.e. the next day) and there was no rainfall on the 17th or 18th. As such the conduit system would have remained in its basal GWL reach during the GWS readings.

3.2.1.1 Claretuam, Belclare and Rusheens

The GWLs measured at Claretuam, Belclare and Rusheens on 18 June 2014 are estimated to be within the upper reach of the conduit system GWL range (but well below the epikarst level seen at Tuam borehole). This suggests these three boreholes intersect minor fissures facilitating drainage from localised, overlying epikarst to the regional conduit system. The transmissivity of the minor fissures is likely to be low, such that a significant gradient may be need to drive leakage from the epikarst to the conduits via such fissures. As a result the rest GWL at a borehole intersecting a minor fissure will be somewhere between the epikarst and conduit extremes, and represents the head loss along the fissure as water is driven from epikarst to fissure. In more descriptive terms, the GWL reflects the relatively slow draining of water from epikarst to conduit via the low yielding minor fissure pathways when conduit water levels are low, and is analogous to groundwater baseflow to a stream in a conventional (non-karst) groundwater setting.

In this context the three GWS sources would be expected to be moderate (40 to 100 m^3/day) to good (100 to 400 m^3/day) yielding boreholes with localised ZOCs drawing on leakage from the overlying epikarst.

Where a borehole intersects a large fracture, clogging of the fractures with moderate or low permeability sediment could give similar hydraulic characteristics to those outlined for a small fissure. The permeability of the infill would have a significant impact on the water level response of the borehole.

The original pump test for **Claretuam GWS** suggested a yield of 43 m^3/day for a 7 m steady drawdown. Current estimates by the GWS suggest a maximum yield of 108 m^3/day. This would be a moderate to borderline-good yield. The well depth is 72 m.

The current abstraction rate at **Belclare GWS** is approximately 157 m^3/day, which would be at the low end of the range for a good yield (100 to 400 m^3/day). The well depth is approximately 46 m.

The driller's yield estimate for the **Rusheens GWS** current source borehole (drilled in October 2012) was 216 m^3/day. Instantaneous flow rates displayed on the flow meter on 18 June 2014 were of the order of 8.2 m^3/hr (197 m^3/day). This would be a good yield. The well depth is 64 m. The current Rusheens borehole has a grout seal in the borehole annulus to a depth of 30 mbgl, which should seal off and direct epikarst inflow to the borehole. The only inflow to the open section of the well was logged between 49 m and 54 mbgl as very broken rock with a large, sandy inflow. This may be a case where a large fracture has been clogged by infill that restricts its interaction with the regional conduit system. The pumping water level was approximately 9 m above the GWL in the regional conduit system as seen at the nearby Lackagh borehole. The strong gradient from the borehole to the conduit system suggests that there is unlikely to be leakage out of the conduit system to the borehole under rest or pumping conditions at the borehole. Overall therefore, a localised ZOC drawing on leakage from the epikarst seems likely.

3.2.1.2 Anbally and Carheenlea

The GWLs measured at Anbally and Carheenlea on 18 June 2014 are in the basal GWL range of the regional conduit system. This suggests that these two boreholes are in good hydraulic continuity with the deep, regional conduit system.

In this context the two GWS sources would be expected to have good to excellent yields and to have ZOCs reflecting both a localised contribution by "baseflow" leakage from the epikarst, but also a regional component reflecting a probable significant inflow from the conduit system upgradient of the pumping boreholes.

There is no data on the long term daily abstraction rate at **Anbally GWS**. Instantaneous flow meter readings on 18 June 2014 suggest a pumping rate of 2.6 m^3/hr (63 m^3/day). Diskin (2014) indicates that the scheme has 95 domestic connections plus approximately 20 additional connections to agricultural land. Assuming a demand of 1.2 m^3/day per connection (i.e. 6 PE at 0.2 m^3/PE/day) would suggest a demand of 138 m^3/day. This would be a moderate to good yield. A report on a camera survey of the well by Well Solutions (2010) made reference to anecdotal reports of a low water level at the borehole during the summer of 2009, and suggests the borehole may be operating close to its sustainable yield (Well Solutions, 2010). The well is approximately 99 m deep and has its main water strike at approximately 97 mbgl. Three trial boreholes for the scheme in the nearby village failed due to "clay in the limestone solution fissures" (Table 1). The fact that the borehole appears to only have a moderate to good yield suggests that its hydraulic continuity with the conduit system may be limited. This may be due to clay infill in conduits in the area, as seen at the failed trial boreholes. This in turn may suggest a localised ZOC; however a component of regional flow cannot be discounted.

The borehole source at **Carheenlea GWS** was drilled to 61 mbgl and is reported by the GWS to have a yield of 216 m^3/d. This is a good yield but is less than would be expected in a borehole with good hydraulic continuity with the regional conduit system. The corresponding GWL in Graph 01 is a pumping water level. It may be that the abstraction generates a large drawdown and that the borehole rest water level resides in the upper reach of the regional karst conduit range, similar to Claretuam and Belclare; alternatively clay infilling of conduits in the vicinity could be the cause of the relatively low yield. Overall a localised ZOC is plausible; however a component of regional flow cannot be discounted.

GSI (2004) suggests that there may be an increase in borehole yield form south to north across the study area, which would correlate with clay infilling of conduits in the vicinity of Rusheens, Anbally and Carheenlea.

3.2.2 OPW turlough level data

Some data on turlough flood elevation in the vicinity were obtained from available OPW flooding records. Just northeast of Belclare GWS the flood water level at Turloughnaroyer on 10 April 1995 was recorded as 101.4 ft OD (Poolbeg). This is equivalent to 28.2 mOD. This is above the observed water levels at the Belclare borehole and is above the maximum GWL observed in the Lackagh and Corbally boreholes. Therefore, when the turlough has been flooded by inflow from the regional conduit system there is a strong lateral hydraulic gradient between the flooded turlough and the nearby GWS boreholes. It is possible that some of the turlough water could migrate laterally to the borehole via the epikarst, when the borehole is pumping.

3.3 Spring Flow Data and EPA GWMP ZOCs

Two large springs monitored by the EPA, Bunatubber and Corrandulla, are located to the southwest of the GWS source boreholes (Figure E). Bunatubber has a yield of up to 1,000 l/s (86,000 m^3/day), while Corrandulla has a mean yield estimated at 7,000 m^3/day. Both springs are considered to be focal points for discharge from the regional scale karst conduit system which stretches to the northeast across the study area. The EPA have delineated preliminary ZOCs for the springs (Figure E). The Claretuam, Belclare and Rusheens borehole sources are contained within the Bunatubber ZOC. The Anbally source borehole is contained within the Corrandulla ZOC. The Carheenlea borehole is not within a delineated area.

The preliminary EPA ZOCs give an indication of the large areas that may provide partial contributions to groundwater discharges supplied by a regional scale karst conduit system. For Claretuam, Belclare, Rusheens and Anbally the extent of the EPA ZOCs up gradient of the individual sources is a reasonable estimate of the additional ZOC where it is suspected that there may be a partial contribution to the source from the conduit system, over and above localised leakage from the overlying epikarst.

3.4 Well Yields

The GSI well database was interrogated for data points within the study area. Figure F shows the trends in excellent, good, moderate and poor well yields in the area based on the available data.

Within the EPA delineated ZOCs for Bunatubber and Corrandulla there were 81 records, of which 60 had accompanying yield data. Those records included 5 boreholes with excellent yields and 33 boreholes with good yields (100 to 400m3/d). Figure F shows a noticeable alignment of good and excellent yielding wells along lines heading roughly northeast to southwest towards Bunatubber and Corrandulla springs. This correlates with the tracer test data which suggest that the predominant flow direction and highest flow velocity is in the northeast to southwest direction.

The remaining yield data indicate the presence of 7 boreholes with moderate yield (40-100 m3/d BH) and 15 boreholes with poor yield (<40 m^3/day). These are generally scattered amongst the good wells; however there does appear to be a small NNE to SSW oriented cluster in the vicinity of the artificial reach of the Abbert River (between Anbally and Carheenlea), which may indicate a zone of low transmissivity in that area.

The good and excellent borehole yield data in the vicinity of Carheenlea GWS show similar trends.

3.5 Karst Features & Floods (Dbase, OSi Hist, OPW)

Table 2 shows the karst features in the vicinity of the GWS sources, identified from the GSI karst database, OSi historical mapping and OPW flood mapping. The locations of the features are shown on Figure G.

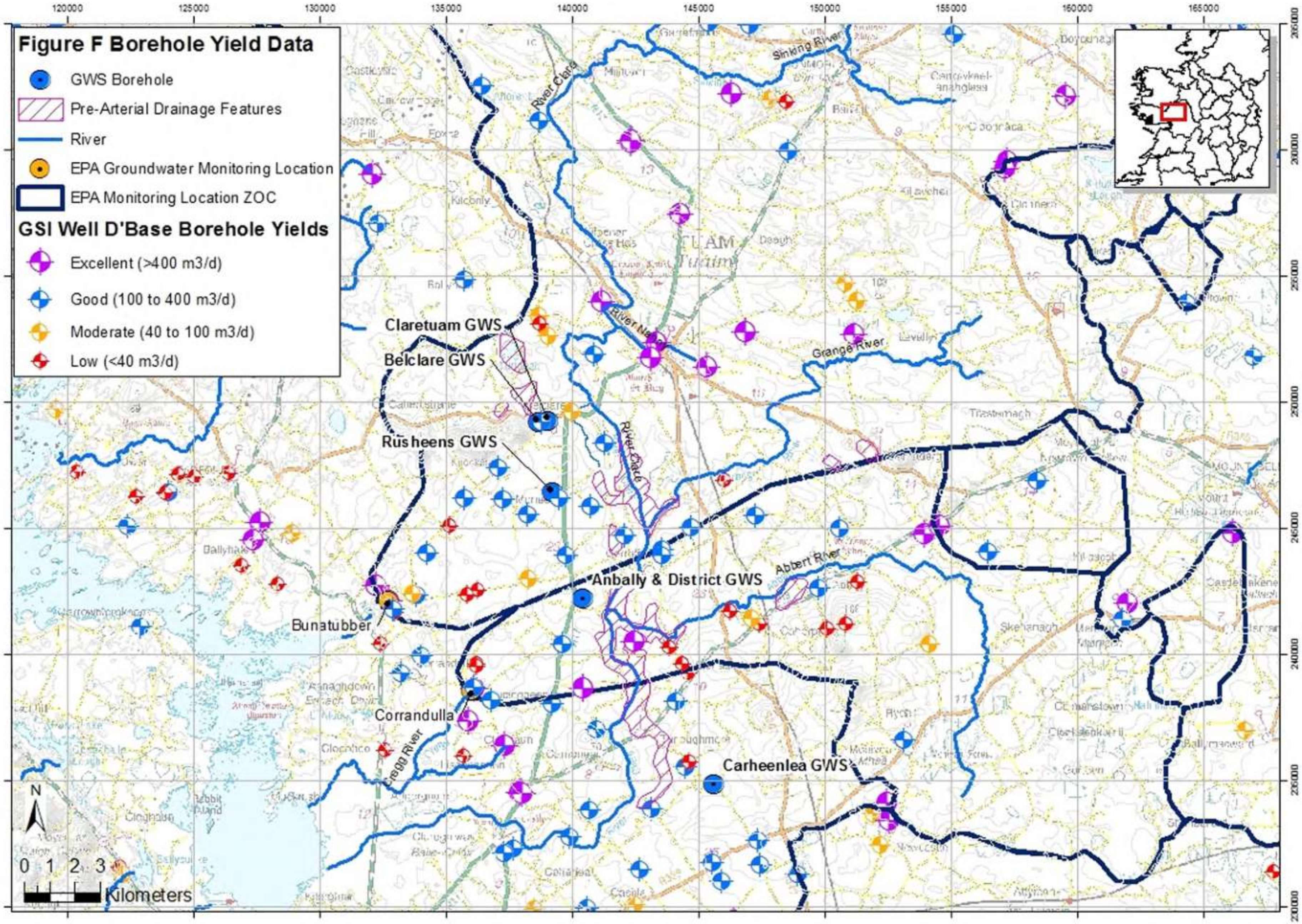


Figure F Borehole Yield Data
GWS Borehole
Pre-Arterial Drainage Features
River
EPA Groundwater Monitoring Location
EPA Monitoring Location ZOC
GSI Well D'Base Borehole Yields
Excellent (>400 m3/d)
Good (100 to 400 m3/d)
Moderate (40 to 100 m3/d)
Low (<40 m3/d)
Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Bunatubber
Corrandulla
Carheenlea GWS
River Clare
River Nanny
Sinking River
Grange River
Abbert River
Cregg River
TUAM
N
0 1 2 3
Kilometers
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000

Table 2. Karst Features Data

Dataset	Claretuam (CT)	Belclare (BC)	Rusheens (RSH)	Anbally (ANB)	Carheenlea (CHL)
OSi Hist	Map of surface water courses from late 1700s in Ryan Hanley (2010) shows a large lake in Monivea (north of Corofin); A huge turlough at Turloughmore which has no outflow, i.e. no Clare River south of the Turloughmore; no Abbert River west of Ballyglunin (i.e. it sinks and doesn't link to the Turloughmore). Rivers rise again along spring line east of Lough Corrib, e.g. Bunatubber and Corrandulla. 6" Hist map shows extensive "liable to flooding" east of Claretuam & Rusheens (Cloonmore, Clonkeen Lough) down to Corofin. Numerous turlough & karst townlands: CT & BC – Turloughnaroyer, Pollaturk (Newgarden), Polldarragh; RSH & ANB – Turloughour, Turloughcartron, Turloughmartin, Turloughrevagh; CHL – Turloughmore. No Abbert River in area south of Corofin and modern Clare River not constructed yet 25" map provides similar picture to 6" map. More individual turloughs delineated – these have been picked up by the GSI karst database. Modern Courses or Clare and Abbert Rivers in place.				
	6" map shows main path of R. Clare flows along the now redundant watercourse through Cloonmore, past Lackagh BH, and discharges into mid west boundary of Clonkeen Lough. By 25" map R. Clare created, Clonkeen Lough drained and old Cloonmore channel reduced to a drain. 25" flow arrows show drain flows south (arrow at Rusheens North) towards Lackagh BH area, to 3 dead end channels.				
GSI Karst Dbase	CT & BC – Turloughnaroyer.		Turloughour 2.8km SE, Tobernamucka Sp 2 km SSW; Cave 1.5km South; (they are all about the same distances but North from Anbally). Numerous Turloughs and springs to SW at Bunatubber.	9 turloughs to SE @1.3 to 4km distance – Pollakilleen, Meelick, Pollnacloya, Cloghdo, Turloughnarevagh + 4 unnamed. 3 Springs – Pollabullaun, Betty's Hole + 1 unnamed. BallygluninCave & Swallow holes ~5km E. Auclogeen SP to WSW.	Tobar Suibne Sp 2.7km West; Turloughmore Common 2.8km NW; 3 EncDep 3km East & 8 Enc Dep 2 to 3 km NE. Claregalway GWS SP & Intermediate Sp to WSW at Claregalway.
OPW	Large swathes of land on either side of Clare River in the vicinity of these sources mapped as benefitting lands (BL) - following flood plains of Clare River plus tributaries. For Claretuam and Belclare the BL extends around to the north and northwest and includes				Benefitting Lands immediately adjacent to source (at Flood ID

Dataset	Claretuam (CT)	Belclare (BC)	Rusheens (RSH)	Anbally (ANB)	Carheenlea (CHL)
	Turloughnaroyer, Pollaturk and Polldarragh. The BL is typically 0.4 to 1km distant. For Rusheens the most significant BL is the sinking distributary (original channel of Clare River) & former Clonkeen Lough area in the Rusheens/Cloonmore townland areas 1 km east of the source. This area is also less than 1 km east of Claretuam. At Anbally the former full extent of Turloughmore extends north to Corofin and sits approximately 1 km east of the source. Karst related flood points (Flood ID) include: CT & BC: Pollaturk (575); Turloughnaroyer (968); N17 Headford Tuam Rd/Claretuam (1808); Carrowbeg (1826); Headford Road Jn (1853);. RSH: Cummer Turlough (628); Turloughour (1017); Curry Eighter (1807); Ballybanagher Corofin (10801) ANB: Pollakilleen Turlough (1005); Meelick Turlough (1006); Pollnacloya Turlough (1007); Cloghdo Turlough (1008); Tonmace Turlough (1012); Corrandrum Turlough (1013); Turloughrevagh (1014); Turlough – Common (1015); Ballaun Turlough (1016); Ballyglooneen area Recurring (1803); Clare Corbally Recurring (1806); Flooding at Ardskeaghmore, Corofin Co. Galway Nov2009 (10800); Flooding at Ballyglunin Corofin Co Galway November 2009 (10802); Flooding at Annagh Corofin Co Galway in November 2009 (10803); Flooding at Bullaun Corofin Co Galway Nov 2009 (10804).				1878). Clare River BL approx 2.5 to 3km West. Karst related flood points (Flood ID) include: Lackagh Beg (630); Turloughmore Common (1009); Ballynasheoge Recurring (1877); Rathlee Recurring (1878). Rathlee (1878) – Floods every year after heavy rain. The water flows off high land. Large area can be flooded to an estimated depth of 6 to 8 feet. (GWS identified this as a Turlough).

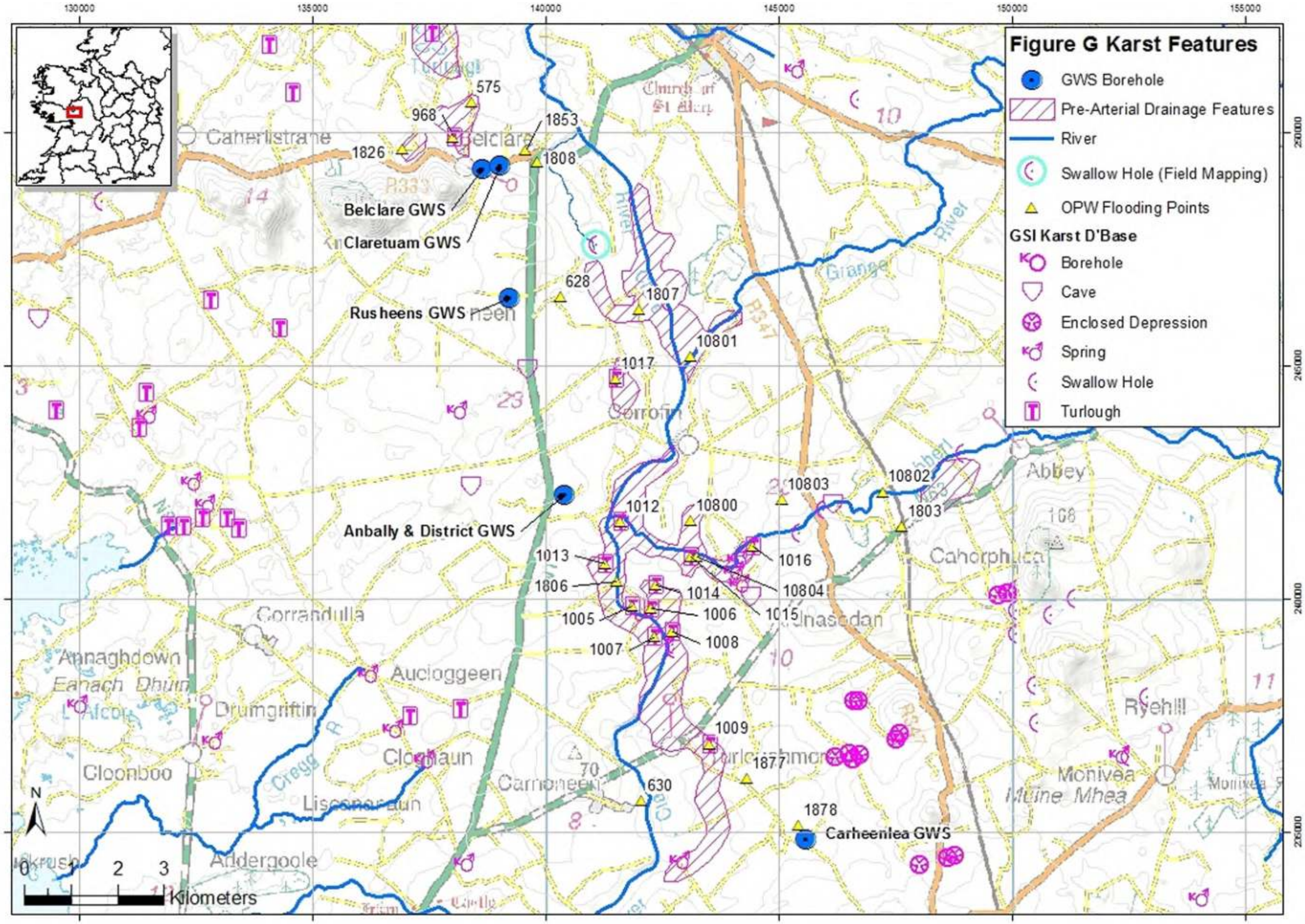


Figure G Karst Features
GWS Borehole
Pre-Arterial Drainage Features
River
Swallow Hole (Field Mapping)
OPW Flooding Points
GSI Karst D'Base
Borehole
Cave
Enclosed Depression
Spring
Swallow Hole
Turlough
Belclare GWS
Claretuam GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
Caherlistrane
Corrandulla
Annaghdown
Auclogeen
Drumgriffin
Cloonboo
Abbey
Cahorphuca
Ryehill
Monivea
Muine Mhea
0 1 2 3 Kilometers
N

Figure G shows the intensity of major surface karst features in the vicinity of the sources, which is an indication of the subsurface intensity of karst conduits. It is likely that karst conduits operate in the vicinity of each of the GWS source boreholes.

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Establishment of Groundwater Zones of Contribution

Balrobuckbeg Group Water Scheme

March 2015

Prepared by:

Colin O'Reilly, Envirologic Ltd.

and

Geological Survey of Ireland, Groundwater Programme

(Caoimhe Hickey, Monica Lee and Taly Hunter Williams)

And with assistance from:

Balrobuckbeg GWS

The National Federation of Group Water Schemes

Acknowledgements:

Edward Burke (Balrobuckbeg GWS)

Karen Carney (NFGWS)

Document control information

Revision	Date	Author	Checked	Approved
Draft	25/11/14	Colin O'Reilly	ML 06.02.15	
Revised Version	20/03/15	Colin O'Reilly	ML 25.03.15	
Revised Version	30/03/15	Colin O'Reilly	ML 02.04.15	

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' 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 Balrobuckbeg 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 that 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.

Balrobuckbeg GWS is supplied by a borehole in a regionally important aquifer with karstfied conduit flow (Rk_c). The current abstraction rate is 214 m^3/d.

[1] Geological Survey of Ireland, 1999.

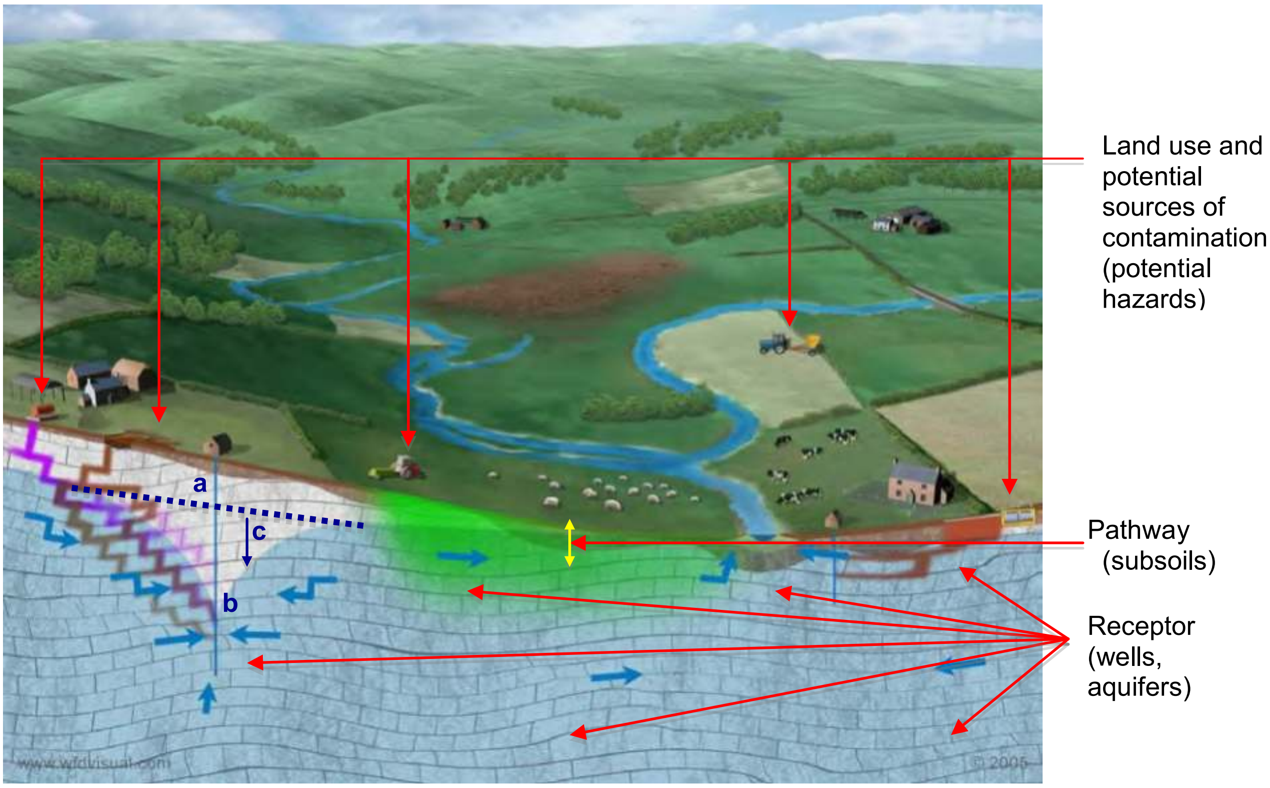

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Balrobuckbeg Group Water Scheme (GWS) is supplied from a borehole that lies in the townland of Balrobuckbeg, County Galway **(Figure 1)**. The current scheme demand is 214 m^3/d, which provides water to 190 domestic houses and has 340 metered connections in total.

The GWS is located in central County Galway: 8 km southeast of Headford, 15 km southwest of Tuam and 17 km north of Galway city centre. The borehole sits on the western side of a local road located c.1.5 km east of the N84.

The borehole wellhead sits inside 2.5 m by 2.5 m roofed pumphouse. The wellhead offers good protection to the borehole. The upper section of the borehole is lined with six inch steel casing, which is flush with floor level within the pumphouse. The borehole top is covered with a 0.3 m cube-shaped steel frame. A split galvanised sheet rests on the borehole top. The concrete pumphouse floor is in good condition and is marginally above road level. A 50 mm stainless steel rising main and power cable exit the chamber through a hole in the galvanised cover sheet (**Photos 1 and 2**).

The GWS site was originally a spring sump that was historically used as a bucket collection drinking water supply by locals. Galway County Council subsequently installed a handpump. The base of the spring is 1.5 m below pumphouse floor and is dry which suggests current borehole pumping has reduced water level below spring base level).

The current borehole was installed in 1974 and is 6 m deep. A 100 mm variable speed borehole pump supplies directly to the mains. Abstracted water passes through a cumulative flowmeter and is treated by chlorination and ultra-violet treatment.

A small laneway passes in front of the borehole door and provides access to an agricultural field to the west. To the rear of the pumphouse is an unused plot, behind which is a heavily vegetated wooded area. A large spring (Bunatober) exists 300 m to the northwest, and is used to support a local fish-farming industry.

The caretaker reports that during prolonged rainfall, groundwater levels rise to ground surface on the opposite side of the road and flow southwest, often overflowing a culvert beneath the local road.

Diagram 2 presents a schematic plan of the immediate area surrounding the source. Photos of the pumphouse and borehole chamber can be seen in Photos 1 to 4 below. Table 1 provides a summary of existing information relating to the borehole. There is no drilling log available for the borehole, nor is there any record of a pumping test having been carried out.

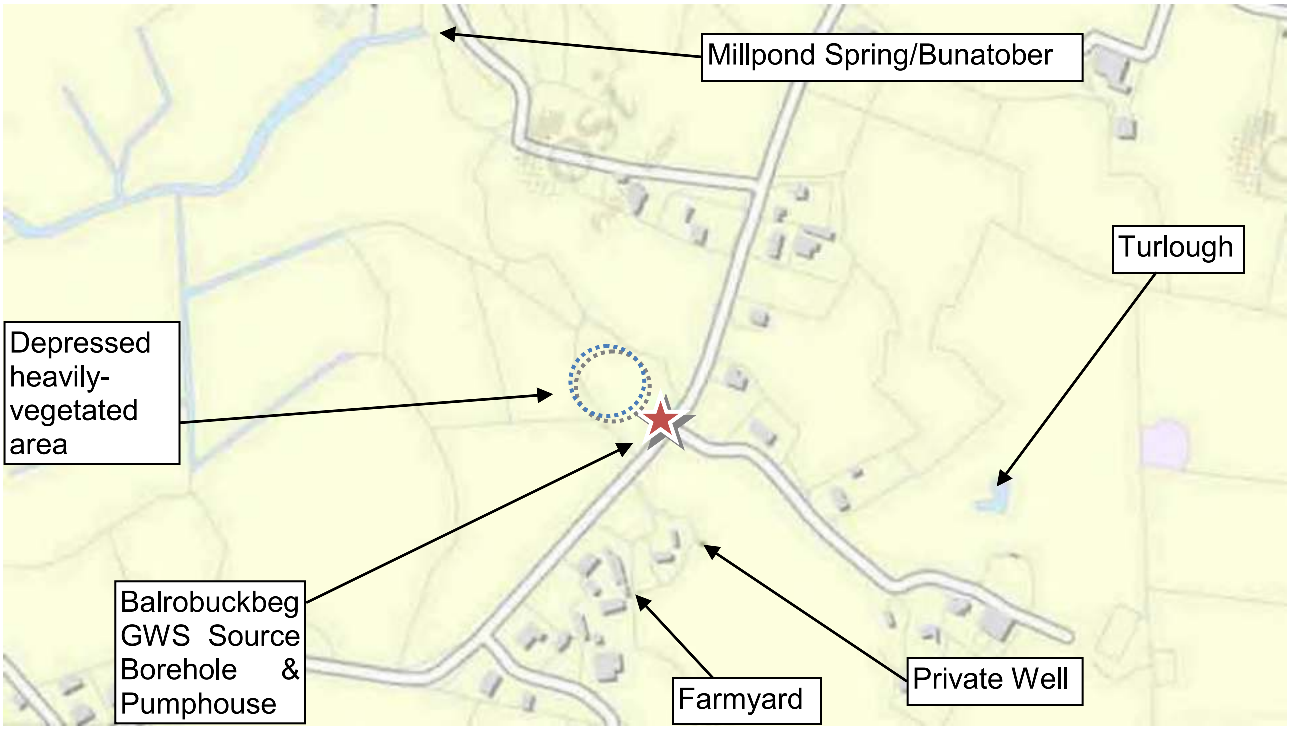

Diagram 2. Schematic Plan of the GWS Site

Photo 1: Borehole headworks

Photo 2: Borehole headworks (note split galvanised sheet cover)

Photo 3: Borehole location on side of road (viewing southwest)

Photo 4: Unused lands to rear of pumphouse

Table 1. Supply Details

	Balrobuckbeg Borehole
Grid reference	132,892 m Easting; 241,845 m Northing
Townland	Balrobuckbeg
Source type	Borehole
Drilled	1974
Drilling Contractor	Original borehole by Galway County Council.
Owner	Balrobuckbeg GWS
Elevation	Ground level = 12.36 mOD Malin
Total depth (m)	6.5 m
Construction details	150 mm steel casing to ~ 5.0 mbgl; Assume open hole 5.0 – 6.5 mbgl
Depth to rock (m bgl)	Rock at surface in several locations close to borehole
Static water level (SWL)	Unknown. (SWL 19/08/2014 = maximum water level observed following 20 minutes recovery = 5.06 mbgl; however water level still rising so of limited relevance). Local groundwater elevations suggest non-pumping groundwater level may be around 9.0 mOD (3.3 mbgl).
Pump intake depth (m bgl)	6.0 m
Current abstraction rate (GWS)	1,500 m^3 per week (+ or - 30 m^3) (equivalent to 214 m^3/d; 2.5 l/s)
Reported yield (m^3/d)	Unconfirmed, no long-term pumping test has been performed. The pump is just off the base of the borehole and amount of water above the pump is minimal. Caretaker reports that following dry spells or prolonged periods of frost the groundwater level drops to the pump level. Therefore, the well is assumed to be pumping at it's capacity and there is no scope to increase the current abstraction rate. The scheme is currently exploring feasibility of installing a second deeper borehole in the vicinity of the pumphouse.

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical Characteristics of the Area

Table 2. Physical Characteristics of the Area of Interest

	Caherlea Borehole	Description/Comments	
Annual Rainfall (mm)	1167	Met Éireann average annual rainfall data 1981-2010	
Annual Evapotranspiration Losses (mm)	463	487.5 mm PE (average annual potential evapotranspiration data, Galway SWS, 1961-1990). 463 AE (Actual Evapotranspiration, assumed to be 95% of PE).	
Annual Effective Rainfall (mm)	704	Annual rainfall less annual evapotranspiration losses	
Topography **(Figure 1)**	Lands in the wider area slope gently down to the west-southwest from a hilltop at Knockmaa (162 mOD) 7 km to the north, and from a local hummock at Carrownaherick (50 mOD). Approaching the site, slopes become slightly steeper, with some undulations, before flattening out again approaching Lough Corrib. The well itself is in a slight topographical depression, with lands to the north, east and south being slightly higher. Ground continues to fall away into a minor valley to the southwest, which after a short distance turns northwest to a local stream. To the immediate west of the site lands are depressed in what appears to be an isolated hollow.		
Land use	Land in the area is predominantly used for moderate intensity agriculture. The borehole is situated on the edge of an unused grassland field. The pumphouse is fronted by a junction between two local roads. Several farmyards and dwellings are located within 300 m of the borehole. A fish farm is 350 m to the northwest.		
Surface Hydrology **(Figure 2)**	The many localised breaks in slope in the area give rise to a high density of features in quite a small area. Within a 1 km radius of the GWS, turloughs are present in topographical hollows (240 m east, 420 m southwest, 570 m southeast and 770 m to the southwest). Similarly a number of springs rise where lands fall below regional groundwater level. These tend to be on a north-south orientation between springs at Ballycasey 3.3 km to the north, and Corrandulla 4.5 km to the southeast. The most significant of these is Millpond Spring (Bunatober) 350 m to the northwest, which has an estimated discharge of 1 m^3/s. There are no surface watercourses between the GWS and the Clare River, 10 km to the east. The local springs form the headwaters of several local streams which join together, flowing west beneath the N84 before entering Lough Corrib, 2.3 km southwest of the GWS.		
Topsoil	The region is dominated by deep, well-drained basic mineral soils, which become thinner on elevated ground/where bedrock outcrops. Lacustrine deposits are mapped in hollows (turloughs). Some soils on low-lying lands adjacent to streams are permanently waterlogged and have degraded to peats. Alluvial deposits are mapped as flanking some stream sections.		
Subsoil (**Figure 3**)	Carboniferous limestone till (Teagasc, 2006). Subsoils may not be present where bedrock is close to surface.		
Groundwater Vulnerability (**Figure 4**)	Extreme (E) immediately around the borehole, and pockets throughout the wider area, indicating rock is close to surface. Presence of High (H) and moderate (M) vulnerability in the minor valley feature to the south and west of the GWS. **See Appendix 2.**		
Geology Formation: Rock Unit Group (**Figure 5**)	Dinantian Pure Bedded Limestones. Bedrock formation is the Knockmaa Formation which is a thick-bedded pure limestone. GSI 6" field sheets indicate outcrops are weathered and jointed. Regionally, north-south and east-west joint sets are expected to occur (Gatley et al., 2006).		
Aquifer (**Figure 6**)	The DPBL limestones are classified by the GSI as a Regionally Important Karstified Bedrock Aquifer, dominated by conduit flow (Rkc). Mapped surface karst features are shown in Figure 6.		
Groundwater Body (**Appendix 3**)	Clare-Corrib GWB (GSI, 2004)	Categorised as having a 'poor' status.	
Recharge Coefficient (**Appendix 4**)	80 %	Low drainage density, well-drained soils, moderate permeability subsoils, and extreme vulnerability, plus point recharge via karst features suggest a high recharge coefficient.	
Recharge (mm)	563		

3.2 Hydrochemistry and water quality

Table 3: Water Quality Data

	Untreated Water		Treated Water 2007-2011		
Parameter	Number of Values	Result (24/07/14)	Number of Values	Mean	Parametric Value
pH (lab.)	1	7.2	12	7.2	6.5 < pH < 9
Electrical Conductivity (lab.) (uS/cm)	1	551	12	623	800
Colour (PtCo units)	1	< 4	7	7.4	acceptable to consumers and no abnormal change
Turbidity (NTU)	1	0.2	8	0.71	
Nitrate (mg NO_3/l)	1	9.03	10	9.83	37.5
Nitrite (mg NO_2/l)	1	< 0.017	6	0.014	0.375
Orthophosphate (mg PO_4-P/l)	1	0.036			
Hardness (mg/l as $CaCO_3$)	1	367			
Ammonium (mg NH_4/l)	1	< 0.01	10	0.03	0.3 (SI 278 2007)
Iron (ug Fe/l)	1	19	7	36.6	200 (SI 278 2007)
Manganese (ug Mn/l)	1	< 5	6	13.7	50 (SI 278 2007)
Aluminium (ug Al/l)	1	2	9	18.2	200 (SI 278 2007)
E.coli (cfu/100 ml)	1	0	0	12	0
Total coliforms (cfu/100 ml)	1	0	0	12	0

Table 4 – NUIG Microbial Sampling Data 2013

Date	Sample Type	Microbiological parameter	MPN/100 ml	VTEC
02/10/13	Raw	total coliforms	67.7	O157 & O26 detected. VTX 1+2 toxin genes
		e. coli	1	
	Treated	total coliforms	0	none detected
		e. coli	0	
14/10/13	Raw	total coliforms	49.6	O157 detected. VTX 1+2 toxin genes
		e. coli	5.1	
	Treated	total coliforms	0	none detected
		e. coli	0	
23/10/13	Raw	total coliforms	410.6	O157 & O26 detected. VTX 1+2 toxin genes
		e. coli	238.2	
	Treated	total coliforms	0	none detected
		e. coli	0	

One untreated water sample was collected for the Balrobuckbeg GWS borehole on 24/07/2014 and analysed by CLS, Ros Muc, Co. Galway (**Appendix 5**). A dataset containing results taken at various points of network between 2008 and 2011 was also referred to. Four sample sets (consisting one sample of raw water and one sample of treated water per set) were also collected and analysed by NUIG during 2013/2014 as part of a study into microbial contamination.

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

Some parameters were measured in the field on 19/08/14. Electrical conductivity measured 678 µS/cm; pH measured 7.5; temperature measured 11.9°C.

The available water quality data show that the water is moderately hard and has a slightly alkaline pH, which reflects the limestone bedrock.

Nitrate concentrations are relatively low which is consistent with the low to moderate intensity farming in the area. Orthophosphate levels are slightly elevated, suggesting possible contamination from landspreading, leaky underground slurry storage tanks, improper septic tanks or inadequate percolation areas.

Microbial analysis shows faecal contamination was detected in the raw water supply on each sampling occasion, which would reinforce that grazing animals, landspreading, underground slurry tanks septic tanks and percolation areas are potentially a source of ongoing contamination. The microbial contamination, which in one instance was indicative of a gross contamination event, also supports that the supply borehole is abstracting from a shallow groundwater system.

All microbial samples were collected in the month of October. Year round sampling would be needed to confirm any seasonality.

Where coliform contamination was detected in the raw water sample it had been removed following treatment. This confirms that the chlorination and ultraviolet treatment system is effective, when working.

VTECs (verocytotoxigenic Escherichia coliforms) are a more virulent and aggressive form of microbial contamination. VTEC O157 and O25 were detected in the raw water supply, the sources of these being cattle, sheep and goat faeces. VTEC were not detected in the treated water entering the supply line.

The nearby GWS at Clough Cummer detected VTEC in their borehole, which is 30 m deep. This would suggest that VTEC are present in the upper groundwater regime. It is not evident that the source of VTEC is the groundwater flow at depths of greater than 30 m.

4 Zone of Contribution

4.1 Conceptual model

It is recognised that the scale of this study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Balrobuckbeg GWS supply borehole with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. However, based on the analysis of the available information, the current understanding of the geological and hydrogeological setting is given as follows (see Diagram 3).

The location of the borehole and local springs, regional drainage and topography patterns, as well as this[2] and previous[3] groundwater investigations, suggests that groundwater flow emanates from the east-northeast. A large proportion of the rainfall (c.80%) is considered to infiltrate to groundwater as both ‘diffuse’ recharge, through any soils/subsoils across the entire land surface, and ‘direct’ recharge, at specific karst points of entry (such as swallow holes in turloughs and enclosed depressions, known as dolines).

Once the infiltrating rainfall reaches the limestone bedrock aquifer, it will flow southwestwards through interconnected joints, fissures and fractures, which are likely to have been enlarged or ‘karstified’ (by rainfall slowly dissolving some of the limestone). These interconnected joints, fissures and fractures are frequently found to be much more numerous and dense in the upper, more weathered zone of the limestone bedrock aquifer (e.g. upper c.3-10 m), which is known as the ‘epikarst’ layer.

The borehole, which is developed on the site of a naturally occurring spring, intercepts the groundwater that is moving through this epikarst zone. It is considered that flow through the epikarst is likely to be supplying the majority of the abstraction, which will probably have a relatively small, localised catchment area (or Zone of Contribution; ZOC). It is considered that recharge from within the catchment can reach the borehole within 100 days, as evidenced by the frequent presence of coliforms in the untreated water.

The relatively small ZOC would explain why the water level in the borehole decreases during drier/frosty periods. However, given the complex nature of the karstifed aquifer, and results of previous groundwater studies in the local area[3], there is a possibility that deeper groundwater may also be contributing to the abstraction. If this is the case, it would significantly alter the ZOC, which would become considerably larger.

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[2] A regional well survey performed on 6th September 2014 indicated that groundwater flow is towards the southwest, driving discharges towards Lough Corrib, and a series of springs on it’s periphery.

[3] Tracing studies performed previously by the GSI showed that some water is leaked from the River Clare and discharges at the Millpond Spring.

4.2 Boundaries

The boundaries of the area contributing to the source are based on hydrogeological and topographical setting, and are considered below. Inside the boundaries groundwater flow in the upper groundwater flow regime is expected to reach the borehole. The current ZOC has been delineated on the basis of the epikarst supplying the borehole. The potential zone of contribution is shown in Figure 7.

The **northeastern** boundary is the uphill (upgradient) boundary and is based on the local topographic divide in Parknaliddaun. Groundwater in the epikarst layer flows southwest from this boundary towards Bunatober Spring, Balrobuckbeg, and ultimately Lough Corrib. The emergence of springs in the area is due to the break in slope, where elevation drops quite significantly relative to the upgradient area.

The **northwestern and southeastern boundaries** are based on the assumed groundwater flow direction, which is inferred from a survey of wells and turloughs. The turlough to the southeast of the GWS has also been included in the ZOC. The width of the ZOC is assumed to be influenced by the local topography around the well itself i.e. that it is located in a minor valley.

The **southwestern boundary** extends downhill (downgradient) of the borehole, which delineates the area from which groundwater will be drawn back into the well. This has been based on the local topography, although hydrogeological equations were also applied as a cross reference (Appendix 6 and water balance). The downgradient distance of 764 m (as calculated in Appendix 6) is deemed to be unrealistic due to the short duration of the pumping test, and fracture flow influences, which yielded a low T value. Tracing tests carried out in the past suggest much higher T values in this area. The survey of local groundwater levels shows upgradient hydraulic head to be greater than the downgradient head. This differential results in the majority of groundwater supplying the well being sourced from the upgradient (northeast) area.

The abstraction at Balrobuckbeg is not deemed to have an impact on Millpond Spring at Bunatober.

Based on the collection and analysis of the available data for this project, it is recognised that this scale of study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Balrobuckbeg GWS borehole with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. Therefore, the analysis has been used to identify an area that is highly likely to be supplying the borehole. It is possible that additional areas are also contributing to the borehole (depending on the flow regime in operation) so the GWS may want to consider further hydrogeological work/ measures if water quality issues persist, which will provide supporting evidence as to the most likely areas that should be included within the ZOC.

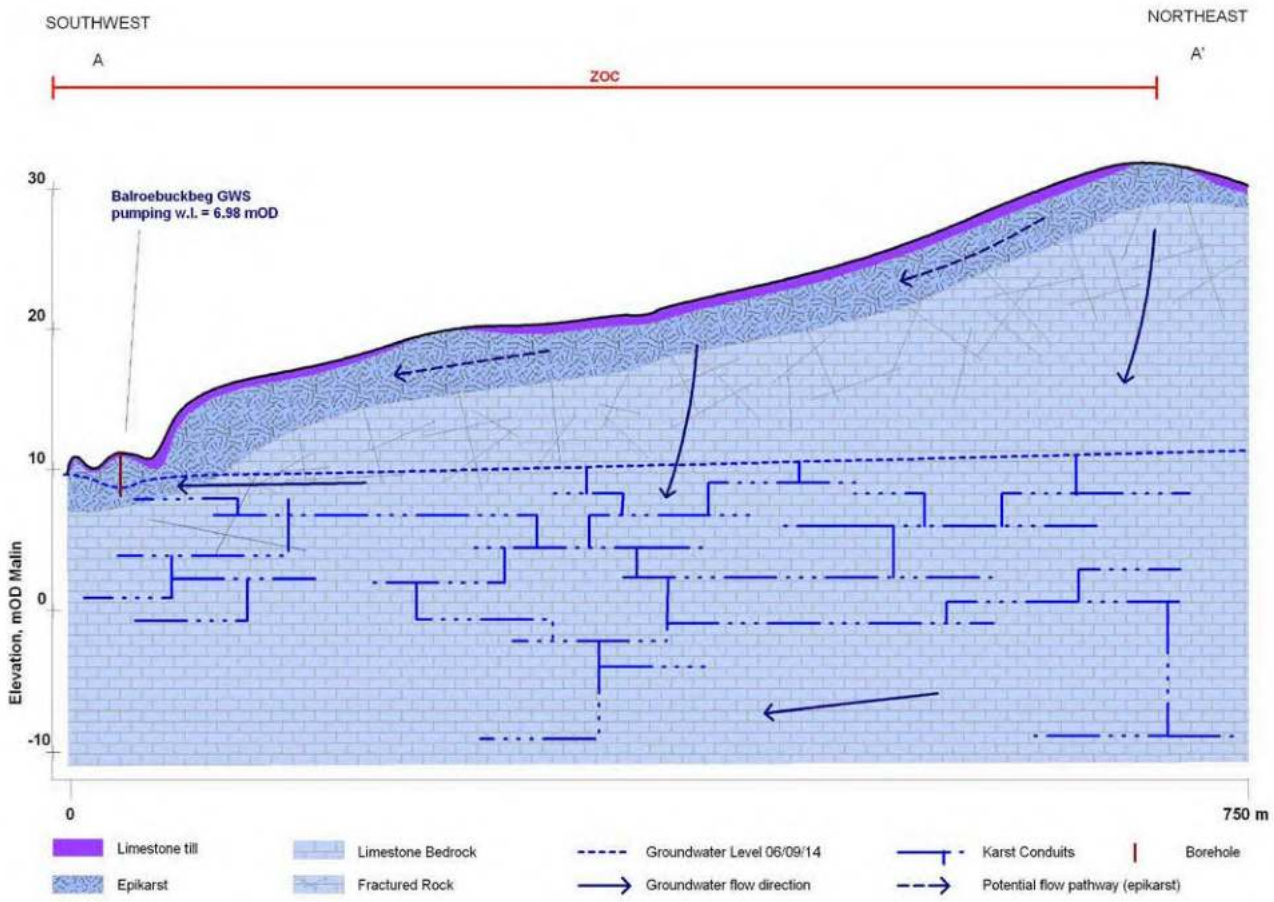

Diagram 3: Schematic Cross Section and Conceptual Model

4.3 Recharge and water balance

The current demand for the Balrobuckbeg GWS is 214 m^3/d. The abstraction is close to maximum sustainable yield that the borehole can provide. In order to accommodate periods of drier weather, 150% of the current demand has been used in the water balance calculations, i.e. 321 m^3/d.

Recharge to the ZOC is estimated as 562 mm/yr (see **Table 2**). At a recharge rate of 562 mm/yr the 321 m^3/d abstraction rate requires a ZOC of 0.2 km^2 (208,442 m^2) to capture the required volume of diffuse recharge to balance this abstraction.

Based on hydrogeological setting and topography, the delineated zone of contribution was estimated as having an area of 0.3 km^2. The water balance shows that the zone of contribution delineated is adequate to supply the borehole abstraction.

5 Conclusions

The current abstraction for the Balrobuckbeg GWS borehole is 214 m^3/d. This is a shallow well, which is thought to be supplied by the upper weathered zone (epikarst) of the underlying limestone bedrock aquifer.

The ZOC delineation was based on hydrogeological mapping and it is considered to be large enough to ensure the long-term sustainability of the supply, although the general indications are that the current abstraction is already towards the maximum yield that the well can supply.

The groundwater vulnerability within the ZOC is predominantly mapped as either Extreme (X – rock close to surface or karst) or Extreme (E). 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.

Recent data for the borehole suggests that the supply is highly susceptible to bacterial contamination.

The difficulties of delineating definitive ZOC boundaries due to the hydrogeological complexity of this area and the limited scale of this study (i.e. predominantly desk study) have already been noted. Based on the available information, the most likely area contributing to the borehole supply has been identified, which will allow the GWS to focus appropriate landuse management with the aim of improving the water quality. However, 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 water quality monitoring should be carried out **on raw water** at the source. The monitoring programme should include a regular survey of water quality parameters that would include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The chemistry results should be reviewed and if the parameters are generally stable, the frequency (and possibly the list of analytes) could be reduced to quarterly or biannually.

- The GWS should liaise with NFGWS regarding the completion of a cryptosporidium risk assessment.

- Comprehensive hazard mapping within the delineated ZOC should be undertaken. Specific points of interest within the ZOC are a turlough, three farmyard and farm dwellings, and four houses constructed within the last 5 years. Balrobuckbeg GWS should consider liaising with the farmyards within the ZOC to ensure risk from underground slurry storage tanks, silage clamps, and septic tanks is minimised.

- The GWS need to consider restricting cattle access and application of inorganic and organic fertilisers within the vicinity of the turlough to the east. The necessity of this could be confirmed by undertaking dye tracer testing from the turlough to the well (see Desirable Recommendations below).

- The borehole abstraction should continue to be measured on a cumulative flowmeter inside the pumphouse on a daily/weekly basis. This is to ensure that the delineated ZOC remains appropriate.

- The GWS have stated their intention to install a new borehole. Prior to drilling, the GWS should consult with a hydrogeologist and/or the GSI to determine appropriate locations, depths and well construction or advise on alternative options, e.g. mixing different sources of water, in order promote a wholesome, sustainable supply. Generally, targeting the deeper groundwater system often results in improved water quality, but this may not be the case in more complicated karst aquifer environments, such as around the Balrobuckbeg GWS.

- Further to the previous point, if there are changes to the supply, such as increasing the abstraction or drilling another borehole, or water quality issues are found to persist even after remedial action is taken, a more in-depth hydrogeological assessment should be undertaken. Any further assessments should be karst-specific and in particular examine the likelihood of deeper inflow, which are likely to be at a regional scale.

Desirable

- Installation of a fenced compound (e.g. 10 m x 10 m) is recommended to provide sanitary protection for the borehole area.

- Ideally the pumphouse floor level would be raised a minimum of 0.15 m above surrounding ground level. The steel casing should also protrude above pumhouse finished floor level by a further minimum of 0.15 m. This will mitigate against local flooding or internal spillages.

- Karst assessments in the catchment area, which would include a) feature mapping (in particular, enclosed depressions with potential swallow holes) and b) dye tracer testing from any appropriate features, such as the already mapped turlough. The tracer test would examine any connection between the turlough (or other features) and the GWS well, as well as further refine the groundwater flow directions.

- A baseline survey of all the major and minor ions should be undertaken once every 2-3 years and would provide valuable information on the background water chemistry and quality.

<u>Other</u>:

- The following guidelines may serve as future useful reference documents for the Balrobickbeg 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[4].
    - 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[5].
    - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[6]
    - European Union (Good Agricultural Practice for Protection of Waters) Regulations 2014 – Part 4
    - the EPA Guidance Note 11: Technical guidance in relation to proposing landspreading exclusion zones

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

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

[6] http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html#.UpNR8eJ9KEo

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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

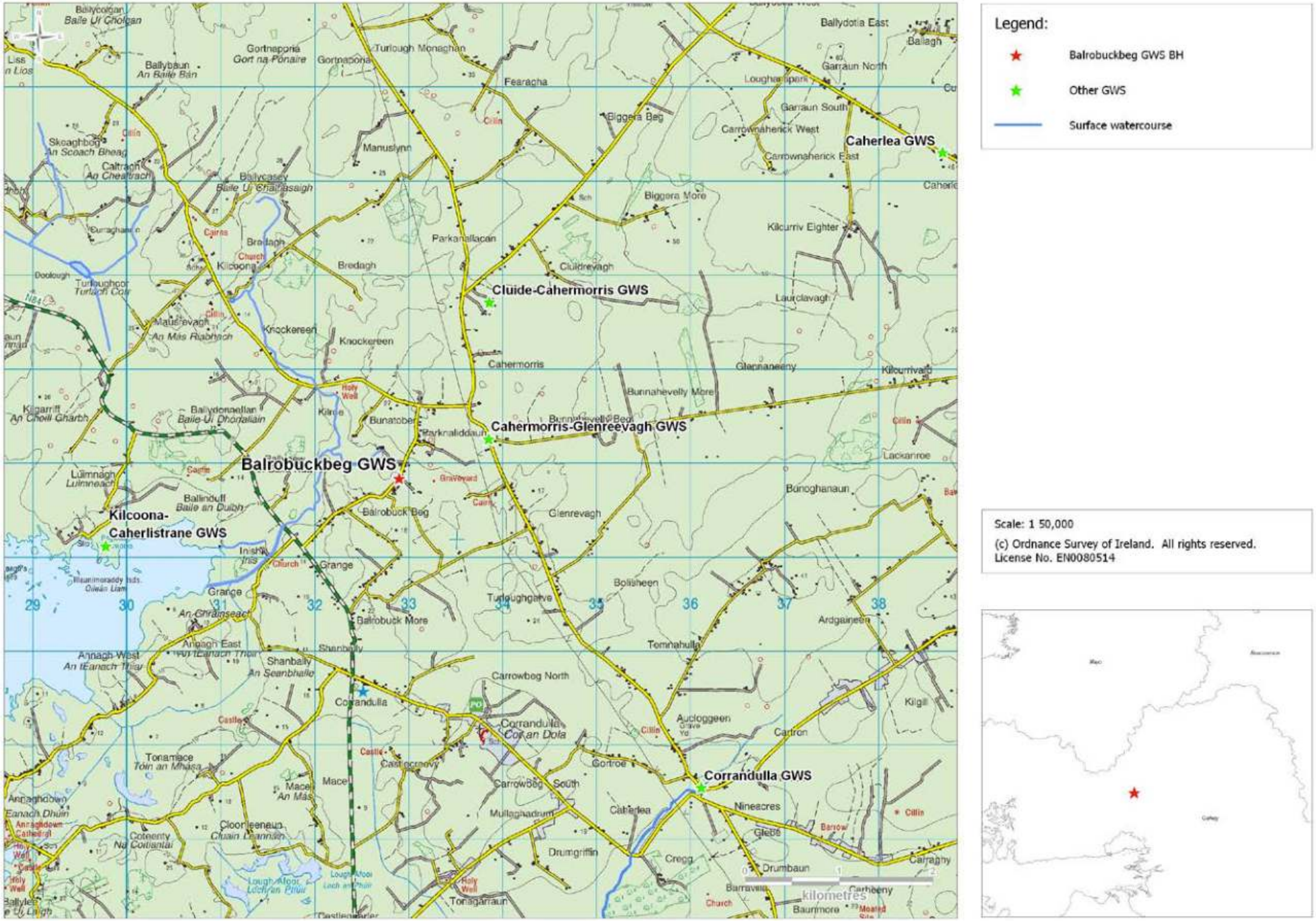


Figure 1: Location Map (OSI Discovery Map Series Map. 1: 50,000 scale)

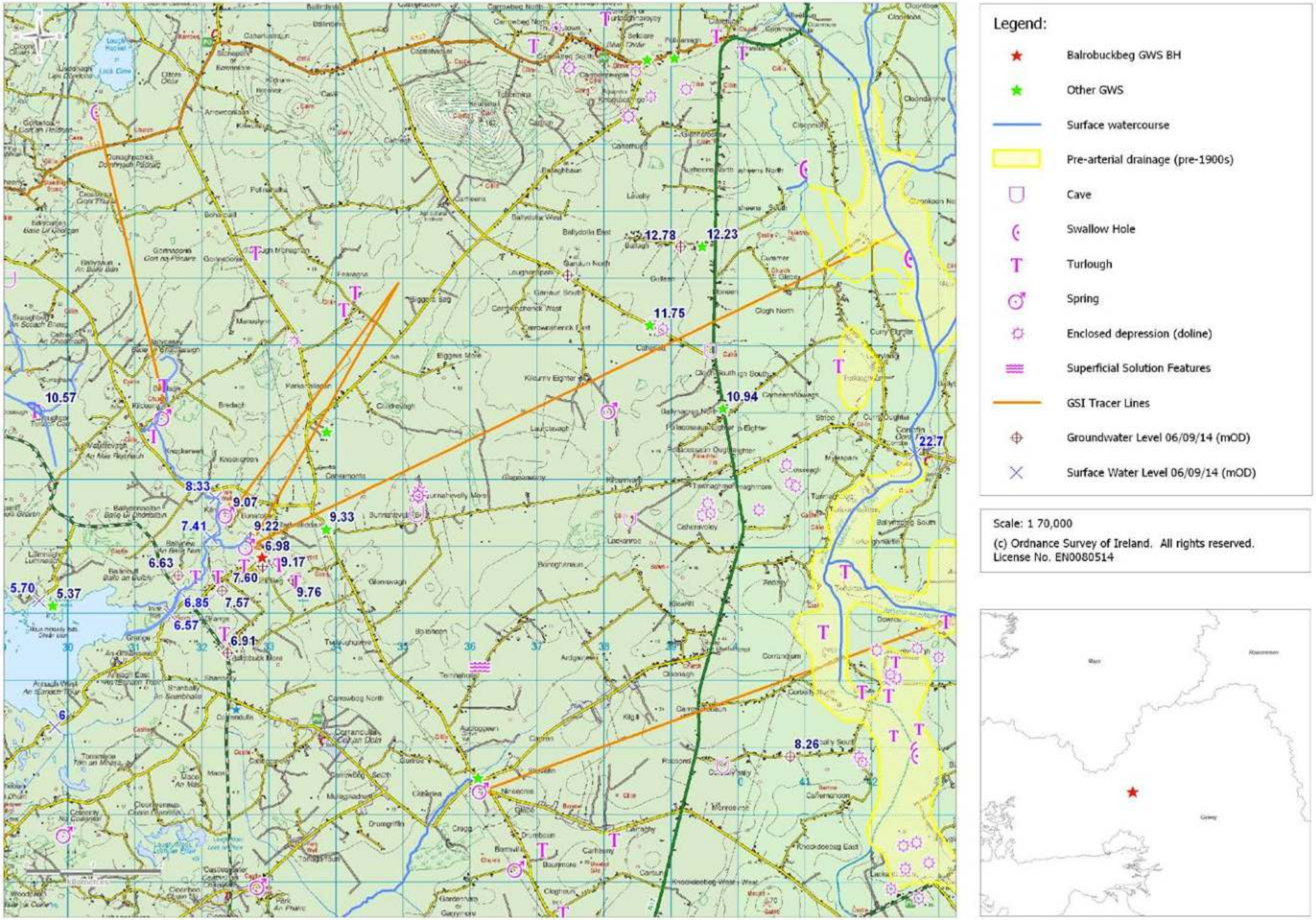


Figure 2: Topography and Drainage

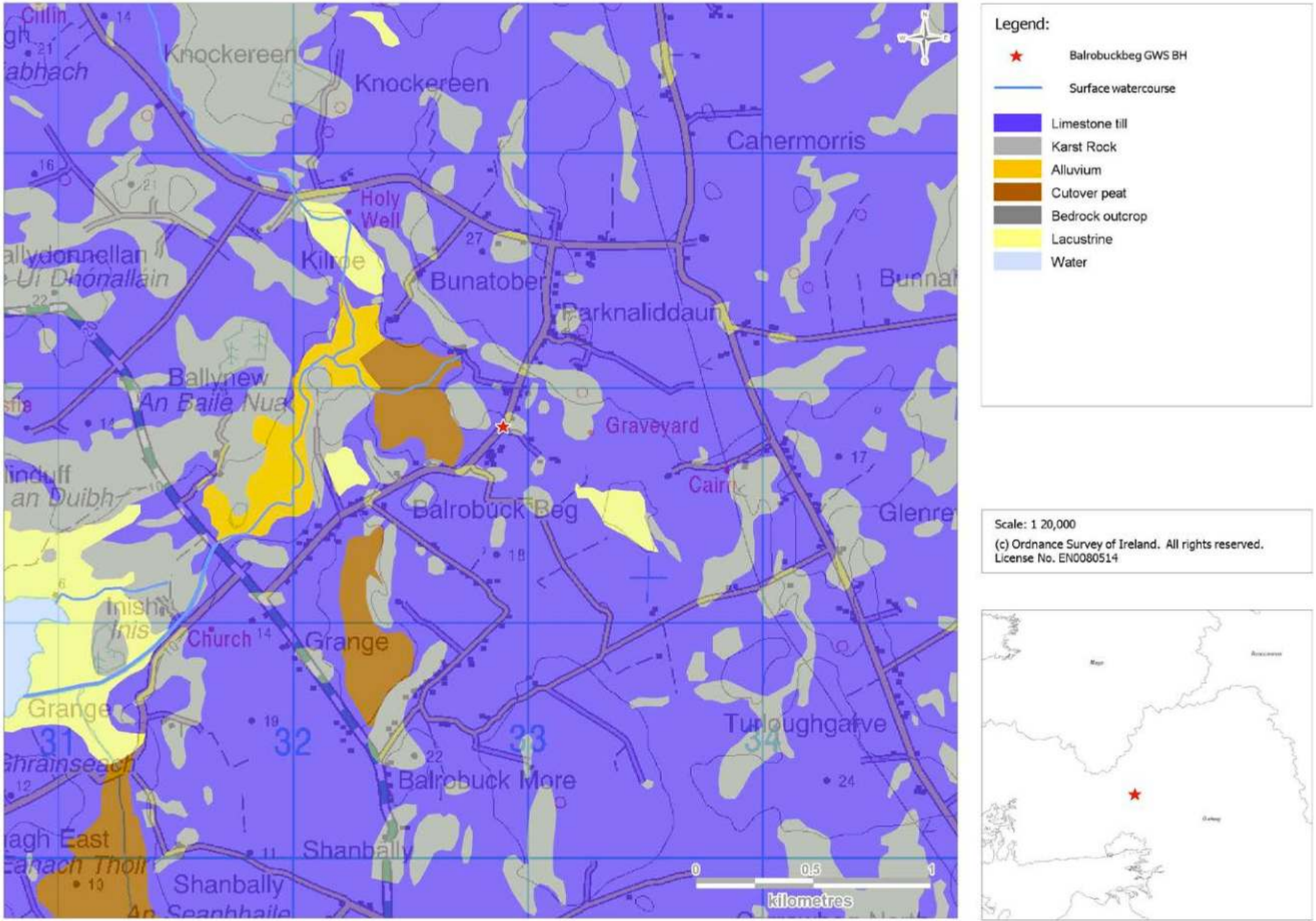


Figure 3: Subsoils Map

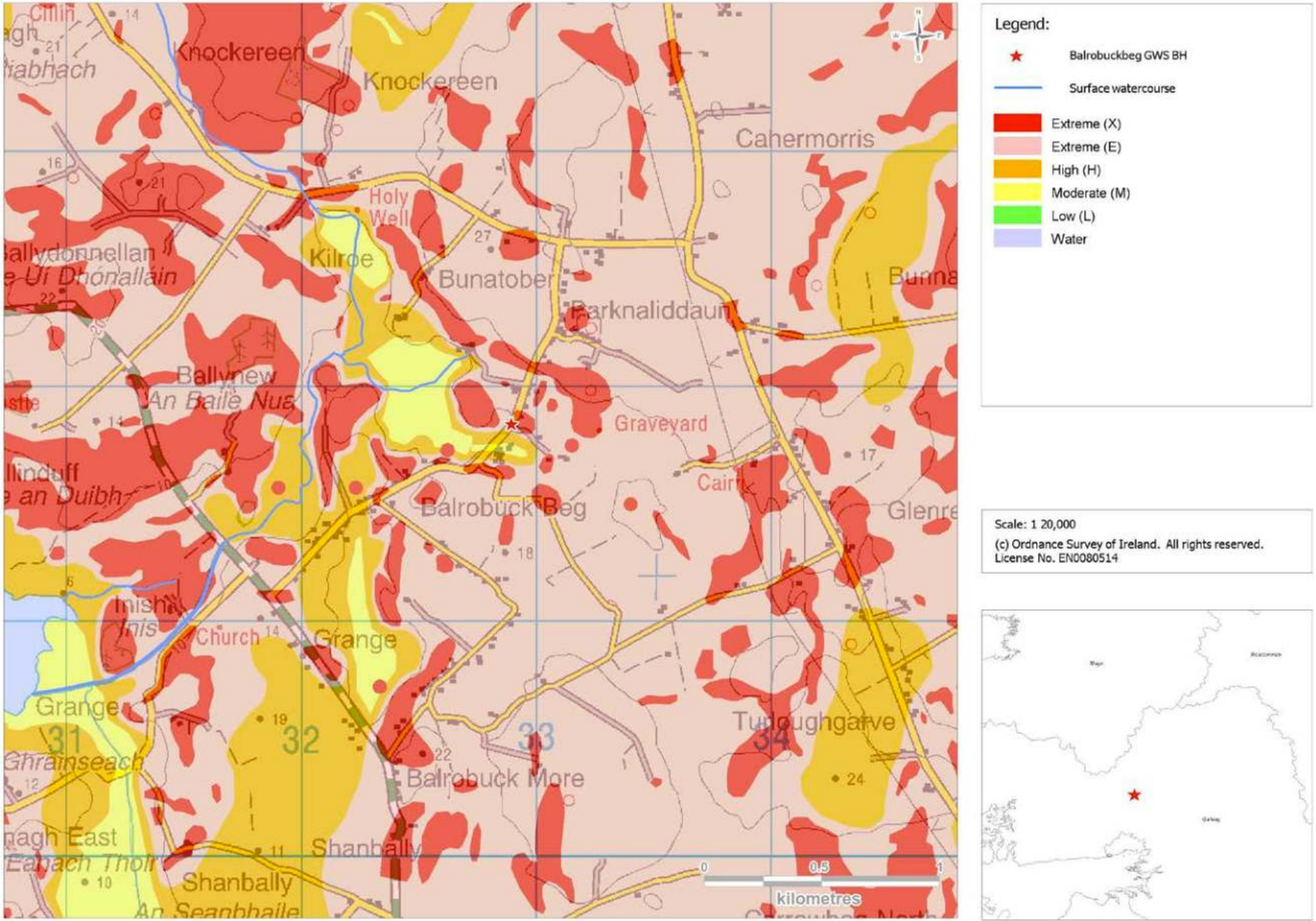


Figure 4: Groundwater Vulnerability Map

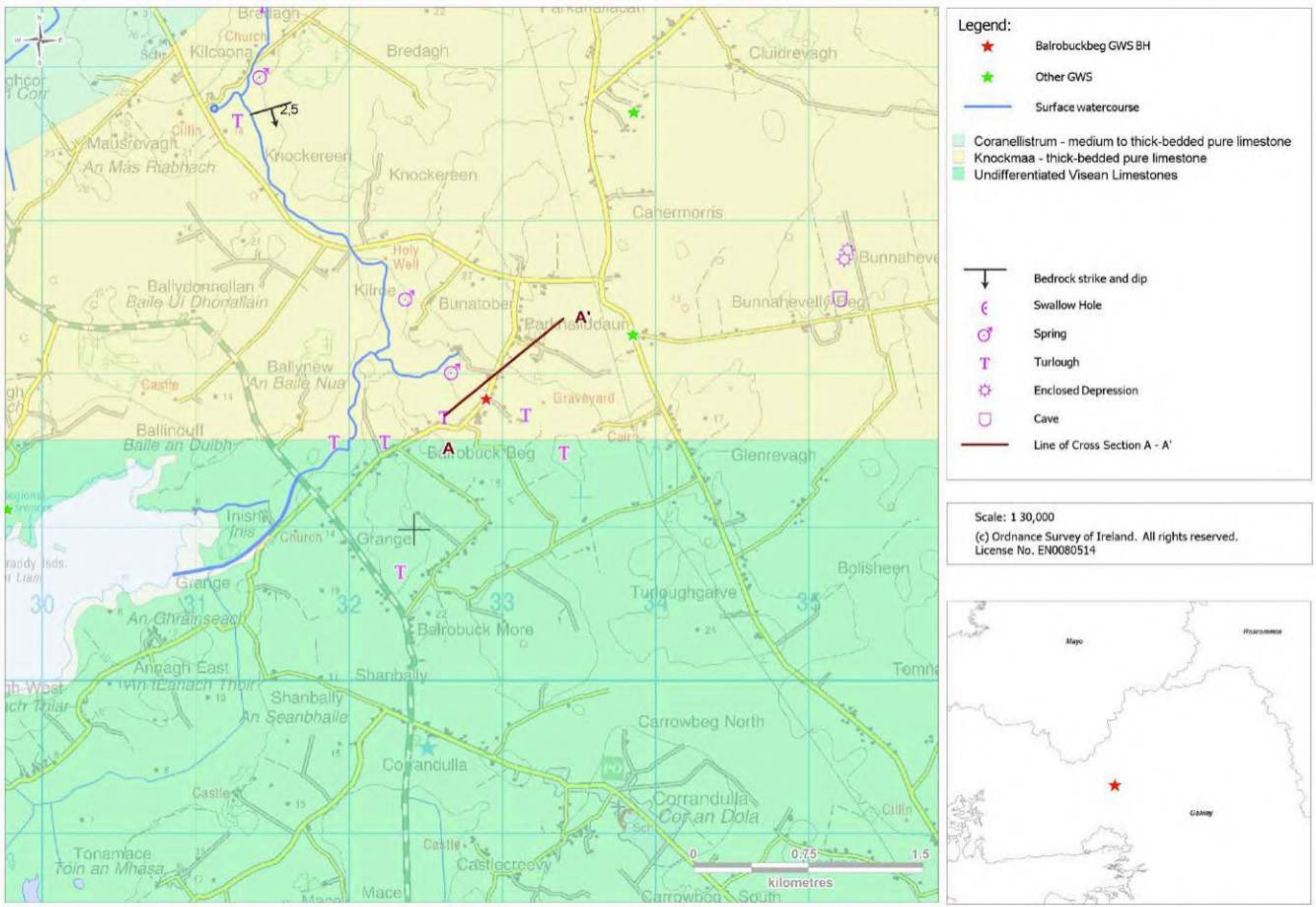


Figure 5: Rock Unit Group Map

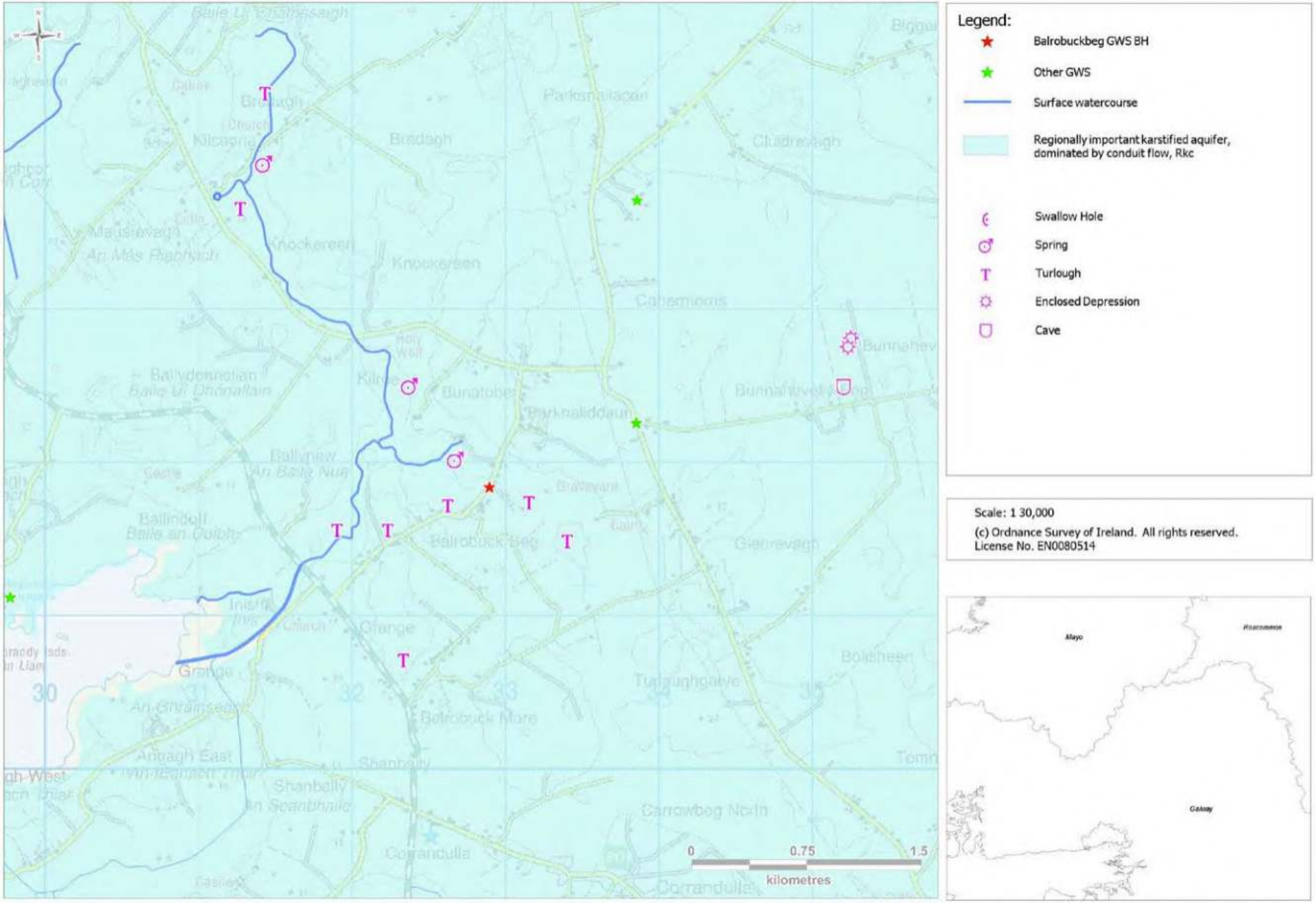


Figure 6: Aquifer Map

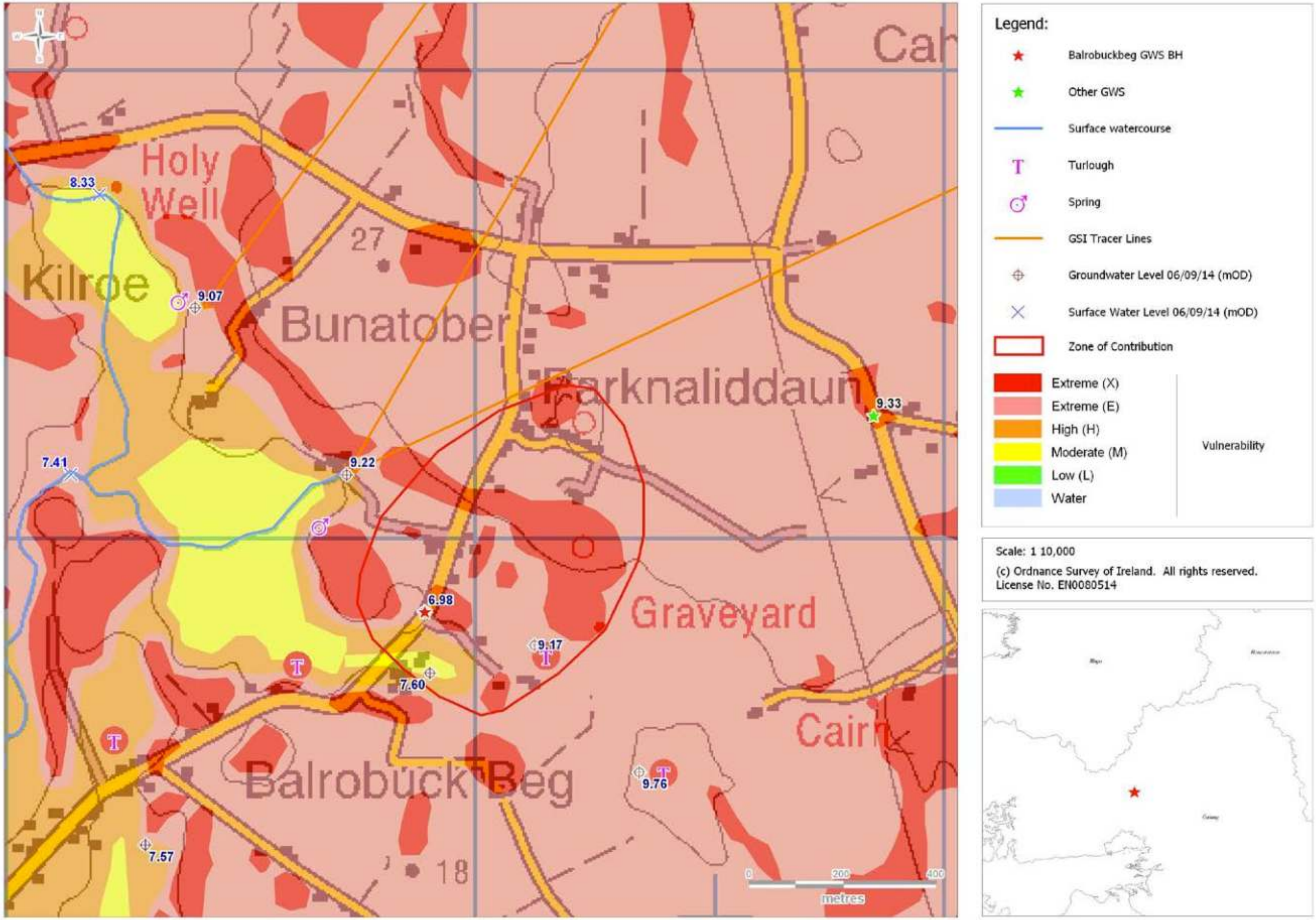


Figure 7: ZOC Boundary

APPENDIX 1

Mini-Pumping Test Data

A brief pumping test was carried out on 19/08/14. Flow rate was measured intermittently and appeared stable, although the output from the variable speed pump is controlled by demand in the system. The pumping cycle was halted when water level was deemed to be approaching the pump. For the test period the pumping period was 22 minutes, followed by a non-pumping recovery period of 20 minutes. The duration of the test, combined with the high discharge rate, is deemed adequate to overcome influence of well storage on interpretation. A limitation of the pumping test is that it did not commence at static water level. Depth to groundwater level was recorded at intervals throughout; recorded results are shown in Table A1.

Table A1 – Mini-Pumping Test Data

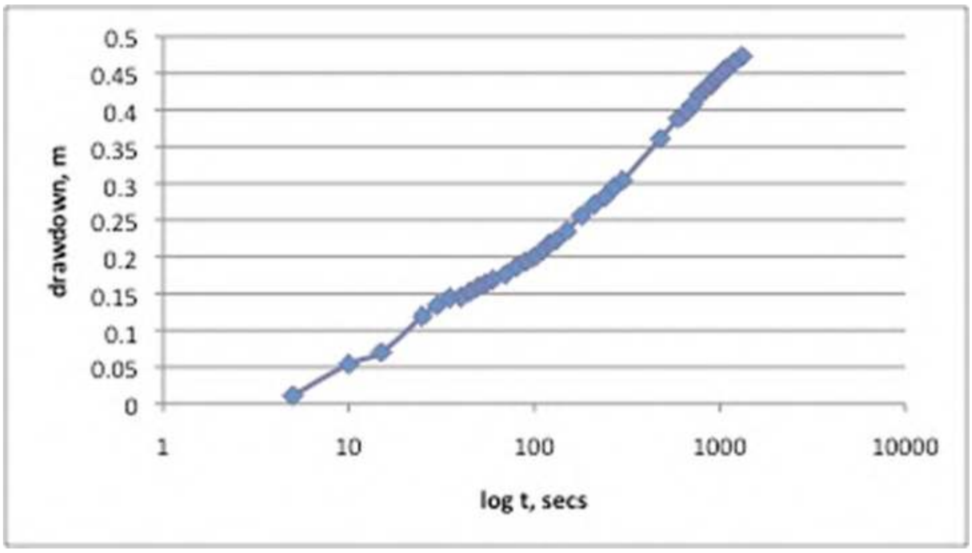
T (secs)	Depth to water table (mbtoc)	Drawdown (m)	Groundwater elevation (mOD)
Pumping @ 2.67 l/s = 231 m^3/d			
0	5.036	0	7.324
5	5.047	0.011	7.313
10	5.09	0.054	7.27
15	5.106	0.07	7.254
25	5.155	0.119	7.205
30	5.17	0.134	7.19
35	51.8	0.144	7.18
40	5.181	0.145	7.179
45	5.188	0.152	7.172
50	5.195	0.159	7.165
55	5.20	0.164	7.16
60	5.205	0.169	7.155
70	5.212	0.176	7.148
80	5.222	0.186	7.138
90	5.23	0.194	7.13
100	5.235	0.199	7.125
110	5.244	0.208	7.116
120	5.253	0.217	7.107
130	5.258	0.222	7.102
150	5.271	0.235	7.089
180	5.292	0.256	7.068
210	5.307	0.271	7.053
240	5.317	0.281	7.043
270	5.331	0.295	7.029
300	5.34	0.304	7.02
480	5.397	0.361	6.963
600	5.424	0.388	6.936
660	5.433	0.397	6.927
720	5.444	0.408	6.926

T (secs)	Depth to water table (mbtoc)	Drawdown (m)	Groundwater elevation (mOD)
780	5.457	0.421	6.903
840	5.465	0.429	6.895
900	5.47	0.434	6.89
960	5.48	0.444	6.88
1020	5.485	0.449	6.875
1080	5.492	0.456	6.868
1200	5.501	0.465	6.859
1320	5.509	0.473	6.851
Recovery			
0	5.509	0.473	6.851
5	5.47	0.434	6.89
10	5.46	0.424	6.90
15	5.452	0.416	6.908
20	5.445	0.409	6.915
30	5.439	0.403	6.921
40	5.427	0.391	6.933
50	5.423	0.387	6.937
60	5.415	0.379	6.945
70	5.407	0.371	6.953
80	5.40	0.364	6.96
90	5.397	0.361	6.963
100	5.391	0.355	6.969
110	5.386	0.35	6.974
120	5.38	0.344	6.98
130	5.378	0.342	6.982
140	5.375	0.339	6.985
150	5.367	0.331	6.993
180	5.355	0.319	7.005
210	5.345	0.309	7.015
240	5.333	0.297	7.027
270	5.324	0.288	7.036
300	5.314	0.278	7.046
330	5.309	0.273	7.051
360	5.299	0.263	7.061
390	5.294	0.258	7.066
420	5.285	0.249	7.075

T (secs)	Depth to water table (mbtoc)	Drawdown (m)	Groundwater elevation (mOD)
450	5.277	0.241	7.083
480	5.272	0.236	7.088
510	5.266	0.230	7.094
540	5.259	0.223	7.101
570	5.253	0.217	7.107
600	5.246	0.21	7.114
630	5.236	0.20	7.124
660	5.20	0.164	7.16
1200	5.057	0.021	7.303

Time was plotted on a logarithmic scale against drawdown incurred during pumping as shown in Graph A1.

Graph A1 – Mini-Pumping Test Data



Transmissivity is then calculated using Jacob's Method (Cooper and Jacob, 1946), using a relationship between discharge and the drawdown over one log cycle of time (equal to 0.25 m in this test):

$$T = (2.3 \times Q) / (4 \times \pi \times \Delta s)$$

$$T = (2.3 \times 231\ m^3\ d^{-1}) / (4 \times \pi \times 0.25\ m)$$

$$T = 531.3\ m^3\ d^{-1} / 3.142\ m$$

$$T = 169\ m^2\ d^{-1}$$

The calculated transmissivity value of 169 $m^2\ d^{-1}$ is considered to be low for a regionally important karst aquifer. Tracing studies in the area have shown groundwater flow velocities in the range 360 m/d – 4800 m/d. The potential error is likely due to the duration of the mini-pumping test, which is too short to overcome storage in surrounding fractures.

APPENDIX 2

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

Except where point recharge occurs (*e.g*. at swallow holes), the groundwater vulnerability depends on the type, permeability and thickness of the subsoil. The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown in Table 1.

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 3

Groundwater Body Description

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Clare-Corrib GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
30 Galway, Mayo Roscommon Co.Co's	**Rivers:** Abbert River, Black River, Cregg River, Dalgan River, Grange River, Killaclogher River, Kilshanvy River, River Clare, River Nanny, Sinking River, Togher River, Waterdale River **Lakes:** Corrib	000296 LISNAGEERAGH BOG AND BALLINASTACK TURLOUGH 000247 SLIEVE BOG 001237 BOYOUNAGH TURLOUGH 000224 ALTORE LAKE 000301 LOUGH LURGEEN BOG/GLENAMADDY TURLOUGH 000215 RATHBAUN TURLOUGH 001282 KILTULLAGH LOUGH 000263 DRUMBULCAUN BOG 000297 LOUGH CORRIB 000323 RICHMOND ESKER NATURE RESERVE 000289 KNOCKAVANNY TURLOUGH 000295 LEVALLY LOUGH 001254 DERRINLOUGH BOG 001255 DERRYNAGRAN BOG AND ESKER 000282 KILLOWER TURLOUGH 000331 TURLOUGH O'GALL 000234 BELCLARE TURLOUGH 001319 SUMMERVILLE LOUGH 001294 LOUGH HACKET 001288 KNOCKMAA HILL 000385 ROSTAFF TURLOUGH 002038 CASTLE HACKETT SOUTERRAIN 001322 TURLOUGH MONAGHAN 001788 TURLOUGHCOR 001280 KILLACLOGHER BOG 000307 LOUGH TEE BOG 001709 TIAQUIN BOG 000311 MONIVEA BOG 000287 KILTULLAGH TURLOUGH	~1422

Topography	The land surface is characterised by small hills and low ridges, with ground elevations ranging from 10-160 mAOD. The topographic surface slopes gently westwards. Elevations are highest (100-160 mAOD) in the north (south of Ballyhaunis, west of Ballinlough) and south (just north of Monivea). To the west of a line running north-south from Claremorris to Athenry the elevation is 10-40 mAOD, and to the east of this line, the elevation is 40-70 mAOD.

Geology and Aquifers	**Aquifer categories**	The main aquifer category in this GWB is: **Rk^c:** Regionally important karstified aquifer dominated by conduit flow. There are some small areas (in the vicinity of Headford) with an aquifer category of: **Ll:** Locally important aquifer which is moderately productive only in local zones.
	Main aquifer lithologies	This GWB is composed primarily of Dinantian Pure Bedded Limestones. There are some small areas (in the vicinity of Headford) of Dinantian Pure Unbedded Limestones.
	Key structures	Few faults are mapped in this area; this may reflect the lack of major variation in the rock lithology. The dips over the GWB area are generally less than 10°, except near faults, where steeper dips result from fault drag. Shallow synclines aligned with the axes in an E-W direction cross the GWB.
	Key properties	**Karstification** is widespread in this GWB. Recorded karst features number 219, but are considered to represent only a fraction of existing features. A histogram showing the different types of karst features currently in the database is provided in Figure 3. **Transmissivity and Storativity:** Well yields are variable, being distributed through all the well yield categories. Using 60 wells located in the GWB, 59% are either "excellent" (>400 m^3/d) or "good" (100-400 m^3/d), and 23% are either "poor" (<40 m^3/d) or "failed", with the remainder "moderate" (40-100 m^3/d). The median yield is 131 m^3/d. Histograms showing the distribution of well yields and productivity are given in Figures 4 and 5. Note: productivity is an index relating specific capacity to yield - the higher the productivity the higher the transmissivity. Productivity values are distributed throughout all the productivity categories, indicating the variability of the aquifer properties throughout the GWB. Analysis of the areal distribution of the data suggests that it is difficult to predict the aquifer properties in any particular place, with a few possible exceptions. For instance, in the vicinity of Tuam the well yields that are "excellent" are accompanied by several large springs, and just north of Monivea there is a cluster of "failed" wells (also due in part to silting up of the boreholes) which suggests that there may be an increase in yield from south to north across the GWB. Water table levels have high annual variations, which indicates that the storage is low - approximately 0.01-0.02 (Daly, 1985). The springs in the GWB also reflect the low storativity as many of the spring flows rise and fall quickly in response to rainfall events. Furthermore during prolonged drought many springs cease to flow and well yields drop significantly.
	Continues next page	**Groundwater velocity:** Tracer tests indicate variable groundwater velocities. Furthermore, tracer test data illustrates anisotropy in the transmissivity, with higher east-west transmissivity. Groundwater velocities in the E-W domain are in the order of 100-450 m/hr, as evidenced by the following tests: Lassanny Swallow hole to Ballyhaunis spring (440m/hr); Ballyglunin Cave to Aucloggeen Spring (200m/hr). Groundwater velocities in the N-S domain are in the order of 6-35m/hr, as evidenced by the following tests: L.Hackett to Kilcoona spring (35m/hr); Pollnahallia to Bunatober spring (6m/hr). Extensive conduit systems exist, as exemplified by the Ballyglunin Cave system. The mapping of this system indicates conduit development along the N-S and W-E joint sets, with an overall dip to the west (Drew and Daly, 1993).

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		Groundwater flow directions and gradients: Overall, flow directions are to the southwest, with all groundwater discharging to L. Corrib. Although, there are six surface water catchments within the GWB, a *key* aspect is that groundwater can flow across the surface water divides and beneath surface water channels, as evidenced by the tracer test data. Examples of this key property are listed as follows: 1) water that sinks at Ballyglunin Cave emerges at Aucloggeen Spring, which crosses two surface water catchments. 2) water sinking along an losing stretch of the River Clare remerges as the headwater of the Black River. 3) recent tracing tests in the Ballinlough area of Roscommon indicate a link across the Shannon RBD into the Western RBD, from Coolcam (Roscommon) to Meeltraun (Mayo). 4) water along an losing stretch of the Sinking River flows about 10 km underground to join the River Clare. Drew (1976 (a)) suggests that groundwater flow is concentrated along the axes of shallow synclines. Gradients are variable, irregular due to the uneven distribution of transmissivity and are in the order of 0.01-0.002 (Drew and Daly, 1993; Daly, 1985)).
	Thickness	The Dinantian Pure Bedded Limestones are generally over 100 m thick. Most groundwater flows in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation.
Overlying Strata	**Lithologies**	Till is the dominant subsoil type, covering approximately 65% of the GWB. Cutover Peat comprises 23% of the area, sand/gravel covers approximately 3% and alluvium 2%. A full breakdown of the subsoil lithology is given in Table 1. A large proportion of the sand/gravel forms a random hummocky topography, although long sinuous, braided ridges of sand/gravel (eskers) have also been deposited especially in the east. A small portion of the north eastern area of the GWB around Cloonfad is described under the Roscommon Groundwater Protection Scheme (Lee and Daly, 2003) The till in this area is described as "SILT" (BS 5930), and is classed as "Moderate" permeability. There are also areas of "clayey" till, often underlying areas of raised bog (Drew and Daly, 1993). The thin till cover over much of the west part of the area is generally free draining (Daly, 1985).
	Thickness	East of a line linking Athenry – Tuam – Dunmore, the subsoil is "generally thicker" (Daly, 1985; Drew and Daly, 1993). This is supported by the occurrence of rock at or near surface, which is generally restricted to the western and southwestern part of the GWB. Analysis of the available depth to bedrock borehole data is limited as most of the data are clustered in three main areas: western, northeastern and central (area around Tuam) parts of the GWB. Nevertheless the data show a *general* increase in subsoil thickness in an easterly direction: average depth to bedrock increases from 4 m to 9 m from the west to east. In addition, there are instances of depth to bedrock greater than 20 m around Dunmore (northeast of GWB). However, there are also pockets of deeper till in the southwestern part of the GWB.
	% area aquifer near surface	50% of the GWB to the west of the line Athenry – Tuam – Dunmore is only covered by shallow till. 4% of the total GWB area has rock at or near surface.
	Vulnerability	The vulnerability for a small portion of the north eastern area of the GWB around the area of Cloonfad is described in the County Roscommon Groundwater Protection Scheme (Lee and Daly, 2003). In this area the vulnerability classification is variable dependent on the depth to bedrock. For the rest of the area. *[Information to be added at a later date]*
Recharge	**Main recharge mechanisms**	Both point and diffuse recharge occur in this GWB. Diffuse recharge occurs over the GWB via rainfall percolating through the permeable subsoil. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. Dolines have been recorded even in areas of thick peat deposits (Hickey et al, 2002). Point recharge occurs via many small sinks that are present in the low permeability till areas where the subsoil is breached. Recharge also occurs along 'losing' sections of streams. There are well defined stretches of the River Clare, Sinking River and Abbert River that are losing (Daly, 1985; Drew and Daly, 1993).
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	**Large springs and large known abstractions (m^3/d)**	Large Springs: Corrandulla GWS (6764 m^3/d), Mullacultra GWS (3270 m^3/d), Ballyhaunis WSS (12000 m^3/d), Gortgarrow, Kilbannon GWS (5995 m^3/d), Barnaderg Group Scheme (5000 m^3/d), Tobernanny, Lettera Large known borehole abstractions: Gallagh GWS (523 m^3/d), Roadstone Ltd (227 m^3/d), Rusheens Tuam GWS (114 m^3/d), Belclare (114 m^3/d). *[Information to be added to and checked]*
	Main discharge mechanisms	The main groundwater discharges are to the streams, rivers and large springs found within the body. The large springs at Kilcoona, Bunatober and Aucloggeen and others issue from the bottom of a limestone scarp that is thought to represent an ancient shoreline of L. Corrib. Further these springs are likely to represent overflow springs and deeper groundwater flow discharges to outlets beneath the present day L. Corrib (Drew, 1993). In winter groundwater will fill the turloughs found in the area and partly discharge via the artificial channels that were installed to alleviate flooding.

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Hydrochemical Signature	The groundwater has a calcium bicarbonate signature. Two groundwater provinces are suggested by Drew and Daly (1993). Firstly, there is a shallow groundwater component that is characterised by high suspended solids and relatively low electrical conductivities (300-400 µS/cm). Springs that are fed by this component typically have a "flashy" throughput and often cease to flow during prolonged drought. Secondly, there is a deeper groundwater component that is characterised by relatively non-turbid groundwater with higher electrical conductivities (>450 µS /cm). Springs fed by this deeper component often have smoother hydrographs where there is a gradual change in discharge. Several large springs comprise both flow components, examples are Lettera, Tobernanny and Bunatober springs.
Groundwater Flow Paths	These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In pure bedded limestones these openings are enlarged by karstification which significantly enhances the permeability of the rock. Karstification can be accentuated along structural features such as fold axes and faults. Groundwater flow through karst areas is extremely complex and difficult to predict. As flow pathways are often determined by discrete conduits, actual flow directions will not necessarily be perpendicular to the assumed water table contours, as shown by several tracing studies (Drew and Daly, 1993). The tracer tests show that groundwater can flow across surface water catchment divides and beneath surface water channels. Flow velocities can be rapid and variable, both spatially and temporally. Rapid groundwater flow velocities indicate that a large proportion of groundwater flow occurs in enlarged conduit systems. Groundwater flow in highly permeable karstified limestones is of a regional scale. Flow path lengths can be up to a several kilometres, for example 9.6 km from Ballyglunin Cave to Aucloggeen Spring. Overall, groundwater flow will be towards the River Clare and L. Corrib, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable.
Groundwater & Surface water interactions	The area is drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Figures 1 and 2 show the pre/post arterial drainage network. According to Coxon and Drew (1983), much of the current stream network is a storm runoff system that is inactive during summer months. Thus, prior to drainage, streams sank underground via the turloughs present in the GWB. Many of the streams have well defined losing stretches where they lose water to the underground system (Daly, 1985). There is a high degree of interconnection between groundwater and surface water in karstified limestone areas such as in this GWB. Even though large areas of peat and tills overlie the body, collapse features in these areas provide a direct connection between the surface and the groundwater systems. The close interaction between surface water and groundwater in karstified aquifers is reflected in their closely linked water quality. Any contamination of surface water is rapidly transported into the groundwater system, and vice versa. Furthermore, there are a number of terrestrial ecosystems within this GWB with varying dependence on groundwater.

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Conceptual model	• The north, south and west groundwater divides of this GWB are topographic highs that coincide with surface water catchment boundaries. It is bounded to the east by Lough Corrib. • The topography is undulating with ground elevations ranging from 10-160 mAOD. A large proportion of the body is overlain by till, which thickens in an easterly direction. • The area is principally drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Much of the current stream network is a storm runoff system and is inactive during summer months. Prior to artificial drainage, streams sank underground via a few turlough sinks in the GWB. • Within the GWB, surface water catchments are often bypassed by groundwater flowing beneath surface water channels and across surface water catchment divides. • A large number of karst features occur within the body. These include turloughs, caves, dolines, swallow holes and springs. • The GWB is composed primarily of high transmissivity karstified limestone (**Rk**^{c}). Transmissivity and well yields are variable. Storage in the GWB is low. • Groundwater flows through a network of solutionally enlarged bedding planes, fissures and conduits. • Rapid groundwater flow velocities have been recorded through groundwater tracing. The tracing indicates an anisotropy in the transmissivity, with faster groundwater flow velocities and higher transmissivity in an E-W direction, which may be linked to shallow E-W trending synclinal axes and steeper E-W hydraulic gradients. • Recharge in this GWB occurs via losing streams, point and diffuse mechanisms. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. • The groundwater in this body is generally unconfined but may become locally confined beneath thick, low permeability subsoil. Most of the groundwater flow occurs in the upper epikarstic layer and in a zone of interconnected solutionally enlarge bedding planes and fissures, generally extending to a depth of 30 m. • In general, the degree of interconnection in karstic systems is high and they support regional scale flow systems. Flow paths have been measured up to 10 kilometres in length. • Some areas in this GWB are of extreme vulnerability due to the thin nature of the subsoil, as well as the frequency of karst features, allowing point recharge. Groundwater storage in karstified bedrock is low and the potential for contaminant attenuation in such aquifers is limited. • The main discharges are to the rivers, large springs and L. Corrib. In winter groundwater discharges to the many turloughs and transmitted via the artificial channels that were installed to alleviate flooding. • There is a high degree of interaction between surface water and groundwater in this GWB. There are a number of terrestrial ecosystems within this GWB which have varying dependence on groundwater. • There are potentially two groundwater provinces within the GWB but this is uncertain. The groundwater has a calcium bicarbonate signature.
Attachments	Figures 1, 2, 3, 4 and 5.
Instrumentation	**Stream gauges:** 30002, 30003, 30004, 30006, 30007, 30010, 30011, 30012, 30013, 30014, 30015, 30020, 30022, 30023, 30024, 30025, 30026, 30029, 30030, 30032, 30040, 30045, 30053, 30055, 30071, 30101, 30103. **EPA Water Level Monitoring boreholes:** Lackagh, GAL287, Tuam (Coca Cola), GAL291, Shrule, MAY085 **EPA Representative Monitoring points:**
Information Sources	Daly, D. (1995) *A report on the Flooding in the Glenamaddy area.* Groundwater Section Report File 2.2.7. 34pp. Daly, D. (1992) *A report on the Flooding in the Claregalway area.* Groundwater Section Report File 2.2.7. 12pp. Daly, D. (1985) *Groundwater in County Galway with particular reference to its Protection from Pollution.* Geological Survey of Ireland report for Galway County Council. 98pp. Drew D.P. and Daly D. (1993) *Groundwater and Karstification in Mid-Galway, South Mayo and North Clare.* A Joint Report: Department of Geography, Trinity College Dublin and Groundwater Section, Geological Survey of Ireland. Geological Survey of Ireland Report Series 93/3 (Groundwater), 86 pp Drew, D.P. (1973a) *Hydrogeology of the north Co. Galway – south Co. Mayo lowland karst area, Western Ireland.* International Speleology 1973, III, Sub –section Ca. Drew, D.P. (1973b). *Ballyglunin core Co. Galway and the hydrology of the surrounding area.* Irish Geography Vol. 6, No. 5. pp 610-617. Doak, M. (1995) *The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland.* Unpublished M.Sc. thesis, Sligo Regional Technical College. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) *Lowland Karst of North Roscommon and Westmeath.* International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report. Lee, M. & Daly D. (2003) *County Roscommon Groundwater Protection Scheme.* Main Report. Roscommon County Council & Geological Survey of Ireland, 54pp. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) Lowland Karst of North Roscommon and Westmeath. International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

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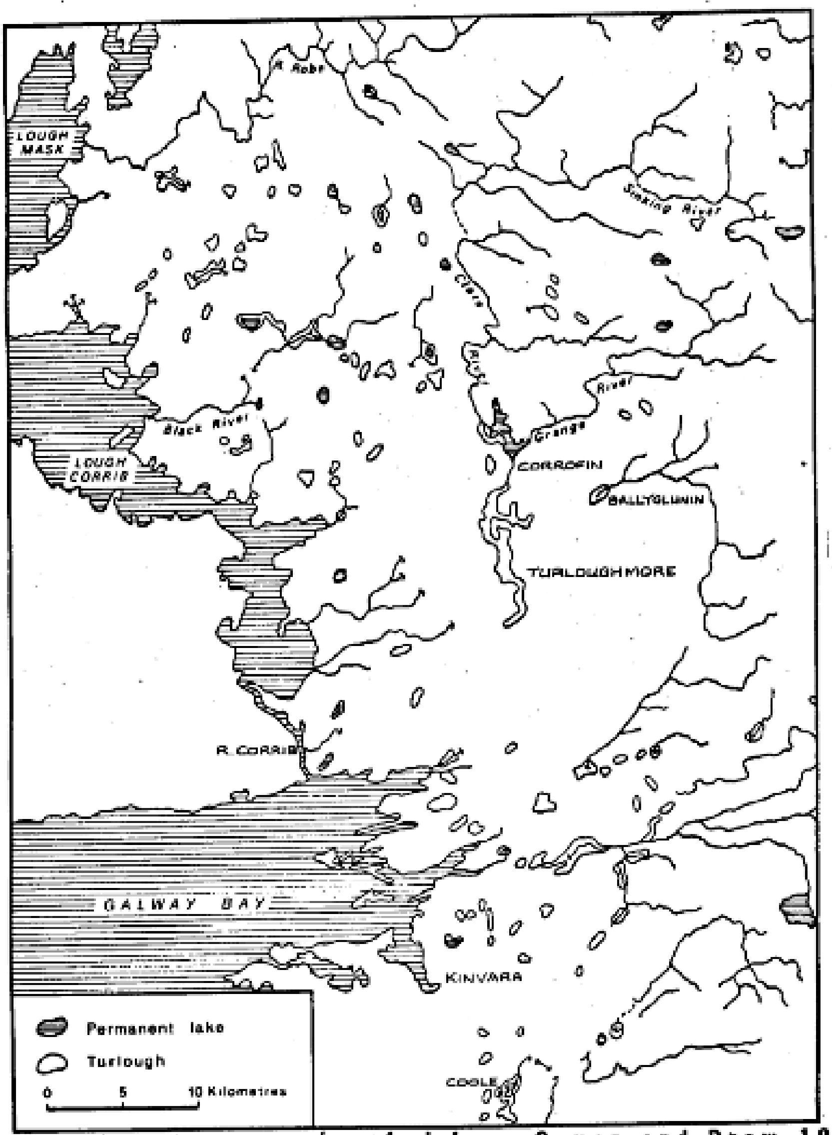
Figure 1 Pre Arterial Drainage.



[copied from Coxon and Drew,1983]

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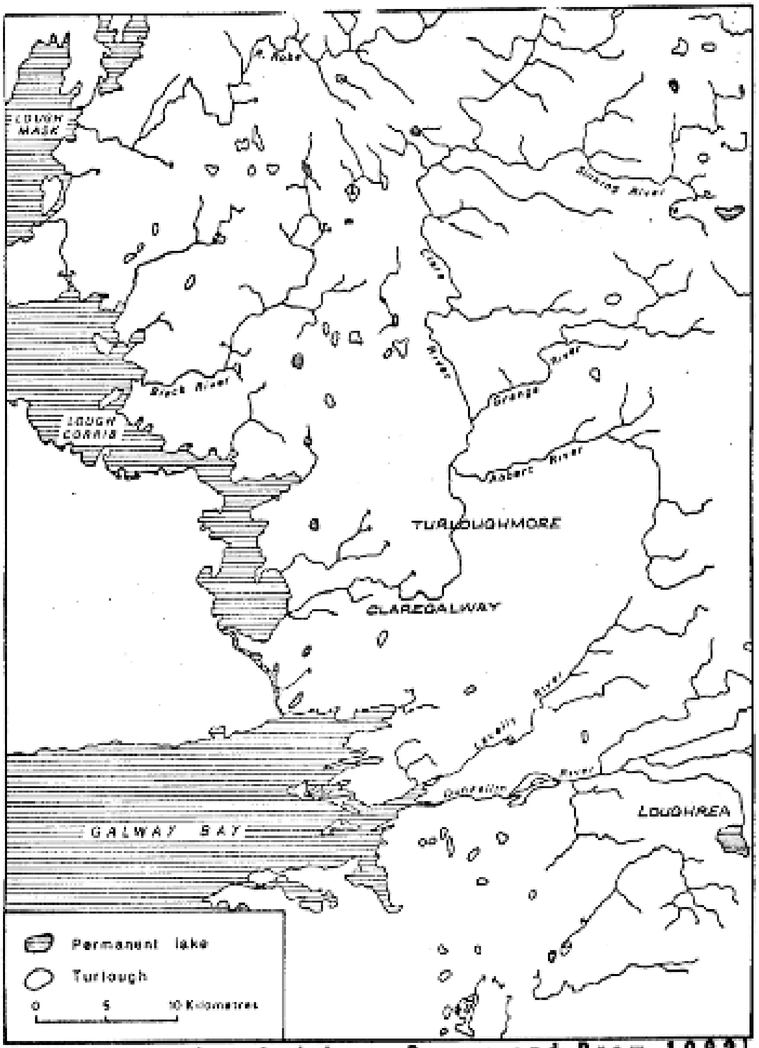
Figure 2 Post Arterial Drainage



[copied from Coxon and Drew, 1983]

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
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear (in press).

APPENDIX 5

Laboratory Certificate of Analysis

Complete Laboratory Solutions

Complete Laboratory Solutions
Ros Muc, Co. Galway.
[Tel] 091 574355
[Fax] 091 574356
[Email] services@cls.ie
[web] www.completelabsolutions.com

Client : Mary Burke
Balrobuckbeg GWS
Ballybeg
Corrandulla
Co. Galway

Report No. : 234456
Date of Receipt : 24/07/2014
Start Date of Analysis : 24/07/2014
Date of Report : 18/08/2014
Order Number :
Sample taken by : CLS

CERTIFICATE OF ANALYSIS

Lab No	Sample Description	Test	Result	Units
531907	Balrobuckbeg GWS. 24/07/14	BOD	<1	mg/l
		COD	<10	mg/l
		Turbidity	0.2	N.T.U.
		pH	7.2	pH Units
		Conductivity @20C	551	uS/cm
		Alkalinity, total	339	mg/l CaCO3
		Sodium, total	14	mg/l
		Chloride	21.1	mg/l
		Ammonium as NH4	<0.01	mg/l
		Nitrate as NO3	9.03	mg/l
		Nitrite as NO2	<0.017	mg/l
		Dissolved Oxygen (%)	53	%Sat
		Potassium, total	4	mg/l
		Total Hardness (Kone)	367	mg/l CaCO3
		Magnesium, total	9	mg/l
		Colour, apparent	<4	mg/l Pt Co
		Sulphate	10.9	mg/l
		Orthophosphate as PO4-P	0.036	mg/l
		Calcium, total	119	mg/l
		Aluminium, dissolved	2	ug/l
		Iron, dissolved	19	ug/l
		Manganese, dissolved	<5	ug/l
		Copper, dissolved	4	ug/l
		Lead, dissolved	<0.5	ug/l
		Chromium, dissolved	<0.5	ug/l
		Nickel, dissolved	3	ug/l
		Cadmium, dissolved	<0.5	ug/l
		Arsenic, dissolved	<0.5	ug/l
		Zinc, dissolved	28	ug/l
		Silica	1.97	mg/l
		Barium, dissolved	22	ug/l
		TOC	1.36	mg/L
		Clostridium Perfringens in Water	0	cfu/100ml
		Strontium, dissolved	436	ug/l
		E coli (Filtration) (Environmental Waters)	0	cfu/100ml
		Total Coliforms (Filtration) (Environmental Waters)	0	cfu/100ml
		Fluoride by ISE	0.2	mg/l

INAB ISO 17025 ACCREDITED TESTING DETAILED IN SCOPE REG NO. 108T

Approved by: Barbara Lee

Barbara Lee
Environmental Scientist

See page 2 for test specifications and accreditation status
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APPENDIX 6

Zone of Contribution Boundary Calculations

Downgradient Distance

The abstraction itself will invoke a cone of depression which may draw groundwater deemed to be downgradient into the borehole. The calculation uses the uniform flow equation (Todd, 1980), which is:

$$\text{Down-gradient distance} = Q / (2\pi * T * i)$$

where

Q is the daily pumping rate: 321 m^3/d. (This allows for 50% increase in the current rate of 214 $m^3\ d^{-1}$).
T is Transmissivity[4] (calculated as 169 $m^2\ d^{-1}$ based on results of mini-pumping test).
i is the background non-pumping hydraulic gradient, taken as that between Caherlea and Cahermorris-Glenreevagh (0.0004 $m\ m^{-1}$).

Downgradient distance is estimated to be approximately 764 m.

[4] Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer. The hydraulic conductivity of the aquifer is defined as the volume of water that will move through a unit area of aquifer perpendicular to the flow direction in unit time under a unit hydraulic gradient, and has units of length / time, e.g. m/day.

Establishment of Groundwater Zones of Contribution

Caherlea Group Water Scheme

April 2015

Prepared by:

Colin O'Reilly, Envirologic Ltd.

and

Geological Survey of Ireland, Groundwater Programme

(Caoimhe Hickey, Monica Lee and Taly Hunter Williams)

And with assistance from:

Caherlea GWS

The National Federation of Group Water Schemes

Acknowledgements:

Paedar Brick & Geraldine Mannion (Caherlea GWS)

Karen Carney (NFGWS)

Document control information

Revision	Date	Author	Checked	Approved
A	27/10/14	Colin O'Reilly	30/3/15	NHW
B	26/04/15	Colin O'Reilly	27/04/15	NHW

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' 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 Caherlea 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 that 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.

Caherlea GWS is supplied by a regionally important aquifer in with karstified flow in enlarged conduits (Rk_c). The current abstraction rate is 27 m^3/d.

[1] Geological Survey of Ireland, 1999.

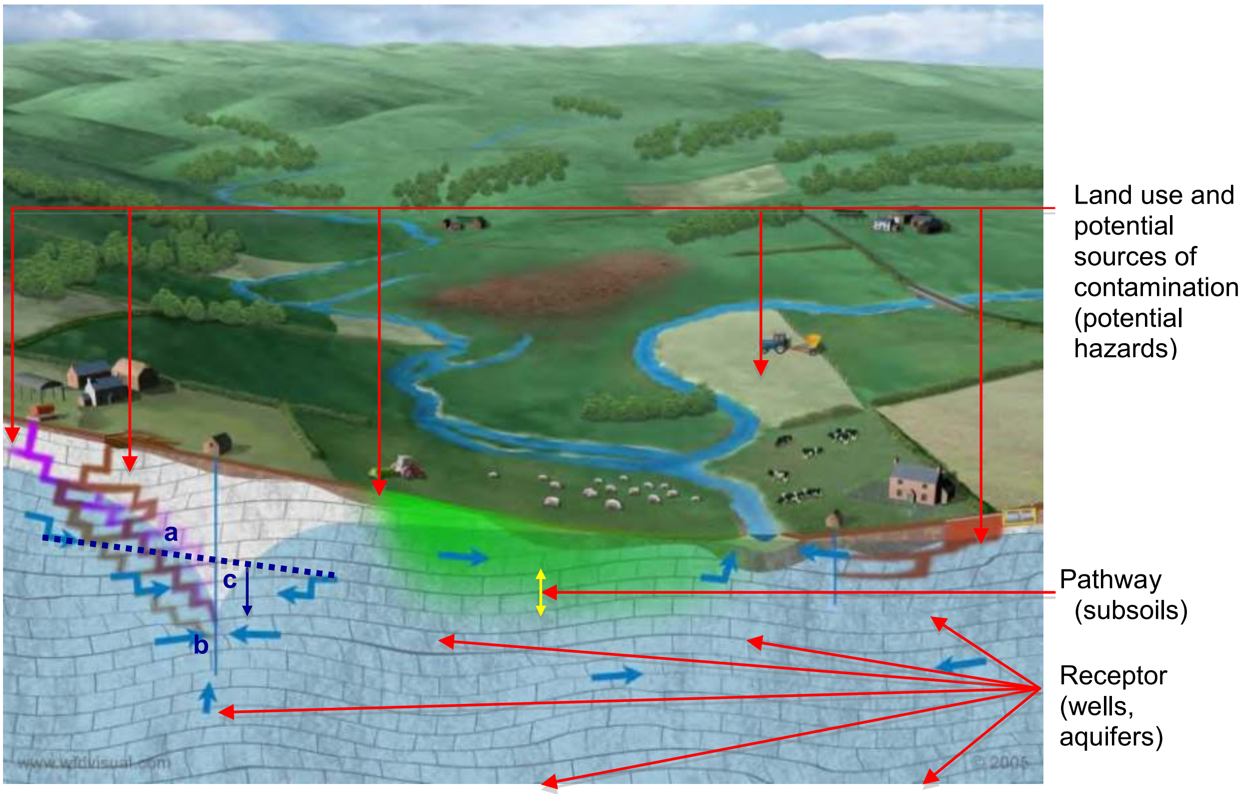

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Caherlea Group Water Scheme (GWS) is supplied from a borehole in the townland of Caherlea, County Galway (**Figure 1**). The current scheme demand is 27 m^3/d, which provides water to 20 domestic connections and 4 farms. Users are not currently metered at point of supply. A 100 mm borehole pump supplies directly to the mains via a 360 litre pressure chamber. There is no estimate of potential maximum borehole yield. The scheme uses chlorination for treatment.

The GWS is located in central Galway: 4 km south of Belclare. The borehole sits adjacent to the northern side of a local road that runs southeast-northwest between the N17 at Clogh, and the R333 near Caherlistrane. The GWS pumphouse is a small 2.9 m by 2.6 m roofed structure situated in the southeastern corner of an agricultural field, set back 10 m from the road (**Diagram 2**).

The borehole wellhead sits outside the pumphouse, within a 1.25 m by 1 m enclosure built to a height of 0.3 m above surrounding field level using concrete blocks. Two concrete pillar caps are used as a cover on the wellhead. The chamber floor is 0.15 m below field level and is comprised of rough concrete. Inside the chamber, the top of the steel casing sits 0.02 m above the chamber floor. Within the chamber the borehole is uncovered. The rising main and cables exit the chamber through a hole in the pumphouse/chamber wall.

The GWS borehole was an old agricultural supply source, and no improvement works appear to have been carried out since its installation in the 1970s. The meter measuring total abstraction entering the supply system is located outside of the chamber and pumphouse, and is exposed to poaching by livestock.

Photos of the pumphouse and borehole chamber can be seen in **Photos 1 to 4** below. **Table 1** provides a summary of existing information relating to the borehole. There is no drilling log available for the borehole, nor is there any record of a pumping test having been carried out.

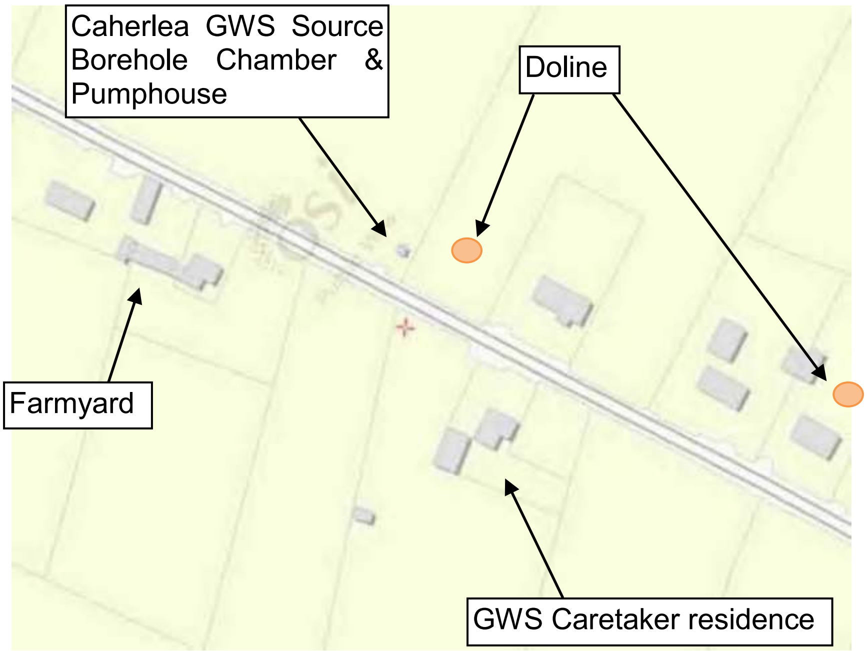

Diagram 2. Schematic Plan of the GWS Site

Photo 1: Pumphouse and adjacent borehole at ground level to right of pumphouse

Photo 2: View to southeast from pumphouse showing doline in adjacent field

Photo 3: Borehole chamber

Photo 4: Inside view of pumphouse

Table 1. Supply Details

	Caherlea Borehole
Grid reference	138,678 m Easting; 245,313 m Northing
Townland	Caherlea
Source type	Borehole
Drilled	pre – 1990
Drilling Contractor	Mulcairs Well Drilling, Loughrea, Co. Galway
Owner	Caherlea GWS
Elevation	47.20 mOD Malin
Total depth (m)	Unconfirmed – assumed to be approximately 60 m
Construction details	No data Assumed 200 mm steel casing from 0.02 m above ground level to 1 m below bedrock; Assume open hole within rock.
Depth to rock (m bgl)	Unconfirmed. Depth to rock at Rusheens GWS, 1.3 km to northeast, is 6.1 m.
Static water level (SWL)	On 19/08/14, when pumping intermittently at rate of 40 m^3/d, groundwater level fluctuated between 36.75 mbgl (10.45 mOD) during pumping and 35.5 mbgl (11.73 mOD) during brief recovery. No report of depth water strike encountered during drilling. Main inflow at Rusheens GWS, 1.4 km NE, noted at 50 mbgl (-16.22 mOD). Main inflow at 3rd party well, 1.2 km N, noted at 77 mbgl (-38.55 mOD). Main inflow at 3rd party well 1.4 km NW, noted at 91 mbgl (-32.45 mOD).
Pump intake depth (m bgl)	52 m bgl (-4.8 mOD)
Current abstraction rate (GWS)	Total daily abstraction = 27 m^3/d On 19/08/14, pump was working on a pumping cycle of 25 seconds at a rate of 40.3 m^3/d, followed by a recovery period of 70 seconds. The timings of this intermittent cycle are dependent upon demand and pressure in the distribution network.
Reported yield (m^3/d)	Unconfirmed, no long-term pumping test has been performed. Mini-pumping test performed during site visit was not of sufficient duration to overcome well storage effects. Maximum potential yield likely to be significantly greater than 40.3 m^3/d

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical Characteristics of the Area

Table 2. Physical Characteristics of the Area of Interest

	Caherlea Borehole	Description/Comments
Annual Rainfall (mm)	1175	Met Éireann average annual rainfall data 1981-2010
Annual Evapotranspiration Losses (mm)	463	487.5 mm PE (average annual potential evapotranspiration data, Galway SWS, 1961-1990). 463 AE (Actual Evapotranspiration, assumed to be 95% of PE).
Annual Effective Rainfall (mm)	712	Annual rainfall less annual evapotranspiration losses
Topography **(Figure 1)**		Ground level at the source is 47.20 mOD. 3.7 km NW, the SW-NE orientated Knockmaa-Knocknacarrigeen ridge reaches 167 moD. From here surface elevation falls very gradually southeast towards the Clare River. Low-lying hills in the area are Garraun North (63 mOD, 1.5 km NW) and Carrownaherick (50 mOD, 1.7 km west) from which land falls away radially. Enclosed depressions (dolines) are present in the area, most locally: 1. 33 m to east of borehole (diameter = 19 m, centre 1.0 m below surface); 2. 210 m southeast of borehole (diameter = 27 m, centre 1.5 m below surface).
Land use		Land in the area is predominantly used for moderate intensity agriculture. Much of this land has been improved, having originally had significant bedrock at surface. The borehole is situated within a grassland field. There is evidence of cattle poaching near the entrance gate, possibly from a temporary feeding trough. There is no fence surrounding the pumphouse or borehole chamber. Local houses are serviced by septic tanks. Local farmyards are sited 80 m west and 400 m SE.
Surface Hydrology **(Figure 2)**		Apart from the Clare River, there are no surface drains or watercourses in the area. The River Clare runs roughly N-S and passes 4.1 km east of the GWS at its closest point. This section of the River Clare is man-made, having been excavated as part of a historical arterial drainage scheme. A now isolated section of the original course of the Clare River runs through Cloonmore and Cummer 2.2 km northeast. Turloughour turlough is located 2.9 m east (this appeared dry on day of survey). The eastern shore of Lough Corrib is 9 km SW of the GWS at its nearest point.
Topsoil		The area is dominated by deep, well-drained basic mineral soils, which become thinner on elevated ground and where bedrock outcrops at surface.
Subsoil (**Figure 3**)		Carboniferous limestone till ('boulder clay') (Teagasc, 2006). Subsoils may not be present where bedrock is close to surface. There are no mapped peats or alluvium deposits flanking the man-made stretch of the Clare River.
Groundwater Vulnerability (**Figure 4**)		Extreme (E) vulnerability covers the area, with Extreme (X) indicating rock at or close to surface. Presence of High (H) and Moderate (M) vulnerability 1 km to west and 1 km to north indicates thicker subsoil cover in those locations. See **Appendix 1**.
Geology Formation: Rock Unit Group (**Figure 5**)		The GWS source and wider area are underlain by the rock unit group Dinantian Pure Bedded Limestones. These are thick-bedded pure limestones. Limestone layers generally dip southeast at 3-4°. There are no mapped faults in the area. GSI 6" field sheets indicate outcrops are weathered and jointed with joints orientated north-northwest in some places on the ridge to the northwest. Regionally, north-south and east-west joint sets are expected to occur (Gatley et al., 2006).
Aquifer (**Figure 6**)		The limestones are classified by the GSI as a Regionally Important Karstified Bedrock Aquifer, dominated by conduit flow (Rkc). Known surface karst features in the area are shown in **Figure 6**.
Groundwater Body		Clare-Corrib GWB Categorised as having a 'poor' status. See http://www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions.htm
Recharge Coefficient (**Appendix 2**)	80 %	Low drainage density, well-drained soils, moderate permeability subsoils, and extreme vulnerability, plus point recharge via karst features suggest a high recharge coefficient.
Recharge (mm)	570	

3.2 Hydrochemistry and water quality

One untreated water sample was collected for the Caherlea GWS borehole on 01/10/2013 and analysed by CLS, Ros Muc, Co. Galway (**Table 3; Appendix 3**). Three sample sets (consisting one sample of raw water and one sample of treated water per set) were also collected and analysed by NUIG during 2013 as part of a study into microbial contamination (**Table 4**).

Existing laboratory results have been compared to the drinking water limits from the Drinking Water Regulations (SI No. 122 of 2014) and, where relevant, average values have been compared to the Threshold Levels in the European Communities Environmental Objectives (Groundwater) Regulations 2010 adopted in Ireland (S.I. No. 9 of 2010).

Table 3: Water Quality Data

Parameter	Number of Values	Result (01/10/13)	Parametric Value
pH (lab.)	1	7.2	6.5 < pH < 9
Electrical Conductivity (lab.) (uS/cm)	1	614	800
Colour (PtCo units)	1	< 4	acceptable to consumers and no abnormal change
Turbidity (NTU)	1	0.4	
Nitrate (mg NO_3/l)	1	12.1	37.5
Nitrite (mg NO_2/l)	1	< 0.017	0.375
Hardness (mg/l as $CaCO_3$)	1	355	
Ammonium (mg NH_4/l)	1	< 0.01	0.3 (SI 122 2014)
Iron (ug Fe/l)	1	12	200 (SI 122 2014)
Manganese (ug Mn/l)	1	< 5	50 (SI 122 2014)
Aluminium (ug Al/l)	1	3	200 (SI 122 2014)

Some hydrochemistry parameters were measured in the field on 19/08/14. Electrical conductivity measured 713 µS/cm; pH measured 7.6; temperature measured 12.3 °C.

The available water quality data indicate that the water is very hard and is alkaline, a signature of groundwater that has travelled through limestone bedrock. The level of dissolved minerals in the groundwater indicates that the groundwater has been in contact with the rock for some time and is from the deeper parts of the aquifer (e.g., Drew and Daly, 1993).

Nutrient concentrations are low which is consistent with the low to moderate intensity farming in the area. The caretaker reported that the field within which the borehole lies is used for grazing only; there is no application of slurry, and perhaps minimal application of artificial fertiliser.

Concentrations of metals analysed are below the threshold limits in the Drinking Water Guidelines and are deemed to be satisfactory.

Microbial analysis (**Table 4**) shows microbial contamination was detected on occasion. No faecal contamination was detected in any of three samples retrieved during October 2013, which suggests that septic tanks, percolation areas, and underground slurry tanks are not a source of ongoing contamination. Landspreading and grazing animals are a potential source. Year round sampling would be needed to confirm this.

Coliforms were detected on two of the three sampling events, although in low numbers. The source of these is unclear. Where coliform contamination was detected in the raw water sample it had been removed following treatment. This confirms that the chlorination treatment system is effective, when working.

Table 4: NUIG Microbial Sampling Data 2013

Date	Sample Type	Microbiological parameter	MPN/100 ml	VTEC	Comments
25/09/13	Raw	total coliforms	0	none detected	
		e. coli	0		
	Treated	total coliforms	0	none detected	
		e. coli	0		
16/10/13	Raw	total coliforms	1	O157 detected, late detection. VTX 1+2 not detected	Raw and treated water essentially the same as chlorine pump had been turned off some hours prior to sampling
		e. coli	0		
	Treated	total coliforms	0	O26 detected, late detection. VTX 1+2 not detected	
		e. coli	0		
30/10/13	Raw	total coliforms	5.2	none detected	
		e. coli	0		
	Treated	total coliforms	0	none detected	
		e. coli	0		

VTECs (verocytotoxigenic Escherichia coli.), a more virulent and aggressive form of microbial contamination, were detected in the treated water entering the supply line. VTEC O157 and O25 were detected, the sources of these being cattle, sheep and goat faeces. It is perhaps unusual that e.coli were not detected in the same samples. It was noted by the sampler that the chlorine pump was not working at the time of sampling, so it is not clear if the dosing regime at this source is adequate. In any case, the fact that the chlorine pump was not working represents a flaw in the dosing method, and a clear risk to consumers occurred.

The nearby GWS at Clough Cummer detected VTEC in their borehole, which is 30 m deep. This would suggest that VTECs are present in the shallower groundwater. It is not evident that the source of VTECs is the deeper groundwater flow regime.

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is presented as a vertical cross-section in **Diagram 3**.

A large proportion of the effective rainfall is assumed to infiltrate to groundwater and recharge it, either percolating diffusely through the bare rock, thin soils and subsoils, or via point recharge at surface karst features (dolines and swallow holes).

Several interconnected groundwater flow zones are envisaged: (i). flow in the extensively karstified 'epikarst' zone in the top few metres of the bedrock; (ii) flow in a number of interconnected fractures and joints; (iii) larger flows associated with conduits of large water-carrying capacity.

The infiltrating water generally percolates downwards in fissures, until it reaches the body of groundwater flowing through conduits and fractures. However, in some cases, the water flows laterally in the very shallowest parts of the bedrock (the 'epikarst').

The direction of flow in the shallow groundwater (i.e. epikarst and jointing) is likely to reflect the local topography. The local well survey (6th September 2014) indicates shallow groundwater flow from northwest to southeast. It is likely that Turloughour Turlough acts as a sink for this groundwater. The swallow hole within the turlough provides a rapid pathway delivering the shallow groundwater to conduits.

Three surrounding boreholes surveyed encountered major water strikes at 50 – 91 metres below ground (equivalent to between -16 and -38.5 metres below ground). Each of these boreholes penetrated water-bearing zones at different depths. Given the depth of the Caherlea borehole, it is assumed it encountered a water strike within this range. A regional well survey performed on 6th September 2014 showed that regional groundwater flow is towards the southwest into Lough Corrib, and a series of springs on its periphery. The potential area contributing to the regional groundwater flow regime is significant.

The different flow paths make it difficult to apply a single zone of contribution with confidence to the well. Overall, though, a reasonable approach is to consider that the primary abstraction from the borehole is supplied from the deeper fractures. Due to the unlined construction of the borehole it likely receives an inflow, though not as great, from the upper fractures and joints and epikarst.

4.2 Boundaries

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

The **northwestern** Boundary is an upgradient boundary. It extends to a distance of 300 m from the borehole in the direction of a local hummock in Carrownaherick West. Groundwater from this raised area flows southeast toward the Clare River. The distance from the source to the upgradient boundary is determined by balancing the GWS abstraction rate with the recharge entering the groundwater (**Section 4.3**). As the borehole is thought to be completely unlined in the bedrock, shallow groundwater flows will enter the borehole freely.

The **northeastern** boundary is also an upgradient boundary and takes into account the regional groundwater flow direction which is from northeast to southwest, i.e. from Clare River to Lough Corrib. This connection was previously confirmed in a tracer study by the GSI. This boundary incorporates a nearby surface depression (doline).

The **southwestern and southeastern boundaries** are flow line boundaries. The orientation of the flow lines is based on the groundwater flow direction.

The **southern boundary** extends downgradient. The abstraction will induce a cone of depression which pulls water back towards the borehole against the natural direction of flow. It is estimated to be approximately 128 m based on calculations using data from the desk study (**Appendix 4**).

Inside the ZOC boundaries, groundwater is expected to enter the borehole. Outside the boundaries, groundwater is expected to flow towards Turloughour Turlough and/or Lough Corrib.

There is likely to be groundwater flowing from the northeast that the borehole intercepts. However, due to the highly complicated and regional scale of the groundwater flow system, it is not possible to fully delineate a ZOC for this component of the groundwater flow.

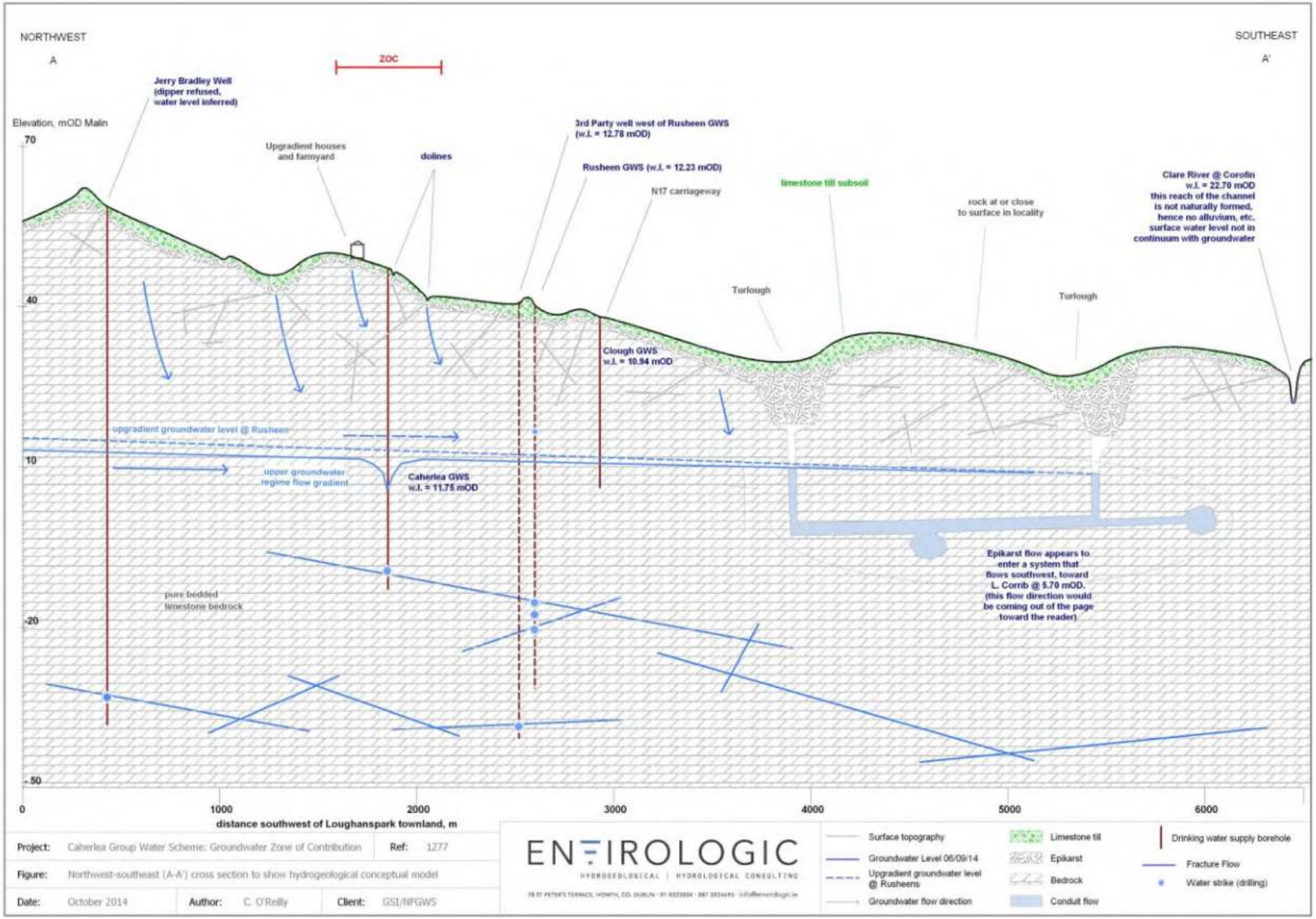

Diagram 3: Schematic Cross Section and Conceptual Model of groundwater flow

4.3 Recharge and water balance

The current demand for the Caherlea GWS is 27 m^3/d. The maximum sustainable yield for the borehole is not known but is considered to be in the order of several hundred cubic metres per day. In order to accommodate potential peak abstraction rates above the average long term demand of 27 m^3/d, 150% of the current demand has been used as the abstraction rate in the water balance calculations, i.e. 40.5 m^3d^1.

Recharge to the ZOC is estimated as 570 mm/yr (see **Table 2**). At a recharge rate of 570 mm/yr the 40.5 m^3/d abstraction rate requires a ZOC of 0.025 km^2 (2.54 ha; 6 ¼ acres) to capture the required volume of diffuse recharge to balance this abstraction.

Based on hydrogeological setting and topography, the delineated zone of contribution was estimated as having an area of 0.063 km^2. The water balance shows that the zone of contribution delineated is adequate to supply the borehole abstraction.

5 Conclusions

The current abstraction for the Caherlea GWS is 27 m^3/d. The borehole is capable of providing a maximum yield significantly in excess of 40 m^3/d.

The ZOC delineation was based on a combination of hydrogeological mapping, and the topographical catchment to the borehole. For a daily abstraction rate of 40.5 m^3/d (i.e. actual abstraction rate plus 50%), the estimated ZOC covers an area of 0.063 km^2 (15.5 acres).

The groundwater vulnerability within the ZOC is mapped as Extreme (E). Two dolines have been included in the ZOC and these are considered to have vulnerability classification of Extreme (X). 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.

Recent data for the borehole suggests groundwater quality in the study area is not subjected to high nutrient loads from agriculture. Instances of microbial contamination have been detected on occasion.

Based on the collection and analysis of the available data for this project, it is recognised that this scale of study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Caherlea GWS borehole with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. It is possible that additional areas are also contributing to the spring so the GWS may want to consider further hydrogeological work/ measures if water quality issues persist, which will provide supporting evidence as to the most likely areas that should be included within the ZOC.

6 Recommendations

<u>Essential</u>

- Routine water quality monitoring should be carried out **on raw water** at the source. The monitoring programme should include a regular survey of water quality parameters that would include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The chemistry results should be reviewed and if the parameters are generally stable, the frequency (and possibly the list of analytes) could be reduced to quarterly or biannually.

- Ultra-violet sterilisation unit to be added to treatment system.

- Ensure chlorination is continuous, and includes a back-up system.

- The wellhead chamber wall should be raised to a height of 0.5 m above ground level using either shuttered concrete wall or rendered concrete block wall.

- The wellhead chamber floor should be filled with finished, levelled concrete to form an impermeable seal between the steel borehole casing and chamber wall.
- The steel borehole casing should be extended so that it is raised above surrounding field level.
- The steel borehole casing should be covered with a watertight plate. A dipping tube should be accessible through the borehole cover.
- Ensure hole transmitting cables and rising main into pumphouse is watertight.

Desirable

- The GWS should liaise with NFGWS regarding the completion of a cryptosporidium risk assessment.
- Comprehensive hazard mapping within the delineated ZOC should be undertaken. Within the ZOC to Caherlea GWS are 2 doline, 1 farmyard and farm dwelling, and several houses. Caherlea GWS should consider liaising with the local upgradient farmyard to ensure risk from underground slurry storage tanks, silage clamps, and septic tanks is minimised.
- Application of inorganic and organic fertilisers should be restricted around the doline to the immediate east of the borehole. A buffer zone of 15 metres around the doline should apply.
- Application of inorganic and organic fertilisers should be restricted where possible along the southwestern boundary of the field within which the borehole is sited.
- All connections within the scheme should be metered.
- The borehole abstraction should be measured on a cumulative flowmeter inside the pumphouse on a daily/weekly basis. This is to ensure that the delineated ZOC remains appropriate.
- Consideration should be given to casing and grouting the upper 40 m of the borehole. This would prevent any groundwater inflows entering from the epikarst, or upper fractures and joint network. This is considered essential given the evidence that VTECs appear to be sourced from this upper zone. This would require sealing the annulus between a centralised small diameter PVC pipe (125 mm) and the rock face using cement grout above a packer or basket.
- It should be noted that the potential zone of contribution to the deeper groundwater system is very large, and that sourcing groundwater from this zone only would not guarantee elimination of microbial contamination.
- A minimum 10 m x 10 m fenced compound is recommended to provide sanitary protection for the borehole area.
- Caherlea GWS should consider investigating the feasibility of connecting to the Rusheens GWS source. Given the relatively small number of connections on the Caherlea GWS it may not be feasible to undertake all of the above recommendations. Rusheens GWS have recently installed a new borehole, with the upper zone sealed off using cement grout. There is extra capacity in the Rusheens GWS borehole to accommodate the demand supplied by Caherlea GWS.

Other:

- The following EPA guidelines may serve as future useful reference documents for the Heath 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[2].

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

- 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[3].
- EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[4].
- European Union (Good Agricultural Practice for the Protetcion of Waters) Regulations 2014[5].

7 References

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

[4] http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html#.UpNR8eJ9KEo

[5] http://www.irishstatutebook.ie/pdf/2014/en.si.2014.0031.pdf

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

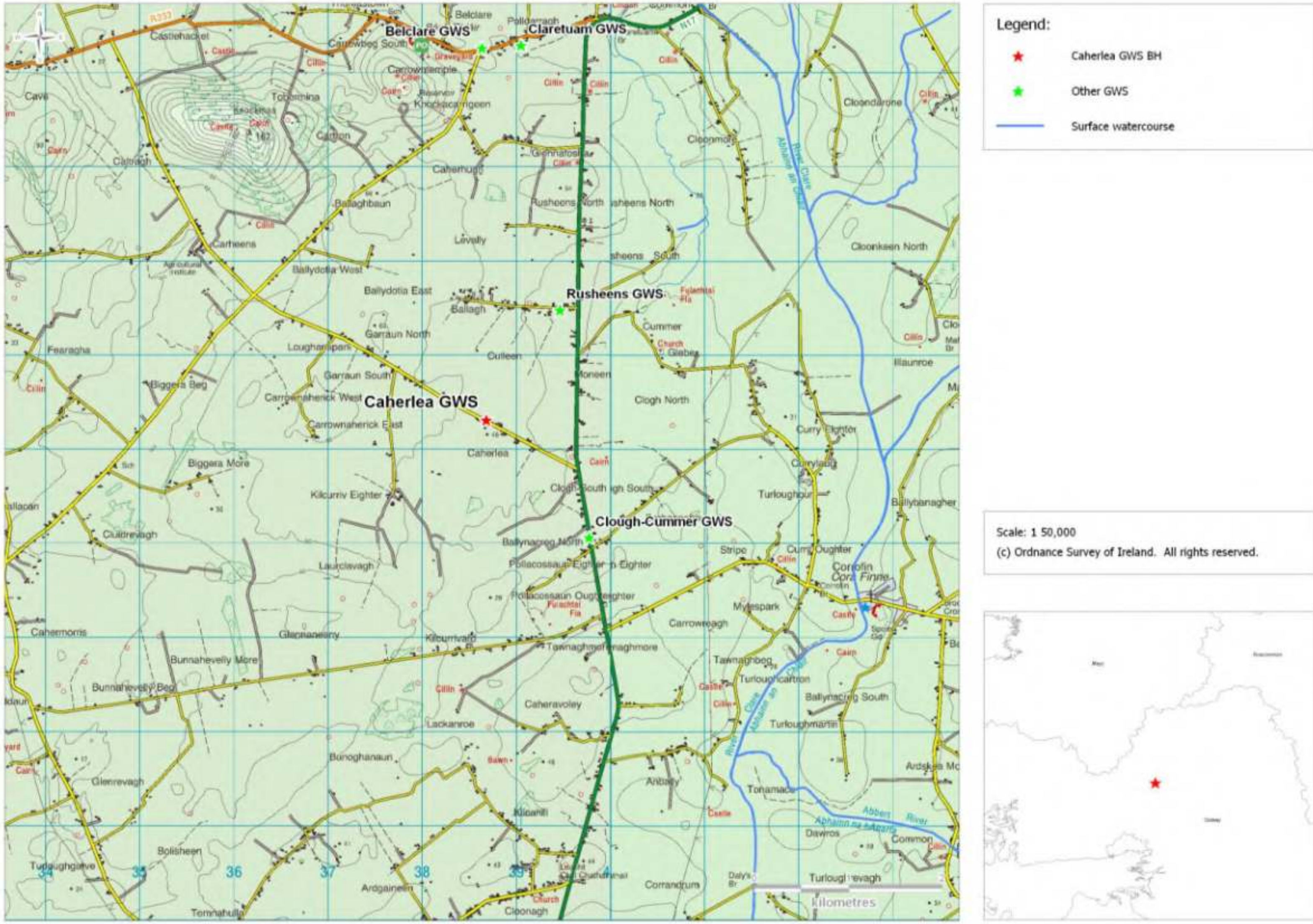

Figure 1: Location Map (OSI Discovery Map Series Map. 1: 50,000 scale)

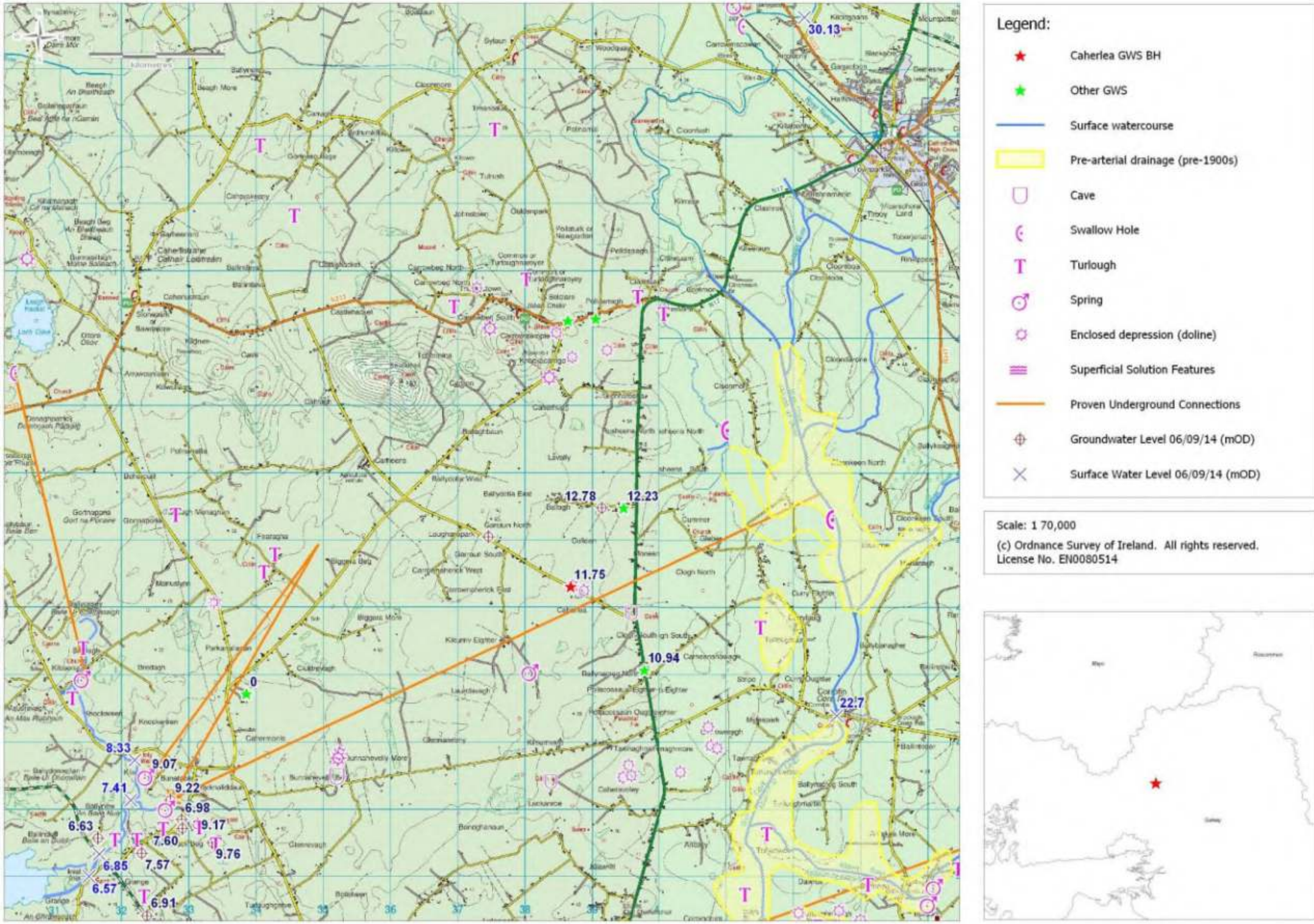

Figure 2: Topography and Drainage

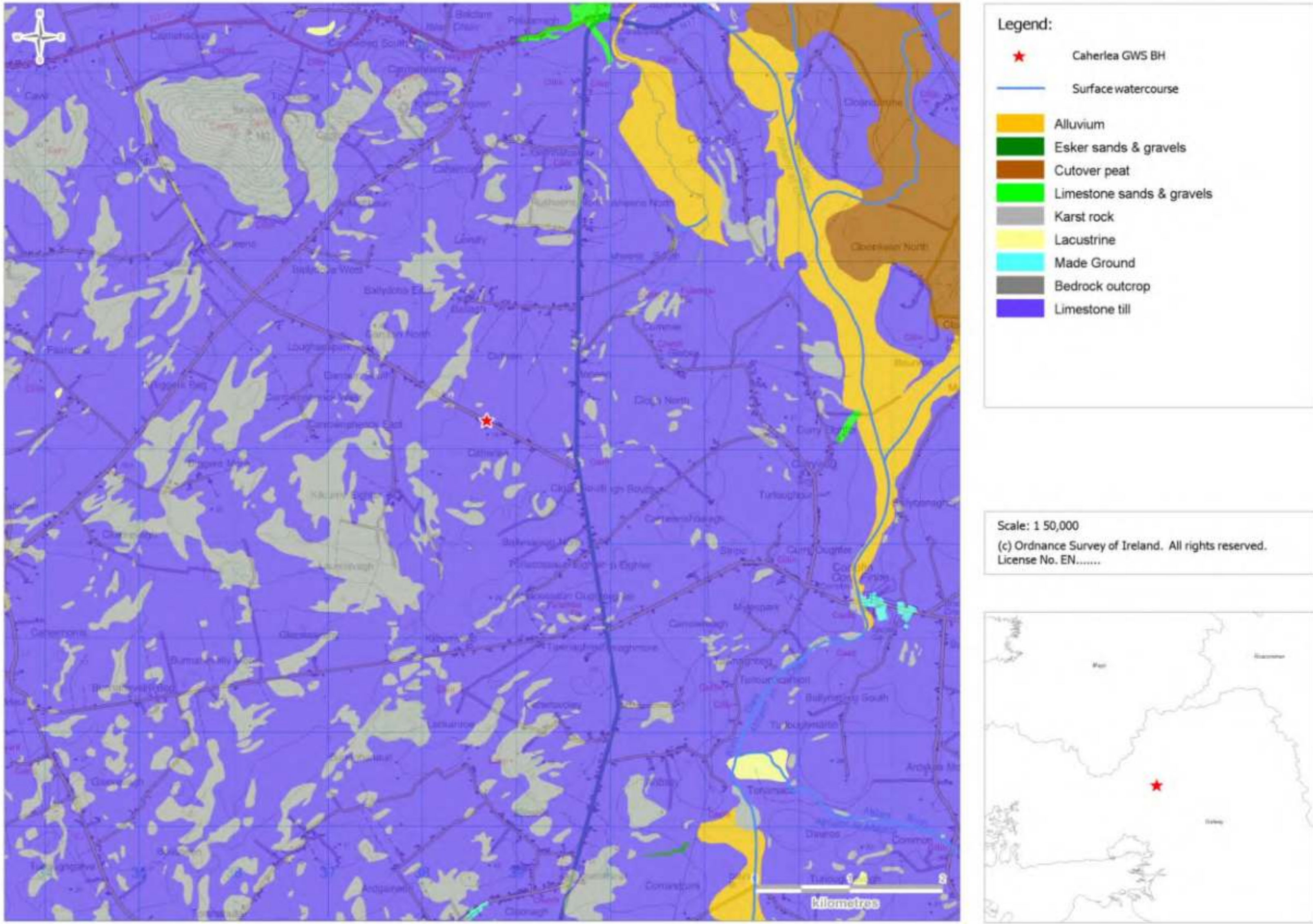

Figure 3: Subsoils Map

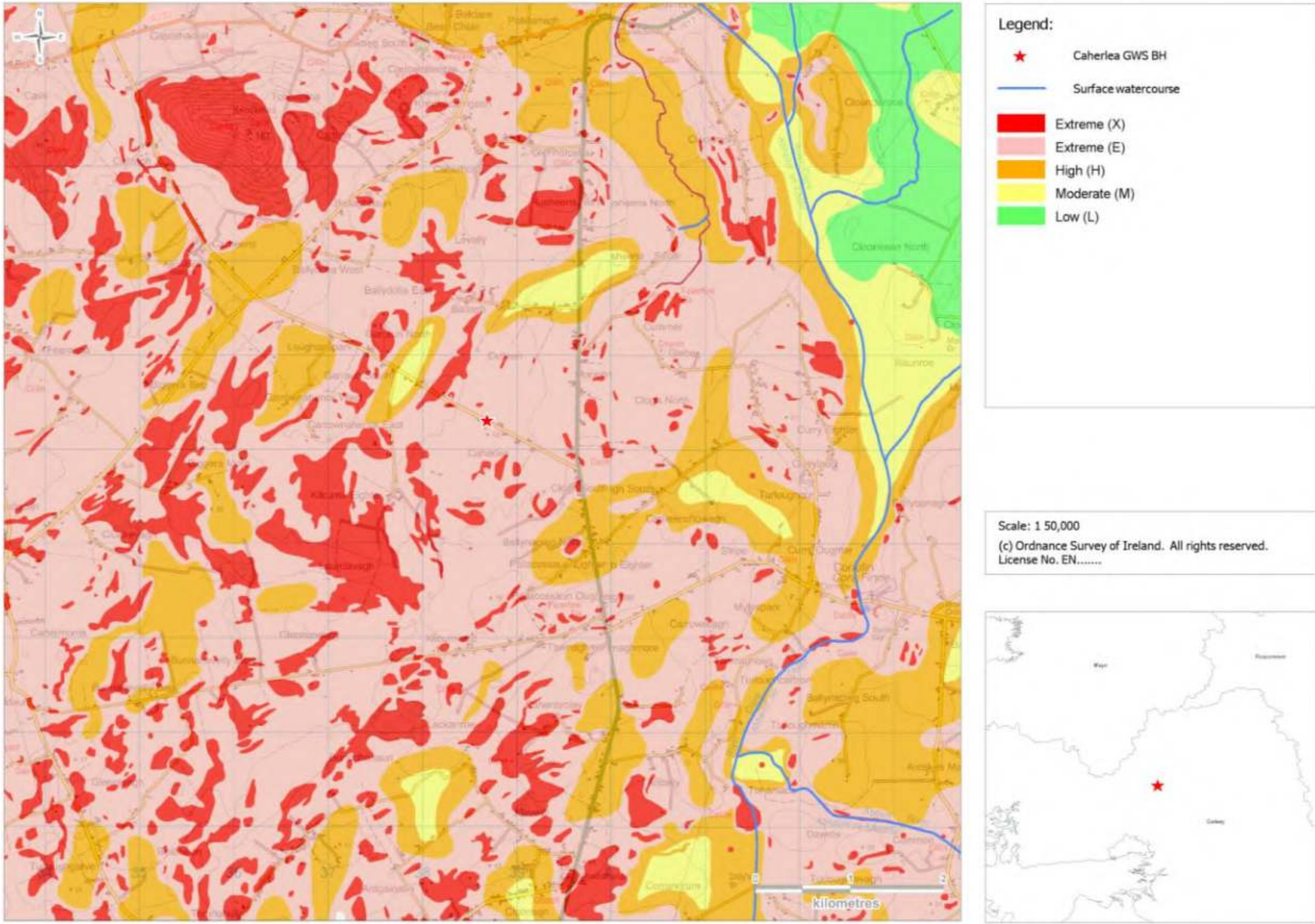

Figure 4: Groundwater Vulnerability Map

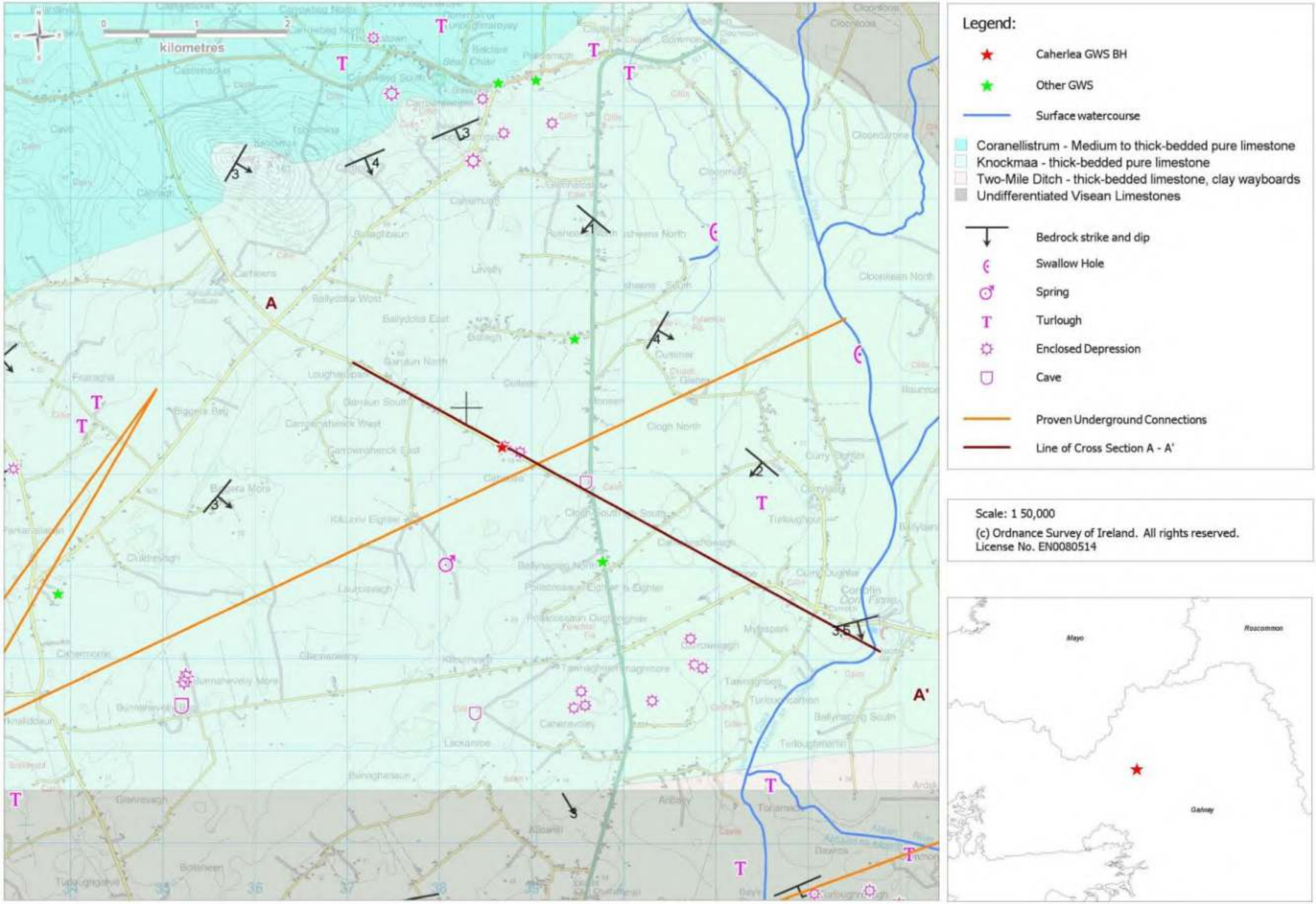

Figure 5: Rock Unit Group Map

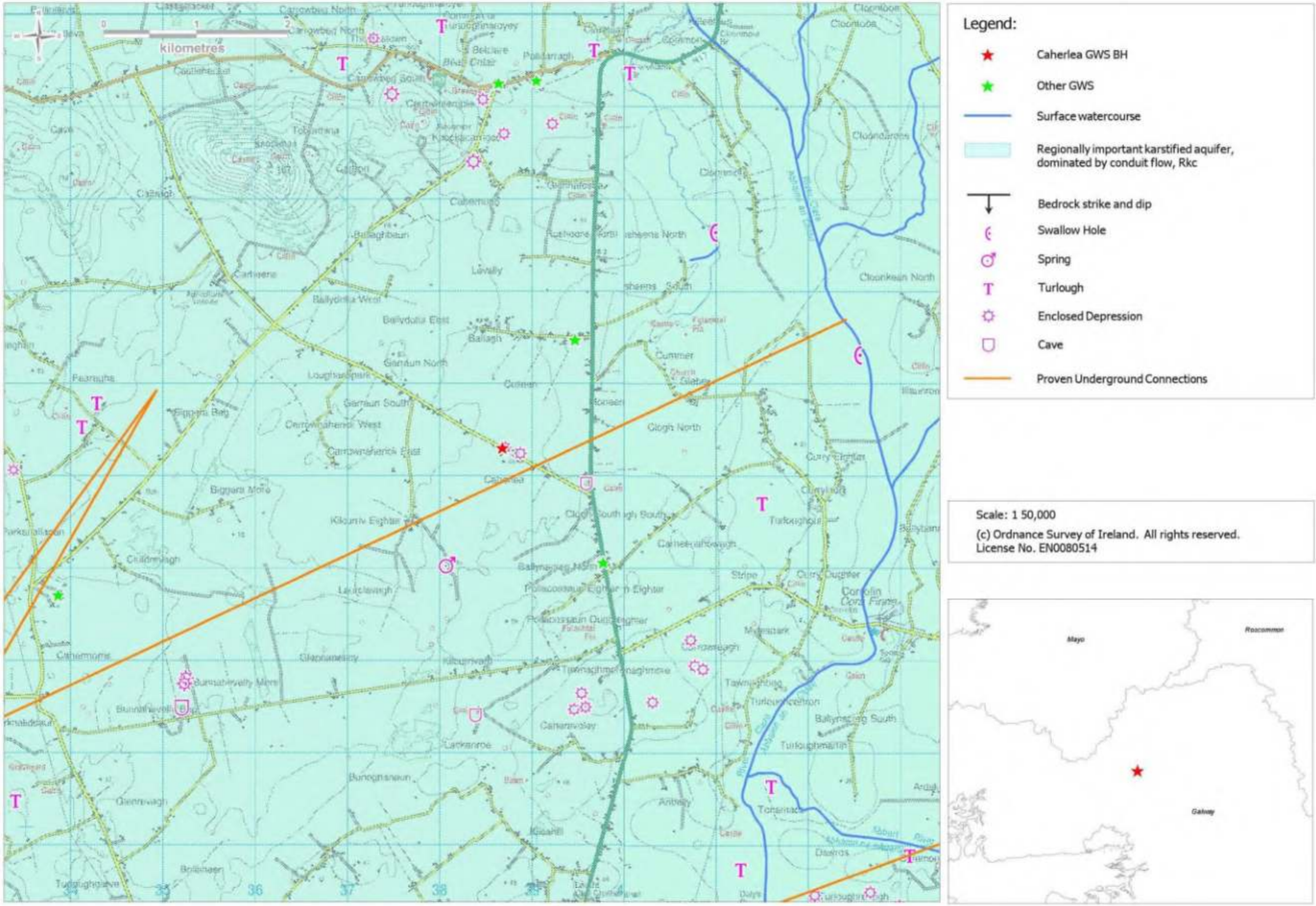

Figure 6: Aquifer Map

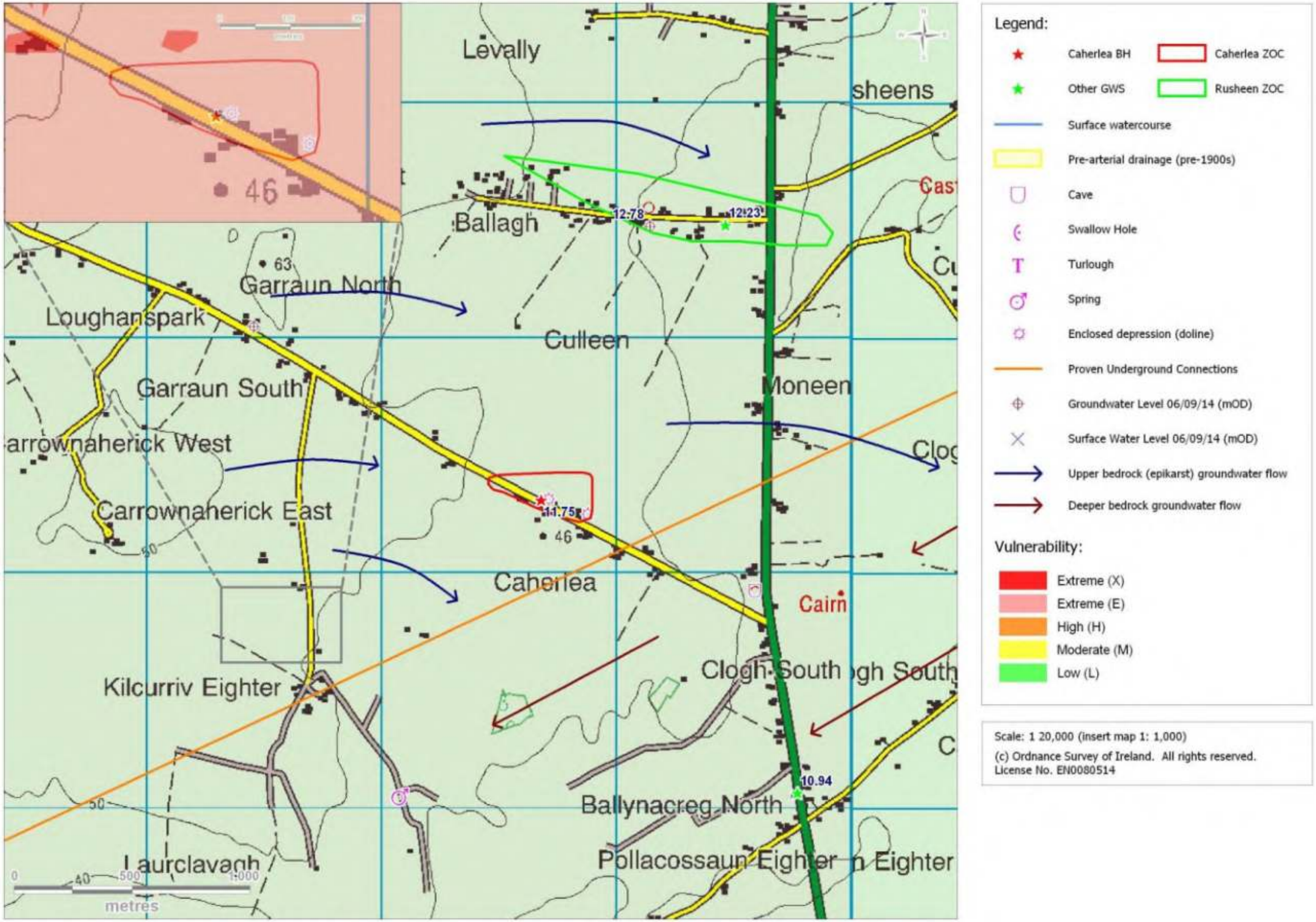

Figure 7: ZOC Boundary

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)

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 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 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
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear (in press).

APPENDIX 3

Laboratory Certificate of Analysis

Complete Laboratory Solutions

Complete Laboratory Solutions
Ros Muc, Co. Galway.
[Tel] 091 574355
[Fax] 091 574356
[Email] services@cls.ie
[web] www.completelabsolutions.com

Client :	Peadar Brick Caherlea Group Water Scheme Caherlea Tuam Co Galway	Report No.	: 207558
		Date of Receipt	: 01/10/2013
		Start Date of Analysis	: 01/10/2013
		Date of Report	: 11/10/2013
		Order Number	:
		Sample taken by	: Client

CERTIFICATE OF ANALYSIS

Results

Lab No	Sample Description	Test	Result	Units	Acceptable Drinking Water Limits
472765	Water Sample	Colour	<4	mg/l Pt Co	Must be acceptable to consumers and no abnormal change
		Turbidity	0.4	N.T.U.	Must be acceptable to consumers and no abnormal change, ideally <1.0NTU
		pH	7.2	pH Units	6.5-9.5 pH Units
		Conductivity @20C	614	uS/cm	2,500µS/cm
		Ammonium as NH4	<0.01	mg/l	0.3mg/l
		Nitrate as NO3	12.1	mg/l	50mg/l
		Nitrite as NO2	<0.017	mg/l	0.5mg/L
		Iron, total	12	ug/l	200ug/l
		Total Hardness (Kone)	355	mg/l CaCO3	
		Manganese, total	<5	ug/l	50ug/l
		Aluminium, Total	3	ug/l	200ug/l

INAB ISO 17025 ACCREDITED TESTING DETAILED IN SCOPE REG NO. 108T

Approved by: Barbara Lee

Barbara Lee
Environmental Scientist

See page 2 for test specifications and accreditation status
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APPENDIX 4

Zone of contribution down-gradient calculations

The **southeastern boundary** extends downgradient to include the doline to the east of the borehole. The abstraction itself will invoke a cone of depression which may draw groundwater deemed to be downgradient into the borehole. It is estimated to be approximately 128 m based on calculations using data from the desk study. The calculation uses the uniform flow equation (Todd, 1980), which is:

$$\text{Down-gradient distance} = Q / (2\pi * T * i)$$

where

Q is the daily pumping rate: 40.5 m^3/d. (This allows for 50% increase in the current rate).

T is Transmissivity[6] (as per Rusheens GWS, Conroy (2014)), an upper range value of 5 m^2/d is taken as a representative value for this aquifer).

i is the background non-pumping gradient, based on the moderately sloping topography in the general area (0.01).

[6] Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer. The hydraulic conductivity of the aquifer is defined as the volume of water that will move through a unit area of aquifer perpendicular to the flow direction in unit time under a unit hydraulic gradient, and has units of length / time, e.g. m/day.

Establishment of Groundwater Zones of Contribution

Cahermorris-Glenreevagh Group Water Scheme

March 2015

Prepared by:

Colin O'Reilly, Envirologic Ltd.

and

Geological Survey of Ireland, Groundwater Programme

(Caoimhe Hickey, Monica Lee and Taly Hunter Williams)

And with assistance from:

Cahermorris-Glenreevagh GWS

The National Federation of Group Water Schemes

Acknowledgements:

Tommy Greaney (Cahermorris-Glenreevagh GWS)

Karen Carney (NFGWS)

Document control information

Revision	Date	Author	Checked	Approved
Draft	23/11/14	Colin O'Reilly	CH 26/01/15	
Revised Version	19/03/15	Colin O'Reilly	CH 09/01/15	
Final Version	10/04/15	Colin O'Reilly	CH 15/04/15	CH 15/04/15

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' 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 Cahermorris-Glenreevagh 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 that 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.

Cahermorris-Glenreevagh GWS is supplied by a regionally important aquifer with karstified flow in enlarged conduits (Rk_c). The current abstraction rate is 75 m^3/d.

[1] Geological Survey of Ireland, 1999.

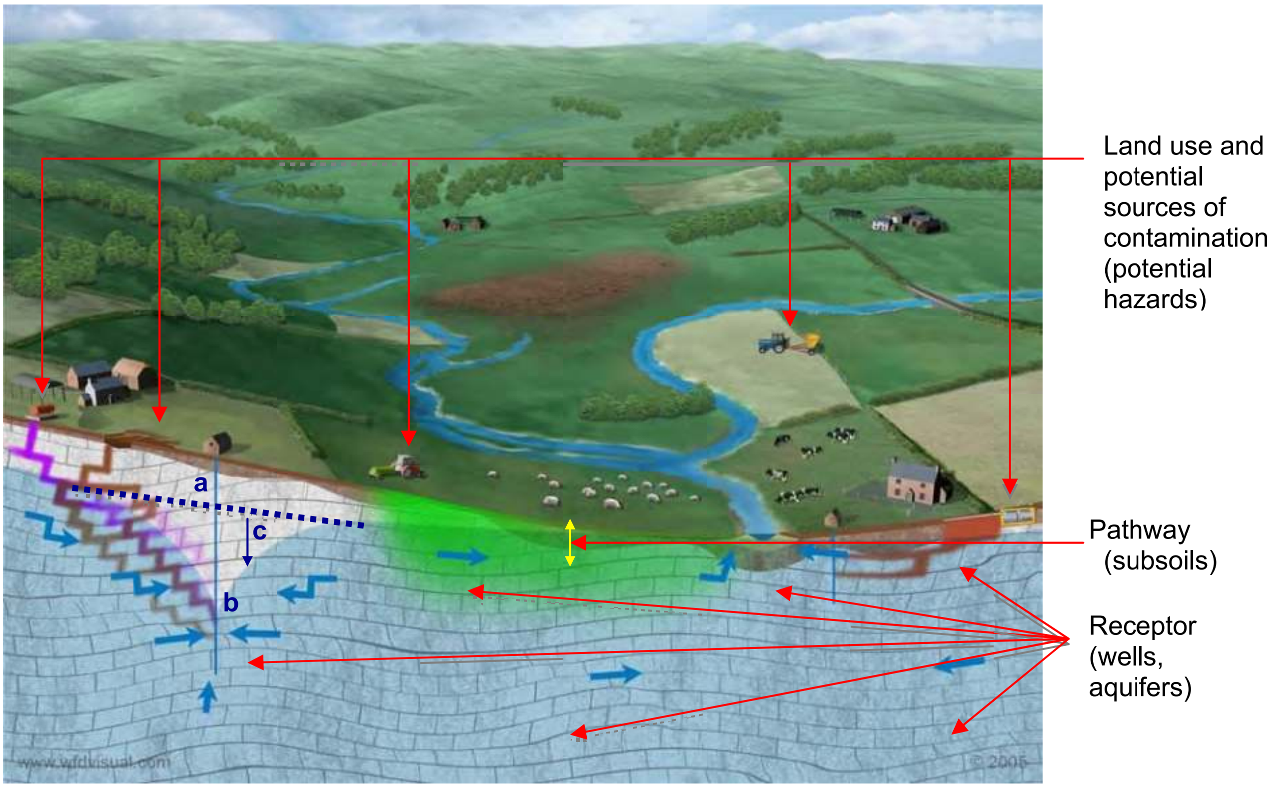

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Cahermorris-Glenreevagh Group Water Scheme (GWS) is supplied from a borehole that lies on the boundary between the townlands of Cahermorris and Glenreevagh in County Galway **(Figure 1)**. The current scheme demand is 75 m^3/d, which provides water to 48 domestic connections and 12 farms. Users are metered at point of supply.

The GWS is located in central Galway: 8.6 km southeast of Headford, 14 km southwest of Tuam and 17 km north of Galway city centre. The borehole sits adjacent to the junction of a local road that runs southeast-northwest between the N17 near Claregalway, and the R333 near Caherlistrane (**Diagram 2**). The GWS pumphouse is a 3.0 m by 3.0 m roofed structure situated on the eastern boundary of an agricultural field, setback 3 m from the road.

The wellhead offers excellent protection to the borehole. The borehole wellhead sits inside the pumphouse. Six inch steel casing protrudes 0.175 m above ground level. This is covered with a 0.18 m diameter steel cap with a rim that sits tightly around the borehole casing, and incorporates a 20 mm flap-covered hole to accommodate a dipmeter. The pumphouse floor is in good condition composed of finished concrete which surrounds the borehole casing and gives a finished floor level 0.14 m above road level. A 50 mm steel rising main and power cable exit the chamber through a hole in the borehole lid.

The GWS borehole was originally a county council source, operated by a handpump. In 1971 the borehole was reportedly deepened to a depth of 122 m, and blasted at the base to improve yield. A 100 mm borehole pump, replaced in 2012, supplies directly to the mains via a 1.5 m^3 pressure chamber. A cumulative flowmeter is located on the discharge line inside the pumphouse. The scheme utilises chlorination and ultra-violet treatment. A raw water tap and treated water tap are positioned between the flowmeter and distribution line.

To the rear of the pumphouse the GWS have installed a perimeter fence setback 1.5 – 2.0 m from the pumphouse. An electric fence defines the agricultural field boundary a further 0.6 m behind this perimeter fence.

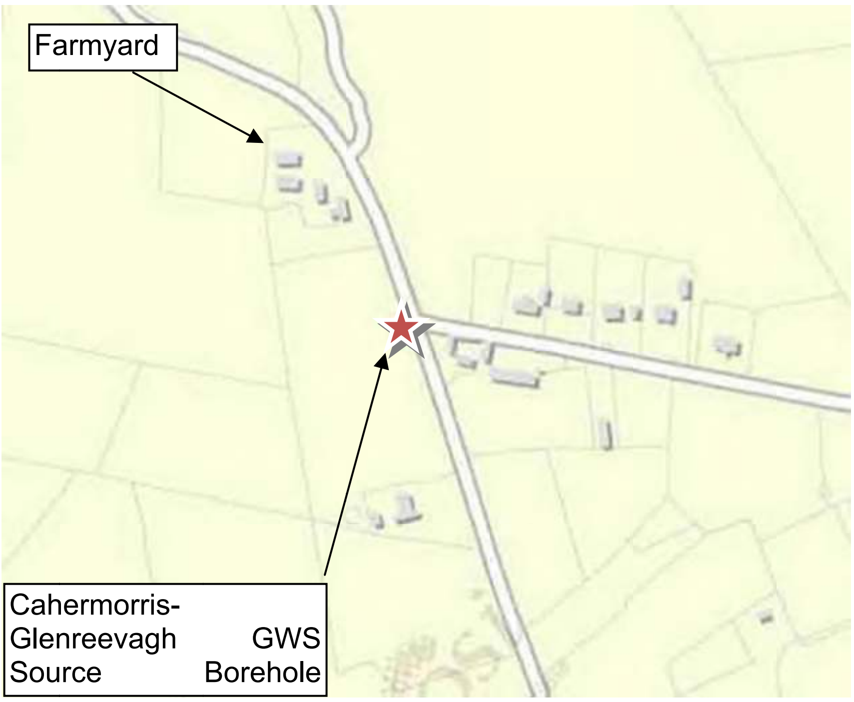

Diagram 2. Schematic Plan of the GWS Site

Photos of the pumphouse and borehole chamber can be seen in Photos 1 to 4 below. Table 1 provides a summary of existing information relating to the borehole. There is no drilling log available for the borehole, nor is there any record of a pumping test having been carried out.

Photo 1: Pumphouse. Borehole head located within pumphouse

Photo 2: Wellhead installation

Photo 3: Flowmeter on mains line

Photo 4: Field to rear of pumphouse facing north (note fenced area)

Table 1. Supply Details

	Cahermorris-Glenreevagh Borehole
Grid reference	133,847 m Easting; 242,263 m Northing
Townland	Boundary of Cahermorris and Glenreevagh
Source type	Borehole
Drilled	1926. Deepened and blasted at base in 1971
Drilling Contractor	Original borehole by Galway County Council. Contractor for 1971 works unconfirmed
Owner	Cahermorris-Glenreevagh GWS
Elevation	pumphouse floor = 25.36 mOD Malin Top of casing = 25.53 mOD
Total depth (m)	122 m
Construction details	150 mm steel casing from 0.175 m above ground level to 2.4 m below surface; Assume open hole within bedrock.
Depth to rock (m bgl)	Approximately 1.8 m
Static water level (SWL)	Unconfirmed On 19/08/14, when pumping intermittently at an estimated rate of 238 m^3/d, groundwater level fluctuated between 24.85 mbgl (0.68 mOD) during 3 minutes pumping, and 16.15 mbgl (9.38 mOD) during 3 minute recovery. No record of depth of any water strikes encountered during drilling.
Pump intake depth (m bgl)	36.5 m bgl (-11.14 mOD)
Current abstraction rate (GWS)	Total daily abstraction = 75 m^3/d On 19/08/14, pump was working on a pumping cycle of around 3 minutes on and 4 minutes off. The timings of this intermittent cycle are variable, being dependant upon demand. Over 24 hours the pump is on 31% of the time, and off 69% of the time. Caretaker maintains weekly records of cumulative flow.
Reported yield (m^3/d)	Unconfirmed, no long-term pumping test has been performed. Mini-pumping test performed during site visit (**Appendix 1**) would initially suggest that the borehole is capable of sustaining 238 m^3/d though a long-term pumping test would be required to confirm this.

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical Characteristics of the Area

Table 2. Physical Characteristics of the Area of Interest

	Caherlea Borehole	Description/Comments
Annual Rainfall (mm)	1166	Met Éireann average annual rainfall data 1981-2010
Annual Evapotranspiration Losses (mm)	463	487.5 mm PE (average annual potential evapotranspiration data, Galway SWS, 1961-1990). 463 AE (Actual Evapotranspiration, assumed to be 95% of PE).
Annual Effective Rainfall (mm)	703	Annual rainfall less annual evapotranspiration losses
Topography **(Figure 1)**		In general, lands are flat and featureless, sloping very gently from the east-northeast towards Lough Corrib, 3 km to the west of the GWS. A hill at Knockmaa, 6.5 km north of the GWS, reaches 167 mOD. Elevation at the foot of this hill is 40 mOD. Between this hill and the site, topography is relatively flat, sloping gently south-southwest, marked by small hummocks such as those at Garraun North (63 mOD, 5.5 km to the northeast) and Carrownaherick (50 mOD, 4.3 km to the northeast), from which land falls away radially.
Land use		Land in the area is predominantly used for moderate intensity agriculture. Much of this land has been improved upon having originally had significant bedrock at surface. A linear ribbon development of one-off housing, serviced by individual septic tanks, exists on the opposite side of the road, aligned west-east. The borehole is situated on the edge of a grassland field. The pumphouse is fronted by a junction between two local roads. A farmyard is located 110 m north of the site.
Surface Hydrology **(Figure 2)**		1 km to the west at Bunatober, and downgradient of the site, a spring rises to form a stream headwater. This stream flows into another watercourse, fed primarily by a spring at Ballycasey. The combined streams enter Lough Corrib 3.4 km to the southwest. The River Clare runs roughly N-S and passes 7.5 km east of the GWS at it's closest point. This section of the River Clare is man-made, having been excavated as part of a historical arterial drainage scheme. River level is not in continuum with groundwater.
Topsoil		The area is dominated by deep, well-drained basic mineral soils, which become thinner on elevated ground and where bedrock outcrops at surface.
Subsoil (**Figure 3**)		Carboniferous limestone till (Teagasc, 2006). Subsoils may not be present where bedrock is close to surface.
Groundwater Vulnerability (**Figure 4**)		Extreme (X) in the immediate vicinity of the borehole, indicating rock at or close to surface. In the wider area Extreme (E) vulnerability dominates. Presence of High (H) vulnerability northeast of the site possibly infers local depressions and slight increase in subsoil depth. **See Appendix 2.**
Geology Formation: Rock Unit Group (**Figure 5**)		The GWS source and wider area are underlain by the rock unit group Dinantian Pure Bedded Limestones. Bedrock formation is the Knockmaa Formation which is a thick-bedded pure limestone. Beds generally dip southeast at 2-3º. There are no mapped faults in the area. GSI 6" field sheets indicate outcrops are weathered and jointed. Regionally, north-south and east-west joint sets are expected to occur (Gatley et al., 2006).
Aquifer (**Figure 6**)		The DPBL limestones are classified by the GSI as a Regionally Important Karstified Bedrock Aquifer, dominated by conduit flow (Rkc). Known surface karst features in the area are shown in Figure 6.
Groundwater Body (**Appendix 3**)	Clare-Corrib GWB (GSI, 2004)	Groundwater body WFD status 2007-2012 is 'Good', but at risk of not achieving good status
Recharge Coefficient (**Appendix 4**)	80 %	Low drainage density, well-drained soils, moderate permeability subsoils, and extreme vulnerability, plus point recharge via karst features suggest a high recharge coefficient.
Recharge (mm)	562	

3.2 Hydrochemistry and water quality

One untreated water sample was collected for the Cahermorris-Glenreevagh GWS borehole on 24/07/2014 and analysed by CLS, Ros Muc, Co. Galway (**Appendix 5**). A dataset containing results taken at various points of supply between 2008 and 2011 was referred to. Four sample sets (consisting one sample of raw water and one sample of treated water per set) were also collected and analysed by NUIG during 2013/2014 as part of a study into microbial contamination.

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

Table 3: Water Quality Data

	Untreated Water		Treated Water 2007-2011		
Parameter	Number of Values	Result (24/07/14)	Number of Values	Mean	Parametric Value
pH (lab.)	1	7.2	12	7.1	6.5 < pH < 9
Electrical Conductivity (lab.) (uS/cm)	1	575	12	666	800
Colour (PtCo units)	1	< 4	9	4.5	acceptable to consumers and no abnormal change
Turbidity (NTU)	1	0.2	11	0.33	
Nitrate (mg NO_3/l)	1	8.11	10	10.3	37.5
Nitrite (mg NO_2/l)	1	< 0.017	7	0.02	0.375
Orthophosphate (mg PO_4-P/l)	1	0.035			
Hardness (mg/l as $CaCO_3$)	1	368			
Ammonium (mg NH_4/l)	1	< 0.01	8	0.02	0.3 (SI 278 2007)
Iron (ug Fe/l)	1	< 10	7	38	200 (SI 278 2007)
Manganese (ug Mn/l)	1	< 5	6	13.7	50 (SI 278 2007)
Aluminium (ug Al/l)	1	< 2	7	11.9	200 (SI 278 2007)
E.coli (cfu/100 ml)	1	17	12	0.1	0
Total coliforms (cfu/100 ml)	1	17	12	0.2	0

Unstable hydrochemistry parameters were measured in the field on 19/08/14. Electrical conductivity measured 714 µS/cm; pH measured 7.2; temperature measured 11.9°C.

The available water quality data suggest that the chemical water quality is moderate. The water is hard and has a slightly alkaline pH, a signature of limestone bedrock. Two groundwater provinces are suggested by Drew and Daly (1993). Firstly, there is a shallow groundwater component that is characterised by high suspended solids and relatively low electrical conductivities (300-400 µS/cm). Secondly, there is a deeper groundwater component that is characterised by relatively non-turbid groundwater with higher electrical conductivities (> 450 µS/cm). On this premise, groundwater is representative of the deeper system.

Nitrate concentrations are relatively low which is consistent with the low to moderate intensity farming in the area. Orthophosphate levels suggest some contamination, possibly from improper septic tanks, inadequate percolation areas or leaky underground slurry storage tanks. The detection of faecal coliforms would reinforce this.

Table 4 – NUIG Microbial Sampling Data 2013

Date	Sample Type	Microbiological parameter	MPN/100 ml	VTEC
21/08/13	Raw	total coliforms	387	O157 & O26 detected. VTX 1+2 toxin genes
		e. coli	191	
	Treated	total coliforms	< 1.0	none detected
		e. coli	< 1.0	
16/09/13	Raw	total coliforms	219	O157 & O26 detected. VTX 1+2 toxin genes
		e. coli	57	
	Treated	total coliforms	0	none detected
		e. coli	0	
10/10/13	Raw	total coliforms	276	O157 & O26 detected. VTX 1+2 toxin genes
		e. coli	45	
	Treated	total coliforms	0	none detected
		e. coli	0	
09/04/14	Raw	total coliforms	37	O26 detected.
		e. coli	2	
	Treated	total coliforms	0	none detected
		e. coli	0	

Microbial analysis shows bacterial contamination was detected in the raw water supply on each sampling occasion. Faecal contamination was detected in all raw water samples, which suggests that landspreading, septic tanks, percolation areas, and underground slurry tanks are potentially a source of ongoing contamination. The lowest level of contamination was detected in Spring. Year round sampling would be needed to confirm any seasonality.

Where coliform contamination was detected in the raw water sample it had been removed following treatment. This confirms that the chlorination and ultraviolet treatment system is effective, when in operation.

VTECs (verocytotoxigenic Escherichia coli.) are a more virulent and aggressive form of microbial contamination, and were detected in all raw water samples. VTEC O26 was detected in all raw samples, whilst O157 was detected in 3 of the 4 samples. These strains are sourced from cattle, sheep and goat faeces. VTECs were not detected in the treated water entering the supply line.

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is presented as a cross-section in **Diagram 3**.

A large proportion of the rainfall is assumed to infiltrate to groundwater as recharge (80%), either diffusely or via point recharge at surface depressions (dolines) or swallow holes (sluggaires).

Diffuse recharge infiltrates the surface and enters the extensively karstified, epikarst zone in the top few metres of bedrock. From here it can flow laterally within the epikarst or continue vertically to enter a network of interconnected joints, fractures and karst conduits. Deeper groundwater flow occurs predominantly within larger fractures or fault structures. Point recharge follows the same fate but may bypass the epikarst zone.

The direction of flow in the upper groundwater regime (i.e. epikarst and jointing) is likely to reflect the local topography. This has been confirmed by GSI tracing studies (see Figure 2) and was reflected in the well survey performed on 6th September 2014, with flow from northeast to southwest, towards Lough Corrib and a number of springs on it's periphery.

Local upgradient group water schemes encountered major water strikes at 50 – 91 metres below ground (equivalent to between -16 and -38.5 mOD). Each of these boreholes penetrated conduits or significant water-bearing fractures at different depths. Given that the Cahermorris-Glenreevagh borehole was deepened it is assumed that it receives inflows at similar depths. The unlined construction of the borehole also means that it is likely to receive inflows from the upper epikarst.

4.2 Boundaries

The boundaries of the area contributing to the source are based on hydrogeological setting and topography and are considered to be as follows (**Figure 7**):

The **Northeastern** Boundary is the upgradient boundary. It extends to a distance of 2.4 km from the borehole in the direction of a local ridge at Bunnahevelly More. Groundwater flow sourced from epikarst and the upper fractures and jointing network flow southwest towards Bunatober Spring, Balrobuckbeg, and ultimately Lough Corrib. As the borehole is completely unlined, lateral flows will enter the borehole freely.

The **northwestern and southeastern boundaries** are flow line boundaries. The orientation of the flow lines is based on the groundwater flow direction, which is inferred from a survey of wells and turloughs, and tracing studies previously carried out by GSI.

The **southwestern boundary** extends downgradient of the borehole for a distance of 263 m. The relatively large downgradient distance is due to the very low hydraulic gradient.

Inside the boundaries groundwater flow in the upper groundwater flow regime is expected to infiltrate the borehole. Outside the boundaries groundwater flow in the upper groundwater regime is expected to flow laterally towards Bunatober and Lough Corrib.

There are two enclosed depressions (dolines) and one cave mapped within the zone of contribution.

Based on the collection and analysis of the available data for this project, it is recognised that this scale of study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Cahermorris-Glenreevagh GWS borehole with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. Therefore, the analysis has been used to identify an area that is highly likely to be supplying the borehole. It is possible that additional areas are also contributing to the borehole (depending on the flow regime in operation) so the GWS may want to consider further hydrogeological work/ measures if water quality issues persist, which will provide supporting evidence as to the most likely areas that should be included within the ZOC.

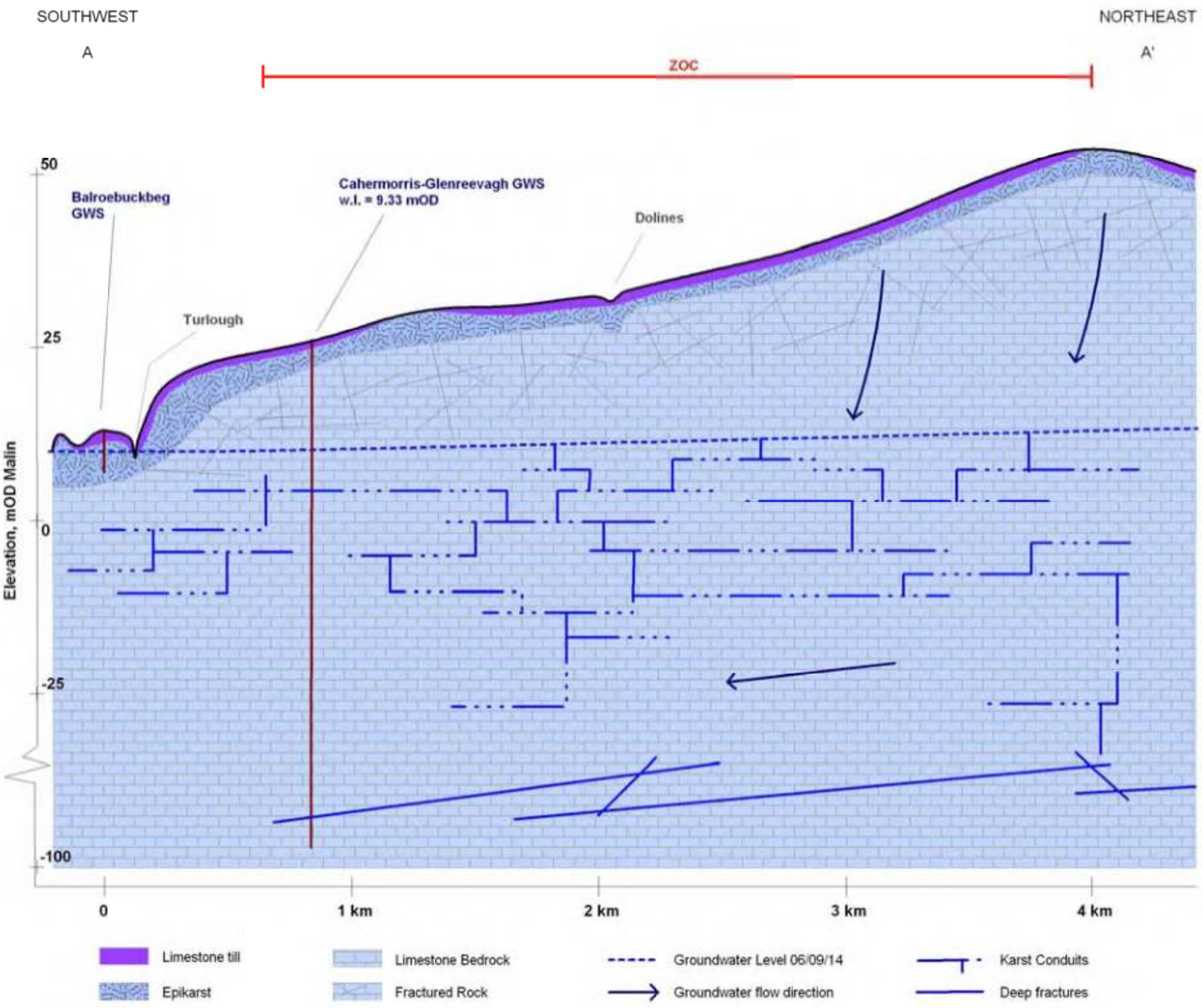

Diagram 3: Schematic Cross Section and Conceptual Model

4.3 Recharge and water balance

The current demand for the Cahermorris-Glenreevagh GWS is 75 m^3/d. The maximum sustainable yield for the borehole is not known but is considered to be in the order of several hundred cubic metres per day (drawdown stabilises quite quickly under the estimated intermittent abstractions of 238 m^3/d). In order to accommodate potential peak abstraction rates above the average long-term demand of 75 m^3/d, the abstraction rate of 238 m^3 d^{-1} is used in the water balance calculations.

Recharge to the ZOC is estimated as 562 mm/yr (see **Table 2**). At a recharge rate of 562 mm/yr the 238 m^3/d abstraction rate requires a ZOC of 0.155 km^2 (15.5 ha; 154,573 m^2) to capture the required volume of diffuse recharge to balance this abstraction.

Based on hydrogeological setting and topography, the delineated zone of contribution was estimated as having an area of 3.03 km^2. The water balance shows that the zone of contribution delineated is adequate to supply the borehole abstraction.

5 Conclusions

The current abstraction for the Cahermorris-Glenreevagh GWS is 75 m^3/d. The borehole is likely to be capable of providing a maximum yield in excess of 200 m^3/d.

The ZOC delineation was based on a combination of hydrogeological mapping, and the topographical catchment to the borehole. For an intermittent abstraction rate of 238 m^3/d, the estimated ZOC covers an area of 3.03 km^2. This ZOC is large enough to ensure the long-term sustainability of the supply.

The groundwater vulnerability within the ZOC is primarily Extreme (E) and Extreme (X), with a smaller area shown as High (H). 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.

Recent data for the borehole suggests groundwater quality in the study area is good in terms of nutrient status. Overall however, water quality is regarded as being poor given the high levels of coliforms detected in raw water samples.

6 Recommendations

Essential:

- Routine water quality monitoring should be carried out **on raw water** at the source. The monitoring programme should include a regular survey of water quality parameters that would include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The chemistry results should be reviewed and if the parameters are generally stable, the frequency (and possibly the list of analytes) could be reduced to quarterly or biannually.

- The GWS should liaise with NFGWS regarding the completion of a cryptosporidium risk assessment.

- An automated ultra-violet sterilisation unit is recommended.

- Comprehensive hazard mapping within the delineated ZOC should be undertaken. Within the ZOC to Cahermorris-Glenreevagh GWS are approximately thirty houses, several of which appear to have been constructed within the last 5-10 years. The density of housing, and the linear arrangement of same, reduces the ability of upgradient groundwater to assimilative treated effluent completely by dilution.

- There are an estimated 7 farmyards within the ZOC. Cahermorris-Glenreevagh GWS should consider liaising with the local farmyards to ensure risk from underground slurry storage tanks, silage clamps, and septic tanks is minimised.

- There is at least one authorised treatment facility (car dismantler) within the ZOC. Other industrial activity within the ZOC was not identified.

Desirable:

- Application of inorganic and organic fertilisers should be restricted where possible along the southeastern boundary of the field within which the borehole is sited.

- The borehole abstraction should be measured on a cumulative metric flowmeter inside the pumphouse and continue to be monitored on a daily/weekly basis. This is to ensure that the delineated ZOC remains appropriate.

- A dipping tube should be installed through the borehole cover to facilitate groundwater level monitoring.

- Consideration should be given to sealing off the upper 40 m of the borehole. This would prevent any groundwater inflows entering from the epikarst, or upper fractures and joint network. This would require sealing the annulus between a centralised small diameter PVC pipe (125 mm) and the rock face using cement grout above a packer or basket.

- A pair of dolines 1.5 km to the east of the borehole have been included in the ZOC (another cluster of dolines 5.5 km to the east have not been included in the ZOC).

- A karst mapping survey is recommended within the ZOC. The limits of the survey can be extended depending on initial findings.

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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

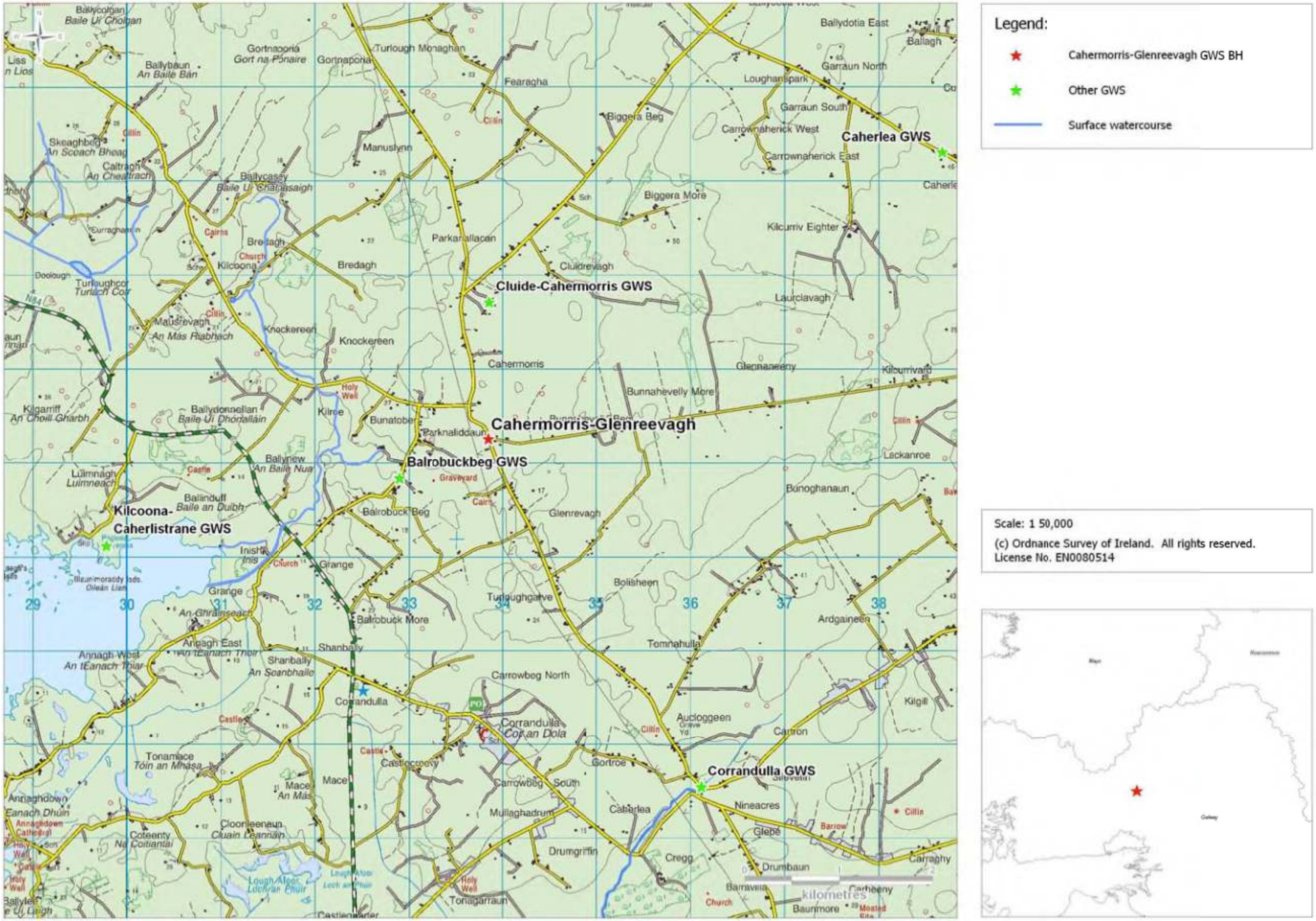


Figure 1: Location Map (OSI Discovery Map Series Map. 1: 50,000 scale)

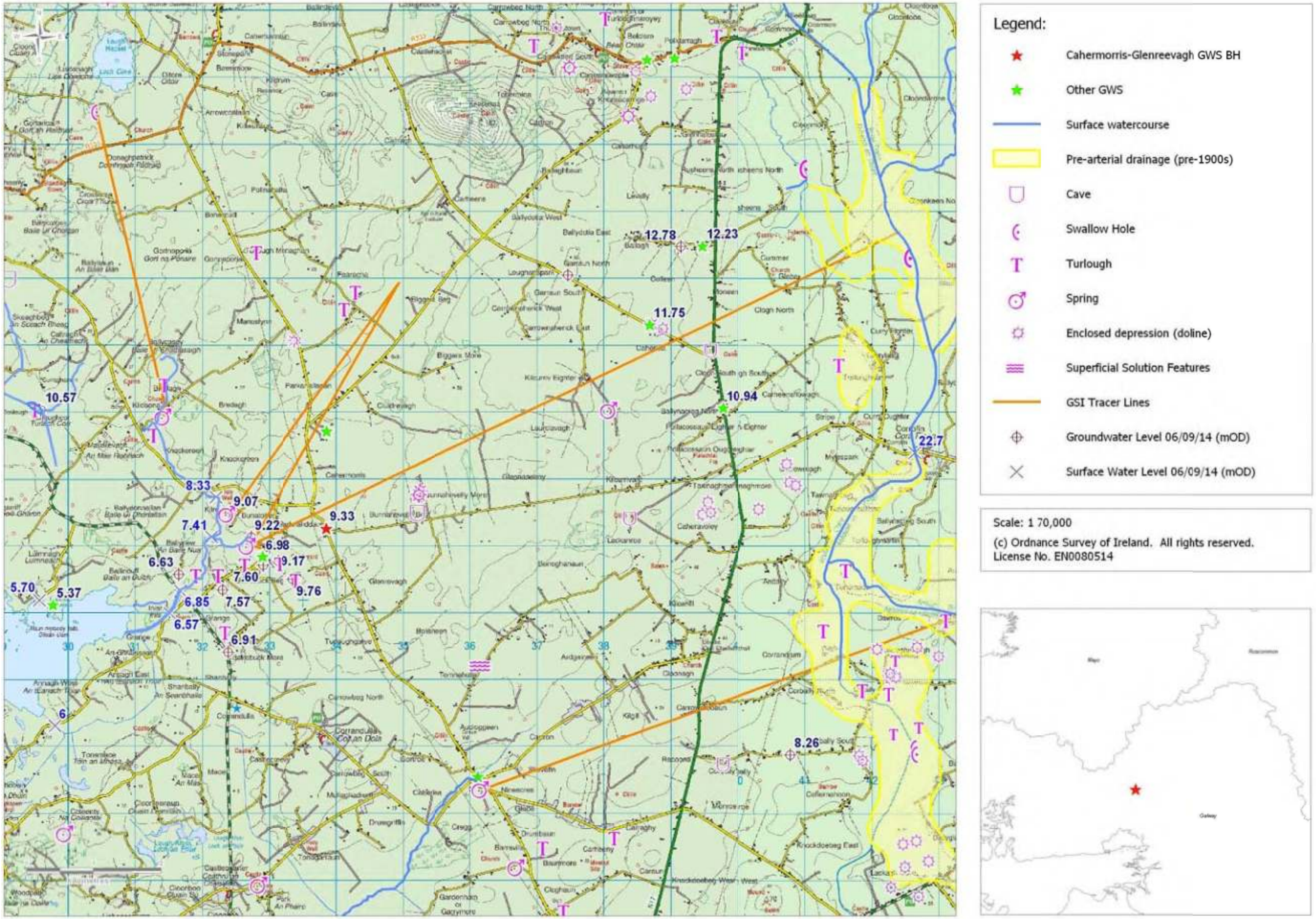


Figure 2: Topography and Drainage

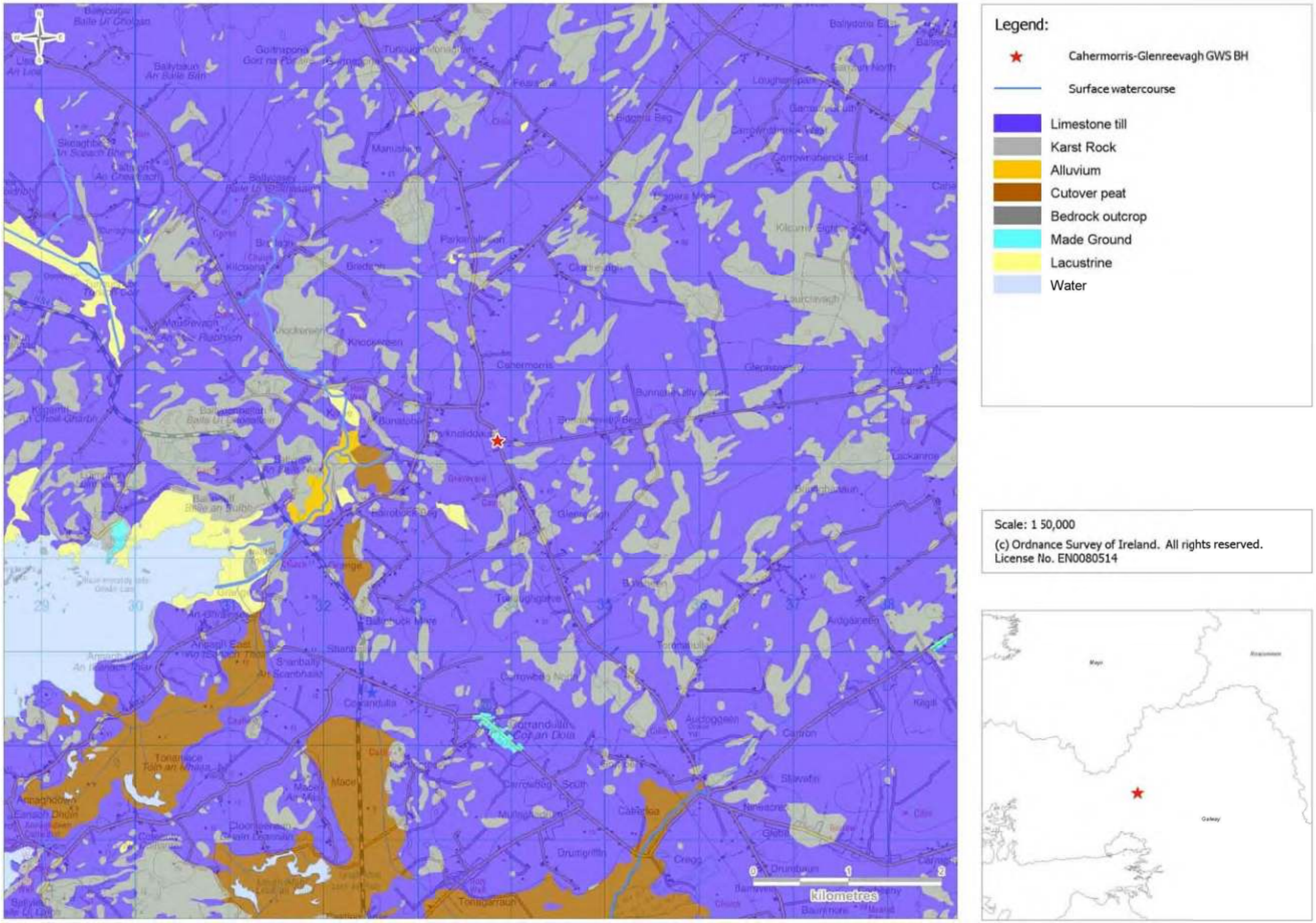


Figure 3: Subsoils Map

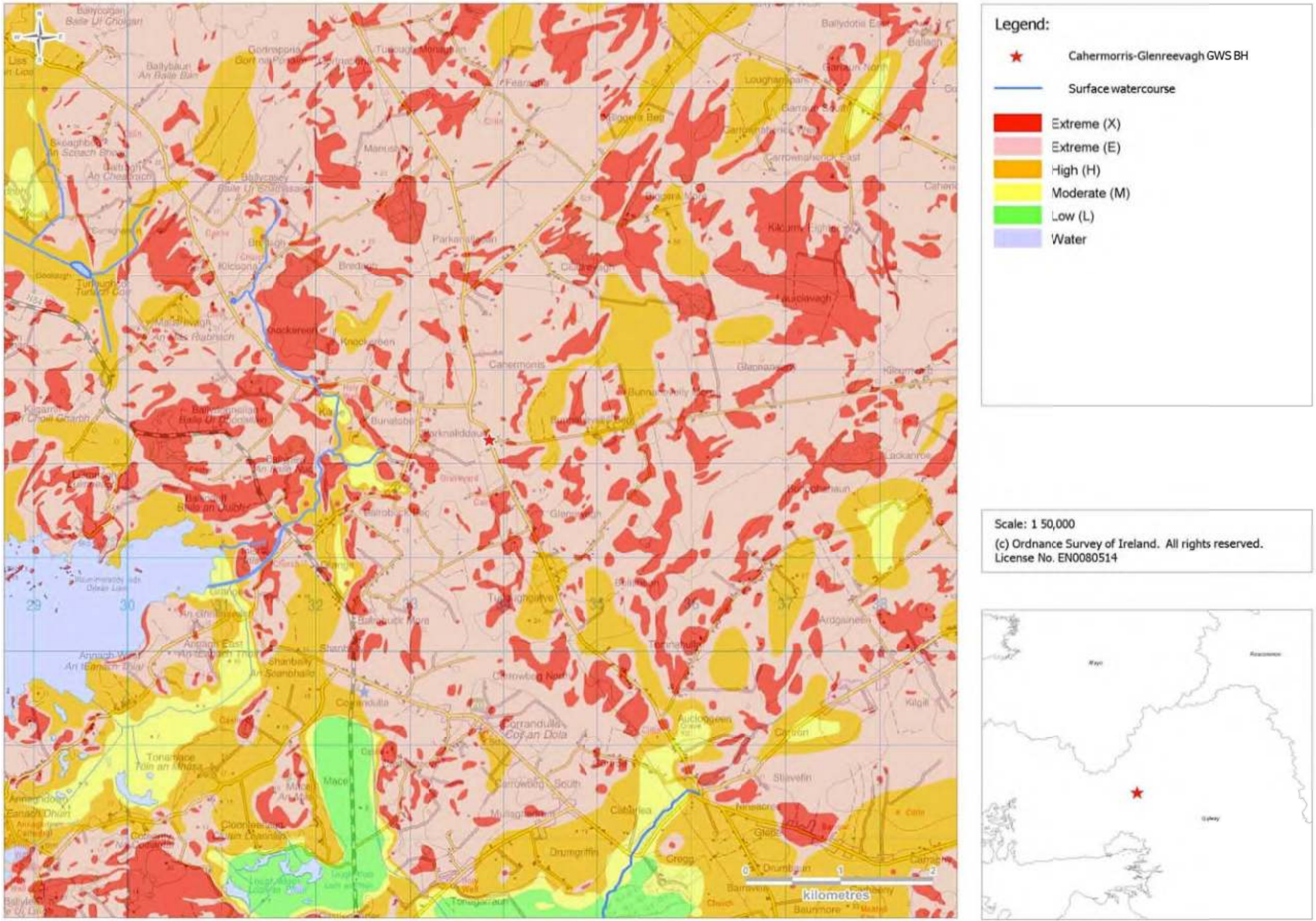


Figure 4: Groundwater Vulnerability Map

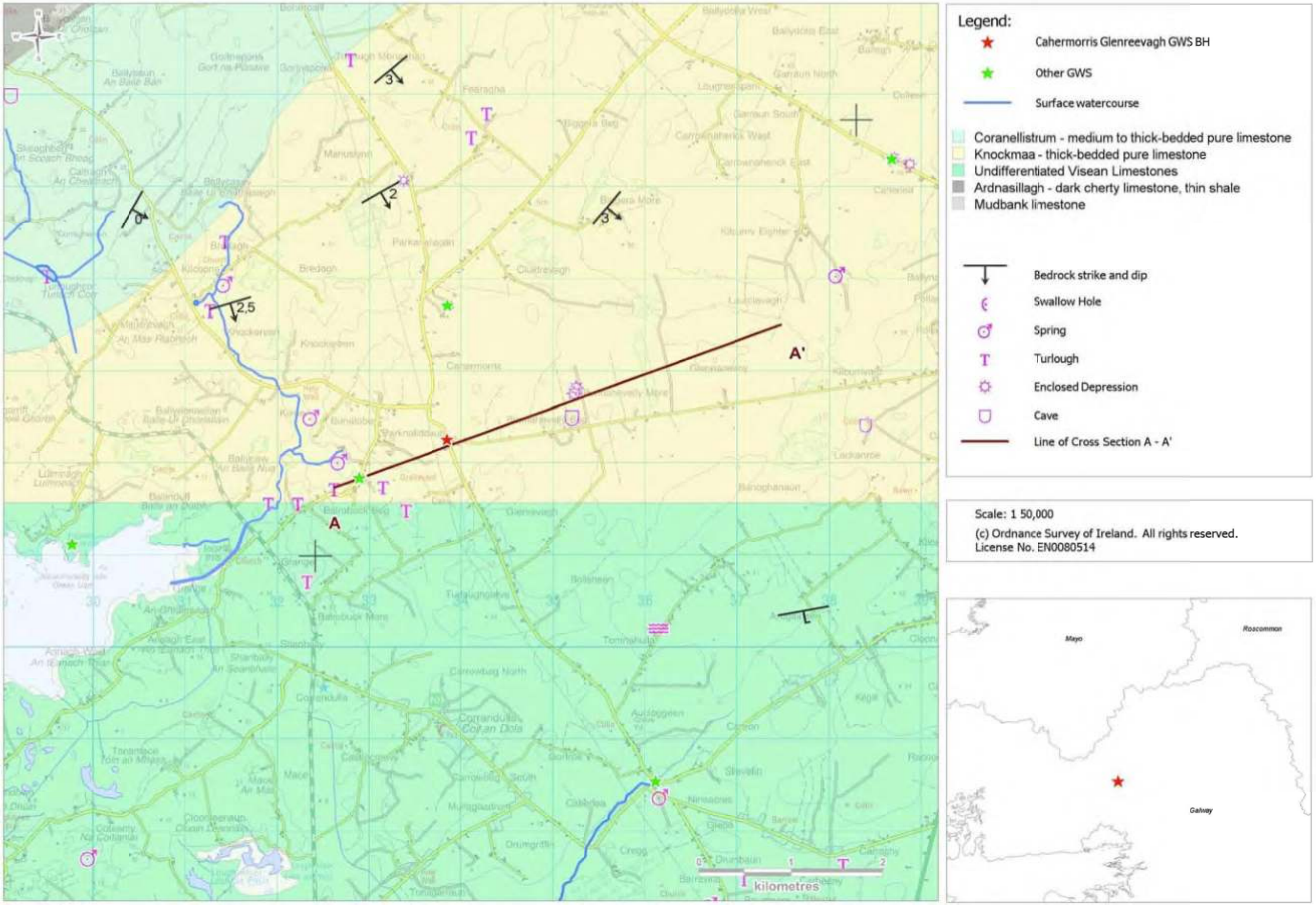


Figure 5: Rock Unit Group Map

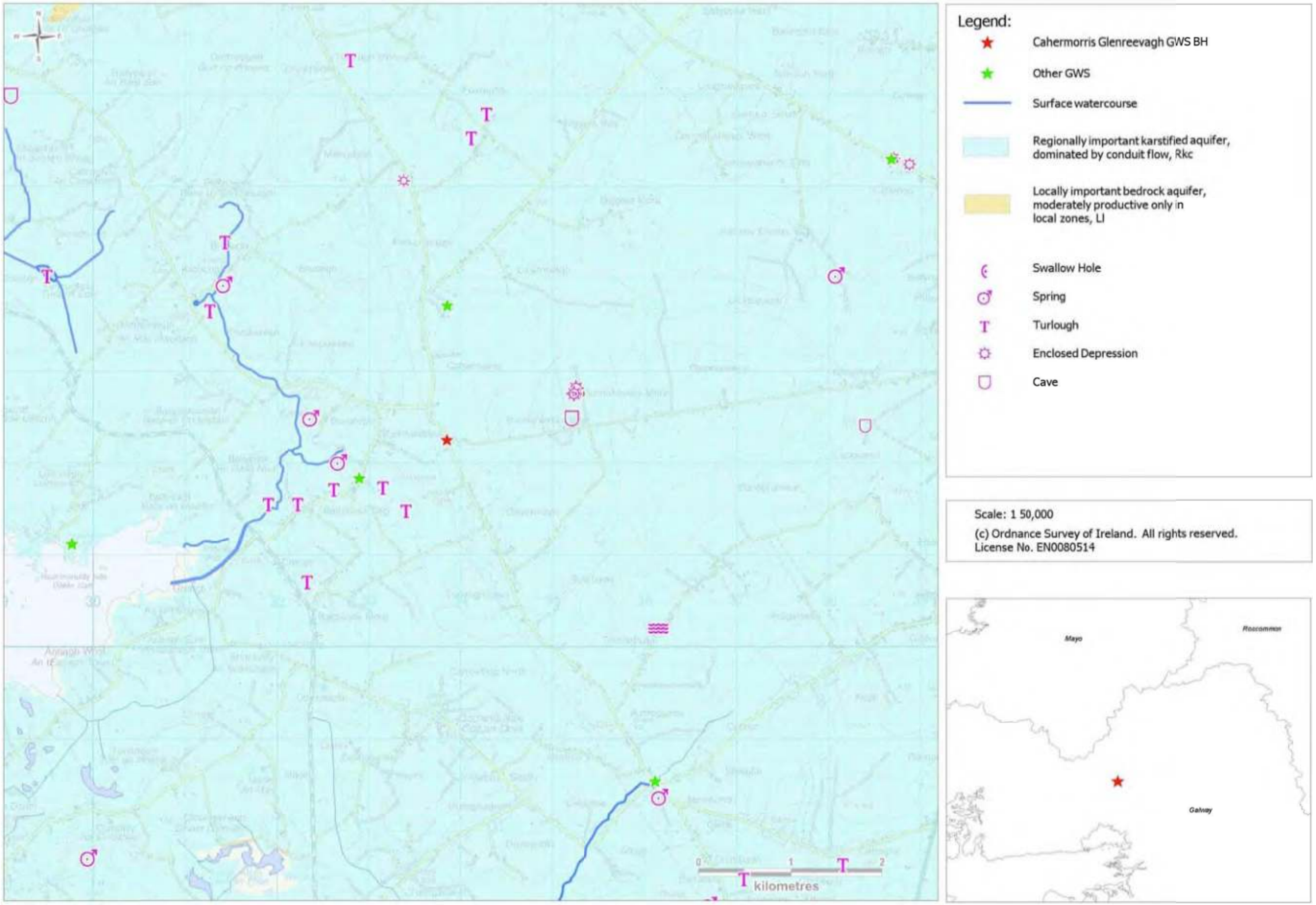


Figure 6: Aquifer Map

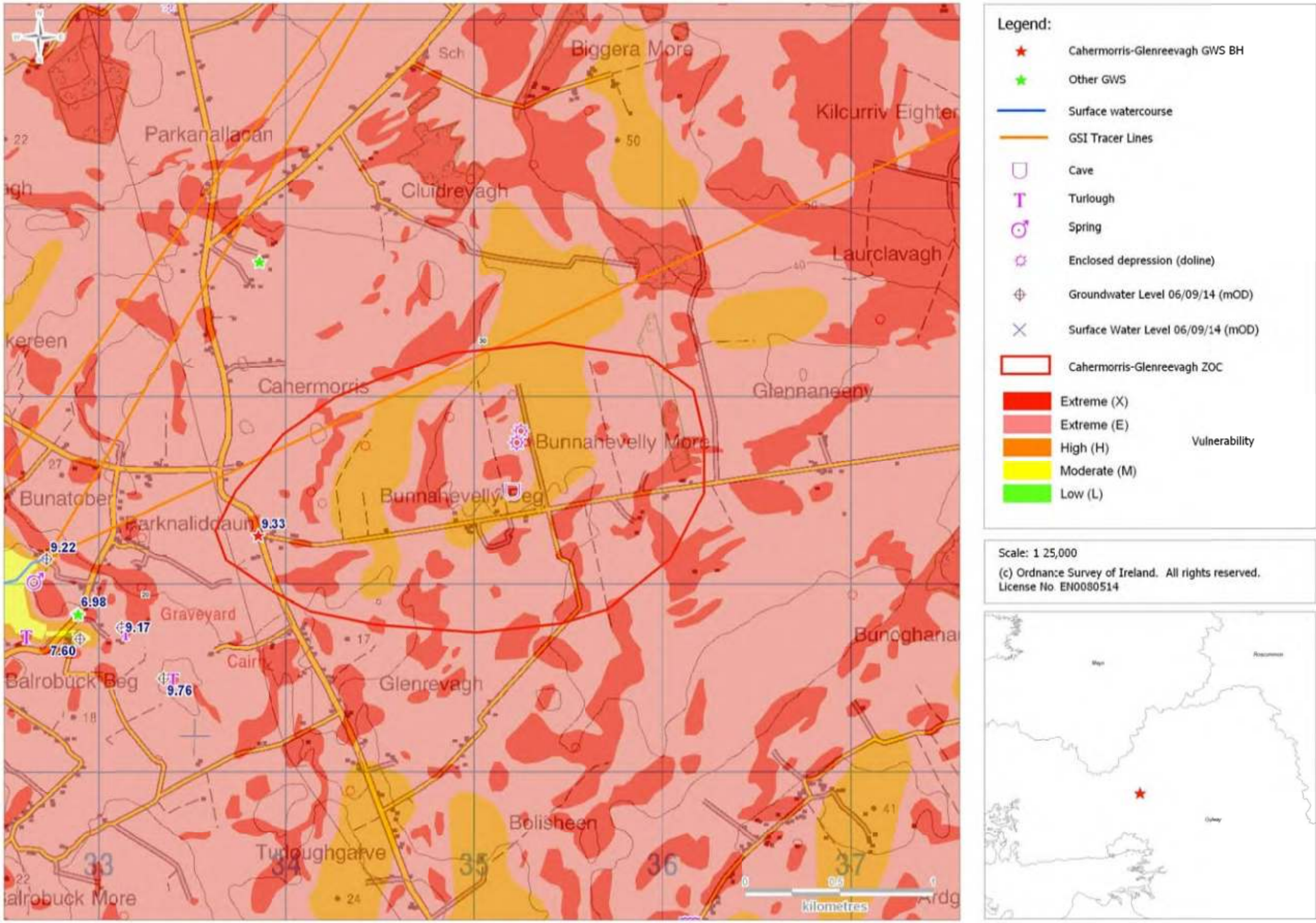


Figure 7: ZOC Boundary

APPENDIX 1

Mini-Pumping Test Data

A brief pumping test was carried out on 19/08/14. The pumping duration was dictated by demand in the system, which is buffered by a 1.5 m^3 pressure cylinder. For the test period the pumping period was 170 seconds, followed by a recovery period of 100 seconds. The duration of the test, combined with the high discharge rate, is deemed adequate to overcome influence of well storage on interpretation.

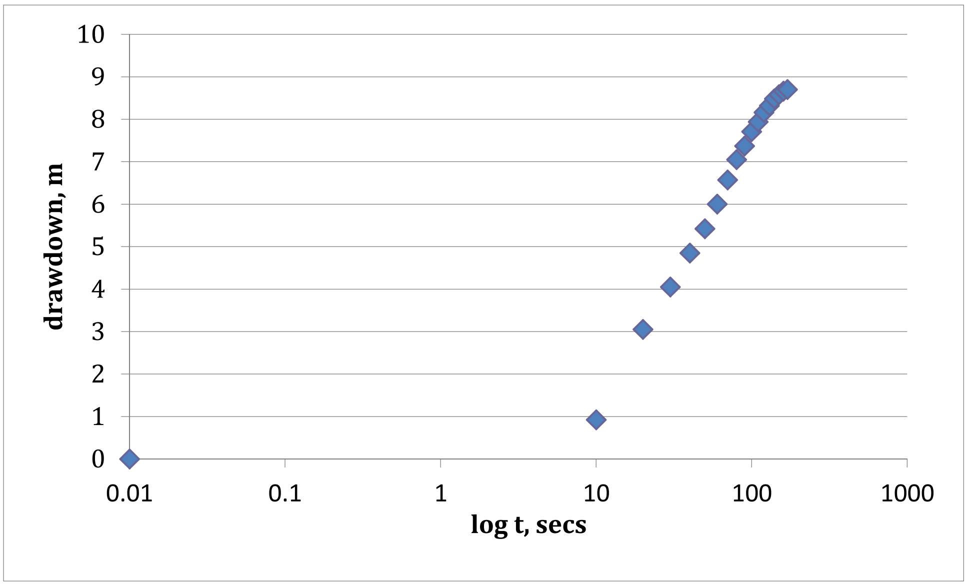
Depth to groundwater level was recorded every 10 seconds throughout; recorded results are shown in Table A1.

Table A1 – Mini-Pumping Test Data

T (secs)	Depth to water table (mbtoc)	Drawdown (m)	Groundwater elevation (mOD)
Pumping @ estimated 238 $m^3 d^{-1}$			
0	16.15	0	9.38
10	17.07	0.92	8.46
20	19.2	3.05	6.33
30	20.2	4.05	5.33
40	21	4.85	4.53
50	21.57	5.42	3.96
60	22.15	6.00	3.38
70	22.72	6.57	2.81
80	23.20	7.05	2.33
90	23.52	7.37	2.01
100	23.86	7.71	1.67
110	24.09	7.94	1.44
120	24.31	8.16	1.22
130	24.47	8.32	1.06
140	24.63	8.48	0.90
150	24.73	8.58	0.80
160	24.81	8.66	0.72
170	24.85	8.70	0.68
Recovery			
180	21.88	5.73	3.65
200	20.82	4.67	4.71
210	19.54	3.39	5.99
220	18.52	2.37	7.01
230	17.57	1.42	7.96
240	17.12	0.97	8.41
250	16.70	0.55	8.83
260	16.39	0.24	9.14
270	16.21	0.06	9.32
280	16.20	0.05	9.33

Time was plotted on a logarithmic scale against drawdown as shown in Graph A1.

Graph A1 – Mini-Pumping Test Data



Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer. The hydraulic conductivity of the aquifer is defined as the volume of water that will move through a unit area of aquifer perpendicular to the flow direction in unit time under a unit hydraulic gradient, and has units of length / time, e.g. m/day. – too complicated for audience – perhaps put in appendix

Transmissivity can be calculated using Jacob's Method (Cooper and Jacob, 1946), using a relationship between discharge and the drawdown over one log cycle of time (equal to 6.79 m in this test):

$$T = (2.3 \times Q) / (4 \times \pi \times \Delta s)$$

$$T = (2.3 \times 238 \text{ m}^3 \text{ d}^{-1}) / (4 \times \pi \times 6.79 \text{ m})$$

$$T = 547.4 \text{ m}^3 \text{ d}^{-1} / 85.33 \text{ m}$$

$$T = 6.4 \text{ m}^2 \text{ d}^{-1}$$

The calculated transmissivity value of 6.4 m^2 d^{-1} is considered to be unrealistically low for a regionally important karst aquifer. Tracing studies in the area have shown groundwater flow velocities in the range 360 m/d – 4800 m/d. The potential error is likely due to the duration of the mini-pumping test, which is too short to overcome well storage.

APPENDIX 2

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

Except where point recharge occurs (*e.g*. at swallow holes), the groundwater vulnerability depends on the type, permeability and thickness of the subsoil. The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown in Table 1.

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 3

Groundwater Body Description

1[st] Draft Clare-Corrib GWB Description June .2004

Clare-Corrib GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km²)
30 Galway, Mayo Roscommon Co.Co's	**Rivers**: Abbert River, Black River, Cregg River, Dalgan River, Grange River, Killaclogher River, Kilshanvy River, River Clare, River Nanny, Sinking River, Togher River, Waterdale River **Lakes**: Corrib	000296 LISNAGEERAGH BOG AND BALLINASTACK TURLOUGH 000247 SLIEVE BOG 001237 BOYOUNAGH TURLOUGH 000224 ALTORE LAKE 000301 LOUGH LURGEEN BOG/GLENAMADDY TURLOUGH 000215 RATHBAUN TURLOUGH 001282 KILTULLAGH LOUGH 000263 DRUMBULCAUN BOG 000297 LOUGH CORRIB 000323 RICHMOND ESKER NATURE RESERVE 000289 KNOCKAVANNY TURLOUGH 000295 LEVALLY LOUGH 001254 DERRINLOUGH BOG 001255 DERRYNAGRAN BOG AND ESKER 000282 KILLOWER TURLOUGH 000331 TURLOUGH O'GALL 000234 BELCLARE TURLOUGH 001319 SUMMERVILLE LOUGH 001294 LOUGH HACKET 001288 KNOCKMAA HILL 000385 ROSTAFF TURLOUGH 002038 CASTLE HACKETT SOUTERRAIN 001322 TURLOUGH MONAGHAN 001788 TURLOUGHCOR 001280 KILLACLOGHER BOG 000307 LOUGH TEE BOG 001709 TIAQUIN BOG 000311 MONIVEA BOG 000287 KILTULLAGH TURLOUGH	~1422

Topography		The land surface is characterised by small hills and low ridges, with ground elevations ranging from 10-160 mAOD. The topographic surface slopes gently westwards. Elevations are highest (100-160 mAOD) in the north (south of Ballyhaunis, west of Ballinlough) and south (just north of Monivea). To the west of a line running north-south from Claremorris to Athenry the elevation is 10-40 mAOD, and to the east of this line, the elevation is 40-70 mAOD.
Geology and Aquifers	**Aquifer categories**	The main aquifer category in this GWB is: **Rk[c]**: Regionally important karstified aquifer dominated by conduit flow. There are some small areas (in the vicinity of Headford) with an aquifer category of: **Ll**: Locally important aquifer which is moderately productive only in local zones.
	Main aquifer lithologies	This GWB is composed primarily of Dinantian Pure Bedded Limestones. There are some small areas (in the vicinity of Headford) of Dinantian Pure Unbedded Limestones.
	Key structures	Few faults are mapped in this area; this may reflect the lack of major variation in the rock lithology. The dips over the GWB area are generally less than 10°, except near faults, where steeper dips result from fault drag. Shallow synclines aligned with the axes in an E-W direction cross the GWB.
	Key properties	**Karstification** is widespread in this GWB. Recorded karst features number 219, but are considered to represent only a fraction of existing features. A histogram showing the different types of karst features currently in the database is provided in Figure 3. **Transmissivity and Storativity:** Well yields are variable, being distributed through all the well yield categories. Using 60 wells located in the GWB, 59% are either "excellent" (>400 m³/d) or "good" (100-400 m³/d), and 23% are either "poor" (<40 m³/d) or "failed", with the remainder "moderate" (40-100 m³/d). The median yield is 131 m³/d. Histograms showing the distribution of well yields and productivity are given in Figures 4 and 5. Note: productivity is an index relating specific capacity to yield - the higher the productivity the higher the transmissivity. Productivity values are distributed throughout all the productivity categories, indicating the variability of the aquifer properties throughout the GWB. Analysis of the areal distribution of the data suggests that it is difficult to predict the aquifer properties in any particular place, with a few possible exceptions. For instance, in the vicinity of Tuam the well yields that are "excellent" are accompanied by several large springs, and just north of Monivea there is a cluster of "failed" wells (also due in part to silting up of the boreholes) which suggests that there may be an increase in yield from south to north across the GWB. Water table levels have high annual variations, which indicates that the storage is low - approximately 0.01-0.02 (Daly, 1985). The springs in the GWB also reflect the low storativity as many of the spring flows rise and fall quickly in response to rainfall events. Furthermore during prolonged drought many springs cease to flow and well yields drop significantly.
	Continues next page	**Groundwater velocity:** Tracer tests indicate variable groundwater velocities. Furthermore, tracer test data illustrates anisotropy in the transmissivity, with higher east-west transmissivity. Groundwater velocities in the E-W domain are in the order of 100-450 m/hr, as evidenced by the following tests: Lassanny Swallow hole to Ballyhaunis spring (440m/hr); Ballyglunin Cave to Aucloggeen Spring (200m/hr). Groundwater velocities in the N-S domain are in the order of 6-35m/hr, as evidenced by the following tests: L.Hackett to Kilcoona spring (35m/hr); Pollnahallia to Bunatober spring (6m/hr). Extensive conduit systems exist, as exemplified by the Ballyglunin Cave system. The mapping of this system indicates conduit development along the N-S and W-E joint sets, with an overall dip to the west (Drew and Daly, 1993).

1st Draft Clare-Corrib GWB Description June .2004

		Groundwater flow directions and gradients: Overall, flow directions are to the southwest, with all groundwater discharging to L. Corrib. Although, there are six surface water catchments within the GWB, a *key* aspect is that groundwater can flow across the surface water divides and beneath surface water channels, as evidenced by the tracer test data. Examples of this key property are listed as follows: 1) water that sinks at Ballyglunin Cave emerges at Aucloggeen Spring, which crosses two surface water catchments. 2) water sinking along an losing stretch of the River Clare remerges as the headwater of the Black River. 3) recent tracing tests in the Ballinlough area of Roscommon indicate a link across the Shannon RBD into the Western RBD, from Coolcam (Roscommon) to Meeltraun (Mayo). 4) water along an losing stretch of the Sinking River flows about 10 km underground to join the River Clare. Drew (1976 (a)) suggests that groundwater flow is concentrated along the axes of shallow synclines. Gradients are variable, irregular due to the uneven distribution of transmissivity and are in the order of 0.01-0.002 (Drew and Daly, 1993; Daly, 1985)).
	Thickness	The Dinantian Pure Bedded Limestones are generally over 100 m thick. Most groundwater flows in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation.
Overlying Strata	**Lithologies**	Till is the dominant subsoil type, covering approximately 65% of the GWB. Cutover Peat comprises 23% of the area, sand/gravel covers approximately 3% and alluvium 2%. A full breakdown of the subsoil lithology is given in Table 1. A large proportion of the sand/gravel forms a random hummocky topography, although long sinuous, braided ridges of sand/gravel (eskers) have also been deposited especially in the east. A small portion of the north eastern area of the GWB around Cloonfad is described under the Roscommon Groundwater Protection Scheme (Lee and Daly, 2003) The till in this area is described as "SILT" (BS 5930), and is classed as "Moderate" permeability. There are also areas of "clayey" till, often underlying areas of raised bog (Drew and Daly, 1993). The thin till cover over much of the west part of the area is generally free draining (Daly, 1985).
	Thickness	East of a line linking Athenry – Tuam – Dunmore, the subsoil is "generally thicker" (Daly, 1985; Drew and Daly, 1993). This is supported by the occurrence of rock at or near surface, which is generally restricted to the western and southwestern part of the GWB. Analysis of the available depth to bedrock borehole data is limited as most of the data are clustered in three main areas: western, northeastern and central (area around Tuam) parts of the GWB. Nevertheless the data show a *general* increase in subsoil thickness in an easterly direction: average depth to bedrock increases from 4 m to 9 m from the west to east. In addition, there are instances of depth to bedrock greater than 20 m around Dunmore (northeast of GWB). However, there are also pockets of deeper till in the southwestern part of the GWB.
	% area aquifer near surface	50% of the GWB to the west of the line Athenry – Tuam – Dunmore is only covered by shallow till. 4% of the total GWB area has rock at or near surface.
	Vulnerability	The vulnerability for a small portion of the north eastern area of the GWB around the area of Cloonfad is described in the County Roscommon Groundwater Protection Scheme (Lee and Daly, 2003). In this area the vulnerability classification is variable dependent on the depth to bedrock. For the rest of the area. *[Information to be added at a later date]*
Recharge	**Main recharge mechanisms**	Both point and diffuse recharge occur in this GWB. Diffuse recharge occurs over the GWB via rainfall percolating through the permeable subsoil. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. Dolines have been recorded even in areas of thick peat deposits (Hickey et al, 2002). Point recharge occurs via many small sinks that are present in the low permeability till areas where the subsoil is breached. Recharge also occurs along 'losing' sections of streams. There are well defined stretches of the River Clare, Sinking River and Abbert River that are losing (Daly, 1985; Drew and Daly, 1993).
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	**Large springs and large known abstractions (m^3/d)**	Large Springs: Corrandulla GWS (6764 m^3/d), Mullacultra GWS (3270 m^3/d), Ballyhaunis WSS (12000 m^3/d), Gortgarrow, Kilbannon GWS (5995 m^3/d), Barnaderg Group Scheme (5000 m^3/d), Tobernanny, Lettera Large known borehole abstractions: Gallagh GWS (523 m^3/d), Roadstone Ltd (227 m^3/d), Rusheens Tuam GWS (114 m^3/d), Belclare (114 m^3/d). *[Information to be added to and checked]*
	Main discharge mechanisms	The main groundwater discharges are to the streams, rivers and large springs found within the body. The large springs at Kilcoona, Bunatober and Aucloggeen and others issue from the bottom of a limestone scarp that is thought to represent an ancient shoreline of L. Corrib. Further these springs are likely to represent overflow springs and deeper groundwater flow discharges to outlets beneath the present day L. Corrib (Drew, 1993). In winter groundwater will fill the turloughs found in the area and partly discharge via the artificial channels that were installed to alleviate flooding.

1st Draft Clare-Corrib GWB Description June .2004

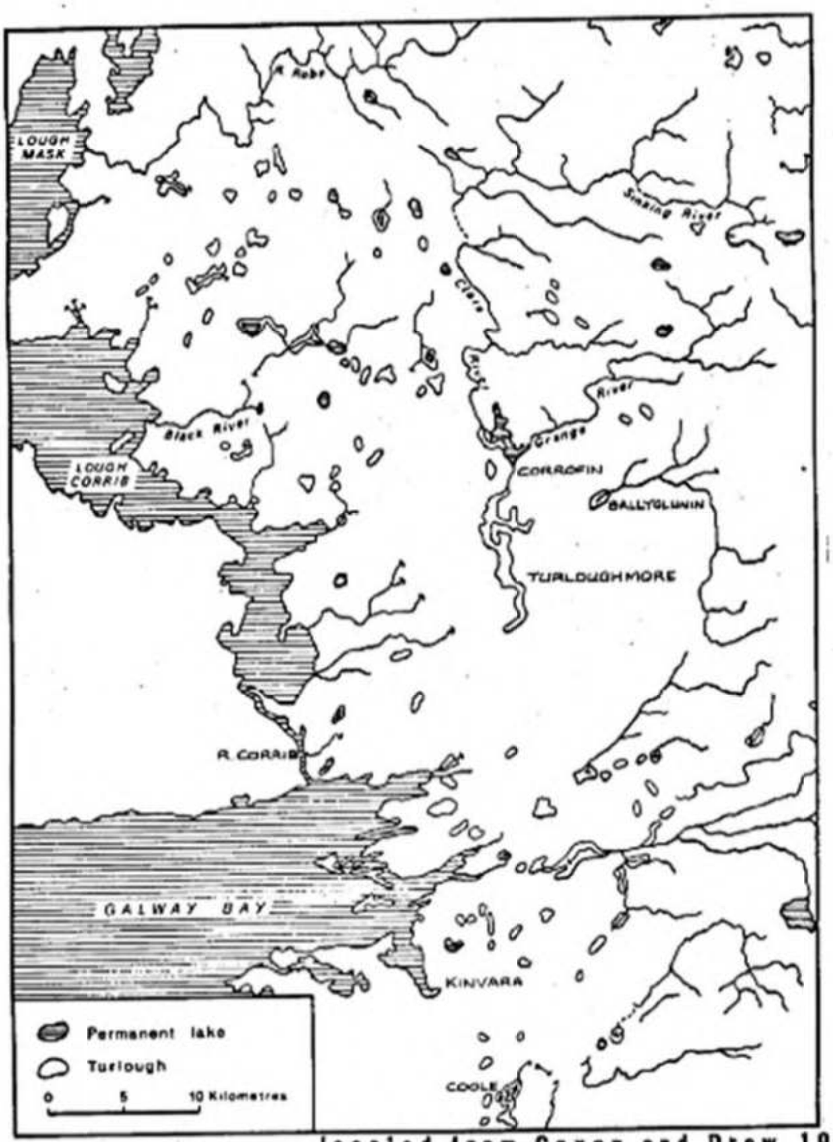
Hydrochemical Signature	The groundwater has a calcium bicarbonate signature. Two groundwater provinces are suggested by Drew and Daly (1993). Firstly, there is a shallow groundwater component that is characterised by high suspended solids and relatively low electrical conductivities (300-400 µS/cm). Springs that are fed by this component typically have a "flashy" throughput and often cease to flow during prolonged drought. Secondly, there is a deeper groundwater component that is characterised by relatively non-turbid groundwater with higher electrical conductivities (>450 µS /cm). Springs fed by this deeper component often have smoother hydrographs where there is a gradual change in discharge. Several large springs comprise both flow components, examples are Lettera, Tobernanny and Bunatober springs.
Groundwater Flow Paths	These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In pure bedded limestones these openings are enlarged by karstification which significantly enhances the permeability of the rock. Karstification can be accentuated along structural features such as fold axes and faults. Groundwater flow through karst areas is extremely complex and difficult to predict. As flow pathways are often determined by discrete conduits, actual flow directions will not necessarily be perpendicular to the assumed water table contours, as shown by several tracing studies (Drew and Daly, 1993). The tracer tests show that groundwater can flow across surface water catchment divides and beneath surface water channels. Flow velocities can be rapid and variable, both spatially and temporally. Rapid groundwater flow velocities indicate that a large proportion of groundwater flow occurs in enlarged conduit systems. Groundwater flow in highly permeable karstified limestones is of a regional scale. Flow path lengths can be up to a several kilometres, for example 9.6 km from Ballyglunin Cave to Aucloggeen Spring. Overall, groundwater flow will be towards the River Clare and L. Corrib, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable.
Groundwater & Surface water interactions	The area is drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Figures 1 and 2 show the pre/post arterial drainage network. According to Coxon and Drew (1983), much of the current stream network is a storm runoff system that is inactive during summer months. Thus, prior to drainage, streams sank underground via the turloughs present in the GWB. Many of the streams have well defined losing stretches where they lose water to the underground system (Daly, 1985). There is a high degree of interconnection between groundwater and surface water in karstified limestone areas such as in this GWB. Even though large areas of peat and tills overlie the body, collapse features in these areas provide a direct connection between the surface and the groundwater systems. The close interaction between surface water and groundwater in karstified aquifers is reflected in their closely linked water quality. Any contamination of surface water is rapidly transported into the groundwater system, and vice versa. Furthermore, there are a number of terrestrial ecosystems within this GWB with varying dependence on groundwater.

1st Draft Clare-Corrib GWB Description June .2004

Conceptual model	• The north, south and west groundwater divides of this GWB are topographic highs that coincide with surface water catchment boundaries. It is bounded to the east by Lough Corrib. • The topography is undulating with ground elevations ranging from 10-160 mAOD. A large proportion of the body is overlain by till, which thickens in an easterly direction. • The area is principally drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Much of the current stream network is a storm runoff system and is inactive during summer months. Prior to artificial drainage, streams sank underground via a few turlough sinks in the GWB. • Within the GWB, surface water catchments are often bypassed by groundwater flowing beneath surface water channels and across surface water catchment divides. • A large number of karst features occur within the body. These include turloughs, caves, dolines, swallow holes and springs. • The GWB is composed primarily of high transmissivity karstified limestone (**Rk**^{c}). Transmissivity and well yields are variable. Storage in the GWB is low. • Groundwater flows through a network of solutionally enlarged bedding planes, fissures and conduits. • Rapid groundwater flow velocities have been recorded through groundwater tracing. The tracing indicates an anisotropy in the transmissivity, with faster groundwater flow velocities and higher transmissivity in an E-W direction, which may be linked to shallow E-W trending synclinal axes and steeper E-W hydraulic gradients. • Recharge in this GWB occurs via losing streams, point and diffuse mechanisms. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. • The groundwater in this body is generally unconfined but may become locally confined beneath thick, low permeability subsoil. Most of the groundwater flow occurs in the upper epikarstic layer and in a zone of interconnected solutionally enlarge bedding planes and fissures, generally extending to a depth of 30 m. • In general, the degree of interconnection in karstic systems is high and they support regional scale flow systems. Flow paths have been measured up to 10 kilometres in length. • Some areas in this GWB are of extreme vulnerability due to the thin nature of the subsoil, as well as the frequency of karst features, allowing point recharge. Groundwater storage in karstified bedrock is low and the potential for contaminant attenuation in such aquifers is limited. • The main discharges are to the rivers, large springs and L. Corrib. In winter groundwater discharges to the many turloughs and transmitted via the artificial channels that were installed to alleviate flooding. • There is a high degree of interaction between surface water and groundwater in this GWB. There are a number of terrestrial ecosystems within this GWB which have varying dependence on groundwater. • There are potentially two groundwater provinces within the GWB but this is uncertain. The groundwater has a calcium bicarbonate signature.
Attachments	Figures 1, 2, 3, 4 and 5.
Instrumentation	**Stream gauges:** 30002, 30003, 30004, 30006, 30007, 30010, 30011, 30012, 30013, 30014, 30015, 30020, 30022, 30023, 30024, 30025, 30026, 30029, 30030, 30032, 30040, 30045, 30053, 30055, 30071, 30101, 30103. **EPA Water Level Monitoring boreholes:** Lackagh, GAL287, Tuam (Coca Cola), GAL291, Shrule, MAY085 **EPA Representative Monitoring points:**
Information Sources	Daly, D. (1995) *A report on the Flooding in the Glenamaddy area.* Groundwater Section Report File 2.2.7. 34pp. Daly, D. (1992) *A report on the Flooding in the Claregalway area.* Groundwater Section Report File 2.2.7. 12pp. Daly, D. (1985) *Groundwater in County Galway with particular reference to its Protection from Pollution.* Geological Survey of Ireland report for Galway County Council. 98pp. Drew D.P. and Daly D. (1993) *Groundwater and Karstification in Mid-Galway, South Mayo and North Clare.* A Joint Report: Department of Geography, Trinity College Dublin and Groundwater Section, Geological Survey of Ireland. Geological Survey of Ireland Report Series 93/3 (Groundwater), 86 pp Drew, D.P. (1973a) *Hydrogeology of the north Co. Galway – south Co. Mayo lowland karst area, Western Ireland.* International Speleology 1973, III, Sub –section Ca. Drew, D.P. (1973b). *Ballyglunin core Co. Galway and the hydrology of the surrounding area.* Irish Geography Vol. 6, No. 5. pp 610-617. Doak, M. (1995) *The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland.* Unpublished M.Sc. thesis, Sligo Regional Technical College. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) *Lowland Karst of North Roscommon and Westmeath.* International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report. Lee, M. & Daly D. (2003) *County Roscommon Groundwater Protection Scheme.* Main Report. Roscommon County Council & Geological Survey of Ireland, 54pp. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) Lowland Karst of North Roscommon and Westmeath. International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

1st Draft Clare-Corrib GWB Description June .2004

Figure 1 Pre Arterial Drainage.



(copied from Coxon and Drew, 1983)

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Figure 2 Post Arterial Drainage

[copied from Coxon and Drew, 1983]

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
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear (in press).

APPENDIX 5

Laboratory Certificate of Analysis

Complete Laboratory Solutions

Complete Laboratory Solutions
Ros Muc, Co. Galway.
[Tel] 091 574355
[Fax] 091 574356
[Email] services@cls.ie
[web] www.completelabsolutions.com

Client : Tommy Greaney
Cahermorris Glenreevagh GWS
15 Woodquay
Galway
Co. Galway

Report No. : 234465
Date of Receipt : 24/07/2014
Start Date of Analysis : 24/07/2014
Date of Report : 18/08/2014
Order Number :
Sample taken by : CLS

CERTIFICATE OF ANALYSIS

Lab No	Sample Description	Test	Result	Units
531928	Cahermorris Glenreevagh GWS. 24/07/14	BOD	<1	mg/l
		COD	<10	mg/l
		Turbidity	0.2	N.T.U.
		pH	7.2	pH Units
		Conductivity @20C	575	uS/cm
		Alkalinity, total	350	mg/l CaCO3
		Sodium, total	13	mg/l
		Chloride	20.7	mg/l
		Ammonium as NH4	<0.01	mg/l
		Nitrate as NO3	8.11	mg/l
		Nitrite as NO2	<0.017	mg/l
		Dissolved Oxygen (%)	80	%Sat
		Potassium, total	4	mg/l
		Total Hardness (Kone)	368	mg/l CaCO3
		Magnesium, total	8	mg/l
		Colour, apparent	<4	mg/l Pt Co
		Sulphate	11	mg/l
		Orthophosphate as PO4-P	0.035	mg/l
		Calcium, total	110	mg/l
		Aluminium, dissolved	<2	ug/l
		Iron, dissolved	<10	ug/l
		Manganese, dissolved	<5	ug/l
		Copper, dissolved	<1	ug/l
		Lead, dissolved	<0.5	ug/l
		Chromium, dissolved	<0.5	ug/l
		Nickel, dissolved	<0.5	ug/l
		Cadmium, dissolved	<0.5	ug/l
		Arsenic, dissolved	<0.5	ug/l
		Zinc, dissolved	<5	ug/l
		Silica	2.14	mg/l
		Barium, dissolved	27	ug/l
		TOC	1.23	mg/L
		Clostridium Perfringens in Water	0	cfu/100ml
		Strontium, dissolved	571	ug/l
		E coli (Filtration) (Environmental Waters)	17	cfu/100ml
		Total Coliforms (Filtration) (Environmental Waters)	17	cfu/100ml
		Fluoride by ISE	0.2	mg/l

INAB ISO 17025 ACCREDITED TESTING DETAILED IN SCOPE REG NO 109T

Approved by: Barbara Lee
Barbara Lee
Environmental Scientist

See page 2 for test specifications and accreditation status
This report only relates to items tested and shall not be reproduced but in full with the permission of Complete Laboratory Solutions.

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APPENDIX 6

Zone of Contribution Boundary Calculations

Downgradient Distance

The abstraction itself will invoke a cone of depression which may draw groundwater deemed to be downgradient into the borehole. The calculation uses the uniform flow equation (Todd, 1980), which is:

$$\text{Down-gradient distance} = Q / (2\pi * T * i)$$

where

Q is the pumping rate: 238 m^3/d.

T is Transmissivity (estimated as being between 360 – 4,800 $m^2 d^{-1}$ based on GSI tracer studies. A value of 360 $m^2 d^{-1}$ was used in calculations).

i is the background non-pumping hydraulic gradient, taken as that between Caherlea and Cahermorris-Glenreevagh (0.0004 m m^{-1}).

Downgradient distance is estimated to be approximately 263 m based on calculations using data from the desk study.

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Geological Survey Ireland

Establishment of Groundwater Zones of Contribution

Cluide - Cahermorris Group Water Scheme, Co. Galway

June 2018

Prepared by:

Laura McGrath, Alison Orr and Les Brown, Arup

Geological Survey Ireland

(Monica Lee, Caoimhe Hickey, Taly Hunter Williams, Sophie O'Connor)

And with assistance from:

Cluide - Cahermorris Group Water Scheme

National Federation of Group Water Schemes

ARUP

Acknowledgements

We would like to acknowledge Martin Fitzpatrick for his input and provision of data.

Document Information

Project title: Establishment of Groundwater Zone of Contribution

Current Document version 2.0

Date 29/06/2018

Prepared By	Date	Comment
Laura McGrath, Alison Orr and Les Brown	29/06/2018	

Reviewed By	Date	Comment
Taly Hunter Williams	29/06/2018	

Approved By	Date	Comment
Taly Hunter Williams	29/06/2018	

Version History

Ver. No.	Ver. Date	Comment	Revised By
1.0	13/04/2018		
2.0	29/06/2018	Update to THM threshold	Alison Orr

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 the Cluide - Cahermorris 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). A glossary of acronyms and terms used in this report is included in the Appendices.

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Diagrams

Photos

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Appendices

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 the overlying soil and subsoil; thick, impermeable clay soil and subsoil provide good protection while thin gravel will provide limited protection. Therefore variation in subsoil type and thickness is 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. 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.

Cluide - Cahermorris GWS (NFGWS ref no g052) is supplied by a borehole interacting with groundwater that flows through fractures and conduits within a Regionally Important Karstified limestone aquifer. The GWS abstracts 68 m^3/d.

Geological Survey of Ireland, 2000.

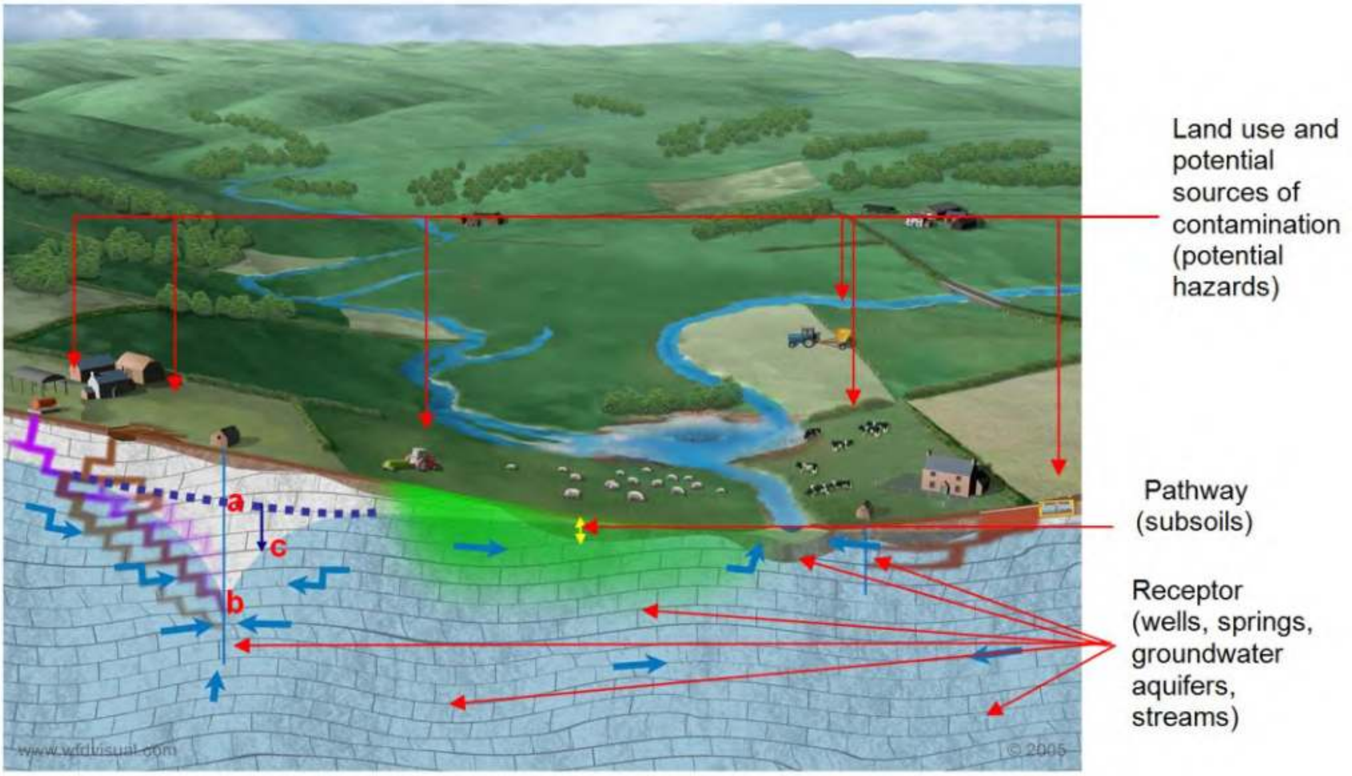

Diagram 1. Rural Landscape highlighting the Interaction between Surface Water, Groundwater and Potential Hazards

2. Location, Site Description, Supply Details and Wellhead Protection

The zone of contribution (ZOC) for the Cluide - Cahermorris Group Water Scheme (GWS) has been delineated according to the principles and methodologies set out in 'Groundwater Protection Schemes' and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

Cluide – Cahermorris GWS is supplied from a borehole located between Cahermorris and Parkanallacan, approximately 7.9 km southeast of Headford (Figure 1). The borehole is located within the pump house. The top of the borehole PVC casing is raised above the pump house floor and is open (Photo 2). The pump and associated tubing is supported from a metal structure above the borehole. The open borehole presents the possibility for contamination such as vermin to enter the borehole.

The surrounding area is used for agricultural and grazing. Roughly 25 years ago grass was present in the pumped water following slurry spreading which was carried out approximately 170 m upgradient of the borehole. After this incident, slurry spreading stopped and no grass has been present since. There is a cluster of single dwellings in close proximity to the borehole which are likely to have a septic tank each. The nearest farmyard is approximately 200 m away (Diagram 2, Photograph 1).

The pump is located approximately 41 meters (135 feet) below ground level and pumps a reported average yield of approximately 68 m^3/d. Yield from the borehole is not seasonally influenced and the scheme has not experienced water supply difficulties during extended periods of dry weather. Drilling of the six inch borehole took place in 1975 by Mulcairs Well Drilling, but the scheme did not become operational until 1977. The borehole is approximately 61 meters (200 feet) below ground level. Bedrock was encountered at 1.8 m below ground level (6 foot). During the site visit by Arup, the GSI and the NFGWS in May 2017 groundwater was recorded at 15.9 m below top of casing when the pump was off and 18.12 m below top of casing when the pump was turned on.

The scheme is an automatic pressurised system. A Pedrolo pump activates when water pressure is between 35 and 55 psi and pumps 10 to 12 hours per day directly into the distribution network.

The disinfection system includes ultra-violet (UV) treatment consisting of two UV lights which were recently tested. Chlorination is not included in the treatment, however the scheme is applying for a validated UV and chlorination system. Treated water quality is tested regularly.

Summary details are presented in **Table 1.**

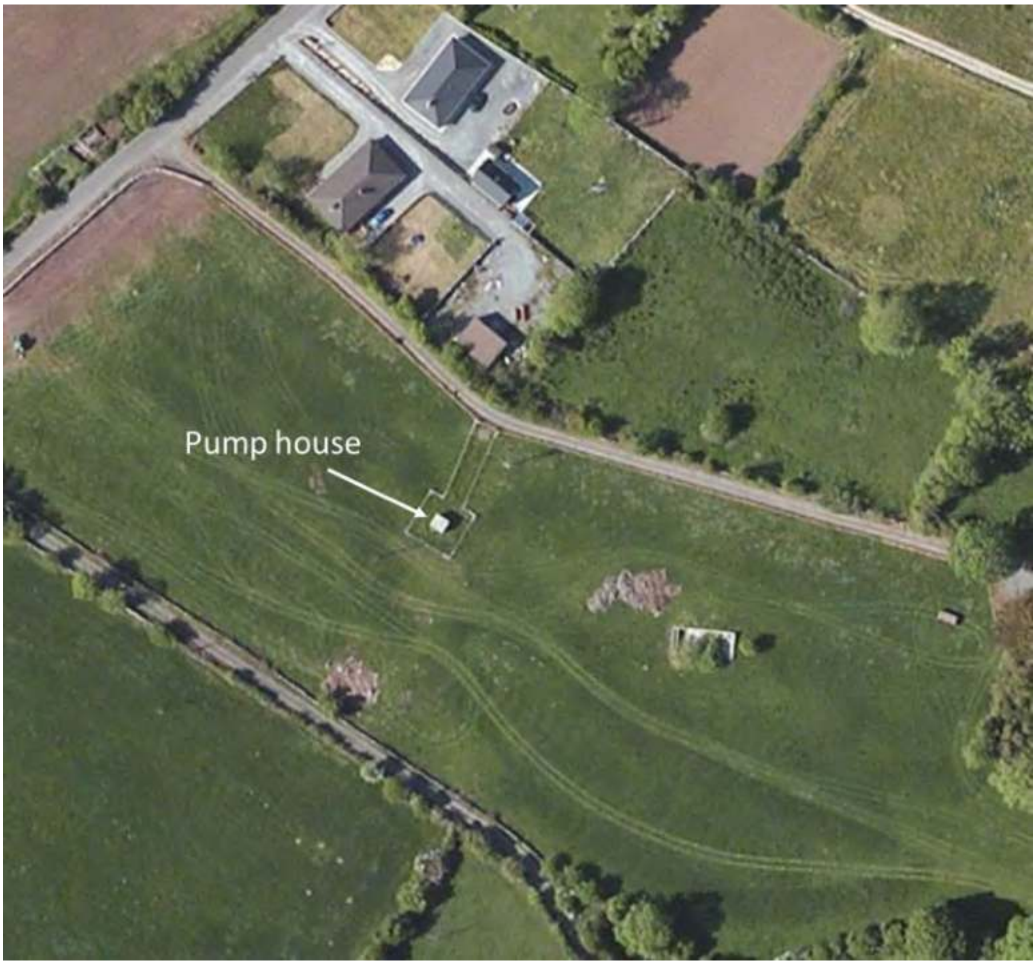

Diagram 2. Aerial photo showing location of GWS abstraction point

Photo 1 Cluide - Cahermorris GWS borehole pump house

Photo 2 Cluide - Cahermorris GWS borehole

Table 1. Water Supply Details

NFGWS No. g052	Cluide - Cahermorris Borehole
Grid reference	ITM: 533675.05, 743800.552
Townland	Cahermorris
Source type	Borehole
Drilled	1975
Drilling Contractor	Mulcair Drilling, Loughrea
Owner	Cluide - Cahermorris GWS
Elevation in metres above Ordnance Datum	c. 30 m aOD (Estimated from OSI 1:2,000 Scale Map)
Total depth (m)	~61 m (200 ft)
Construction details	6 inch casing installed to unknown depth. Drilled into bedrock.
Depth to rock in metres below ground level	c. 1.8 m bgl (6 ft)
Inflow zones (water strikes) mbgl	Water hit at c. 27 mbgl (90 ft)
Static water level (SWL) (m below top of casing) on site visit	15.9
Pumping water level (PWL) (m below top of casing) on site visit	18.12 (unknown pumping rate)
Pump intake depth (m bgl)	41.2 (135 ft)
Current abstraction rate (GWS)	68.1 m^3/d (based on information provided by caretaker).
Number of Connections	47 domestic and 18 non-domestic
Reported yield (m^3/d)	GSI Well Database Yield[1]: 189 m^3/day
Specific Capacity ($m^3/d/m$)	Not available
Transmissivity (m^2/d)	Not available

[1] GSI website www.gsi.ie

3. Physical Characteristics and Hydrogeological Considerations

3.1. Physical characteristics of the area

An overview of the relevant information on rainfall, land use, topography, hydrology and geology for the area around the GWS is provided in Table 2.

Table 2. Physical Characteristics of the Area of Interest

	GWS Well	Description/Comments
Topography (**Figure 1 & Figure 2**)	The borehole is located at approximately 30m above Ordnance Datum (aOD). The land is relatively flat and ranges from 50 to 22 m OD within 3.2 km. A small hilly area rising up to 167 m aOD is located approximately 4.5 km north of the borehole.	
Land use	The land use is dominated by grassland and fields used for cattle and horse grazing. There are 15 one-off rural dwellings within 250 m of the borehole. Additionally, there are clusters of one-off rural dwellings located within 2 km of the borehole.	
Surface Hydrology (**Figure 1 & Figure 2**)	There are no surface water features upgradient of the borehole. Two turloughs are located within the ZOC approximately 2.1 km north-north-east of the borehole. The closest surface water feature is the Ballinduff Stream located approximately 1.8 km south east of the borehole and possibly associated with three springs as well as a number of turloughs. An unmapped spring and stream are located 400 m to 500 m from the borehole. These are dry during the summer.	
Topsoil http://gis.epa.ie/envision	The soils surrounding the borehole are mapped as deep well-drained soils with numerous areas of rocky material.	
Subsoil (**Figure 3**) www.gsi.ie/mapping	The subsoils are dominated by till (boulder clay) derived mainly from limestone with numerous areas of karstified rock at or near surface.	
Groundwater Vulnerability (**Figure 4**) www.gsi.ie/mapping	The area around the borehole is mapped as Extreme (**E**) vulnerability. Areas of rock soil or subsoil are classified as Rock at or Near the Surface or Karst (**X**) vulnerability. There are areas of High (**H**) vulnerability mainly north and east of the borehole	
Geology (**Figure 5**) www.gsi.ie/mapping	The water supply borehole is located in pure bedded limestone bedrock which is part of the Burren Formation.	
Aquifer Classification (**Figure 6**) www.gsi.ie/mapping	The Dinantian Pure Bedded Limestone is classified as a Regionally Important Aquifer which is dominated by karstified conduit flow (**Rk_c**). The pure bedded limestones are generally over 100 m thick with most groundwater flow in an epikarstic layer a couple of meters thick as well as in a zone of interconnected fissures and conduits that extend approximately 30m below this. (www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)	
Groundwater Body (GWB) www.wfdireland.ie	The borehole is located in the Clare-Corrib groundwater body which is categorised as having 'good' status but has a water framework risk score of 'at risk of not achieving good status' (www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)	
Recharge Coefficient (**Appendix 2**)	60% to 85%	Well drained soils overlying high permeability subsoils and areas of karstified rock at or near surface allow a high proportion of effective rainfall to percolate. This aquifer type is considered to have sufficient capacity to accept all recharge compared to less productive, poorer aquifers.
Recharge (mm/yr) www.gsi.ie/mapping	514	

3.2. Hydrochemistry and water quality

Cluide - Cahermorris drinking water returns for the years 2008 to 2015 and GWS rural monitoring data (21/11/2016 and 24/7/2017) were used to assess the hydrochemistry and water quality for Cluide - Cahermorris GWS. Two untreated water samples have been analysed, one in November 2016 and another in July 2017. The sample in 2016 was analysed for a limited suite of parameters including iron and manganese but did not include bacterial analysis. All available water quality data are presented in **Appendix 3**.

The data are summarised in **Table 3** (treated sample) and **Table 4** (untreated samples), where they have been compared to the drinking water limits (DWL) from the Drinking Water Regulations (S.I. No. 122 of 2014) and/or threshold values (TV) from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010).

Table 3. Key Hydrochemistry and Water Quality values in treated water samples

Parameter	No. of samples	Min	Max	Average	Drinking Water Limit (DWL) or Threshold Value (TV)
Electrical Conductivity (µS/cm)	48	465	729	624	800 (TV), 2,500 (DWL)
pH (laboratory)	48	6.80	7.70	7.21	6.5 – 9.5 (DWL)
Total Coliforms (MPN[2]/100 ml)	17	0	0	0	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	17	0	0	0	0 (DWL)
Nitrate (mg/l NO_3)	39	3.40	39.40	15.32	50 (DWL) 37.5 (TV)
Chloride (mg/l)	10	13.50	22.60	17.54	250 (DWL), 24 (TV)
Ammonium (mg/l NH_4)	47	0.01	0.11	0.03	0.3 (DWL), 0.225 [0.175 as N] (TV)
Iron (µg/l)	49	0.00	50.00	27.57	200 (DWL)
Manganese (µg/l)	41	0.00	20.00	11.90	50 (DWL)
Potassium:sodium ratio	Not recorded				

[2] MPN is most probable number

Table 4. Key Hydrochemistry and Water Quality values in untreated water samples

Parameter	No. of samples	Result	Drinking Water Limit (DWL) or Threshold Value (TV)
Total Hardness (mg/l as $CaCO_3$)	1	327.3	[-]
Electrical Conductivity (μS/cm)	1	588	800 (TV), 2,500 (DWL)
pH (laboratory)	1	6.9	6.5 – 9.5 (DWL)
Total Coliforms (MPN[3]/100 ml)	1	**1203**	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	1	**727**	0 (DWL)
Nitrate (mg/l NO_3)	1	15.27	50 (DWL) 37.5 (TV)
Chloride (mg/l)	1	17.05	250 (DWL), 24 (TV)
Ammonium (mg/l NH_4)	1	0.01	0.3 (DWL), 0.225 [0.175 as N] (TV)
Iron (μg/l)	2	0	200 (DWL)
Manganese (μg/l)	2	0	50 (DWL)
Potassium:sodium ratio	1	0.26	0.4 (indicator)

Available data indicate that the water is 'hard', which is typical of limestone aquifers, since limestone dissolves readily into the groundwater. The average field pH is approximately neutral. Electrical conductivity is variable, which suggests a quick response to rainfall and contributions of rapid point recharge into the groundwater system.

Nitrate, ammonium, iron and manganese concentrations are generally low, and well below their respective TVs and DWLs. This may be reflective of relatively low land use pressures.

The full chemical analysis undertaken as part of this study did not show any other naturally-occurring elements dissolved into the groundwater at concentrations that would cause concern for human health.

A raw water sample was collected from the well on 24/7/2017 and analysed for a range of chemical and bacteriological parameters (**Table 3**). Total coliform concentrations were ten times that of the gross contamination limit and faecal coliform concentrations were 7

[3] MPN is most probable number

times higher the gross contamination limit. These results highlight that the abstraction is vulnerable to bacterial contamination and the need to further analysis of the untreated water. The source of the contamination may be from nearby organic sources including farmyard manure, slurry and dirty water or from on-site wastewater treatment systems (such as septic tanks or similar).

4. Zone of Contribution

4.1 Conceptual Model

The current understanding of the geological and hydrogeological setting is given as follows and as shown schematically in **Diagram 3**.

The groundwater is replenished by rainfall percolating diffusely though the soils and subsoils, or directly where the bedrock is exposed at the surface, down to the water table in the bedrock. Where present the subsoils are thin and moderately permeable, thus allowing a good proportion of rainfall to percolate downwards. Over much of the zone of contribution the thin or absent subsoil provides little protection to the underlying aquifer from infiltrating contamination and the aquifer vulnerability is classified as Extreme (E) or Rock at or Near Surface or Karst (X).

The Cluide - Cahermorris GWS is supplied by one borehole which abstracts groundwater from the underlying limestone bedrock. The limestone is a Regionally Important Aquifer which is dominated by karstified conduit flow (Rk_c). Significant flow paths are likely to exist along conduits and fractures within the bedrock.

The general groundwater flow direction within the zone of contribution is from the north east to south west based on tracer tests reported by the GSI[4] (Figure 2). When the infiltrating water reaches the bedrock aquifer it easily enters the groundwater system and travels through the conduit and fracture network. There are two turloughs in the eastern part of the zone of contribution which suggest the presence of conduits with the capacity to transmit large flows in that area. It is also an area within which recharge is likely to recharge directly and rapidly into the bedrock and therefore may be a key area for contamination to enter the aquifer.

[4] GSI website www.gsi.ie

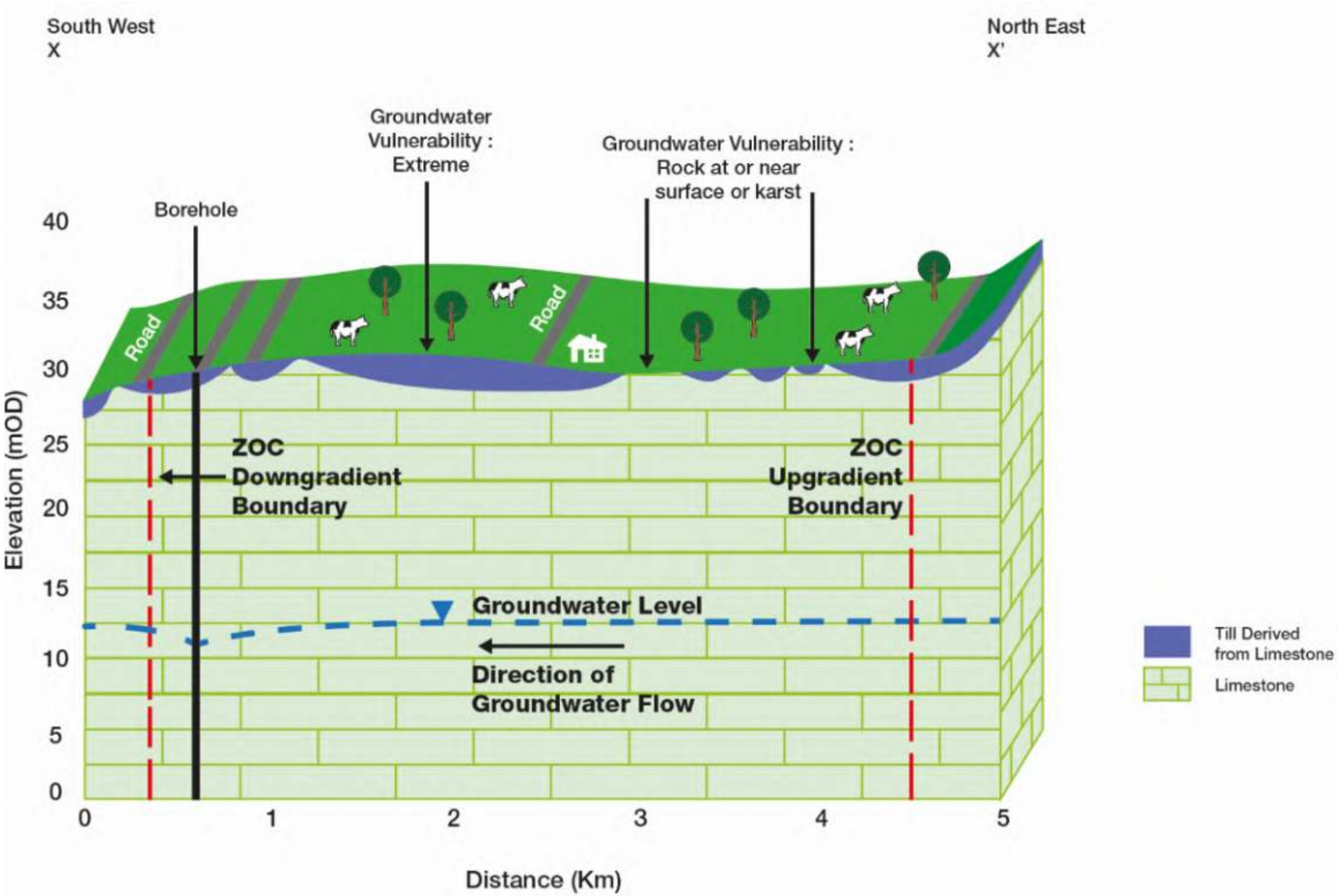

Diagram 3. Conceptual model of groundwater flow

4.2. Boundaries

The Zone of Contribution (ZOC) delineated for Cluide - Cahermorris GWS is based mainly on a combination of hydrogeological mapping and inferences.

The **northern** boundary is based on an assessment of the local groundwater flow. The boundary extends longitudinally to encompass the direction of flow indicated by tracer tests.

The **western** and **eastern** boundaries are based on the topography and the tracer tests. The **eastern** boundary extends further to the east to take into acount the elevated topography assuming that the groundwater reflects the topography.

The **southern** boundary is approximately 200m downgradient of the abstraction which is a conservative measure to ensure adequate protection for the abstraction. It is also supported by calculations based on the groundwater gradient, aquifer permeability and abstraction rate as well as topography. The calculations are presented in **Appendix 5**.

4.3. Recharge and water balance

The recharge and water balance calculations are used to support the hydrogeological mapping and to confirm that the ZOC delineated is big enough to supply the quantity of water at the source.

The average daily abstraction from the GWS source is 68 m^3/day. An additional 50% was added onto this to account for uncertainity which increases the average abstraction rate to 102 m^3/day. Members of the GWS advised the borehole does not dry up during extended periods of dry weather and when running at maximum capacity. It is therefore assumed that this value is representative.

The recharge rate is assumed to be 514 mm/yr based on the recharge rate for the area available from GSI data. The area required to supply the pumping rate is estimated to be

0.07 km^2 (7.26 ha). Refer to calculations in Appendix 5. The mapped ZOC area is 6.5 km^2 as a conservative approach to account for potential longer localised flow paths assocaited with Regionally Important karstified aquifers.

5. Conclusions

Cluide - Cahermorris GWS is sourced by a borehole from which 68 m^3/d is pumped over 10-12 hours per day from a karstified limestone aquifer. Yield from the borehole is not seasonally influenced and the scheme has not experienced water difficulties during dry weather.

Rainfall infiltrates to the groundwater system diffusely through the limestone till and directly where the bedrock is exposed at the surface. The ZOC, which encompasses an area of 6.5 km^2, is defined based on the regional groundwater flow direction and topography. Groundwater in the karstified limestone flows through the network of conduits and fractures. Two turloughs within the ZOC may be connected to the borehole.

The available water quality data suggest the borehole may be susceptible to bacterial contamination. The source of the detected bacterial contamination is likely to be from nearby organic sources including farmyard manure, slurry and dirty water or from on-site wastewater treatment systems.

Based on the collection and analysis of the available data for this project, it is recognised that this scale of study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Cluide - Cahermorris GWS with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. It is possible that additional areas are also contributing to the borehole so the GWS may want to consider further hydrogeological work/measures if water quality issues persist, which will provide supporting evidence as to the most likely areas that should be included within the ZOC.

6. Recommendations

Essential:

- A regular survey of water quality parameters of untreated water that would include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The results should be shared with the GSI. The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist.
- A cap should be installed on the borehole.
- Chlorination should be included as part of the treatment process

Desirable:

- Tracer testing at the two turloughs along the western boundary of the ZOC, and turlough Monaghan, currently outside the ZOC, would be useful to test the connection between the turloughs and the borehole as well as confirm groundwater flow directions and indicate flow rates.
- The site could be revisited during the winter time to assess the catchment area in wet conditions.
- A dip tube would provide access to measure the groundwater level.

Other:

- The following EPA guidelines may serve as future useful reference documents for the GWS:
    - EPA Guidance on Landspreading of Organic Waste[5]
    - 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[6].

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[5] http://www.epa.ie/pubs/advice/waste/waste/EPA_landspread_organic_waste_guide.pdf
[6] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp

- 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[7].
- EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[8]

[7] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo
[8] http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html#.UpNR8eJ9KEo

7. References

DELG/EPA/GSI, 1999. Groundwater Protection Schemes. Dept. of the Environment & Local Government; Environmental Protection Agency; Geological Survey of Ireland.

EPA website www.epa.ie

EPA (2004) Guidance on Landspreading of Organic Waste.

EPA (2011) Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources.

EPA (2011) Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans.

EPA (2013) Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

European Communities (Drinking Water) Regulations (2014). S.I. No. 122 of 2014.

European Communities Environmental Objectives (Groundwater) Regulations (2010) S.I. No. 9 of 2010.

GSI website www.gsi.ie

Hunter Williams, N.H., Misstear, B.D., Daly, D. and Lee, M. (2013) Development of a national groundwater recharge map for the Republic of Ireland. Quarterly Journal of Engineering Geology and Hydrogeology. Vol. 46, No. 4, pp. 493-506.

IGI (2007) Guidelines for Drilling Wells for Private Water Supplies (March 2007). http://www.igi.ie/publications/codes-guidelines.htm

Figures

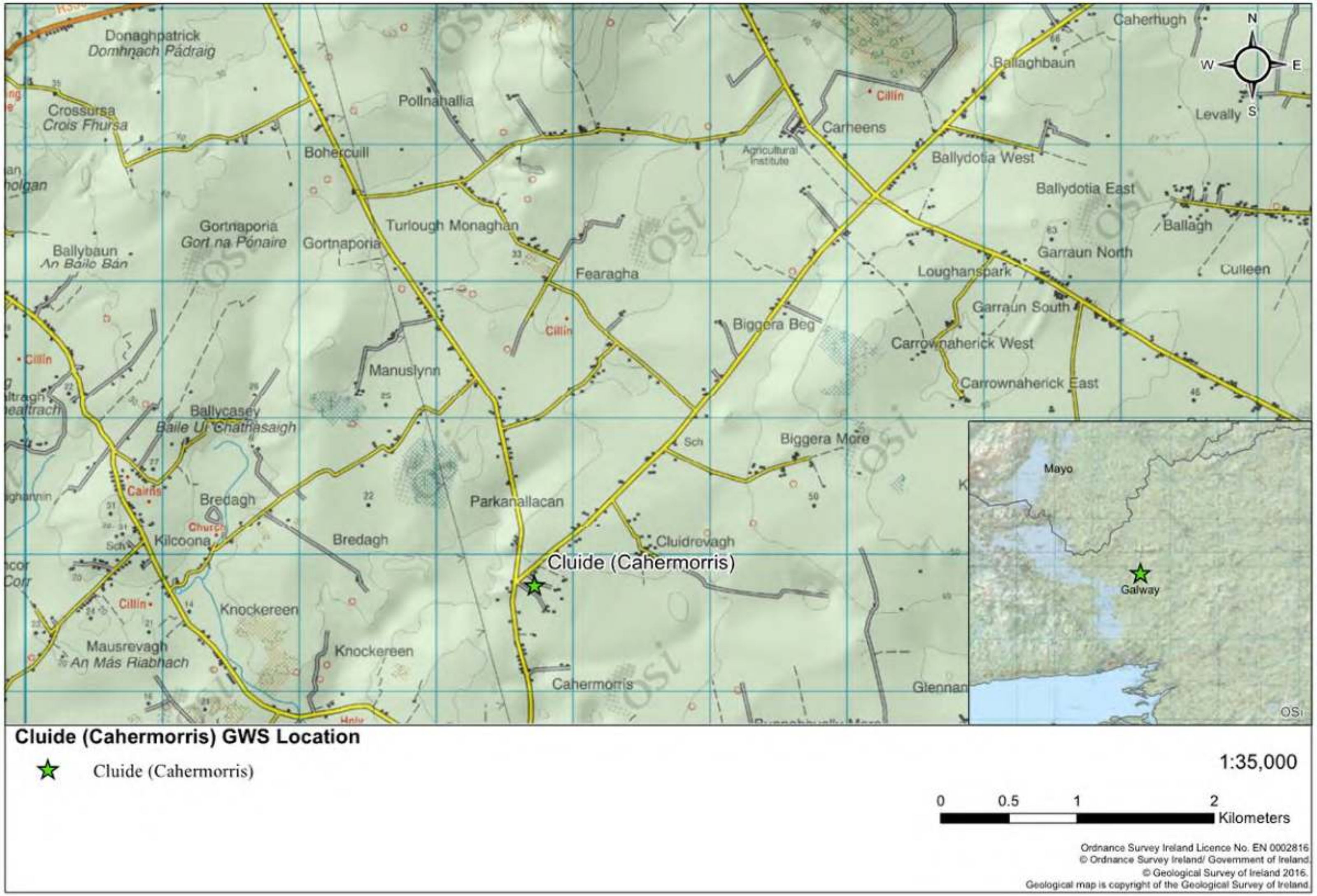

Figure 1 Location Map (OSI 1:50,000 scale for main map)

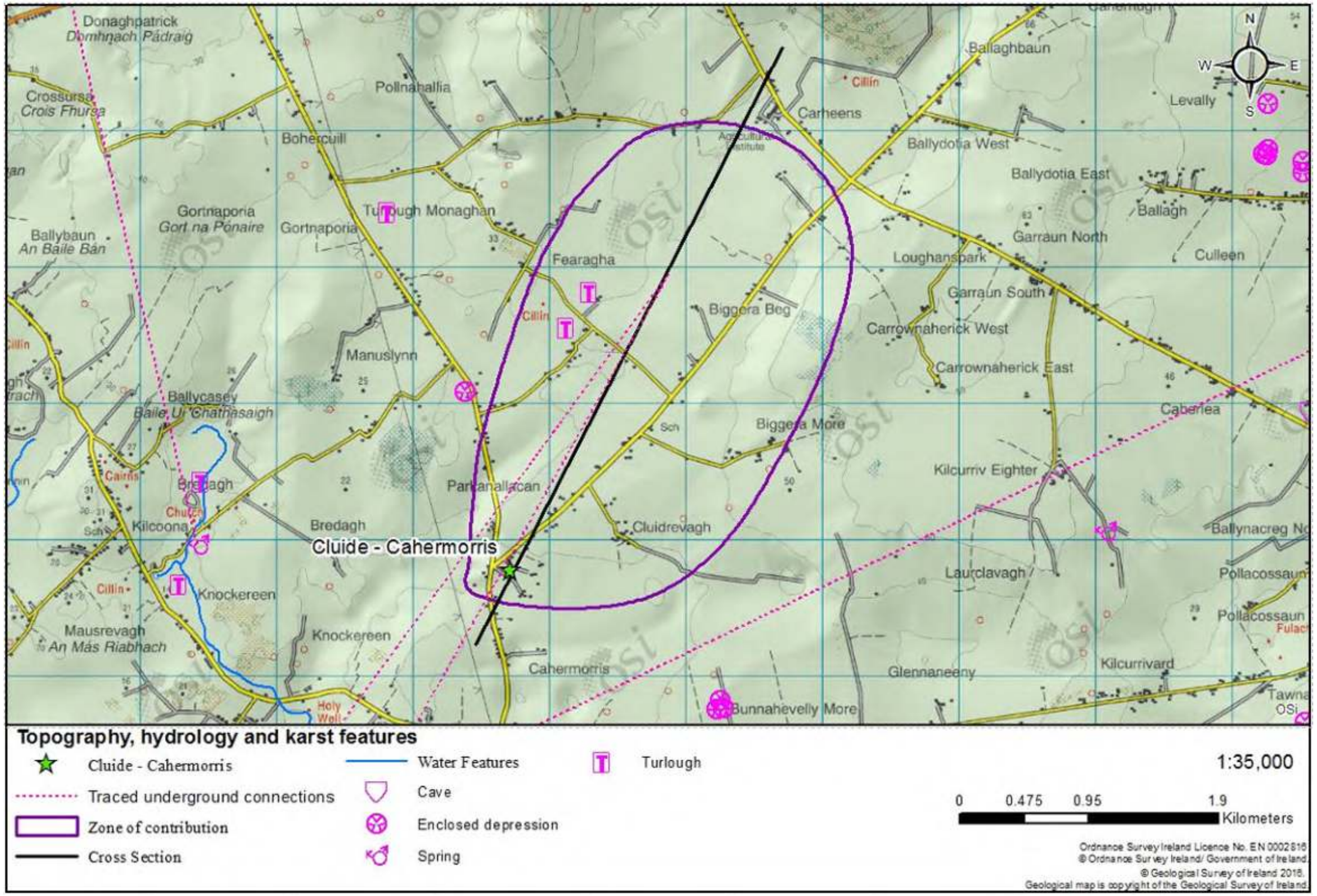

Figure 2 Topography, hydrology and karst features

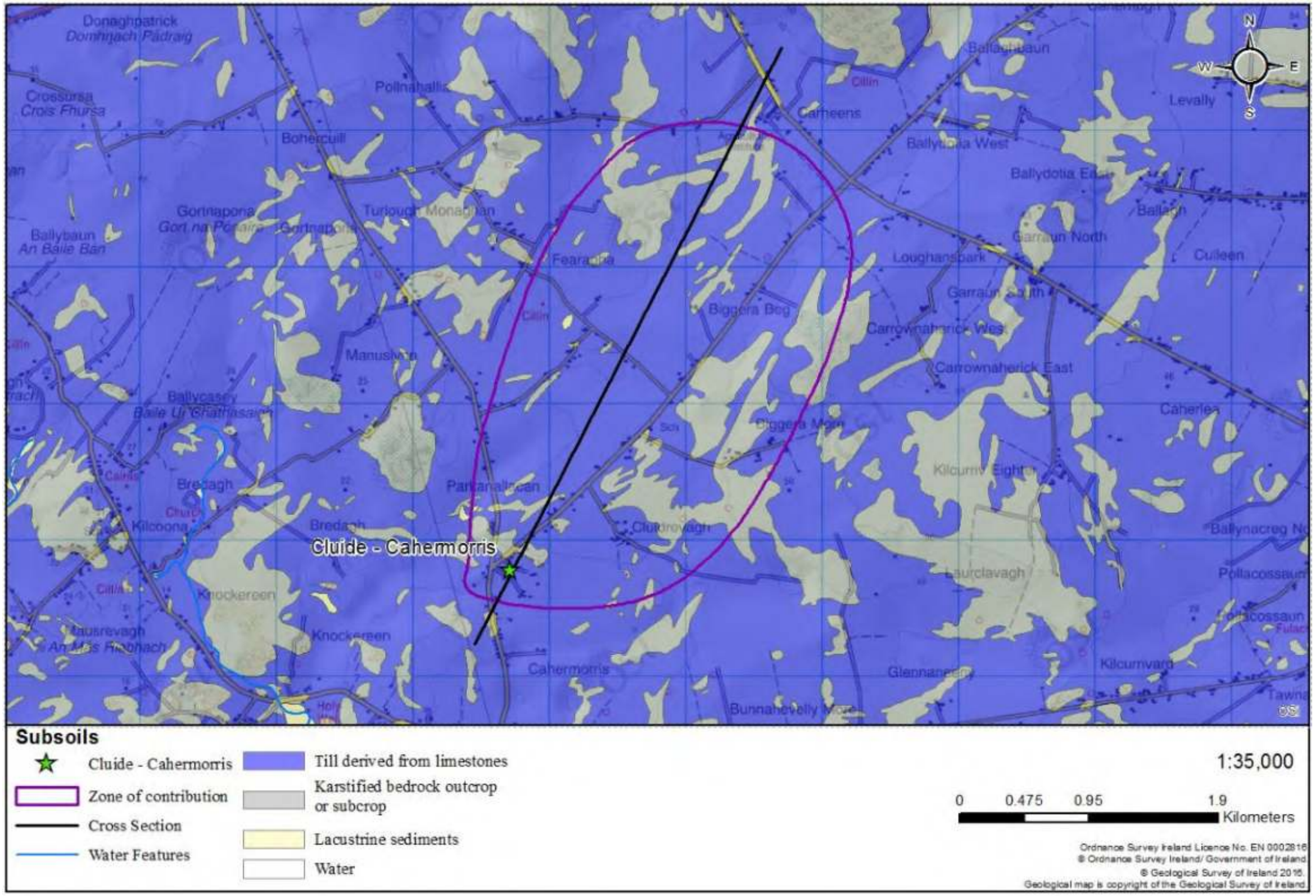

Figure 3 Subsoils

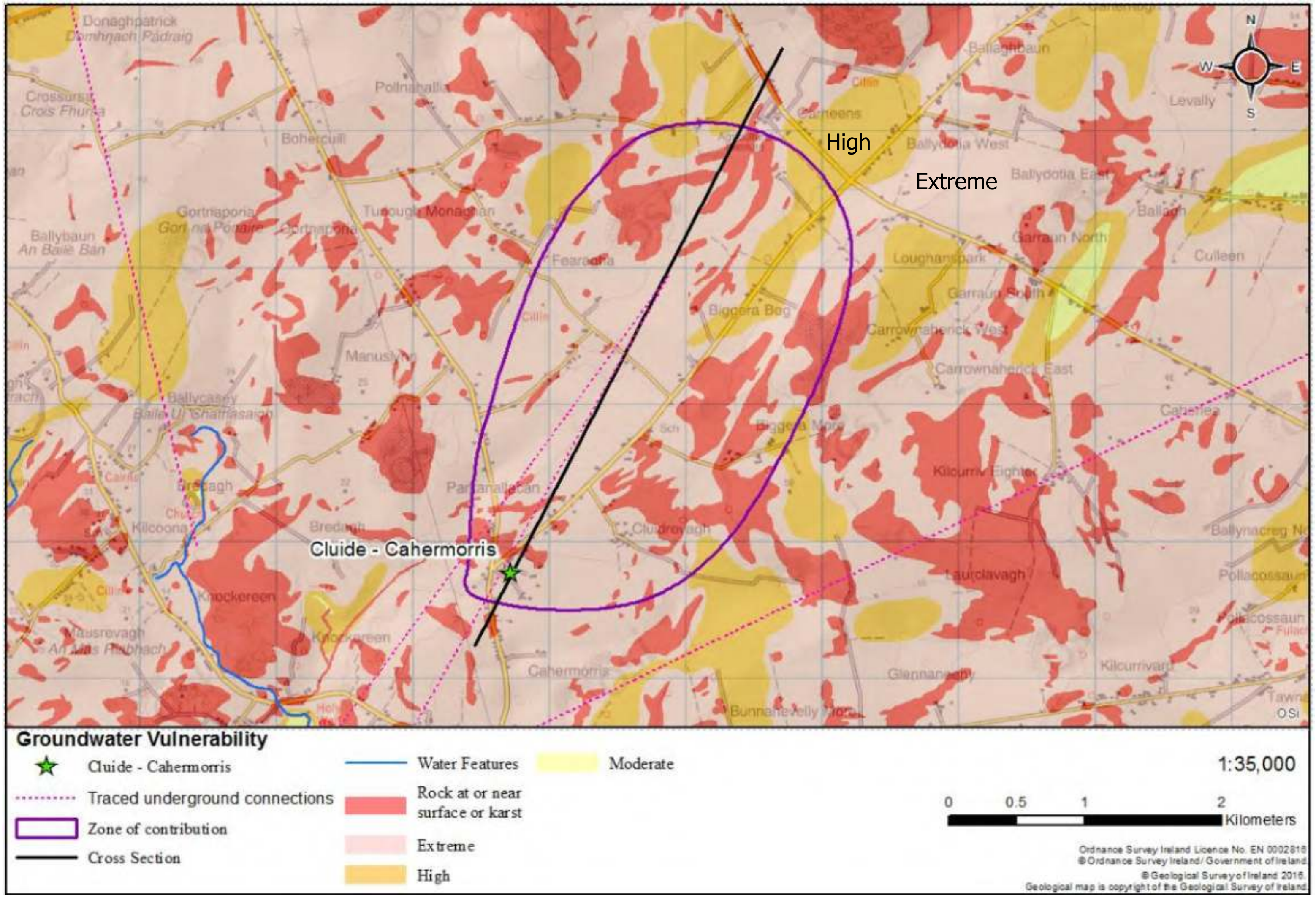

Figure 4 Groundwater Vulnerability Map

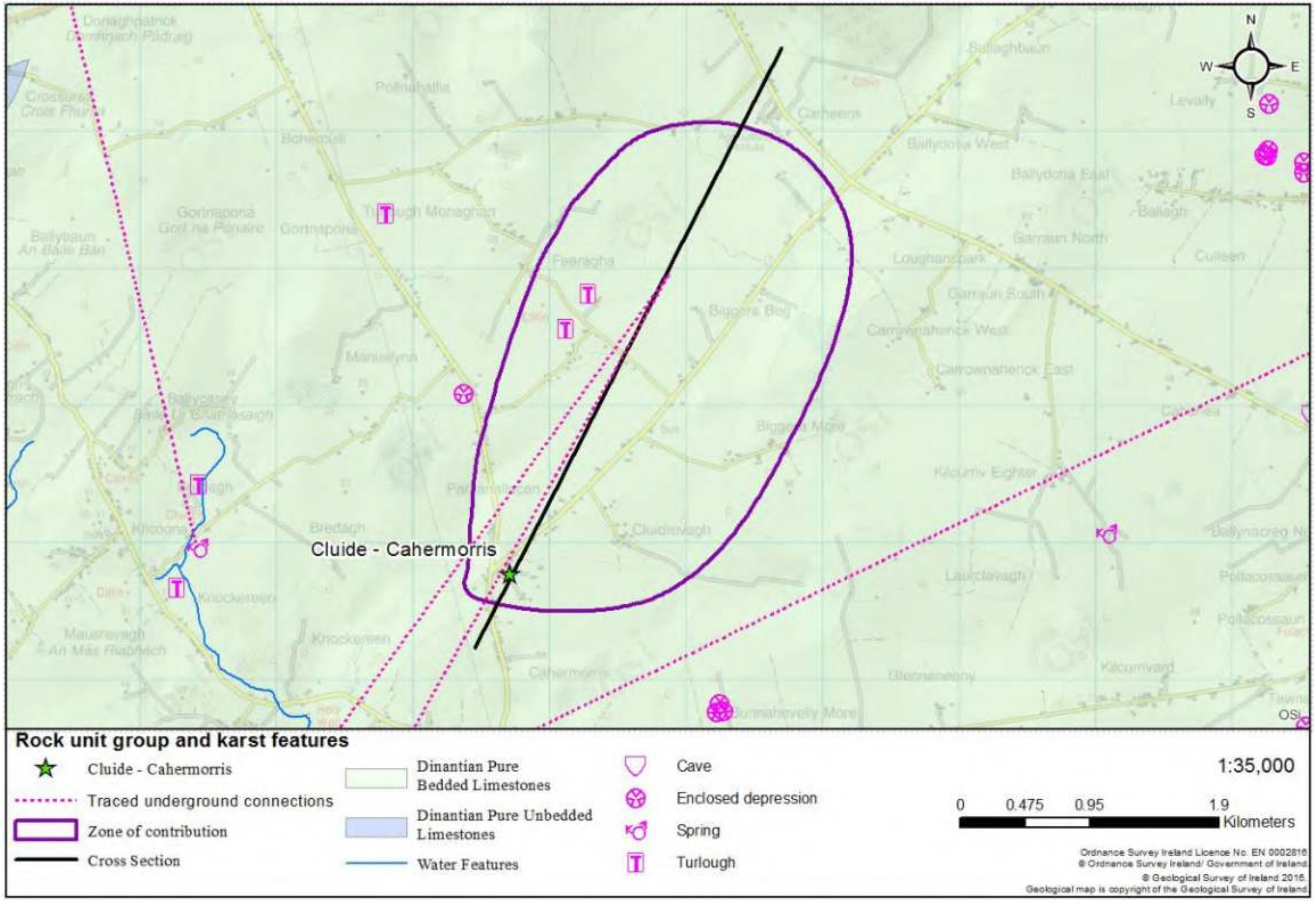

Figure 5 Rock Unit Group Map with karst features

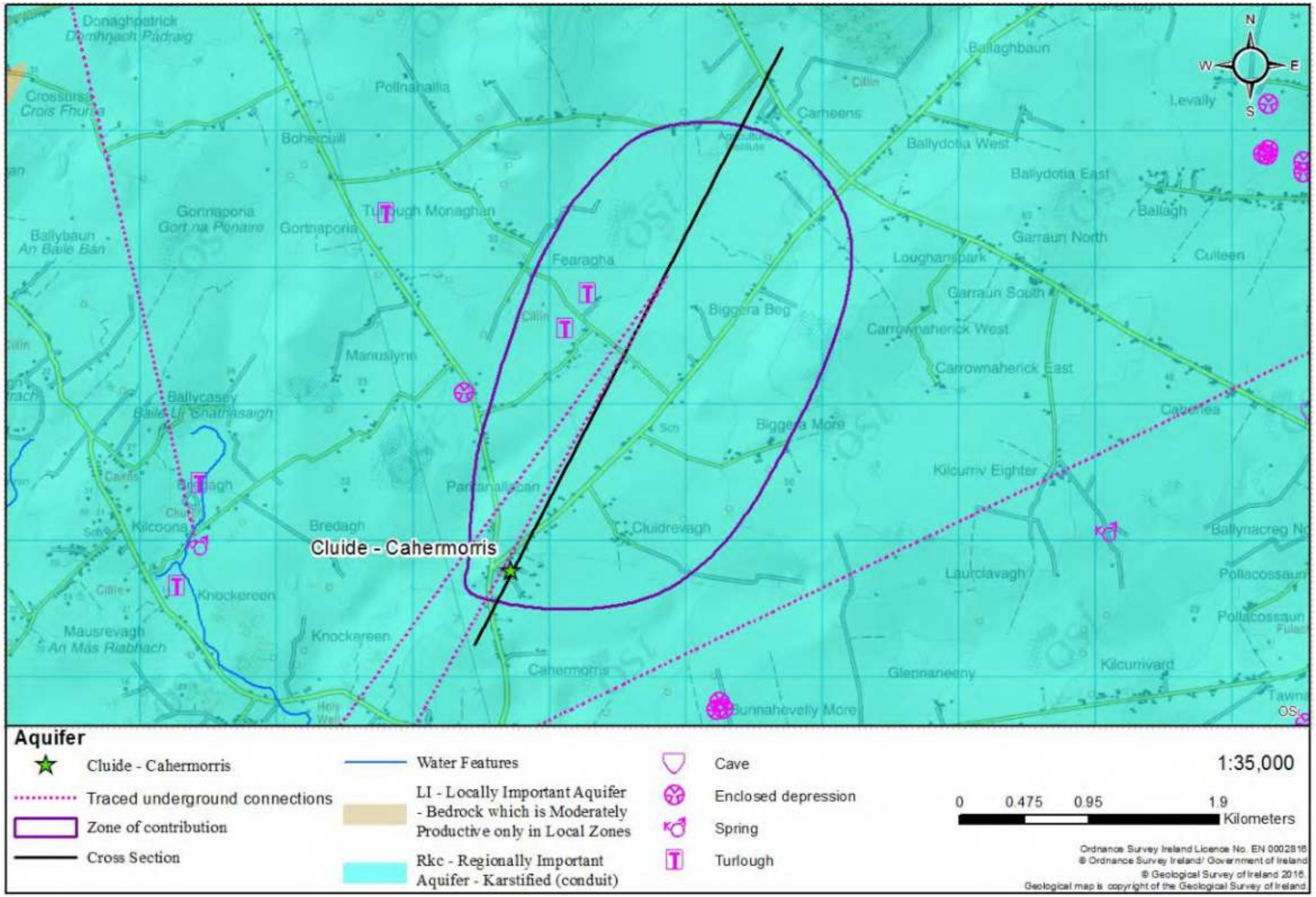

Figure 6 Aquifer Map

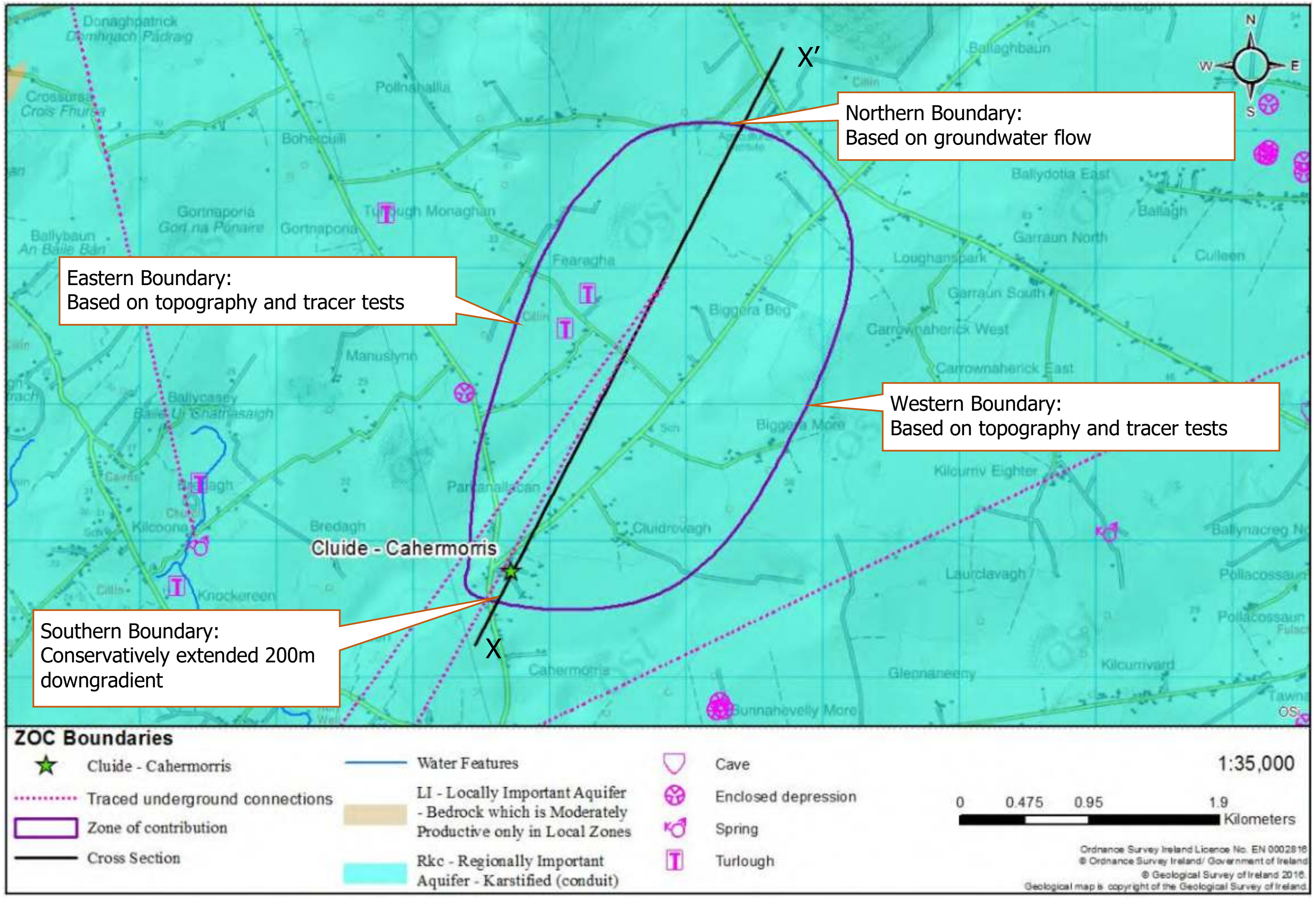

Figure 7 ZOC boundaries

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 below.

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

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

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

Sources of Vulnerability Data

Specific vulnerability field mapping and assessment of previously collected data were carried out as part of this project. Fieldwork focused on assessing the permeability of the different subsoil deposit types 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 Ll aquifers (200 mm/yr) and Pl and Pul aquifers (100 mm/yr). Made ground has recharge coefficient of 20%.

Appendix 3

Water Quality Results

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
03/11/2008	Treated	1,2-dichloroethane	3	µg/l	0.1
10/03/2009	Treated	1,2-dichloroethane	3	µg/l	0.1
24/07/2017	Raw	Alkalinity	No abnormal change	-	326.09
24/07/2017	Raw	Aluminium	200	µg/l	<20
22/05/2008	Treated	Aluminium	200	µg/l	20
29/09/2008	Treated	Aluminium	200	µg/l	20
03/11/2008	Treated	Aluminium	200	µg/l	5
10/03/2009	Treated	Aluminium	200	µg/l	11.11
25/06/2009	Treated	Aluminium	200	µg/l	20
11/12/2009	Treated	Aluminium	200	µg/l	20
26/05/2011	Treated	Aluminium	200	µg/l	7
08/12/2011	Treated	Aluminium	200	µg/l	6.8
22/11/2012	Treated	Aluminium	200	µg/l	7
16/07/2015	Treated	Aluminium	200	µg/l	3
22/05/2008	Treated	Ammonium	0.3	mg/l	0.03
29/09/2008	Treated	Ammonium	0.3	mg/l	0.03
03/11/2008	Treated	Ammonium	0.3	mg/l	0.009
10/03/2009	Treated	Ammonium	0.3	mg/l	0.028
25/06/2009	Treated	Ammonium	0.3	mg/l	0.03
11/12/2009	Treated	Ammonium	0.3	mg/l	0.03
08/03/2010	Treated	Ammonium	0.3	mg/l	0.022
08/12/2011	Treated	Ammonium	0.3	mg/l	0.051

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
31/10/2012	Treated	Ammonium	0.3	mg/l	0.057
22/11/2012	Treated	Ammonium	0.3	mg/l	0.03
13/04/2015	Treated	Ammonium	0.3	mg/l	0.02
24/07/2017	Raw	Ammonium NH4	0.3	mg/l	<0.01
03/11/2008	Treated	Antimony	0.3	mg/l	0.1
10/03/2009	Treated	Antimony	0.3	mg/l	0.1
24/07/2017	Raw	Arsenic	10	µg/l	<10
03/11/2008	Treated	Arsenic	10	µg/l	0.2
10/03/2009	Treated	Arsenic	10	µg/l	0.266
08/03/2010	Treated	Arsenic	10	µg/l	0.6
08/12/2011	Treated	Arsenic	10	µg/l	0.8
31/10/2012	Treated	Arsenic	10	µg/l	1
13/04/2015	Treated	Arsenic	10	µg/l	0.5
24/07/2017	Raw	Barium	500	µg/l	<10
03/11/2008	Treated	Benzene	1	µg/l	0.1
10/03/2009	Treated	Benzene	1	µg/l	0.1
03/11/2008	Treated	Benzo(a)pyrene	0.01	µg/l	0.003
10/03/2009	Treated	Benzo(a)pyrene	0.01	µg/l	0.003
13/04/2015	Treated	Benzo(a)pyrene	0.01	µg/l	0
24/07/2017	Raw	BOD	-	-	<1
03/11/2008	Treated	Boron	1	mg/l	0.02
10/03/2009	Treated	Boron	1	mg/l	0.02
03/11/2008	Treated	Bromate	10	µg/l	1
10/03/2009	Treated	Bromate	10	µg/l	1
24/07/2017	Raw	Cadmium	5	µg/l	<20
03/11/2008	Treated	Cadmium	5	µg/l	0.1
10/03/2009	Treated	Cadmium	5	µg/l	0.1
31/10/2012	Treated	Cadmium	5	µg/l	0.1
24/07/2017	Raw	Calcium	200	mg/l	118.6
24/07/2017	Raw	Chloride	250	mg/l	17.05

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
03/11/2008	Treated	Chloride	250	mg/l	19.4
10/03/2009	Treated	Chloride	250	mg/l	14.2
08/03/2010	Treated	Chloride	250	mg/l	15.1
08/12/2011	Treated	Chloride	250	mg/l	16
31/10/2012	Treated	Chloride	250	mg/l	13.5
13/04/2015	Treated	Chloride	250	mg/l	22.6
24/07/2017	Raw	Chromium	50	µg/l	<20
03/11/2008	Treated	Chromium	50	µg/l	1
10/03/2009	Treated	Chromium	50	µg/l	1
24/07/2017	Raw	Clostridium Perfringens	0	number/ 100 ml	6
22/05/2008	Treated	Clostridium Perfringens	0	number/ 100 ml	0
29/09/2008	Treated	Clostridium Perfringens	0	number/ 100 ml	0
03/11/2008	Treated	Clostridium Perfringens	0	number/ 100 ml	0
10/03/2009	Treated	Clostridium Perfringens	0	number/ 100 ml	0
08/03/2010	Treated	Clostridium Perfringens	0	number/ 100 ml	0
21/04/2010	Treated	Clostridium Perfringens	0	number/ 100 ml	0
15/09/2010	Treated	Clostridium Perfringens	0	number/ 100 ml	0
26/05/2011	Treated	Clostridium Perfringens	0	number/ 100 ml	0
28/11/2011	Treated	Clostridium Perfringens	0	number/ 100 ml	0

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
08/12/2011	Treated	Clostridium Perfringens	0	number/ 100 ml	0
10/02/2012	Treated	Clostridium Perfringens	0	number/ 100 ml	0
31/10/2012	Treated	Clostridium Perfringens	0	number/ 100 ml	0
22/11/2012	Treated	Clostridium Perfringens	0	number/ 100 ml	0
13/04/2015	Treated	Clostridium Perfringens	0	number/ 100 ml	0
16/07/2015	Treated	Clostridium Perfringens	0	number/ 100 ml	0
22/05/2008	Treated	Coliform Bacteria	0	number/ 100 ml	0
29/09/2008	Treated	Coliform Bacteria	0	number/ 100 ml	0
03/11/2008	Treated	Coliform Bacteria	0	number/ 100 ml	0
10/03/2009	Treated	Coliform Bacteria	0	number/ 100 ml	0
25/06/2009	Treated	Coliform Bacteria	0	number/ 100 ml	0
11/12/2009	Treated	Coliform Bacteria	0	number/ 100 ml	0
08/03/2010	Treated	Coliform Bacteria	0	number/ 100 ml	0
21/04/2010	Treated	Coliform Bacteria	0	number/ 100 ml	0
15/09/2010	Treated	Coliform Bacteria	0	number/ 100 ml	0

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
26/05/2011	Treated	Coliform Bacteria	0	number/ 100 ml	0
28/11/2011	Treated	Coliform Bacteria	0	number/ 100 ml	0
08/12/2011	Treated	Coliform Bacteria	0	number/ 100 ml	0
10/02/2012	Treated	Coliform Bacteria	0	number/ 100 ml	0
31/10/2012	Treated	Coliform Bacteria	0	number/ 100 ml	0
22/11/2012	Treated	Coliform Bacteria	0	number/ 100 ml	0
13/04/2015	Treated	Coliform Bacteria	0	number/ 100 ml	0
16/07/2015	Treated	Coliform Bacteria	0	number/ 100 ml	0
21/11/2016	Raw	Colour	Acceptable to consumers, no abnormal changes	-	4.2
24/07/2017	Raw	Colour	Acceptable to consumers, no abnormal changes	-	2.9
22/05/2008	Treated	Colour	Acceptable to consumers, no abnormal changes	-	3.5

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
29/09/2008	Treated	Colour	Acceptable to consumers, no abnormal changes	-	3.9
03/11/2008	Treated	Colour	Acceptable to consumers, no abnormal changes	-	5.97
10/03/2009	Treated	Colour	Acceptable to consumers, no abnormal changes	-	5.7
25/06/2009	Treated	Colour	Acceptable to consumers, no abnormal changes	-	2.1
11/12/2009	Treated	Colour	Acceptable to consumers, no abnormal changes	-	7.7
08/03/2010	Treated	Colour	Acceptable to consumers, no abnormal changes	-	4.92
21/04/2010	Treated	Colour	Acceptable to consumers, no abnormal changes	-	2.3

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
15/09/2010	Treated	Colour	Acceptable to consumers, no abnormal changes	-	5.8
26/05/2011	Treated	Colour	Acceptable to consumers, no abnormal changes	-	4.5
28/11/2011	Treated	Colour	Acceptable to consumers, no abnormal changes	-	5.8
08/12/2011	Treated	Colour	Acceptable to consumers, no abnormal changes	-	8.8
31/10/2012	Treated	Colour	Acceptable to consumers, no abnormal changes	-	4.8
22/11/2012	Treated	Colour	Acceptable to consumers, no abnormal changes	-	10.8
13/04/2015	Treated	Colour	Acceptable to consumers, no abnormal changes	-	7

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
16/07/2015	Treated	Colour	Acceptable to consumers, no abnormal changes	-	5.2
24/07/2017	Raw	Conductivity	2500	µS/cm	588
22/05/2008	Treated	Conductivity	2500	µS/cm	611
29/09/2008	Treated	Conductivity	2500	µS/cm	649
03/11/2008	Treated	Conductivity	2500	µS/cm	632
10/03/2009	Treated	Conductivity	2500	µS/cm	576.57
25/06/2009	Treated	Conductivity	2500	µS/cm	646
11/12/2009	Treated	Conductivity	2500	µS/cm	595
08/03/2010	Treated	Conductivity	2500	µS/cm	632
21/04/2010	Treated	Conductivity	2500	µS/cm	611
15/09/2010	Treated	Conductivity	2500	µS/cm	596
26/05/2011	Treated	Conductivity	2500	µS/cm	563
28/11/2011	Treated	Conductivity	2500	µS/cm	606
08/12/2011	Treated	Conductivity	2500	µS/cm	626
10/02/2012	Treated	Conductivity	2500	µS/cm	625
31/10/2012	Treated	Conductivity	2500	µS/cm	672
22/11/2012	Treated	Conductivity	2500	µS/cm	714
13/04/2015	Treated	Conductivity	2500	µS/cm	616
16/07/2015	Treated	Conductivity	2500	µS/cm	564
24/07/2017	Raw	Copper	2000	µg/l	<20
03/11/2008	Treated	Copper	2	mg/l	0
10/03/2009	Treated	Copper	2	mg/l	0.022
08/03/2010	Treated	Copper	2	mg/l	0.008
08/12/2011	Treated	Copper	2	mg/l	0.026
31/10/2012	Treated	Copper	2	mg/l	0.01
13/04/2015	Treated	Copper	2	mg/l	0.01
03/11/2008	Treated	Cyanide	50	µg/l	5

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
10/03/2009	Treated	Cyanide	50	µg/l	5
13/04/2015	Treated	Cyanide	50	µg/l	3.8
24/07/2017	Raw	Dissolved Oxygen O2	No abnormal changes	-	9.55
24/07/2017	Raw	E. coli	0	number/ 100 ml	727
22/05/2008	Treated	E. coli	0	number/ 100 ml	0
29/09/2008	Treated	E. coli	0	number/ 100 ml	0
03/11/2008	Treated	E. coli	0	number/ 100 ml	0
10/03/2009	Treated	E. coli	0	number/ 100 ml	0
25/06/2009	Treated	E. coli	0	number/ 100 ml	0
11/12/2009	Treated	E. coli	0	number/ 100 ml	0
08/03/2010	Treated	E. coli	0	number/ 100 ml	0
21/04/2010	Treated	E. coli	0	number/ 100 ml	0
15/09/2010	Treated	E. coli	0	number/ 100 ml	0
26/05/2011	Treated	E. coli	0	number/ 100 ml	0
28/11/2011	Treated	E. coli	0	number/ 100 ml	0
08/12/2011	Treated	E. coli	0	number/ 100 ml	0

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
10/02/2012	Treated	E. coli	0	number/ 100 ml	0
31/10/2012	Treated	E. coli	0	number/ 100 ml	0
22/11/2012	Treated	E. coli	0	number/ 100 ml	0
13/04/2015	Treated	E. coli	0	number/ 100 ml	0
16/07/2015	Treated	E. coli	0	number/ 100 ml	0
03/11/2008	Treated	Enterococci	0	number/ 100 ml	0
10/03/2009	Treated	Enterococci	0	number/ 100 ml	0
08/03/2010	Treated	Enterococci	0	number/ 100 ml	0
08/12/2011	Treated	Enterococci	0	number/ 100 ml	0
31/10/2012	Treated	Enterococci	0	number/ 100 ml	0
13/04/2015	Treated	Enterococci	0	number/ 100 ml	0
24/07/2017	Raw	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.34
03/11/2008	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.1

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
10/03/2009	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.1
08/03/2010	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.1
08/12/2011	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.11
31/10/2012	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.1
13/04/2015	Treated	Fluoride	0.8 (fluoridated) - 1.5 (natural)	mg/l	0.23
21/04/2010	Treated	Free Chlorine	-	-	0.03
15/09/2010	Treated	Free Chlorine	-	-	0.03
24/07/2017	Raw	Iron	200	µg/l	<20
21/11/2016	Raw	Iron	200	µg/l	<10
22/05/2008	Treated	Iron	200	µg/l	50
29/09/2008	Treated	Iron	200	µg/l	50
03/11/2008	Treated	Iron	200	µg/l	5
10/03/2009	Treated	Iron	200	µg/l	5
25/06/2009	Treated	Iron	200	µg/l	50
11/12/2009	Treated	Iron	200	µg/l	20
22/11/2012	Treated	Iron	200	µg/l	12
24/07/2017	Raw	Lead	10	µg/l	<20
03/11/2008	Treated	Lead	10	µg/l	0.3
10/03/2009	Treated	Lead	10	µg/l	0.3
08/12/2011	Treated	Lead	10	µg/l	0.4

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
31/10/2012	Treated	Lead	10	µg/l	0.3
13/04/2015	Treated	Lead	10	µg/l	0.3
24/07/2017	Raw	Magnesium	50	mg/l	7.57
24/07/2017	Raw	Manganese	50	µg/l	<20
21/11/2016	Raw	Manganese	50	µg/l	<5
22/05/2008	Treated	Manganese	50	µg/l	20
29/09/2008	Treated	Manganese	50	µg/l	20
03/11/2008	Treated	Manganese	50	µg/l	1
10/03/2009	Treated	Manganese	50	µg/l	1
25/06/2009	Treated	Manganese	50	µg/l	20
11/12/2009	Treated	Manganese	50	µg/l	20
03/11/2008	Treated	Mercury	1	µg/l	0.02
10/03/2009	Treated	Mercury	1	µg/l	0.02
24/07/2017	Raw	Nickel	50000	µg/l	<20
03/11/2008	Treated	Nickel	20	µg/l	0.5
10/03/2009	Treated	Nickel	20	µg/l	1.093
08/03/2010	Treated	Nickel	20	µg/l	0.801
08/12/2011	Treated	Nickel	20	µg/l	1.9
31/10/2012	Treated	Nickel	20	µg/l	1.4
13/04/2015	Treated	Nickel	20	µg/l	1.6
22/05/2008	Treated	Nitrate	50	mg/l	14.8
29/09/2008	Treated	Nitrate	50	mg/l	13.4
03/11/2008	Treated	Nitrate	50	mg/l	11.6
10/03/2009	Treated	Nitrate	50	mg/l	7.85
25/06/2009	Treated	Nitrate	50	mg/l	11.7
11/12/2009	Treated	Nitrate	50	mg/l	9.9
08/03/2010	Treated	Nitrate	50	mg/l	9.22
21/04/2010	Treated	Nitrate	50	mg/l	12.9
15/09/2010	Treated	Nitrate	50	mg/l	13
08/12/2011	Treated	Nitrate	50	mg/l	12.49

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
31/10/2012	Treated	Nitrate	50	mg/l	13.28
13/04/2015	Treated	Nitrate	50	mg/l	16.11
24/07/2017	Raw	Nitrate NO3	50	mg/l	15.27
22/05/2008	Treated	Nitrite (at tap)	0.5	mg/l	0
29/09/2008	Treated	Nitrite (at tap)	0.5	mg/l	0
03/11/2008	Treated	Nitrite (at tap)	0.5	mg/l	4.30E-05
10/03/2009	Treated	Nitrite (at tap)	0.5	mg/l	0.043
25/06/2009	Treated	Nitrite (at tap)	0.5	mg/l	0.02
11/12/2009	Treated	Nitrite (at tap)	0.5	mg/l	0.02
24/07/2017	Raw	Nitrite NO2	0.5	mg/l	<0.03
22/05/2008	Treated	Odour	Acceptable to consumers, no abnormal changes	-	0
29/09/2008	Treated	Odour	Acceptable to consumers, no abnormal changes	-	0
03/11/2008	Treated	Odour	Acceptable to consumers, no abnormal changes	-	0
24/07/2017	Raw	P Orthophosphate P	0.03	mg/l	0.02
03/11/2008	Treated	PAH	0.1	µg/l	0.01
10/03/2009	Treated	PAH	0.1	µg/l	0.01
03/11/2008	Treated	Pesticides - Total	0.5	µg/l	0.01
10/03/2009	Treated	Pesticides - Total	0.5	µg/l	0.01
08/12/2011	Treated	Pesticides - Total	0.5	µg/l	0.03
13/04/2015	Treated	Pesticides - Total	0.5	µg/l	0.03

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
24/07/2017	Raw	pH	≥6.5 and ≤9.5	pH units	6.9
22/05/2008	Treated	pH	≥6.5 and ≤9.5	pH units	7.2
29/09/2008	Treated	pH	≥6.5 and ≤9.5	pH units	7.1
03/11/2008	Treated	pH	≥6.5 and ≤9.5	pH units	7.5
10/03/2009	Treated	pH	≥6.5 and ≤9.5	pH units	7.32
25/06/2009	Treated	pH	≥6.5 and ≤9.5	pH units	7.1
11/12/2009	Treated	pH	≥6.5 and ≤9.5	pH units	7.2
08/03/2010	Treated	pH	≥6.5 and ≤9.5	pH units	7.3
21/04/2010	Treated	pH	≥6.5 and ≤9.5	pH units	7.2
15/09/2010	Treated	pH	≥6.5 and ≤9.5	pH units	7.1
26/05/2011	Treated	pH	≥6.5 and ≤9.5	pH units	7
28/11/2011	Treated	pH	≥6.5 and ≤9.5	pH units	7.1
08/12/2011	Treated	pH	≥6.5 and ≤9.5	pH units	7.1
10/02/2012	Treated	pH	≥6.5 and ≤9.5	pH units	7.5
31/10/2012	Treated	pH	≥6.5 and ≤9.5	pH units	7.2

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
22/11/2012	Treated	pH	≥6.5 and ≤9.5	pH units	7
13/04/2015	Treated	pH	≥6.5 and ≤9.5	pH units	7.2
16/07/2015	Treated	pH	≥6.5 and ≤9.5	pH units	7
24/07/2017	Raw	Potassium	12	mg/l	2.93
03/11/2008	Treated	Selenium	10	µg/l	0.6
10/03/2009	Treated	Selenium	10	µg/l	0.2
08/03/2010	Treated	Selenium	10	µg/l	0.629
08/12/2011	Treated	Selenium	10	µg/l	0.8
31/10/2012	Treated	Selenium	10	µg/l	0.4
13/04/2015	Treated	Selenium	10	µg/l	0.7
24/07/2017	Raw	Silica	No abnormal change	-	4.7
24/07/2017	Raw	Sodium	200	mg/l	11.3
03/11/2008	Treated	Sodium	200	mg/l	12.7
10/03/2009	Treated	Sodium	200	mg/l	10.7
08/03/2010	Treated	Sodium	200	mg/l	9.544
08/12/2011	Treated	Sodium	200	mg/l	9.8
31/10/2012	Treated	Sodium	200	mg/l	10
13/04/2015	Treated	Sodium	200	mg/l	12.4
24/07/2017	Raw	Strontium	-	-	<10
03/11/2008	Treated	Sulphate	250	mg/l	8.9
10/03/2009	Treated	Sulphate	250	mg/l	4.44
08/03/2010	Treated	Sulphate	250	mg/l	7.83
08/12/2011	Treated	Sulphate	250	mg/l	5
31/10/2012	Treated	Sulphate	250	mg/l	4.3
13/04/2015	Treated	Sulphate	250	mg/l	7.9
24/07/2017	Raw	Sulphate SO4	250	mg/l	9.15

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
03/11/2008	Treated	Taste	Acceptable to consumers, no abnormal changes	-	0
03/11/2008	Treated	Tetrachloroethene & Trichloroethene	10	µg/l	0.2
10/03/2009	Treated	Tetrachloroethene & Trichloroethene	10	µg/l	0.2
24/07/2017	Raw	Total Coliforms	0	number/ 100 ml	1203
24/07/2017	Raw	Total Hardness CaCO3	200	mg/l	327.3
21/11/2016	Raw	Total Organic Carbon	no abnormal changes	-	3.94
24/07/2017	Raw	Total Organic Carbon	no abnormal changes	-	1.3
03/11/2008	Treated	Total Organic Carbon	no abnormal changes	-	2
10/03/2009	Treated	Total Organic Carbon	no abnormal changes	-	2.9
08/03/2010	Treated	Total Organic Carbon	no abnormal changes	-	1.77
08/12/2011	Treated	Total Organic Carbon	no abnormal changes	-	3.91
31/10/2012	Treated	Total Organic Carbon	no abnormal changes	-	2.53
13/04/2015	Treated	Total Organic Carbon	no abnormal changes	-	2.35
03/11/2008	Treated	Trihalomethanes(Total)	100	µg/l	5
10/03/2009	Treated	Trihalomethanes(Total)	100	µg/l	39.6

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
24/07/2017	Raw	Turbidity	Acceptable to consumers, no abnormal changes	-	<0.02
21/11/2016	Raw	Turbidity	Acceptable to consumers, no abnormal changes	-	0.4
22/05/2008	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
29/09/2008	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
03/11/2008	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	1.71
10/03/2009	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	1.17
25/06/2009	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.2

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
11/12/2009	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.2
21/04/2010	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
15/09/2010	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
26/05/2011	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.2
08/12/2011	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
10/02/2012	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.2
31/10/2012	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.45

Sample Date	Sample Type	Parameter	Drinking Water Limit	Units	Result
22/11/2012	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.3
13/04/2015	Treated	Turbidity (at tap)	Acceptable to consumers, no abnormal changes	-	0.19
24/07/2017	Raw	Zinc	5000	µg/l	31

Appendix 4

Acronyms and Glossary

Acronyms

EPA – Environmental Protection Agency
DEHLG – Department of Environment Heritage and Local Government
EU – European Union
GSI – Geological Survey of Ireland
GWB – Groundwater Body
GWD – Groundwater Directive (European Union)
GWS – Group Water Scheme
IGI – Institute of Geologists of Ireland
IG – Irish National Grid Reference
m aOD – metres above Ordnance Datum
m bgl – metres below ground level
TVs – Threshold Values
UV – Ultra-Violet
ZOC – Zone of Contribution
WFD – Water Framework Directive

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.

Boulder Clay
See 'Till'

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.

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
Dolines, 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. The area of the groundwater system that has lower groundwater levels than other areas. Opposite of upgradient.

Enclosed Depression
See doline

Fissure
A natural crack in rock which allows rapid water movement.

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 m_3/d, on average, or serving more than 50 persons.

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 m_3/d as an average or serving more than 50 persons.

Hydraulic Conductivity (also known as 'Permeability')
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 Rock
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.

Metamorphic Rock
A rock made out of highly altered existing rock. Common types include marble, schist and quartzite.

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 (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 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.

Sedimentary Rock
A rock composed of sediments (sand, silt, clay, calcium carbonate fragments, shell fragments, etc.) that have been buried and lithified (cemented). Common types include sandstone, shale and limestone.

Soil (topsoil)
The uppermost layer of soil in which plants grow.

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 rock type, or a change in slope.

Subsoil
Unlithified (uncemented) geological strata or materials beneath the topsoil and above bedrock. Common types include Till/Boulder Clay, sand/gravel and peat.

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 (also known as 'Sinkhole')
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 (also known as 'Boulder Clay')
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.

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.

Up-gradient
The direction of increasing groundwater levels, i.e. the direction from which groundwater is flowing. The area of the groundwater system that has higher groundwater levels than other areas. Opposite of down-gradient.

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. This is the level to which water naturally settles in the cracks, cavities and pore spaces underground. Above the water table, the spaces in the rock or sediments are air-filled. Below the water table, the spaces are filled with water.

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

Well
A construction into the ground in order to access groundwater. Can be a dug well, which is generally shallow, with a diameter of a metre of more, or a borewell (see 'Borehole'), which is narrower in diameter and generally deeper.

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 5

ZOC Boundary Calculations

The downgradient boundary and zone of contribution width calculations are used to support the deliniated boundary extents and to confirm that the ZOC delineated is big enough to supply the quantity of water at the source.

The downgradient boundary (Xl) and zone of contribution width boundary (Yl) are calculated using the following equations:

$$Xl = Q/(2\pi Ti) \qquad Yl = Q/(2Ti)$$

Q = pumping rate (m^3/day) = 68.12 m^3/day

T = Transmissitivity[9] (m^2/day) = 66 (m^2/day)

i = hydraulic gradient – estimated based on topographic contours and noted datum locations on OSI map = 0.011.

$Xl = 68.12 / (2\pi \times 66 \times 0.011)$

$Xl = 14.60$ m ≈ 0.01 km

$Yl = 68.12 / (2 \times 66 \times 0.011)$

$Yl = 45.86$ m ≈ 0.05 km

The area required to supply the borehole with flow.

Q = pumping rate (m^3/day)

R = recharge rate (mm/yr)

A = Q/R

Q = 68.1 m^3/day x 150%= 102.2 m^3/day

R = 514 mm/yr = 0.0014 m/d.

A = Q / R

A = 102.2 / 0.0014 = 72,560 m^2 = 0.07 km^2

[9] value taken from Clare-Corrib Groundwater Body Description

Establishment of Groundwater Zones of Contribution

Rusheens Group Water Scheme

July 2015

Prepared by:

Peter Conroy
and
Geological Survey of Ireland, Groundwater Programme

(Monica Lee, Caoimhe Hickey and Taly Hunter Williams)

And with assistance from:

Rusheens GWS

The National Federation of Group Water Schemes

Acknowledgements:

Patrick O'Dea and Mattie Murphy (Rusheens GWS)

Karen Carney (NFGWS)

Document control information

Revision	Date	Author	Checked	Approved
Draft	09/09/2014	Peter Conroy	ML 24.09.14	
Revised	02/12/2014	Peter Conroy	ML 08.01.15	
Final	18/03/2015	Peter Conroy	ML 23.03.15	ML
Issued	20/07/2015	Peter Conroy		ML

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 Rusheens 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.

Rusheens GWS is supplied by a regionally important aquifer with karstified conduit flow (Rk_c). The current abstraction rate is 197 m^3/day and the estimated borehole yield is 216 m^3/day.

[1] Geological Survey of Ireland, 1999.

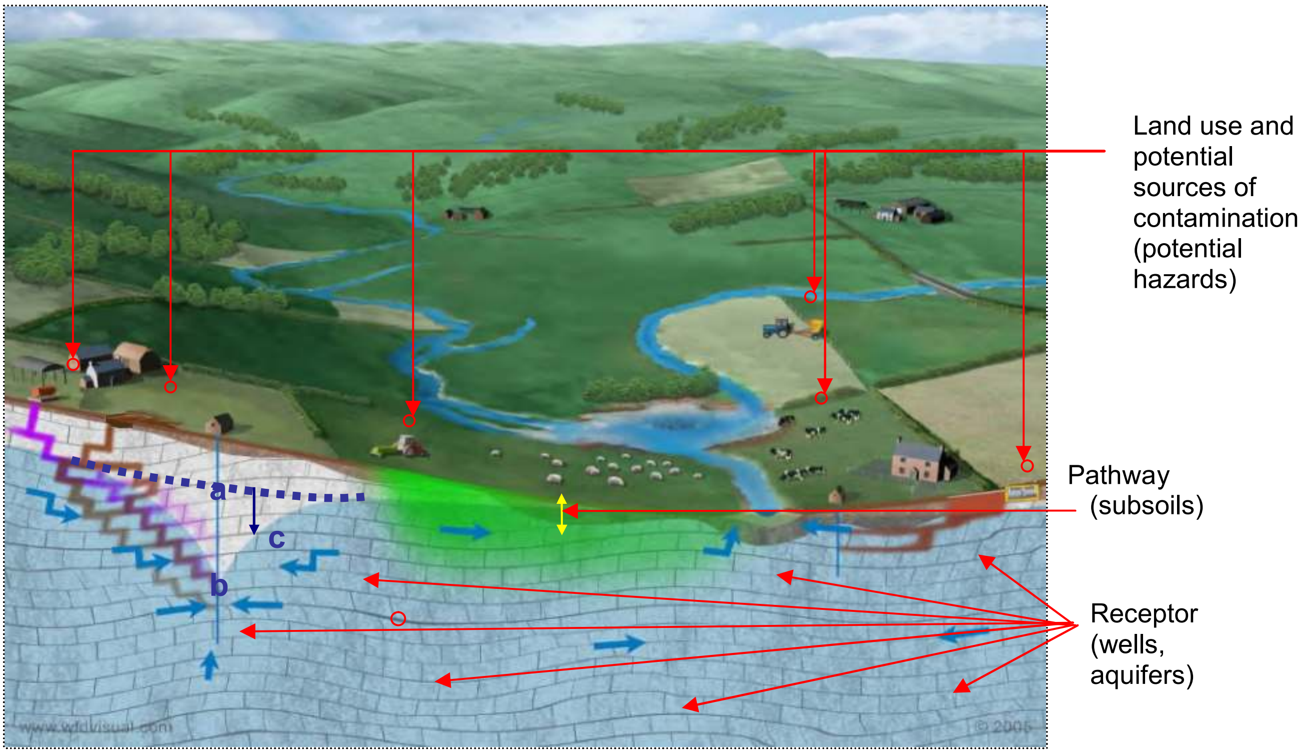

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Rusheens Group Water Scheme (GWS) is supplied from a borehole in the townland of Culleen, 7 km southwest of Tuam, Co. Galway. The borehole sits adjacent to the south side of a local road, approximately 200 m west of its junction with the N17 road. (**Figure 1**). The current scheme demand is 216 m^3/day (with a similar abstraction of 197 m^3/day measured on the site visit; 18th June 2014), supplied by a variable speed pump direct to the mains. The driller's estimate of the borehole yield is 216 m^3/day, while the GWS estimate a maximum yield of approximately 432 m^3/day. The scheme has ultraviolet germicidal irradiation (UV) and chlorination disinfection treatment.

The GWS pumphouse is situated in a triangular, 15 m by 10 m, low-walled compound adjacent to the local road. The current borehole is located 25 m south of the pumphouse compound in an agricultural field. The borehole sits inside its own small 2 m by 2 m compound enclosed by a steel post and rail fence (**Diagram 2**).

The borehole wellhead sits inside a 1 m diameter concrete-ring chamber that is sunk 0.9 m into the ground. The ground surface slopes away from the top of the concrete ring. A large steel plate serves as the roof of the chamber but does not seal the chamber off from the ground surface. The chamber floor is comprised of drill cuttings. Inside the chamber the top of the 150 mm diameter (innermost) steel casing sits approximately 0.05 m above the chamber floor. A 250 mm diameter steel plate cap, with holes for the rising main and pump cables sits flush to the top of the 150 mm diameter steel casing, sealing it. The rising main and cables exit the chamber via a hole in the chamber wall which is sealed with expanding foam. Overall the well head is well constructed and the borehole mouth is sealed. There is no dipper hole in the borehole cap plate. It was not possible to remove the plate to measure the groundwater level during the site visit on 18 June 2014.

The GWS has had two previous source boreholes on the site. The first was an old Galway County Council hand pump well, which is still present and plumbed inside the pumphouse. The second was a bored well drilled in the 1980s, 5 m south of the current source. A broken pump became wedged within the borehole in 2012; the borehole was abandoned and backfilled with cement grout. The current borehole was drilled as a replacement.

Photos of the pump house and borehole can be seen in Photos 1 to 5 below. **Table 1** provides a summary of currently known information relating to the borehole.

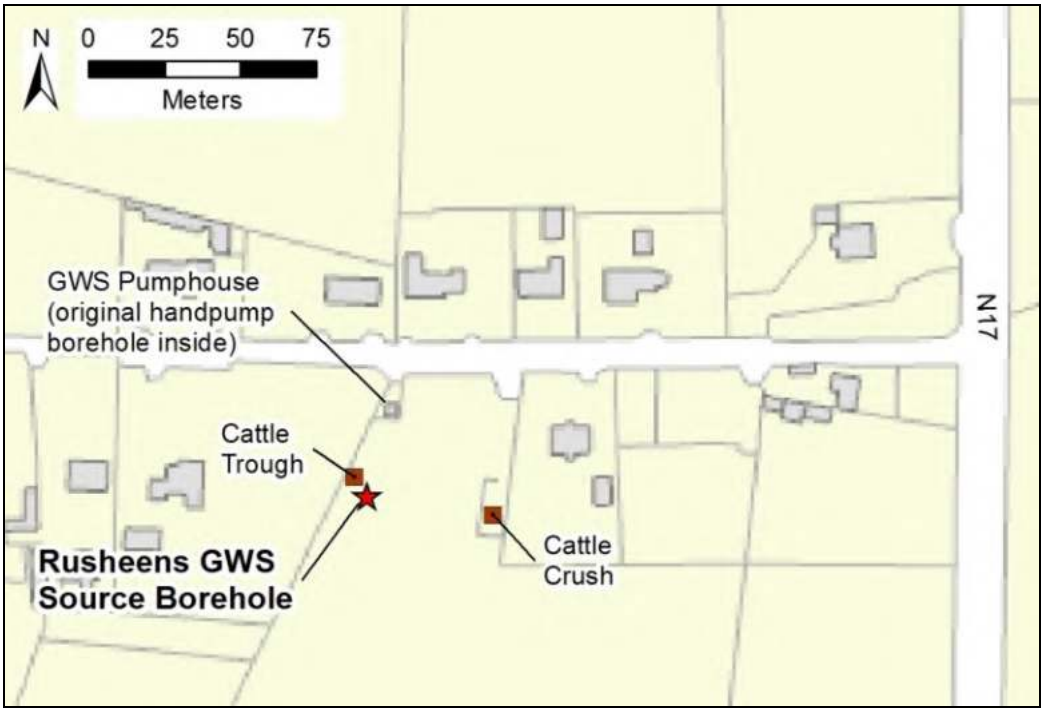

Diagram 2. Schematic Plan of the GWS Site

Photo 1: Rusheens GWS wellhead with pump house to rear (view northeast)

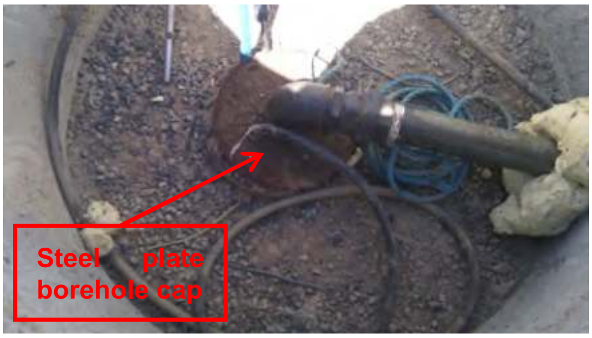

Photo 2: Rusheens GWS – inside the borehole chamber

Photo 3: Rusheens GWS – Pumphouse (Internal)

Photo 4: Old hand pump borehole inside pumphouse

Photo 5: UV Lamps and flow meter inside pumphouse

Table 1. Supply Details

	Current GWS Borehole Source (2012 onwards)	Second Borehole (1980s to 2012)	Old Borehole (1977 to 1980s)
Grid reference	E: 139454, N: 246453	E: 139454, N: 246445	E:139468, N: 246487
Townland	Culleen		
Source type	Borehole		
Drilled	24 September to 02 October 2012	1980s	1970s
Drilling Contractor	Patrick Briody	No data	Old Galway CoCo hand pump bore
Owner	Rusheens GWS		
Elevation (m OD)	Approximately 35 mOD (based on 1:50,000 topographic map)		
Total depth (m)	64	No data	65
Construction details (Borehole log & sketch in **Appendix 1**)	Drilled 380 mm: 0 to 6.1 mbgl; Installed 250 mm steel casing (SC): 0 to 6.1 mbgl; Drilled 250 mm: 6.1 to 64 mbgl; Installed 200 mm SC: 0 to 21 mbgl & cleaned hole; Installed 125 mm uPVC: 0 to 61 m, slotted 36 to 61 mbgl; Installed gravel pack: 30.5 to 61 m; Installed 5 bags of bentonite above 36 m and then pumped 30 bags of cement grout up to 15 mbgl, then 20 bags bentonite up to 0 mbgl. Airlifted for 14 hrs in total before PVC and after gravel.	Abandoned October 2012: backfill of clean gravel overlain by bentonite plug, then pumped cement grout by tremie pipe from 9.1 mbgl to near surface, then concrete plug up to ground level.	No data. (Assume steel casing to competent rock, then open hole)
Depth to rock (m bgl)	6.1 m	No data	No data
Pumping (PWL) and Static water levels (SWL)	No Data (no dipper access to borehole) Water Strike data: • 22 m^3/day at 9 mbgl in broken limestone (sealed off); • Small inflow at 17.2 mbgl in very broken limestone (sealed off); • Large water and sand in very broken limestone at 49 to 54.3 mbgl (main inflow).	No data	18 June 2014 – borehole not in use but SWL potentially drawndown by pumping in current GWS borehole: measured water level = 19.75 m below datum (approx. 15.25 mOD). [note: WL datum = pump house floor / ground level]
Pump intake depth (m bgl)	50	N/a	50
Current abstraction rate (GWS)	GWS estimate = 216 m^3/day. Readings on 18 June 2014: Instantaneous Flow = 197 m^3/day Cumulative Flow = 308638 m^3.	N/a	Plumbed in and still used occasionally
Reported yield (m^3/d)	Driller's estimate = 216 m^3/day GWS est. of max. yield = 432 to 540 m^3/day	No data	No data. GWS say yield exceeded pump capacity.
Transmissivity (m^2/day)	No data		
Other Information	2nd borehole had sandy sediment in the abstraction (caused ongoing clogging of monitoring probes); The new borehole does not have this problem to date – probably because shallow sandy inputs are sealed off or due to better development of main water strike.		Abstraction limited by small borehole/pump diameter; GWS consider the main water strike was the same as in the current borehole.

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

<table>
<tr><th></th><th>Rusheens Borehole</th><th>Description/Comments</th></tr>
<tr><td>Annual Rainfall (mm)</td><td>1140</td><td>Belclare Agricultural Resource Centre rainfall station, 3.5 km to the west (1961-1990)</td></tr>
<tr><td>Annual Evapotranspiration Losses (mm)</td><td>463</td><td>487.5 mm PE (average annual Potential Evapotranspiration data, Galway: 1961-1990).
463 AE (Actual Evapotranspiration, assumed to be 95% of PE)</td></tr>
<tr><td>Annual Effective Rainfall (mm)</td><td>677</td><td>Annual rainfall minus the annual evapotranspiration losses</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Topography (Figure 2)</td><td colspan="2">Topography slopes gently east/SE towards the Clare River and ground level is approx. 35 mOD near the GWS source. 3.8 km WNW the Knockmaa-Knockacarrigeen SW to NE oriented ridge reaches 167 mOD. Lower hummocks occur closer to the source at Ballaghbaun (86 mOD, 2.3 km WNW), Garraun North (63 mOD, 1.9 km W) and Rusheens North (54 mOD, 1.3 km N).</td></tr>
<tr><td>Land use</td><td colspan="2">Landuse is predominantly agricultural. Domestic residences with septic tank systems are located to the east and west of the source along the local road and north and south along the N17. In the field containing the GWS source, there is a cattle trough adjacent to the borehole and a cattle crush 40 m east at the field boundary. Caherlea-Currane GWS is located 2.2 km west of the source.</td></tr>
<tr><td>Surface Hydrology (Figure 2)</td><td colspan="2">The River Clare runs roughly north to south approx 2.8 km ENE of the source. A cut off reach of the original course of the Clare River runs through Cloonmore and Cummer, 1 km west and sinks at a swallow hole 1.9 km NE. The Cummer turlough is located 860 m east. The mapped extent of the former Clonkeen lake comes within 1.4 km east of the source.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Topsoil[2]</td><td colspan="2">Across most of study area soils are mainly deep, well drained basic mineral soils, becoming shallow on areas high ground and rock outcrop. Cutover peat is mapped further north. Alluvial soils and poorly drained peaty soils occur along original and modern Clare River courses.</td></tr>
<tr><td>Subsoil[2]
(Figure 3)</td><td colspan="2">Subsoils are mainly made up of limestone till. Cutover peat is mapped further north. Bedrock outcrops on a ridge to WNW and in pockets across the surrounding area. Alluvium and poorly drained peaty soils occur along original and modern Clare River courses[2]. GSI 6” field sheets indicate marl and peat present in area of former Clonkeen Lough (Cloonmore to Corofin area to the east and SE).</td></tr>
<tr><td>Groundwater Vulnerability (Figure 4)</td><td colspan="2">Extreme across most of the outlying area surrounding the source. A pocket of moderate vulnerability occurs immediately north of to the source (1.5 km long NE to SW and 0.3 km wide), with a halo of high vulnerability around it. The GWS pumphouse sits within the moderate vulnerability area, while the current source borehole sits within the high vulnerability halo. See Appendix 2.</td></tr>
<tr><td>Geology[3]
Formation:
Rock Unit Group
(Figure 5)</td><td>Dinantian Pure Bedded Limestone (DPBL).</td><td>DPBL (bedded limestone) underlies the study area.
Beds generally dip SSE at 3^O to 4^O. No mapped faults in the area. GSI 6” Field sheets indicate outcrops are weathered and jointed with joints oriented NNW in some places on ridge to NW. Regionally N-S and E-W joint sets are expected to occur[4].</td></tr>
<tr><td>Aquifer
(Figure 6)</td><td colspan="2">The limestones are classified as a Regionally Important Aquifer – Karstified (Conduit) (Rk_c). Known surface karst features in the vicinity of the GWS source are shown in Figure 6.</td></tr>
<tr><td>Groundwater Body</td><td>Clare-Corrib GWB</td><td>The Rk_c aquifer is in the Clare-Corrib GWB.
http://www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions.htm</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Recharge Coefficient (Appendix 3)</td><td>80 %</td><td rowspan="2">Low drainage density, well drained soils, moderate permeability subsoils, and high to extreme vulnerability, plus point recharge via karst features suggest a high recharge coefficient.</td></tr>
<tr><td>Recharge (mm)</td><td>541</td></tr>
</table>

[2] Teagasc, 2006.
[3] Gatley *et al.*, 2005
[4] Geological Survey of Ireland, 2004.

3.2 Hydrochemistry and water quality

One untreated water sample was collected and analysed by CLS Laboratories on behalf of the NFGWS on 24 July 2014. Eleven untreated water samples were collected and analysed for the Second Rusheens GWS borehole (now abandoned) between November 2000 and November 2001 under a DCENR initiative. 26 treated samples were collected and analysed between January 2002 and November 2011 by Galway County Council. The analytical results are summarised in Table 3. The full data set is in **Appendix 4**.

The existing laboratory results have been compared to the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were recently 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	SP01 Untreated Water		SP01 Treated Water		**Parametric Value**/(Comment)
	Number of Values	Average	Number of Values	Average	
pH (Lab)	12	7.0	26	7.13	**6.5 < pH < 9** / (untreated range 6.7 to 7.2) (treated range 6.9 to 7.8)
Electrical Conductivity (Lab) (uS/cm)	12	736	26	675	**800** / (untreated range 599 to 780) (treated range 610 to 802)
Colour (PtCo Units)	12	4.3	26	4.19	(untreated range 2.5 to 7.5) (treated range 0 to 7.8)
Odour (Descriptive)	11		23	None	(treated samples had no odour)
Turbidity (NTU)	12	0.8	26	0.8	**Acceptable to Consumers/No Abnormal Change** (untreated range 0.3 to 2.8) (treated range <0.01 to 4.4)
Nitrate (mg/l NO_3)	12	2.3	24	12.05	**37.5** / (untreated range 0.8 to 8.1) (Treated range 7.8 to 17.5)
Nitrite (mg/l NO_2)	12	0.02	26	0.01	**0.375** (Untreated range 0.001 to 0.05) (Treated range <0.02 to 0.04)
Ammonia (mg/l N)	12	0.13	26	0.02	**0.175** / (untreated range <0.1 to 0.2) (treated range <0.02 to 0.07)
Chloride (mg/l)	1	20.4	8	19.6	**0.24**/ (treated range 17.2 to 24.2)
Coliform Bacteria (cfu/100ml)	12	51	24	14.5	**0** / (untreated range <1 to 211) (treated range 0 to 201)
E. Coli (cfu/100ml)	12	16	24	18.2	**0** / (untreated range <1 to 62) (treated range 0 to 201)
Clostridium Perfringens (cfu/100 ml)	1	0	21	1	**0**/ (treated range 0 to 18)
Potassium:Sodium Ratio	1	0.17			**0.3**

The field parameters pH, electrical conductivity (EC) and temperature were measured at the borehole during the site visit on 18 June 2014. The EC measured 795 uS/cm, pH measured 6.85 and temperature measured 10.9^{O}C.

The moderately wide range and high upper end in untreated colour and turbidity values suggests a component of turbulent flow to the borehole that can mobilise sediments in the karst system, which is consistent with the observation of sand in the main water strike on the driller's log (**Appendix 1**). Occasional turbid and coloured inputs may indicate some interaction with the karst conduit system.

The intermittent detection of total and fecal coliforms in the untreated water samples suggests that the well may be influenced by point recharge via the karst conduit system. Clostridium perfringens is an indicator for cryptosporidium and its detection in the treated water suggests a cryptosporidium risk. There are no cryptosporidium analysis data on record.

4 Zone of Contribution

4.1 Conceptual model

It is recognised that the scale of this study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Rusheens GWS supply borehole with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. However, based on the analysis of the available information, the current understanding of the geological and hydrogeological setting is given as follows (see cross section: **Diagram 3)**.

A large proportion of the rainfall (80%) is assumed to infiltrate to groundwater as recharge,. This may occur 'diffusely', i.e. across the entire land surface, infiltrating down through the soils and subsoils until it reaches the aquifer, or ' as 'point recharge', i.e. direct routes into the aquifer, bypassing the any soils or subsoil layers, which occurs at certain surface karst features, such as swallow holes, dolines and turloughs. The remainder of rainfall (20%) is expected to runoff to surface water.

Once the infiltrating water reaches the bedrock aquifer, flow occurs in joints, fractures and conduits, and along bedding planes in the limestone bedrock. Three main interconnected flow zones are envisaged: 1) flow in the extensively weathered and karstified, zone in the top few metres of the bedrock ("epikarst"); 2) flow in a network of interconnected fractures and karst conduits up to 30 m below the rock surface; 3) deeper flows occurring in areas associated with faults or dolomitisation (which results in zones of increased groundwater flow).

Any groundwater flows that may predominantly occur in the epikarst are likely to reflect the local topography i.e. moving downslope towards points of vertical infiltration to the interconnected fractures/deeper conduit system, or to surface water courses e.g. the Clare River. Boreholes will capture groundwater flow through the epikarst where they intersect and are open to it. Where the epikarst system is well connected with the underlying groundwater systems (2 and 3 above), recharge may pass almost immediately into these deeper systems[5]. Groundwater flow in the deeper conduit system is expected to be directed southwest (**Appendix 5**).

Overall, the current GWS borehole appears to be predominantly supplied by two components, i) interception of groundwater infiltrating down through fractures from the epikarst[6], and ii) the capture of water from the regional conduit system by drawing it in via the zone of broken rock at c. 50 mbgl[7], which is likely to be well connected to the regional system. It is possible that the latter component may be the dominant component of the borehole supply. Nearby surface karst features which could be linked to the source via point recharge are shown in **Figure 7**.

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[5] Caoimhe Hickey, personal communication, 17 October, 2014

[6] The construction of the current borehole, which includes an annular grout seal, should ensure that direct, shallow inflows from the epikarst to the borehole do not occur. However, the nearby Old Borehole (not grouted) may provide a rapid pathway for shallow inflows to migrate directly to the zone of deep, broken rock intersected by the current borehole.

[7] The current GWS borehole log implies that the borehole draws water from a sandy water strike in broken limestone at 49 m to 54 mbgl

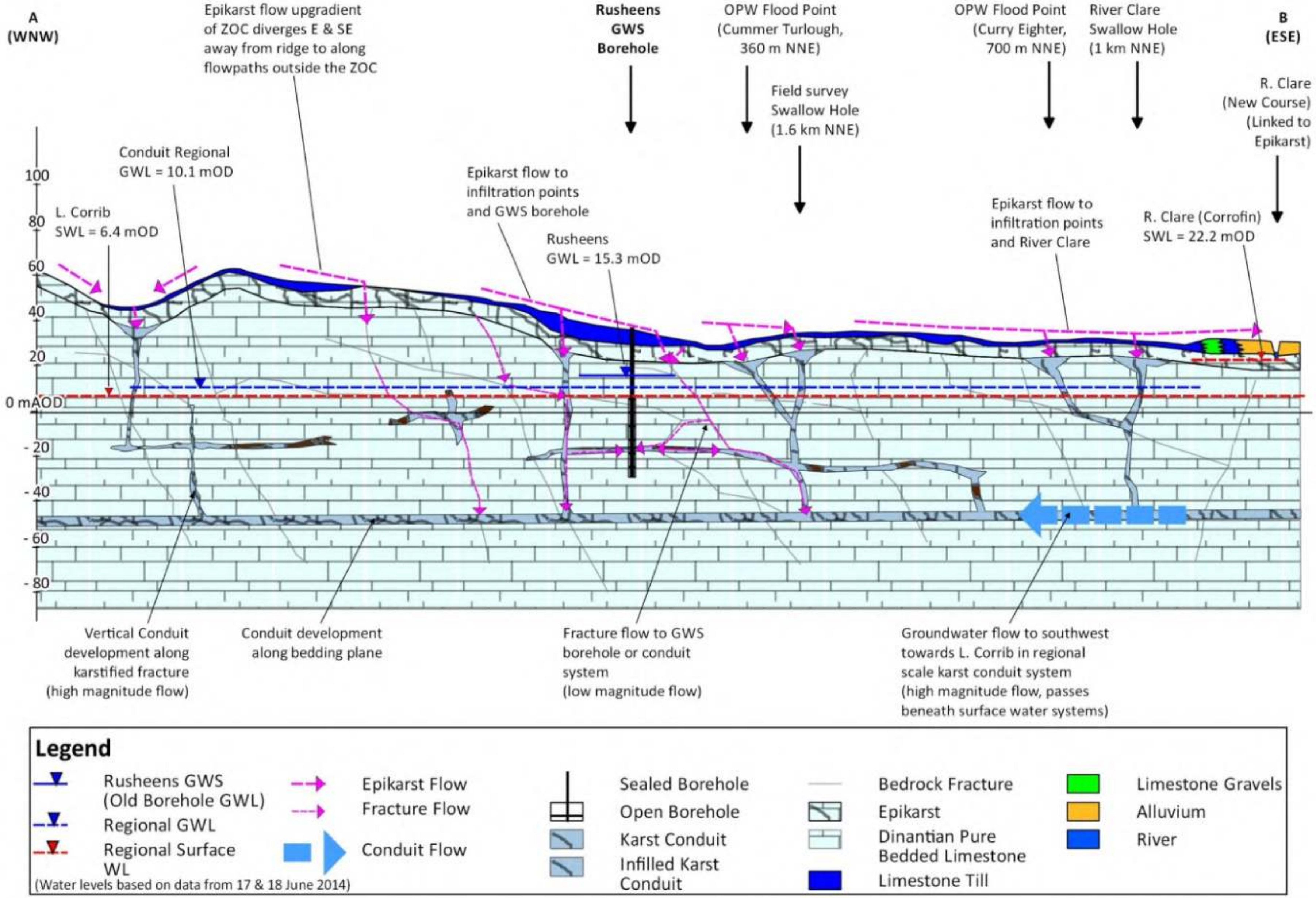

Diagram 3: Schematic Cross Section and Conceptual Model

4.2 Boundaries

The difficulties of delineating definitive ZOC boundaries due to the hydrogeological complexity of this area and the limited scale of this study (i.e. predominantly desk study) have already been noted. However, based on the available information, the most likely areas contributing to the borehole supply have been identified, which will allow the GWS to focus appropriate landuse management with the aim of improving the water quality. These areas are shown in Figure 7 and described below:

Area to the EAST: an area that reflects the regional flow direction (approximately east to west), which is highly likely to be supplying to the borehole i.e. the inflow from the deep fractures, This delineated zone, which is the most likely area to be contributing to the groundwater, includes a number of mapped, and likely (as yet unrecorded) karst features (swallow holes, dolines, turloughs), which are possibly providing rapid pathways down to the groundwater supplying the borehole (see Figure 7).

The **Western Boundary** is the distance downhill (or 'downgradient') that groundwater may be drawn back towards the pumping borehole. This is estimated to be approximately 100 m.

The **Northern and Southern Boundaries** are based on the likely groundwater flow directions towards the borehole. The northern and southern boundaries are delineated to pass within 100 m of the known karst point recharge features. The northern boundary also includes a buffered length of the Clare River, which is known to sink underground at one of the mapped karst swallow holes, therefore directly inputting in to the groundwater system. The buffer is 10 m wide and has been applied to the length of river up to its confluence with the main channel. Although any incidents in the river upstream of this confluence may impact on the groundwater, and therefore possibly on the borehole water itself, including the entire upstream river would not be practical for the GWS to manage. Therefore, the inclusion of the buffered stream is mainly to highlight that this area (and potential sources of contamination) may require management.

The **Eastern Boundary** is based on the Clare River. It is acknowledged that groundwater further east of the Clare River may be contributing to the borehole supply because: groundwater flow moving from east to west beneath the Clare River has been identified; groundwater flowpaths of greater than 10 km have been recorded in this region; and leakage of water from the Clare River into the groundwater system has been recorded (**Appendix 5)**. However, this is considered to be a reasonable and practical boundary for GWS landuse management purposes.

Area to the WEST: an area that may be supplying the borehole from local flow, predominantly originating and flowing through the epikarst zone, but then flowing down the Old Borehole, which may be providing a rapid pathway from the surface to the lower parts of the aquifer system that are more likely to be supplying the current borehole i.e. length that is not grouted off.

The **Western Boundary** is positioned over a topographic saddle 1.8 km west northwest of the source borehole at Ballydotia East. An epikarst groundwater divide is assumed to occur beneath the saddle such that groundwater in the epikarst to the east of the saddle flows east, and to the west it flows west.

The **Northern and Southern Boundaries** follow the topography and delineate a roughly rectangular ZOC area for the Epikarst ZOC component. The rectangular shape reflects the uncertainty in the delineation of this component.

The **Eastern Boundary** is the distance downhill (or 'downgradient') that groundwater may be drawn back towards the pumping borehole. This is estimated to be approximately 450 m.

It is possible that additional areas may also be contributing to the borehole supply so the GWS may want to consider further hydrogeological work/ measures if water quality issues persist once the above delineated area have been assessed.

4.3 Recharge and water balance

The current demand for the Rusheens GWS is 216 m^3/day. The maximum sustainable yield for the borehole is considered to be between 432 and 540 m^3/day by the GWS. In order to accommodate potential peak abstraction rates above the average long term demand of 216 m^3/day, 150% of the current demand has been used as the abstraction rate in the water balance calculations, i.e. 324 m^3/day.

Recharge to the ZOC is estimated as 541 mm/year (see **Table 2**). At a recharge rate of 541 mm/yr the 324 m^3/day abstraction rate requires a ZOC of 0.22 km^2 to capture the required volume of diffuse recharge to balance the abstraction.

Area to the East: Regional ZOC Component Water Balance

The area of the delineated regional ZOC component is 4.1 km^2. This area could potentially contribute 6,000 m^3/day of recharge to the regional groundwater flow system from diffuse infiltration. This could be topped up by inflow of surface water at point recharge locations. The borehole is not considered to be capable sustaining an abstraction of this magnitude. Rather the regional ZOC component reflects a likely potential area from which the actual abstraction might derive.

Area to the West: Epikarst ZOC Component Water Balance

The delineated epikarst ZOC has an area of 0.83 km^2 and thus receives a diffuse recharge contribution equal to almost 400% of the current demand of the scheme. It is likely that most of the recharge to this area leaks down to the deeper aquifer as the epikarst groundwater flows east southeast. If an epikarst component reaches the abstraction it is considered likely that it would derive from within the delineated area.

5 Conclusions

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. It is also acknowledged that this scale of study (i.e. predominantly desk study) cannot delineate a definitive ZOC for the Rusheens GWS supply borehole due to the complicated nature of the karst aquifer in this region As such, the maps should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

The current abstraction for the Rusheens GWS is 216 m^3/day. The maximum demand that the borehole can sustain is considered to be between 432 m^3/day and 540 m^3/day by the GWS.

The ZOC delineation was based on a combination of hydrogeological mapping and the topographical catchment of the borehole. The delineated ZOC has a regional component deriving from the deep conduit flow system, and potentially a localised component deriving from the perched epikarst system.

- A 4.1 km^2 area to the east and northeast of the source has been delineated within the regional scale flow system. This regional ZOC component reflects a likely potential area from which the actual abstraction might derive, and which has been prioritised for risk management.

- An area of 0.83 km^2 ZOC to the west-northwest of the source has been delineated within the localised epikarst flow system, which may be reaching the borehole via the Old Borehole, which has not been grouted off or decommissioned. The delineated area conservatively encompasses a recharge area equivalent to 400% of the current demand of the PWS. If an epikarst component reaches the abstraction it is considered likely that it would derive from within the delineated area.

The groundwater vulnerability within the overall ZOC (i.e. combined regional and epikarst component areas) is mapped as Extreme (X) (12%), Extreme (E) (58%), High (20%) and Moderate (10%). 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 available water quality data show occasional turbid and coloured inputs and intermittent microbial contamination may indicate some interaction with the karst conduit system. Clostridium perfringens is an indicator for cryptosporidium and its detection in the treated water suggests a cryptosporidium risk. There are no cryptosporidium analysis data on record.

6 Recommendations

Essential

A water-tight, lockable lid should be fitted to the top of the borehole chamber to replace the current, loose steel lid that sits on top of the concrete-ring, chamber wall.

A 10 m x 10 m compound is recommended to provide sanitary protection for the borehole area.

The cumulative flow reading on the meter should be recorded along with the time and date of the reading on a weekly basis.

Routine analysis of the untreated or raw water along with the existing analysis of treated water around the distribution network should be undertaken. It is recommended that this is carried out on a monthly or quarterly basis for a period of 12 months, and at least once after a rainfall event. If the water quality appears generally stable during this period then the monitoring could be reduced.

The following water quality parameters are considered essential:

- 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 4**).

Desirable

- The GWS should seek advice with respect to undertaking a cryptosporidium risk assessment for this supply.
- Tracer testing at surface karst features in the vicinity of the source (**Figure 7**) would be worthwhile as a precaution to investigate if there is interaction between the borehole and local point recharge inputs to the regional scale karst conduit system. If tracing shows the borehole to be connected to these locations, this will reinforce the need for landuse management if the delineated regional ZOC component. If tracer tests are to be carried out it may be economical to collaborate with the nearby **Caherlea-Currane GWS** in the planning and execution of the tests.
- Comprehensive hazard mapping within the delineated ZOC should be undertaken. 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**).
- If there are any septic tank systems located within 60 m of the source they should be assessed with a view to possible management/replacement. Any new, replacement system should comply with the EPA Code of Practice on Wastewater Treatment and Disposal Systems for Single houses.
- The animal watering-trough adjacent to the current source borehole and the cattle-crush in the field containing the borehole should be re-sited to a different field at locations at least 60 m from the source borehole.
- The GWS should seek advice with respect to decommissioning the Old Borehole.
- The untreated water rising main should be fitted with a turbidity and associated supply shut-off threshold and alarm.

- The following EPA guidelines may serve as future useful reference documents for the Rusheens 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] .

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

[1]http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp
[2] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo

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

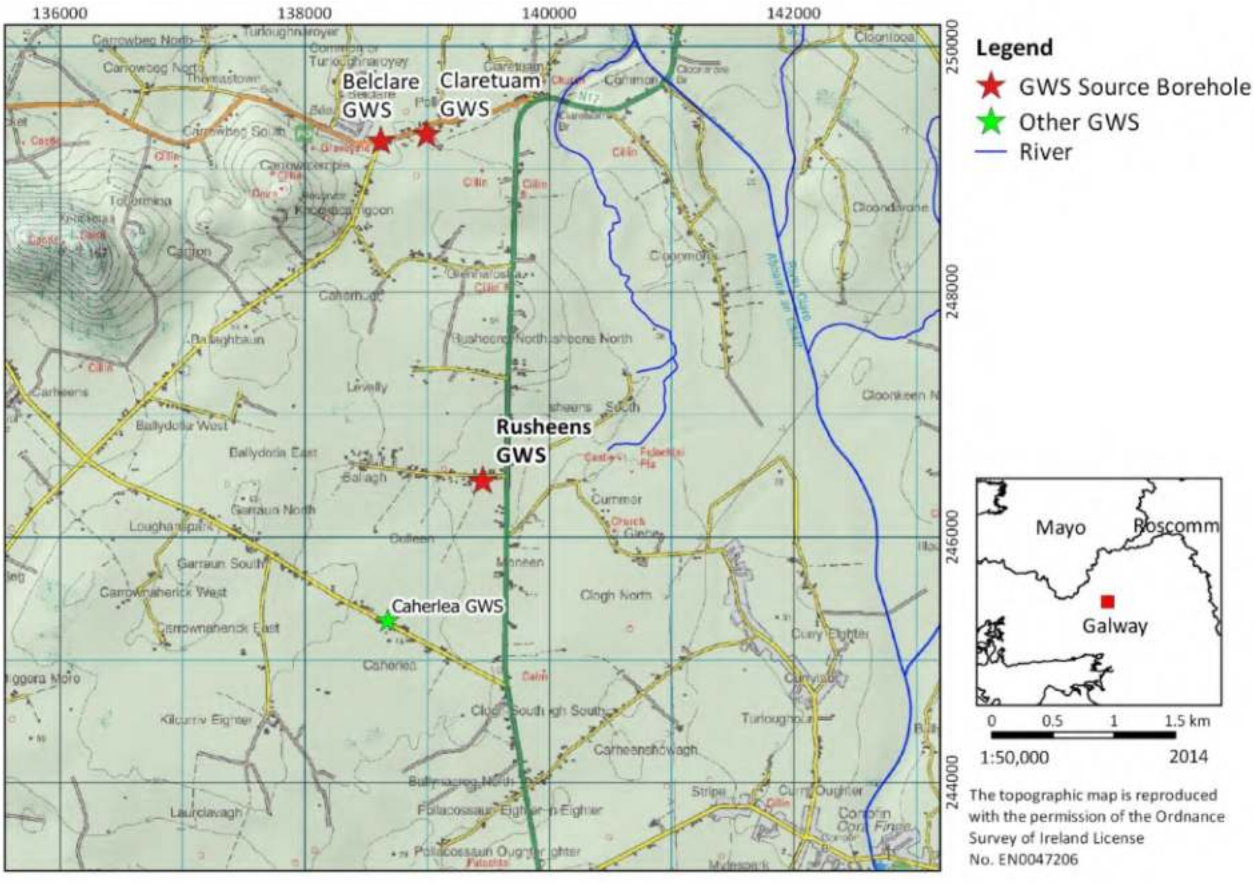


Figure 1: Location Map (OSi Discovery Series Map. 1:50,000 Scale)

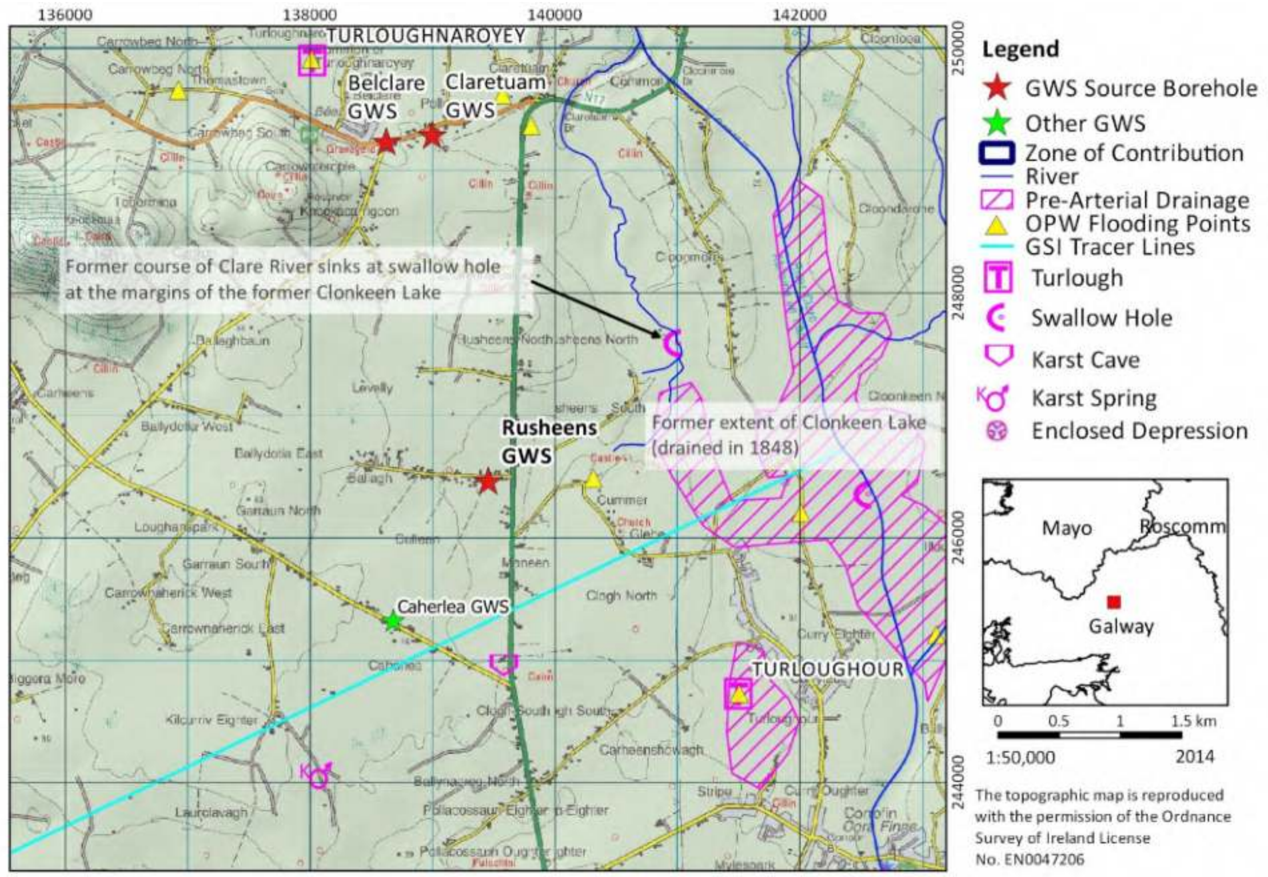


Figure 2: Topography and Drainage

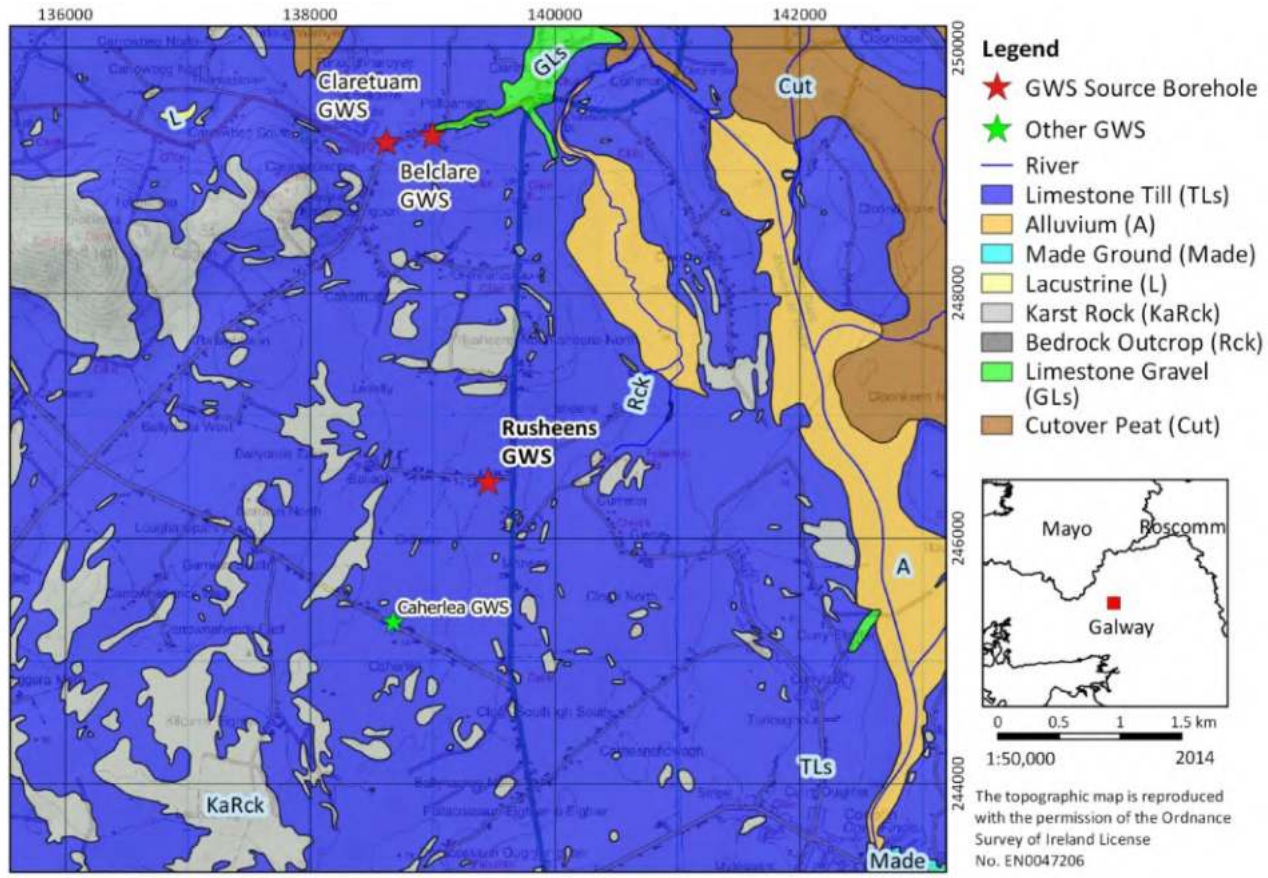


Figure 3: Subsoil Map

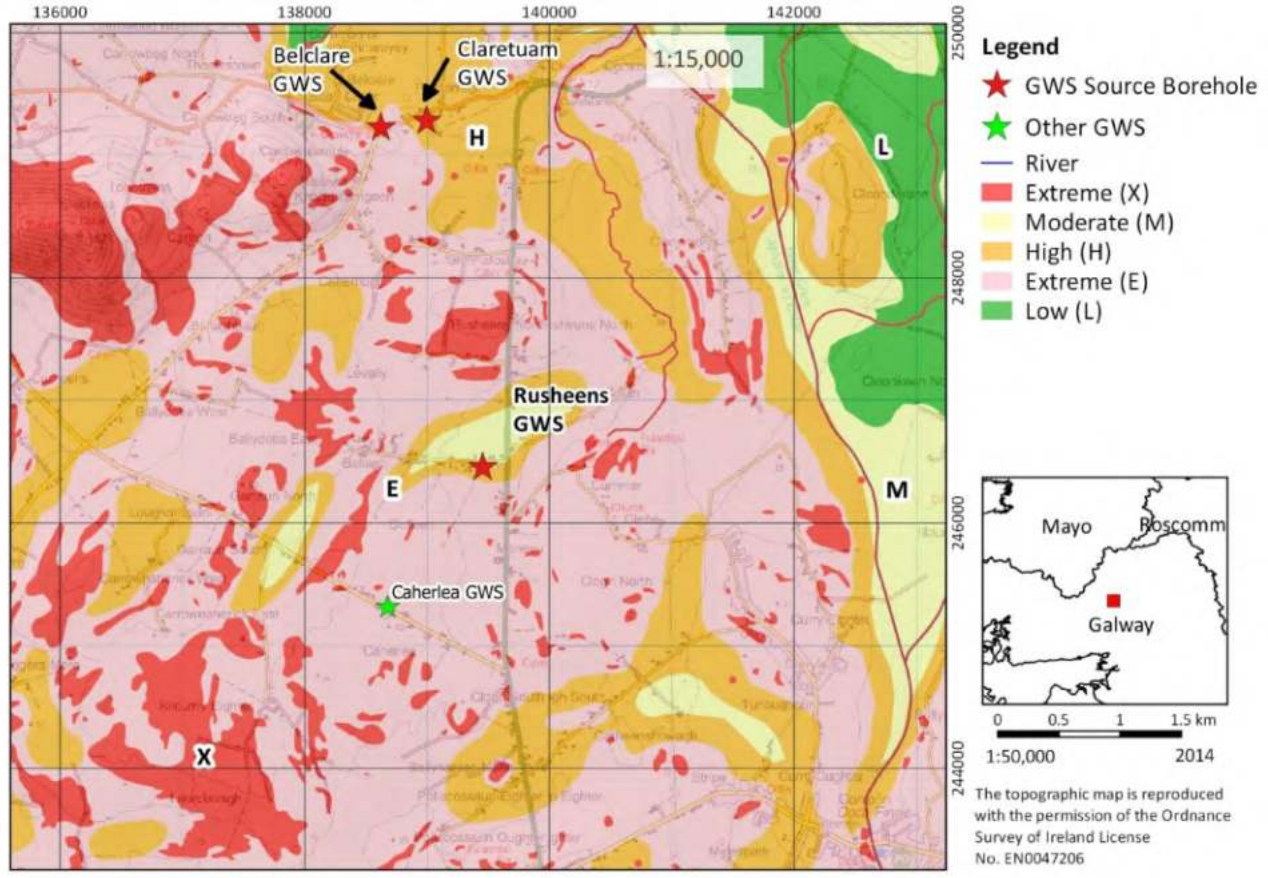


Figure 4: Groundwater Vulnerability Map

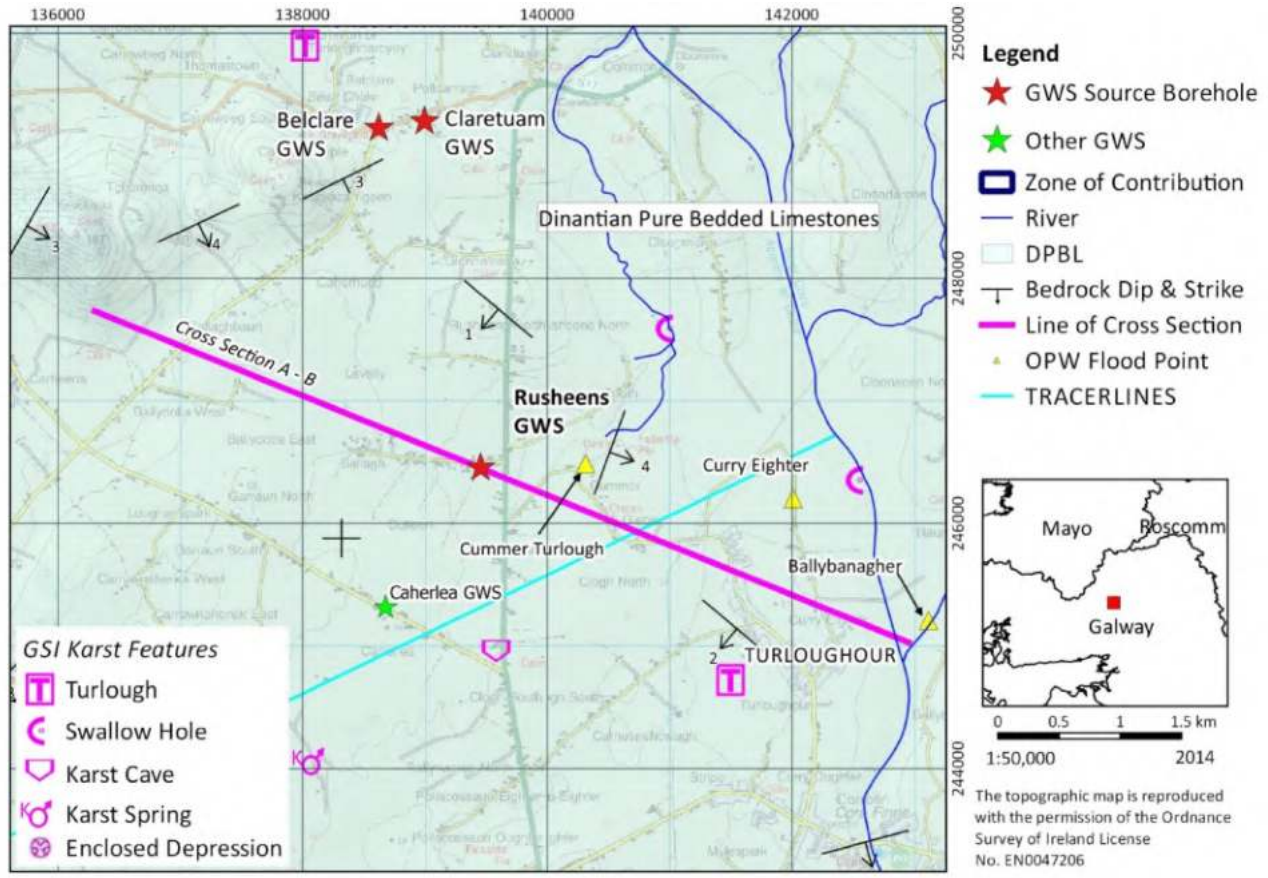


Figure 5: Rock Unit Group Map

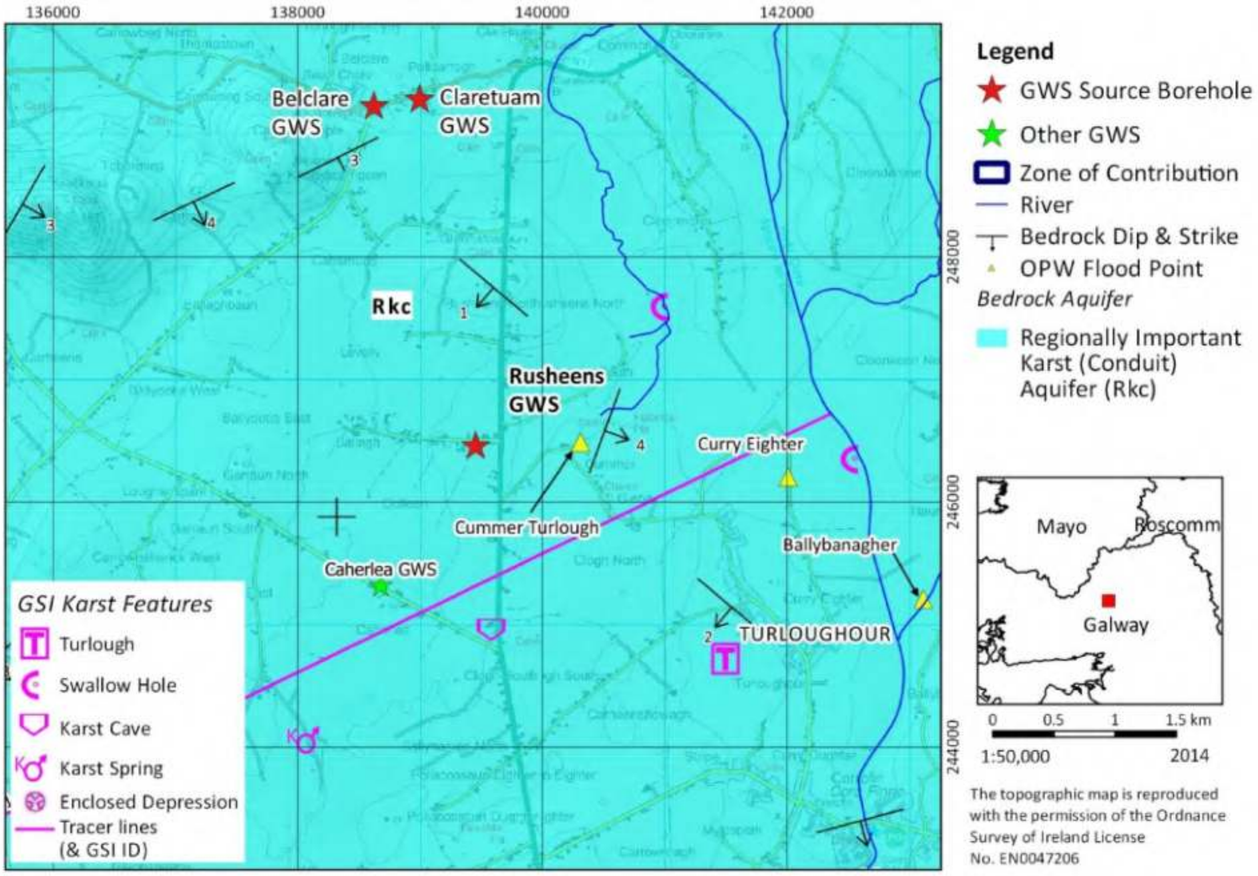


Figure 6: Aquifer Map

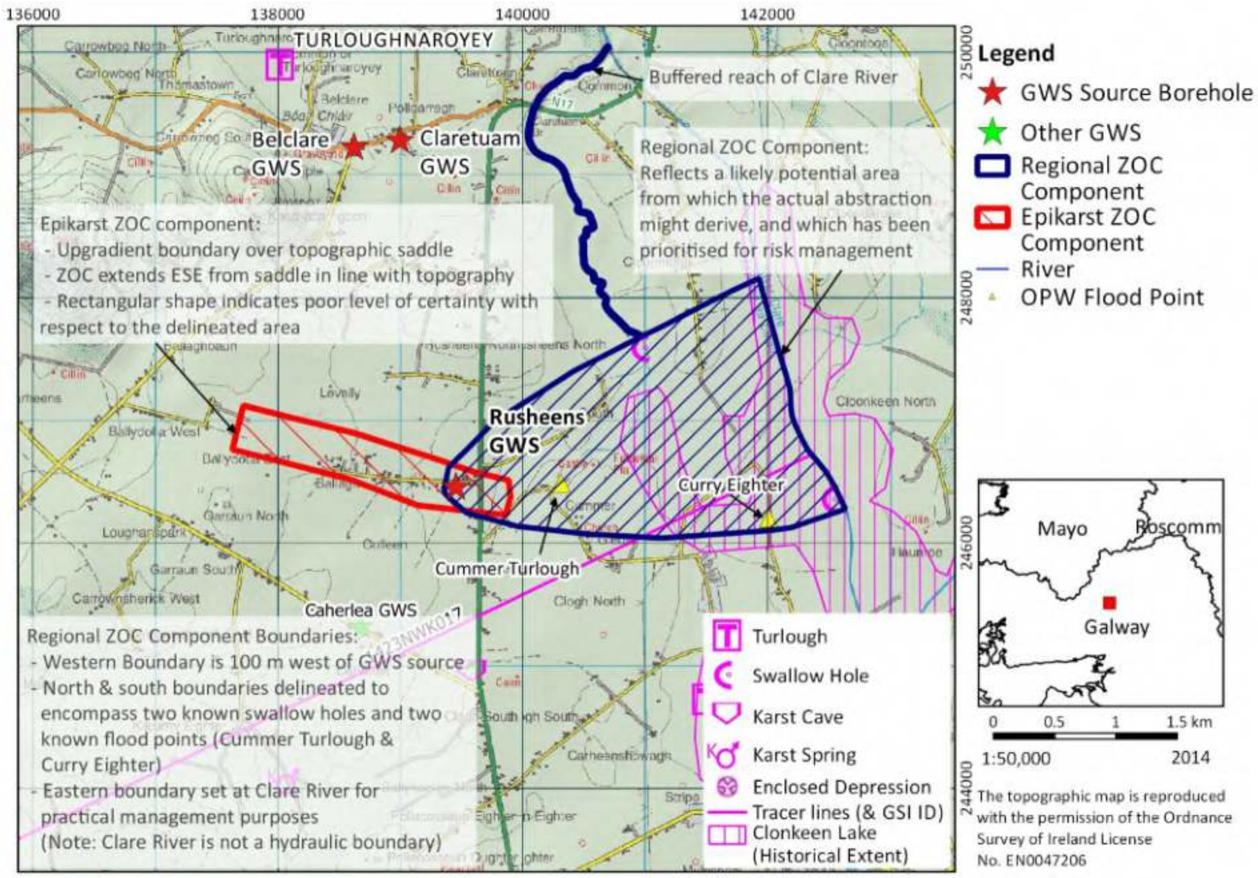


Figure 7: ZOC Boundaries

APPENDIX 1

Borehole Log

Patrick Briody & Sons Ltd.

DRILLING LOG

AQUADRILL SERVICES **Well Drilling & Site Investigation Contractors**

The Grove,
Rathangan, Co. Kildare.
Tel (045) 524...
Fax (045) 524...
e-mail: info@briodydrilling.com

Consultant/Engineer: Matthew Hughes
Client: ... G.W.S., Belclare, Tuam, Galway
Borehole Reference No: BH1 Sheet 1 of 2
Borehole Location: 30m behind pumphouse

0886

Date of Drilling	Depth (from - to)	Annual Drilling Diameter	Drilling Conditions / Water Strike
21-9-12	0 - 20'	250mm	boulder clay & sand
2-10-12	20 - 23	160mm	bedrock limestone
	23 - 28	"	broken clay & stones roughly 200 gph
	28 - 45	"	good limestone
	45 - 58	"	small amount water but very broken clay & sand
	58 - 162	"	competent rock
	162 - 178	"	very broken with large water & sand
	178 - 210	"	competent limestone

Drilled 15" and installed 20' x 10" steel shell 10" to 210' then installed 70' x 8" steel and cleaned out hole.

Total Depth of Well ...
Estimated Yield ...
Depth to Rock ...
Steel Casing Installed ...
P.V.C. Casing/Screen Installed ...
Other Remarks ...

Schematic View

Lead Driller ... Drilling Rig ...
Engineer Approval ...

Patrick Briody & Sons Ltd.

DRILLING LOG

AQUADRILL SERVICES — **Well Drilling & Site Investigation Contractors**

The Grove,
Rathangan, Co. Kildare.
Tel (045) 524380
Fax (045) 524735
e-mail: info@briodydrilling.com

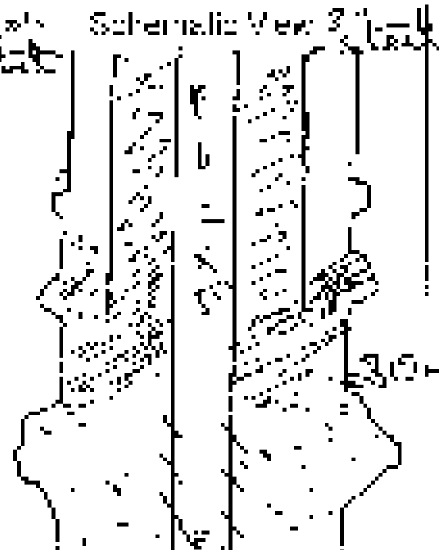
0887

Consultant/Engineer: Malachy Murphy
Client: Kilchreest [illegible] G.W.S., Ballyboy, Tuam, Galway
Borehole Reference No: BH [illegible]   Sheet 1 of 2
Borehole Location: 30m behind pumphouse

Date of Drilling	Depth (m - ft) BGL	Actual Drilling Diameter	Drilling Conditions / Water Strike
[illegible]	Installed uPVC x 8" to 195'		
12-10-12	115' x solid		
	80' x screen		
	gravel pack		back from 195' to 100'
	then 5 bags of bentonite		
	then pumped		30 bags of cement back to 50'
	then 20 bags of bentonite back to 0		
	Airlift for 6 hours = total		
	before P.V.C and after gravel.		

Total Depth of Well: 195'
Estimated Yield: 2,000 gls/hr
Depth to Rock: 90'
Steel Casing Installed: 20' x 10" [illegible] 70' x 8"
PVC Casing/Screen Installed: 200' x PVC
Other Remarks: Development of borehole [illegible] comprising backfill of clean gravel, bentonite and pumped [illegible] of cement from [illegible] [illegible] surface [illegible] [illegible]
Lead Driller: [illegible]   Drilling Rig: [illegible]
Engineer Approval: [illegible]

Schematic View of Well



APPENDIX 2

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

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

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 3

Groundwater Recharge

Introduction

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using 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
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

Acknowledgement: many of the recharge coefficients in this table are based largely on a paper submitted by Fitzsimons and Misstear (in press).

APPENDIX 4

Rusheens GWS Borehole Untreated Water Quality Data

Rusheens GWS Borehole Treated Water Quality Data

Untreated Groundwater Quality Monitoring Parameter Suite

Geological Survey of Ireland
Rusheens GWS Zone of Contribution

Rusheens GWS - Untreated Water Quality 2000 to 2014

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliform	Faecal Coliform	BOD
Units	Hazen	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	0.23	11.3	0.15	200	200	50	0/100ml	0/100ml	
Nov-00	2.5	<0.01	730	6.65	0.1	1	0.05	<4	5	<6	<1	<1	
Dec-00	5	<0.01	705	6.88	0.2	1.6	0.05	<4	<5	<6	**1**	<1	
Jan-01	5	0.88	737	6.99	0.1	2	0.05	7	6	<6	<1	<1	
Feb-01	5	0.54	766	6.89	0.1	2	0.05	<4	15	<6	<1	<1	
May-01	5	0.63	775	6.75	0.1	0.8	0.004	11	9	<6	**30**	**13**	
Jun-01	**7.5**	0.4	744	6.8	0.2	1.8	0.002	11	6	<6	**12**	**5**	
Jul-01	2.5	0.44	754	7.09	0.1	8.1	0.003	<4	<5	<6	**9**	**7**	
Aug-01	2.5	0.33	770	7.14	0.1	2.2	0.008	8	<5	<6	**100**	**25**	
Sep-01	5	<0.01	741	7.09	0.15	1.5	0.004	8	7	6	**79**	**2**	
Oct-01	2.5	0.85	729	7.2	<0.1	2.4	0.001	26	31	<6	**211**	**62**	
Nov-01	5	**2.81**	780	7.14	<0.1	2.4	0.007	28	27	7	**8**	**5**	
24-Jul-14	11 mg/l pt Co	0.4	599	7.1	<0.008	1.29	<0.005	18	62	<5	**5**	**5**	<1
Count	12	12	12	12	12	12	12	12	12	12	12	12	1
Average	4.3	0.8	736	7.0	0.13	2.3	0.02	14.6	19	7	51	16	<1
Max	7.5	2.8	780	7.2	0.20	8.1	0.05	28.0	62	7	211	62	0.0
Min	2.5	0.3	599	6.7	<0.1	0.8	0.001	7.0	5	6	<1	<1	0.0

Parameter	COD	Alkalinity	Sodium, Total	Chloride	Dissolved O2	Potassium, Total	Hardness, Total	Magnesium Total	Silica	Sulphate	Orthophosphate	Calcium, Total	Copper, Dissolved
Units	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	mg/l	ug/l
SI278of 2007 - DWS			200	250						250			2000
Nov-00													
Dec-00													
Jan-01													
Feb-01													
May-01													
Jun-01													
Jul-01													
Aug-01													
Sep-01													
Oct-01													
Nov-01													
24-Jul-14	<10	351	14	20.4	32	4	372	8	2.05	13.6	0.035	103	3
Count	1	1	1	1	1	1	1	1	1	1	1	1	1
Average	<10	351	14	20.4	32.0	4.0	372	8	2.1	13.6	0.035	103	3
Max	0.0	351	14	20.4	32.0	4.0	372	8	2.1	13.6	0.035	103	3
Min	0.0	351	14	20.4	32.0	4.0	372	8	2.1	13.6	0.035	103	3

Parameter	Lead, Dissolved	Chromium, Dissolved	Nickel, Dissolved	Cadmium, Dissolved	Arsenic, Dissolved	Zinc, Dissolved	Barium, Dissolved	TOC	Clostridium Perfringens	Strontium	Fluoride	Potassium: Sodium Ratio
Units	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	cfu/100ml	ug/l	mg/l	
SI278of 2007 - DWS	10	50	20	5	10			NAC			0.8	
Nov-00												
Dec-00												
Jan-01												
Feb-01												
May-01												
Jun-01												
Jul-01												
Aug-01												
Sep-01												
Oct-01												
Nov-01												
24-Jul-14	<0.5	<0.5	4	<0.5	<0.5	6	33	3.19	0	453	0.2	0.17
Count	1	1	1	1	1	1	1	1	1	1	1	1
Average	<0.5	<0.5	4	<0.5	<0.5	6	33	3.19	0	453	0.2	0.17
Max	0	0.0	14	20.4	0.0	4	33	3.2	0	453	0.2	0.17
Min	0	0.0	14	20.4	0.0	4	33	3.2	0	453	0.2	0.17

Rusheens GWS Drinking Water Quality - Treated Water Quality 2002 to 2014

Date							22/01/2002	03/09/2002	15/04/2004	08/07/2004	14/10/2004	05/04/2005	24/08/2005	09/11/2005	13/12/2005
Location	Units (Assumed)	SI278of 2007 - DWS	Count	Average	Max	Min	Ryder's House,	Eithne Skyrnes House				Silke's DH	Mattie Murphy	Silkes House	Silkes House
1,2-dichloroethane	ug/l	3	8	0.05	0.10	0.00						<0.06			
Acrylamide			0												
Aluminium	ug/l	200	19	37.04	**241.00**	0.00			<0.006	<0.006	0.006	<5			
Ammonium	mg/l	0.3	26	0.03	0.09	0.00	<0.025	<0.025	<0.01	<0.01	0.04	<0.0089	<0.025	<0.025	<0.025
Antimony	ug/l	5	6	0.06	0.11	0.00						<0.17			
Arsenic	ug/l	10	8	0.42	0.60	0.30						<0.12			
Benzene	ug/l	1	8	0.05	0.10	0.00						<0.09			
Benzo(a)pyrene	ug/l	0.01	8	0.00	0.00	0.00						<0.003			
Boron	mg/l	1	8	0.05	0.23	0.00						0.23			
Bromate	ug/l	10	8	0.50	1.00	0.00						<1.1			
Cadmium	ug/l	5	8	0.15	0.30	0.10						<0.44			
Chloride	mg/l	250	8	19.55	24.20	17.20						24.2			
Chromium	ug/l	50	8	0.66	1.30	0.00						<0.9			
Clostridium Perfringens	no/100 ml	0	21	1.00	**18.00**	0.00			0	0	0	0			
Coliform Bacteria	no/100 ml	0	24	14.52	**201.00**	0.00	**105**	**201**	0	0	0	0		0	0
Colony Count @ 22°C	no/100 ml		2	17.00	18.00	16.00						18			
Colour		AC & NAC	26	4.19	**7.80**	0.00	3.3	2.3	**7.5**	2.5	2.5	**5.6**	4.6	**5.5**	**7.8**
Conductivity	uS/cm	2500	26	674.80	812.00	610.00	739	812	644	690	662	716	668	663	674
Copper	mg/l	2	6	0.07	0.17	0.00						0.064			
Cryptosporidium			2	0.00	0.00	0.00									
Cyanide	ug/l	50	6	2.50	5.00	0.00						<5			
E. coli	no/100 ml	0	24	18.21	**201.00**	0.00	**24**	**201**	0	**1**	0	0		0	0
Enterococci	no/100 ml	0	9	2.86	**20.00**	0.00						0			
Epichlorohydrin			2	0.00	0.00	0.00									
Fluoride	mg/l	0.8	8	0.32	**0.84**	0.14						**0.84**			
Free Chlorine	mg/l		8	0.24	0.45	0.00									
Giardia			2	0.00	0.00	0.00									
Hardness	mg/l as CaCO3		3	377.00	377.00	377.00									
Iron	ug/l	200	26	18.57	64.00	0.00	<50	<50	<6	24	6	<6	<50	<50	<50
Lead	ug/l	25 (10)	8	1.35	2.00	0.57						<2.2			
Manganese	ug/l	50	24	7.47	20.00	0.00	<20	<20	<2	8	2	<0.9	<20	<20	<20
Mercury	ug/l	1	8	0.01	0.02	0.00						<0.046			
Nickel	ug/l	20	9	2.29	4.10	1.23						<2			
Nitrate	mg/l	50	24	12.05	17.50	7.80	14.5	10.9	14.8	10.9	16.8	14.4	8.2	13.6	13.5
Nitrite (at tap)	mg/l	0.5	26	0.01	0.04	0.00	<0.020	<0.020	0.002	<0.001	0.014	<0.006	<0.020	<0.020	<0.020
Nitrites (at WTW)			0												
Odour		AC & NAC	23	0.00	0.00	0.00	None	None				None	None	None	None
Oxidisability			2	0.00	0.00	0.00									
PAH	ug/l	0.1	6	0.01	0.01	0.00						<0.01			
Pesticides - Total	ug/l	0.5	6	0.01	0.01	0.00						<0.01			
pH	[-]	6.5-9.5	26	7.13	7.80	6.90	7.1	6.9	6.93	7.17	7.09	7.1	7.4	7.2	7.2
Selenium	ug/l	10	8	1.23	1.96	0.29						1.65			
Sodium	mg/l	200	6	12.70	17.90	10.47						17.9			
Sulphate	mg/l	250	8	12.09	19.20	8.01						19.2			
Taste		AC & NAC	9	0.00	0.00	0.00						None			
Tetrachloroethene & Trichloroethene	ug/l	10	10	1.72	5.00	0.00						<0.18			
Total Chlorine			3	0.52	0.52	0.52									
Total Indicative Dose			2	0.00	0.00	0.00									
Total Organic Carbon	mg/l	NAC	8	2.56	3.50	1.60						3.07			
Trihalomethanes(Total)	ug/l	100	16	11.36	20.15	5.00						18.36		8	5
Tritium			2	0.00	0.00	0.00									
Turbidity (at tap)	NTU	AC & NAC	26	0.80	**4.40**	0.00	0.3	0.48	<0.01	<0.01	0.01	0.4	1	0.5	0.4
Turbidity (at WTW)			0												
Vinyl Chloride			2	0.00	0.00	0.00									

Rusheens GWS Drinking Water Quality - Treated Water Quality 2002 to 2014

31/08/2006	16/11/2006	28/08/2007	11/10/2007	29/11/2007	03/07/2008	23/07/2008	02/09/2008	21/04/2009	07/05/2009	28/09/2009	13/04/2010	07/10/2010	14/12/2010	17/06/2011	13/07/2011	10/11/2011
David Tierney	Paddy Reilly	Brian Murphys House	Paddy Joe Reillys house	Paddy Joe Reillys House	Tierneys Private House	Tierneys Private House	Paddy Joe Reillys House.	Tierneys Private House	Paddy Joe Reillys House.	Paddy Joe Reillys House.	Paddy Joe Reillys House.	Paddy Joe Reillys House.	Tierneys Private House	Patrick O Dea Rusheens	Paddy Joe Reillys House.	Stephen Durrane Rusheens Tuam
		<0.1				0.1		0.1					0		0	
		47.8			100	12.5	**241**	5	20	20	0	0	56.3	6	0	10
<0.03	<0.03	0.079	<0.03	<0.03	0.06	0.089	0.03	0.009	0.03	0.03	0.03	0	0	0.03	0	0.011
		0.1				0.1		0.1					0		0	
		0.4				0.3		0.301					0.508		0.6	
		<0.1				0.1		0.1					0		0	
		<0.003				0.003		0.003					0		0	
		0.02				0.02		0.02					0		0	
		<1				1		1					0		0	
		0.2				0.1		0.1					0.106		0.3	
		19.3				18.5		19.4					17.2		18.7	
		1.3				1		1					0		0	
		0	0	**18**	0	0	**1**	0	0	0	0	0	0	0	0	0
	0	**10**	**18**	**>201**	0	0	0	0	0	0	0	0	0	0	0	0
		16														
3.8	4.5	4.7	2.9	3.8	4	**5.57**	**7.3**	2.99	**6.5**	2	**6.6**	2.3	4.4	**6**	0	0
680	663	690	680	662	654	689	677	671.9	694	706	620	610	627	620	674	659
		0.038				0.000263		0.17					0.152		0.021	
		<5.0				5		5					0		0	
	0	**2**	**8**	**201**	0	0	0	0	0	0	0	0	0	0	0	0
		0		**20**		0		0					0		0	
		0.26				0.14		0.14					0.26		0.3	
							0		0.28	0.25	0.14	0.32	0.45			
					377											
<50	<50	<5.0	<50	<50	50	5	64	7.567	50	20	0	0	8.42	13	0	12
		1.6				1.7		0.899					0.573		2	
<20	<20	1.7	<20	<20	20	4.4	20	1	20	20	0	0	0		0	
		<0.02				0.02		0.02					0		0	
		<0.5				2.7		1.232			4.1		1.296		2.1	
10.7	12.5	13.16	10.9	17.5	12.2	11.1	10.3	10.7	10.8	8.7	7.8	16.5	7.86		10.9	
<0.02	<0.02	<0.043	<0.02	<0.02	0	0.000043	0	0.043	0.02	0.02	0	0	0	0	0	0
0	0	None	None	None	0	0	0	0	0	0	0	0	0	0	0	0
		<0.01				0.01		0.01					0		0	
		<0.01				0.01		0.01					0		0	
7.2	6.9	7.1	7	7	7.2	7.8	7	7.4	7	7	7.2	7	7.3	7	7.1	7
		0.5				1.8		0.291					1.957		1.2	
		11.5				10.47		13.75					10.79		11.8	
		8.4				9.7		8.01					17.3		9.9	
						0		0					0	0	0	0
		<0.2	<5	<5	5	0.2	5	0.1					0		0	
													0.52			
		2.3				3.5		1.6					3.17		1.74	
5	<10	<5.0	<10	<10	10	5	10	17.7					14.4		20.15	
0.3	0.5	0.72	1	0.8	1.9	**3.44**	**4.4**	0.91	0.4	0.2	0.2	0.6	0.148	0.4	0	0.3

Raw Water Analysis Parameters Required for ZOC Delineation
Turbidity
pH
Conductivity @20C
Alkalinity, total
Sodium, total
Chloride
Ammonium as NH4
Nitrate as NO3
Dissolved Oxygen (%)
Iron, total
Potassium, total
Total Hardness (Kone)
Magnesium, total
Colour, apparent
Sulphate
Orthophosphate as PO4-P
Manganese, total
Calcium, total
TOC
E coli (Filtration) (Environmental Waters)
Total Coliforms (Filtration) (Environmental Waters)
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),
Clostridium perfringens
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.

APPENDIX 5

Regional Hydrogeology Summary

1 The Study Area

The group water schemes (GWS) at Claretuam, Belclare, Rusheens, Anbally and Carheenlea are under consideration for this study. They are located in central Galway between Tuam and Claregalway (Figure A).

2 Historical Drainage and Regional Scale Groundwater Flow

The present day drainage system within the study area has been greatly altered by artificial drainage works over the last 150 years. The original, natural, drainage system that existed in the area in the late 1700s is shown in Figure B (Coxon and Drew, 1983), which shows the entire Clare River sinking to groundwater. The current altered state of the drainage system in comparison to the condition in the late 1700s is shown in Figure C. Handwritten notes on the GSI 6" historical field sheets for the area indicate that the Clonkeen Lake area is "rarely flooded since Board of Works Operations in 1848".

The artificial drainage was intensified by an OPW arterial drainage scheme in the 1950s and 1960s, which was designed to provide basic conditions for increased crop production and improvement of stock by drainage of 135,000 km^2 of wetlands for agricultural use (Ryan Hanley, 2010). The scheme involved continuous channel excavation along the whole length of the Clare River involving deepening and widening or both, and creating the deep rock cuts at Lackagh, Corofin and Conagher (above Milltown) (Ryan Hanley, 2010).

In large river catchments groundwater within the river catchment is expected to flow towards the river and discharge to it as baseflow. This may be only partly true for the Clare River within the study area due to the strong interaction that evolved between the original drainage system and the underlying karstified limestone bedrock aquifer (Box 1). The following paragraphs elucidate this point.

Box 1. Bedrock Aquifer

The limestone bedrock aquifer in the study area is classified as a Regionally Important Karstified Aquifer dominated by Conduit Flow (Rk_c). These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In the pure bedded limestones which occur in the study area these openings are enlarged by karstification *(i.e. . rock gets dissolved by the flowing groundwater)* which significantly enhances the permeability of the rock. Most groundwater flows in a highly permeable epikarst **(Box 2)** layer a couple of metres thick at the top of the rock, and in a zone of interconnected karstification-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation (i.e. magnesium limestone) (GSI, 2004).

Box 2. Epikarst

Epikarst is likely to form at the top of the limestone aquifer wherever rock is close to surface or where permeable subsoils occur, such that rainfall infiltrates freely. The epikarst can be visualised as a perched aquifer system channelling infiltrating water to points of entry into the deeper groundwater flow system (CDM, 2012). The water penetrates vertically where vertical fissures occur. The water flow enlarges the fissures in a positive feedback loop which creates preferential vertical flow paths. Deeper Underground, the waters from the preferential vertical pathways and any networks of smaller fissures unite to form small streams and in turn these join and excavate correspondingly large conduits and even cave systems.

Extensive karst conduit systems exist in the limestone bedrock in the study area, as exemplified

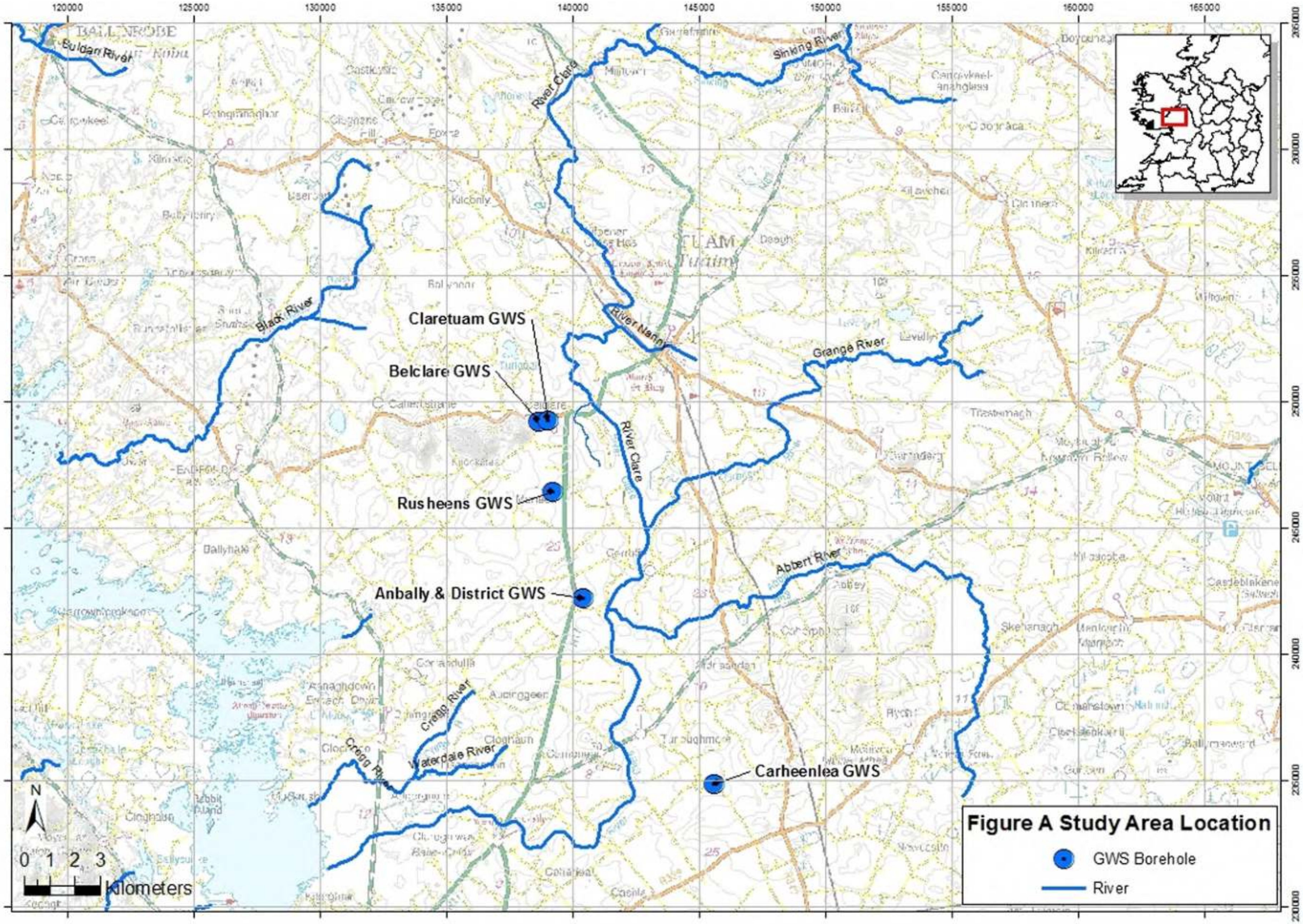
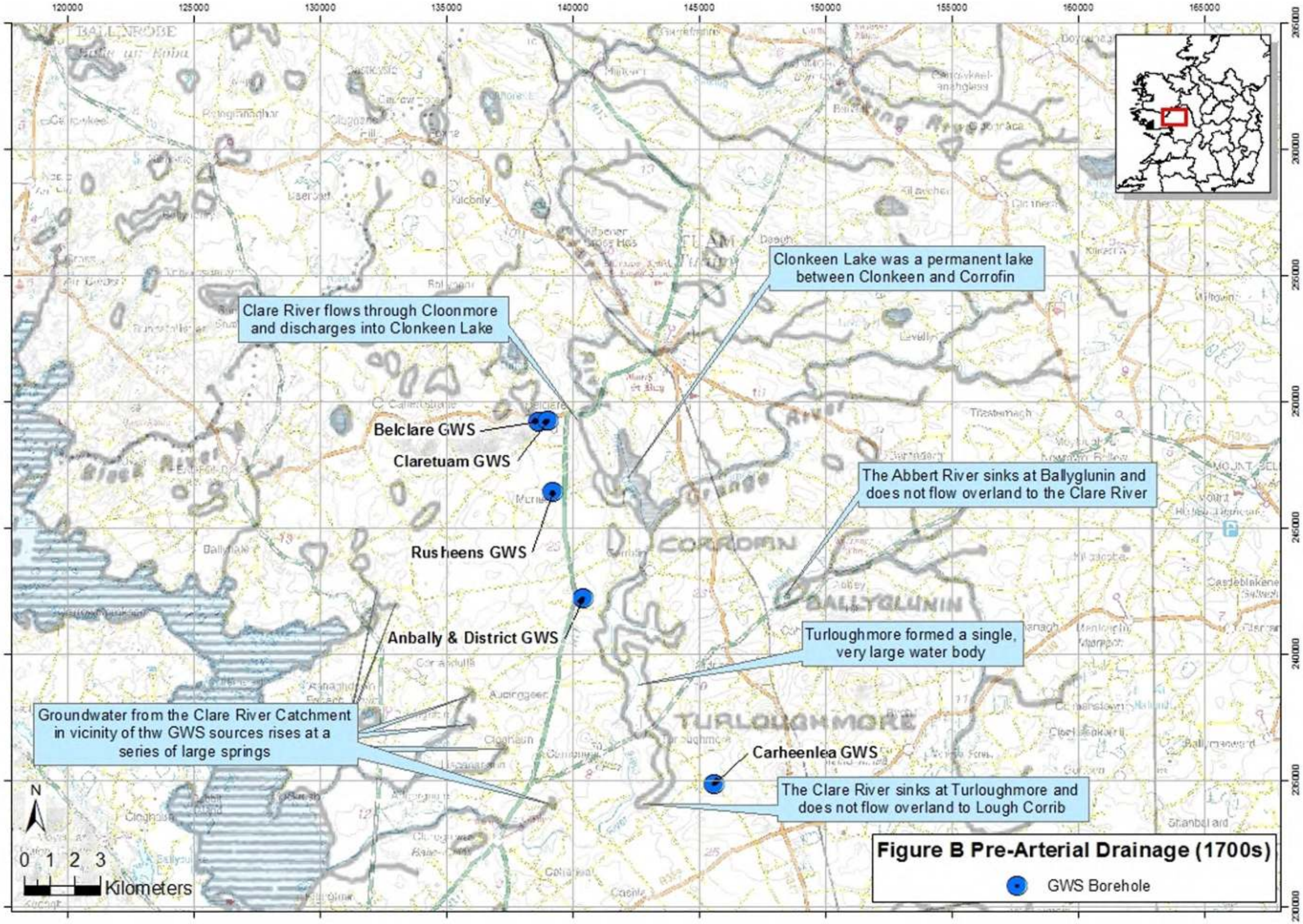


Figure A Study Area Location
GWS Borehole
River
Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
Black River
River Clare
River Nanny
Grange River
Abbert River
Sinking River
Cregg River
Waterdale River
Bulgan River
TUAM
N
0 1 2 3
Kilometers
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000


Clare River flows through Cloonmore and discharges into Clonkeen Lake
Clonkeen Lake was a permanent lake between Clonkeen and Corrofin
Belclare GWS
Claretuam GWS
Rusheens GWS
Anbally & District GWS
The Abbert River sinks at Ballyglunin and does not flow overland to the Clare River
Turloughmore formed a single, very large water body
Groundwater from the Clare River Catchment in vicinity of thw GWS sources rises at a series of large springs
Carheenlea GWS
The Clare River sinks at Turloughmore and does not flow overland to Lough Corrib
N
0 1 2 3
Kilometers
Figure B Pre-Arterial Drainage (1700s)
GWS Borehole

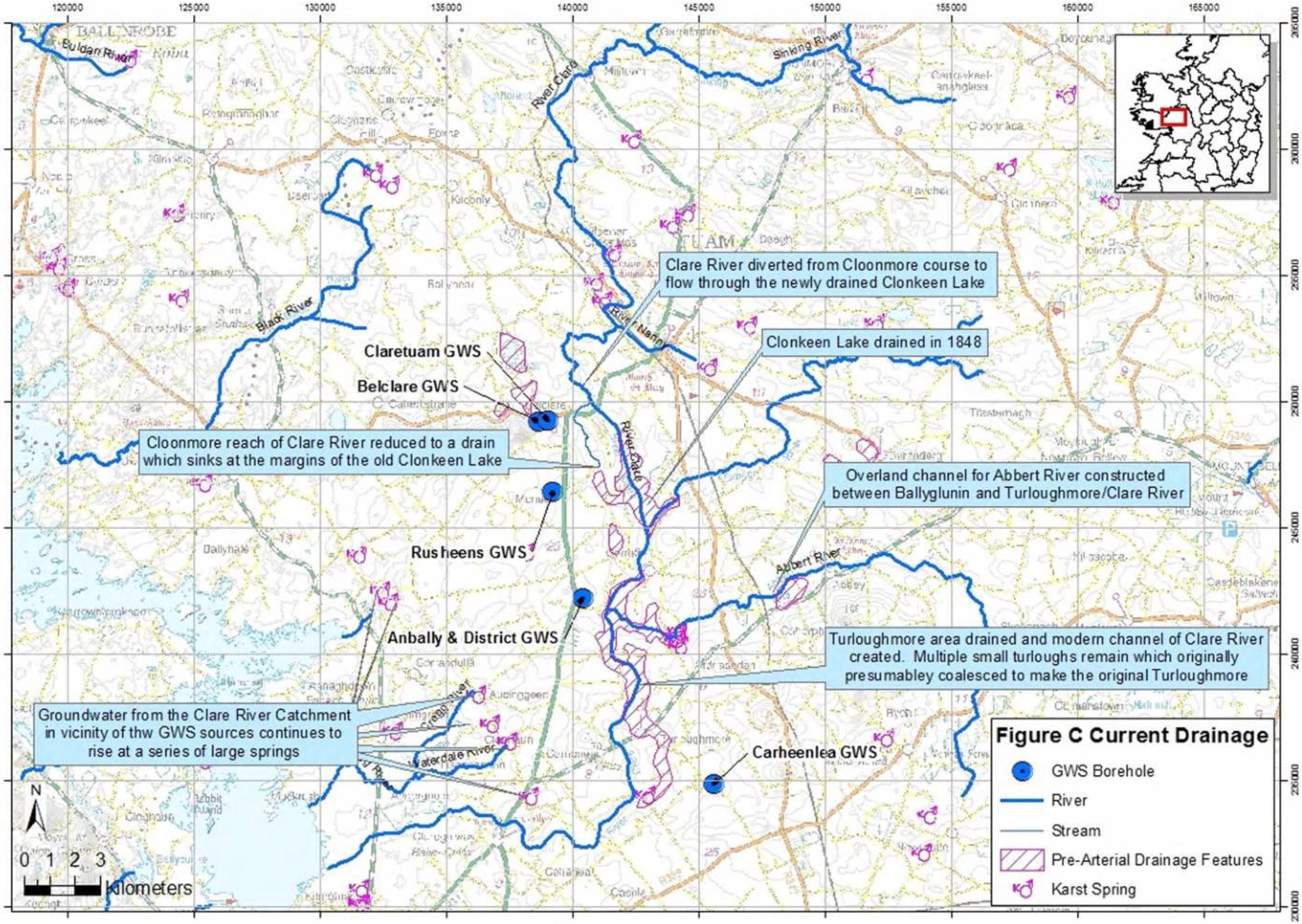


Figure C Current Drainage
GWS Borehole
River
Stream
Pre-Arterial Drainage Features
Karst Spring
Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
Clare River diverted from Cloonmore course to flow through the newly drained Clonkeen Lake
Clonkeen Lake drained in 1848
Cloonmore reach of Clare River reduced to a drain which sinks at the margins of the old Clonkeen Lake
Overland channel for Abbert River constructed between Ballyglunin and Turloughmore/Clare River
Turloughmore area drained and modern channel of Clare River created. Multiple small turloughs remain which originally presumabley coalesced to make the original Turloughmore
Groundwater from the Clare River Catchment in vicinity of thw GWS sources continues to rise at a series of large springs
River Clare
River Nanny
Black River
Abbert River
Sinking River
Waterdale River
Bulgan River
Kilometers
0 1 2 3
N
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000

by the Ballyglunin Cave system. The mapping of this system indicates conduit development along north to south and west to east joint sets, with an overall dip to the west (Drew and Daly, 1993).

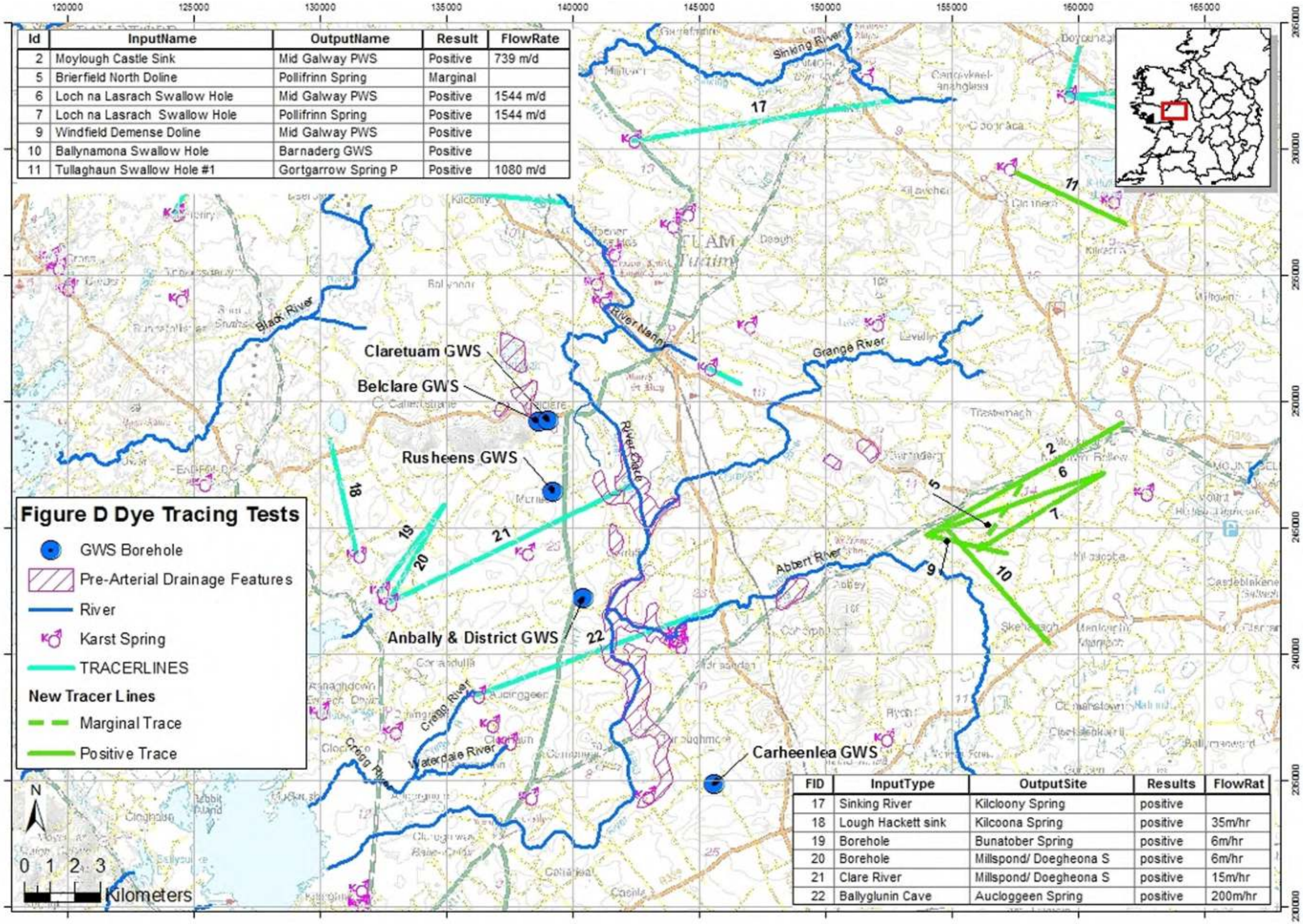
Overall, groundwater flow will be westwards towards the River Clare and L. Corrib, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable (GSI, 2004). Dye tracing tests between swallow holes and springs within the study area show that groundwater can flow across the surface water divides and beneath surface water channels, e.g. the traced groundwater connection between Ballyglunin Cave and Aucloggeen Spring, which passes underneath both the Abbert and Clare Rivers (Drew & Daly, 1993). Connections proven by dye traces between swallow holes and springs in the study area are shown in Figure D. Details of the individual "tracer-tests" are also shown on Figure D. The flow paths exemplified by these tests are regional in scale, e.g. Ballyglunin to Aucloggeen is a straight line distance of 9.6 km. High groundwater flow velocities occur along the corresponding karst conduits. The data provided on Figure D indicates that groundwater velocity from traces bearing north to south range from 6 m/hr to 35 m/hr (144 to 840 m/d) whereas traces bearing east to west have velocities ranging from 15 m/hr to 200 m/hr (360 to 4800 m/d). Regionally the data suggest that velocities are larger in the east to west direction compared to the north south direction (GSI, 2004). By inference, conduit sizes follow the same trend.

Figure D shows a strong correlation between the tracer-tests proving east to west connections, and areas where the current Clare River did not exist under the original drainage system, i.e. Clonkeen Lake and Turloughmore. In these areas, in line with the tracer-test results, it seems likely that the original drainage system had evolved underground drainage pathways which allowed water to drain westwards along preferential karst conduit pathways from Clonkeen and Turloughmore/Ballyglunin to Lough Corrib. The fact that these pathways have been proven by tracer-tests under the modern drainage regime shows that the pathways are still active in the present day.

In terms of the hydraulic connectivity of the modern Clare River system and the underlying bedrock aquifer therefore, the conventional model of discharge of groundwater as baseflow to the river is unlikely to provide the full picture.

It is expected that with the OPW arterial drainage works, extensive hydraulic continuity may have been established between the Clare River and the underlying limestone bedrock aquifer, particularly where deep rock cuts were made. It is likely that this hydraulic continuity is chiefly between the river and the epikarst layer at the top of the bedrock. As such, it is likely that the Clare River may act as a drain for the epikarst layer, with the epikarst saturated to at least the elevation of the river. The saturated epikarst will still be connected to the underlying deep karst conduit system by preferential vertical infiltration points (Box 2).

When the water pressure in the conduit system is lower than in the epikarst, the shallow groundwater will drain down to the deeper system, while (presumably) simultaneously draining laterally to the Clare River. Where the Clare River bed intersects a swallow hole from the original Clonkeen Lake or Turloughmore systems, some river water is also likely to sink down to the deep conduit system. When the pressures are reversed the deep conduit system is likely to discharge some groundwater to the epikarst and river via the same pathways, in reverse. In both scenarios, the deep conduit system is likely to continue discharging westwards at depth towards the lowest head in the system at Lough Corrib, irrespective of the type of interaction with the overlying shallow groundwater and river catchments.



Id	InputName	OutputName	Result	FlowRate
2	Moylough Castle Sink	Mid Galway PWS	Positive	739 m/d
5	Brierfield North Doline	Pollifrinn Spring	Marginal	
6	Loch na Lasrach Swallow Hole	Mid Galway PWS	Positive	1544 m/d
7	Loch na Lasrach Swallow Hole	Pollifrinn Spring	Positive	1544 m/d
9	Windfield Demense Doline	Mid Galway PWS	Positive	
10	Ballynamona Swallow Hole	Barnaderg GWS	Positive	
11	Tullaghaun Swallow Hole #1	Gortgarrow Spring P	Positive	1080 m/d

FID	InputType	OutputSite	Results	FlowRat
17	Sinking River	Kilcloony Spring	positive	
18	Lough Hackett sink	Kilcoona Spring	positive	35m/hr
19	Borehole	Bunatober Spring	positive	6m/hr
20	Borehole	Millspond/ Doegheona S	positive	6m/hr
21	Clare River	Millspond/ Doegheona S	positive	15m/hr
22	Ballyglunin Cave	Aucloggeen Spring	positive	200m/hr

The implications of the system described above for GWS borehole sources in the study area are outlined in Box 3.

Box 3. Implications for GWS Borehole Sources

Based on the system of surface water/groundwater interactions occurring in the Clare-Corrib Catchment, the following scenarios may be relevant where a GWS borehole source has been drilled into the system:

- Borehole only intersects a shallow epikarst water strike:
  - Borehole distant from Clare River – Borehole yield is likely to be moderate to good. Pumping drawdown likely to induce localised inflow from the epikarst. Drawdown likely to dewater the strike before abstraction can increase sufficiently to establish a gradient generating leakage from the river to the borehole. ZOC likely to be localised.
  - Borehole close to the Clare River – Borehole yield may be good. Pumping drawdown likely to induce localised inflow from the epikarst. Drawdown might establish a gradient generating leakage from the river to the borehole which would allow increased abstraction. ZOC likely to be localised but partial contribution from surface water catchment is possible.
- Borehole only intersects a deep water strike (epikarst sealed off by grout):
  - Borehole intersects a small fissure – may result in a moderate yield. Abstraction drawdown will increase the downwards vertical gradient from the overlying epikarst. Drawdown might reverse the gradient between the fissure and conduits in the same area, with some potential for a minor partial contribution by leakage from the conduits back along the fissure to the borehole, depending on the proximity of the conduit. ZOC likely to be localised and fed by downward leakage from the epikarst through the fissure, but a partial contribution from the conduit system is possible.
  - Borehole intersects a conduit – may result in a good to excellent well. Abstraction will mainly derive from the regional scale conduit system upgradient of the borehole. The zone of contribution may extend beyond the immediate surface water catchment. There may also be partial contributions from losing reaches of local and distant surface water courses that contribute to the regional conduit flow. Localised, indirect epikarst input is also likely to occur via natural vertical pathways that contribute to the conduit.
- Borehole intersects a deep water strike and epikarst not sealed off:
  - This situation is likely to result in a mix of the previous scenarios.

3 Data Relevant to Groundwater Flow Conceptualisation at each GWS

3.1 Geological Data from GSI 6" Field Sheets

Table 1 summarises the most relevant site specific annotations on the 6" Field sheets in the vicinity of Claretuam, Belclare, Rusheens, Anbally and Carheenlea.

3.2 Groundwater Elevation Data

EPA groundwater monitoring locations are shown on Figure E. Three of the locations shown within the study area are boreholes with long term groundwater level monitoring records available, i.e. Tuam, Lackagh and Corbally. There are no borehole construction data available for the boreholes, except for Corbally which is noted to be 80 m deep in the relevant EPA groundwater monitoring point site (GWMP) folder.

The available groundwater level data for the three EPA boreholes and the five GWS boreholes are shown in Graph 01, along with the elevation of the Clare River bed at Corofin and the high water elevation for Lough Corrib.

Table 1. Summary of relevant data from GSI 6" field sheets

Dataset	Claretuam & Belclare	Rusheens	Anbally	Carheenlea
GSI 6" Hist	Well exposed dark grey to black limestone (Lst) Crags and outcrop to south, dips flat to 3 degrees to SSE; weathered and much-jointed in places; in some places joints noted oriented NNW; Outcrop to east of old course in Cloonmore dips flat to west at 3 to 5 degrees, beds approx 18" thick, "this band of exposed rock stretches for nearly 100 yds w/o a single crack or joint and is perfectly smooth – Glacial action?"; Clonkeen Lough callow semi drained – noted to be peat and chiefly shell marl, old course of Clare R. has peat and marl. Large bog to north & NE of the sources to north of Polldarragh.	Outcrop to SE flat to dipping W and NW (6^{O}?). To the SE at Turloughour = well bedded dark grey Lst, dip SSW	Outcrop at Turloughcartron to ENE = dark grey thin bedded Lst, full of calcite infilled cells about potato sized. Just SE of source modern note says "3 bores failed here due to clay in Lst solution fissures". Dark grey beds to SE at Tonmace; white bed , dips east to ESE at 3 to 5^{O}. Bore at Dawros 83', WL 18.5m. Large outcrop to W at Cahernavoley most dips SSE at 3 to 10^{O}; dip of 3^{O} NE at south end of outcrop. Dolomite Lst at Corrandrum 2km SSW	Map for immediate area not available to download. NW at Lackaghbeg, large outcrop shows dark blue Lst, dip 3^{O} to SE, joints N60W, cross joints, irregular. Faults & calcite spar veins noted nearby to NE at Clare R. in Lackaghmore. Just E Kilskea dip NNW at 3 to 5^{O}, angular cross joints N15E, and nearby joints N80E & N10E, N70W & N20E To the N at Laraghmore outcrop dip 3^{O}W and full of irregular cross joints N10W and N75E

The Tuam groundwater level (GWL) data are significantly higher than all of the other level data. The Tuam borehole is on the east side of the Clare River, i.e. upgradient in terms of the nominal regional hydraulic gradient. On the basis of Section 2, it is considered that the Tuam borehole probably intersects the epikarst only. The GWL in this layer is likely to be controlled by the head in the Clare River, with the head in the epikarst reflecting the gradient needed to drive groundwater through the epikarst to discharge to the river. The GWL range in the Tuam borehole is not particularly flashy, which suggests GWL buffering by storage in the epikarst and a high permeability.

The Lackagh and Corbally boreholes are on the west side of the Clare River, i.e. nominally downgradient. The two boreholes have a GWL range of approximately 16 m. They follow very similar flashy trends suggesting they are part of the same groundwater system. The high GWL range and flashy water level response suggests the boreholes may be in hydraulic continuity with a karst conduit system with low storage capacity and influenced by point recharge[1]. The GWLs are much lower than at the Tuam borehole. In line with Section 2 this further suggests interaction with a deep conduit system (as opposed to the perched epikarst system).

The Clare River bed level at Corofin is 22.2mOD (Ryan Hanley,2010). This bed level (halfway between Lackagh and Corbally) exceeds all but the peak flashy water levels at Lackagh and Corbally. This suggests that the deeper karst system generally operates at a lower pressure head than the epikarst-Clare River

[1] Point recharge means rapid transmission of surface water into the groundwater system, e.g. by a stream sinking at a swallow hole.

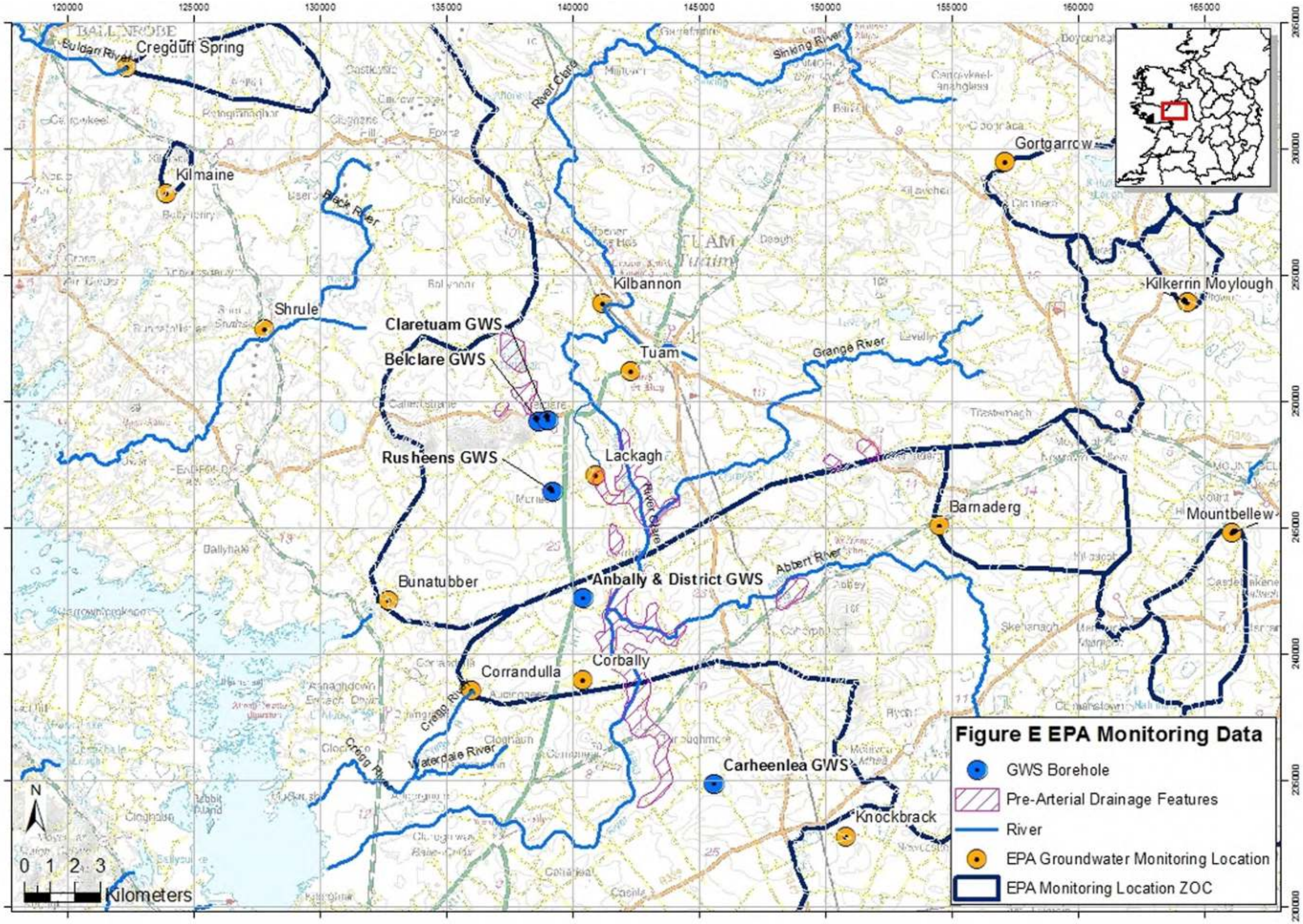
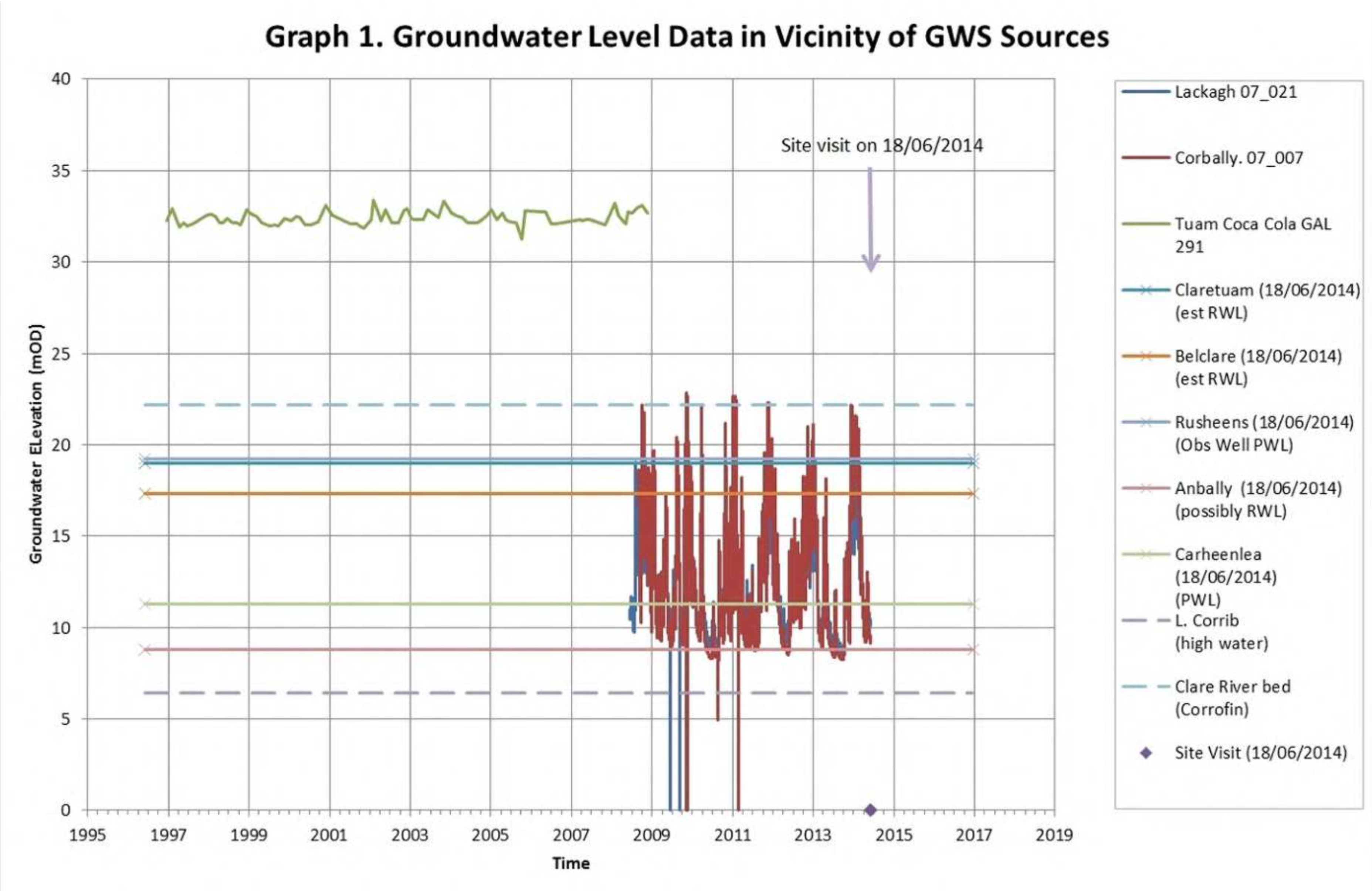


Figure E EPA Monitoring Data
GWS Borehole
Pre-Arterial Drainage Features
River
EPA Groundwater Monitoring Location
EPA Monitoring Location ZOC
Cregduff Spring
Kilmaine
Shrule
Claretuam GWS
Belclare GWS
Rusheens GWS
Bunatubber
Corrandulla
Corbally
Anbally & District GWS
Lackagh
Kilbannon
Tuam
Carheenlea GWS
Knockbrack
Barnaderg
Mountbellew
Kilkerrin Moylough
Gortgarrow
Grange River
Abbert River
Sinking River
River Clare
Black River
Waterdale River
Clegg River
Bulcarr River
N
0 1 2 3
Kilometers


Graph 1. Groundwater Level Data in Vicinity of GWS Sources
Site visit on 18/06/2014
Groundwater ELevation (mOD)
Time
40
35
30
25
20
15
10
5
0
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
Lackagh 07_021
Corbally. 07_007
Tuam Coca Cola GAL 291
Claretuam (18/06/2014) (est RWL)
Belclare (18/06/2014) (est RWL)
Rusheens (18/06/2014) (Obs Well PWL)
Anbally (18/06/2014) (possibly RWL)
Carheenlea (18/06/2014) (PWL)
L. Corrib (high water)
Clare River bed (Corrofin)
Site Visit (18/06/2014)

system and therefore would generally receive leakage from any vertical pathways connecting the two systems. The leakage direction would only be reversed during times of peak GWL in the conduit system. The generally lower head in the conduit system compared to the river also means that hydraulically it should be more favourable for deep groundwater in conduits east of the Clare River to flow on westwards in conduits beneath the river, rather than to discharge upwards to the river. The maximum water elevation at Lough Corrib of 6.44 mOD is the lowest in the system, and therefore also favours this scenario. This is in agreement with the indications from tracer tests as discussed in Section 2.

3.2.1 Groundwater Levels at the GWS Source Boreholes

The spot GWL measurements at the five GWS sources are also shown on Graph 01. Some inferences have been drawn from these data; however one measurement per source is insufficient to draw any firm conclusions with respect to any or all of the sources.

Furthermore the GWLs depicted for Claretuam and Belclare are estimated rest GWLs based on short recovery periods monitored at each source; the GWL for Rusheens is the water level in an observation well 30 m from the GWS source borehole, while source well was pumping; the GWL for Anbally was taken when the pump was off and may be close to the rest GWL; and the GWL for Carheenlea is a pumping GWL.

The time series data for the Lackagh and Corbally boreholes runs to 17 June 2014 and shows that the GWLs in the boreholes (and therefore the conduit system) were in the basal reach of the known GWL range. The site visit measurements were taken on 18 June 2014 (i.e. the next day) and there was no rainfall on the 17th or 18th. As such the conduit system would have remained in its basal GWL reach during the GWS readings.

3.2.1.1 Claretuam, Belclare and Rusheens

The GWLs measured at Claretuam, Belclare and Rusheens on 18 June 2014 are estimated to be within the upper reach of the conduit system GWL range (but well below the epikarst level seen at Tuam borehole). This suggests these three boreholes intersect minor fissures facilitating drainage from localised, overlying epikarst to the regional conduit system. The transmissivity of the minor fissures is likely to be low, such that a significant gradient may be need to drive leakage from the epikarst to the conduits via such fissures. As a result the rest GWL at a borehole intersecting a minor fissure will be somewhere between the epikarst and conduit extremes, and represents the head loss along the fissure as water is driven from epikarst to fissure. In more descriptive terms, the GWL reflects the relatively slow draining of water from epikarst to conduit via the low yielding minor fissure pathways when conduit water levels are low, and is analogous to groundwater baseflow to a stream in a conventional (non-karst) groundwater setting.

In this context the three GWS sources would be expected to be moderate (40 to 100 m^3/day) to good (100 to 400 m^3/day) yielding boreholes with localised ZOCs drawing on leakage from the overlying epikarst.

Where a borehole intersects a large fracture, clogging of the fractures with moderate or low permeability sediment could give similar hydraulic characteristics to those outlined for a small fissure. The permeability of the infill would have a significant impact on the water level response of the borehole.

The original pump test for **Claretuam GWS** suggested a yield of 43 m^3/day for a 7 m steady drawdown. Current estimates by the GWS suggest a maximum yield of 108 m^3/day. This would be a moderate to borderline-good yield. The well depth is 72 m.

The current abstraction rate at **Belclare GWS** is approximately 157 m^3/day, which would be at the low end of the range for a good yield (100 to 400 m^3/day). The well depth is approximately 46 m.

The driller's yield estimate for the **Rusheens GWS** current source borehole (drilled in October 2012) was 216 m^3/day. Instantaneous flow rates displayed on the flow meter on 18 June 2014 were of the order of 8.2 m^3/hr (197 m^3/day). This would be a good yield. The well depth is 64 m. The current Rusheens borehole has a grout seal in the borehole annulus to a depth of 30 mbgl, which should seal off and direct epikarst inflow to the borehole. The only inflow to the open section of the well was logged between 49 m and 54 mbgl as very broken rock with a large, sandy inflow. This may be a case where a large fracture has been clogged by infill that restricts its interaction with the regional conduit system. The pumping water level was approximately 9 m above the GWL in the regional conduit system as seen at the nearby Lackagh borehole. The strong gradient from the borehole to the conduit system suggests that there is unlikely to be leakage out of the conduit system to the borehole under rest or pumping conditions at the borehole. Overall therefore, a localised ZOC drawing on leakage from the epikarst seems likely.

3.2.1.2 Anbally and Carheenlea

The GWLs measured at Anbally and Carheenlea on 18 June 2014 are in the basal GWL range of the regional conduit system. This suggests that these two boreholes are in good hydraulic continuity with the deep, regional conduit system.

In this context the two GWS sources would be expected to have good to excellent yields and to have ZOCs reflecting both a localised contribution by "baseflow" leakage from the epikarst, but also a regional component reflecting a probable significant inflow from the conduit system upgradient of the pumping boreholes.

There is no data on the long term daily abstraction rate at **Anbally GWS**. Instantaneous flow meter readings on 18 June 2014 suggest a pumping rate of 2.6 m^3/hr (63 m^3/day). Diskin (2014) indicates that the scheme has 95 domestic connections plus approximately 20 additional connections to agricultural land. Assuming a demand of 1.2 m^3/day per connection (i.e. 6 PE at 0.2 m^3/PE/day) would suggest a demand of 138 m^3/day. This would be a moderate to good yield. A report on a camera survey of the well by Well Solutions (2010) made reference to anecdotal reports of a low water level at the borehole during the summer of 2009, and suggests the borehole may be operating close to its sustainable yield (Well Solutions, 2010). The well is approximately 99 m deep and has its main water strike at approximately 97 mbgl. Three trial boreholes for the scheme in the nearby village failed due to "clay in the limestone solution fissures" (Table 1). The fact that the borehole appears to only have a moderate to good yield suggests that its hydraulic continuity with the conduit system may be limited. This may be due to clay infill in conduits in the area, as seen at the failed trial boreholes. This in turn may suggest a localised ZOC; however a component of regional flow cannot be discounted.

The borehole source at **Carheenlea GWS** was drilled to 61 mbgl and is reported by the GWS to have a yield of 216 m^3/d. This is a good yield but is less than would be expected in a borehole with good hydraulic continuity with the regional conduit system. The corresponding GWL in Graph 01 is a pumping water level. It may be that the abstraction generates a large drawdown and that the borehole rest water level resides in the upper reach of the regional karst conduit range, similar to Claretuam and Belclare; alternatively clay infilling of conduits in the vicinity could be the cause of the relatively low yield. Overall a localised ZOC is plausible; however a component of regional flow cannot be discounted.

GSI (2004) suggests that there may be an increase in borehole yield form south to north across the study area, which would correlate with clay infilling of conduits in the vicinity of Rusheens, Anbally and Carheenlea.

3.2.2 OPW turlough level data

Some data on turlough flood elevation in the vicinity were obtained from available OPW flooding records. Just northeast of Belclare GWS the flood water level at Turloughnaroyer on 10 April 1995 was recorded as 101.4 ft OD (Poolbeg). This is equivalent to 28.2 mOD. This is above the observed water levels at the Belclare borehole and is above the maximum GWL observed in the Lackagh and Corbally boreholes. Therefore, when the turlough has been flooded by inflow from the regional conduit system there is a strong lateral hydraulic gradient between the flooded turlough and the nearby GWS boreholes. It is possible that some of the turlough water could migrate laterally to the borehole via the epikarst, when the borehole is pumping.

3.3 Spring Flow Data and EPA GWMP ZOCs

Two large springs monitored by the EPA, Bunatubber and Corrandulla, are located to the southwest of the GWS source boreholes (Figure E). Bunatubber has a yield of up to 1,000 l/s (86,000 m^3/day), while Corrandulla has a mean yield estimated at 7,000 m^3/day. Both springs are considered to be focal points for discharge from the regional scale karst conduit system which stretches to the northeast across the study area. The EPA have delineated preliminary ZOCs for the springs (Figure E). The Claretuam, Belclare and Rusheens borehole sources are contained within the Bunatubber ZOC. The Anbally source borehole is contained within the Corrandulla ZOC. The Carheenlea borehole is not within a delineated area.

The preliminary EPA ZOCs give an indication of the large areas that may provide partial contributions to groundwater discharges supplied by a regional scale karst conduit system. For Claretuam, Belclare, Rusheens and Anbally the extent of the EPA ZOCs up gradient of the individual sources is a reasonable estimate of the additional ZOC where it is suspected that there may be a partial contribution to the source from the conduit system, over and above localised leakage from the overlying epikarst.

3.4 Well Yields

The GSI well database was interrogated for data points within the study area. Figure F shows the trends in excellent, good, moderate and poor well yields in the area based on the available data.

Within the EPA delineated ZOCs for Bunatubber and Corrandulla there were 81 records, of which 60 had accompanying yield data. Those records included 5 boreholes with excellent yields and 33 boreholes with good yields (100 to 400m3/d). Figure F shows a noticeable alignment of good and excellent yielding wells along lines heading roughly northeast to southwest towards Bunatubber and Corrandulla springs. This correlates with the tracer test data which suggest that the predominant flow direction and highest flow velocity is in the northeast to southwest direction.

The remaining yield data indicate the presence of 7 boreholes with moderate yield (40-100 m3/d BH) and 15 boreholes with poor yield (<40 m^3/day). These are generally scattered amongst the good wells; however there does appear to be a small NNE to SSW oriented cluster in the vicinity of the artificial reach of the Abbert River (between Anbally and Carheenlea), which may indicate a zone of low transmissivity in that area.

The good and excellent borehole yield data in the vicinity of Carheenlea GWS show similar trends.

3.5 Karst Features & Floods (Dbase, OSi Hist, OPW)

Table 2 shows the karst features in the vicinity of the GWS sources, identified from the GSI karst database, OSi historical mapping and OPW flood mapping. The locations of the features are shown on Figure G.

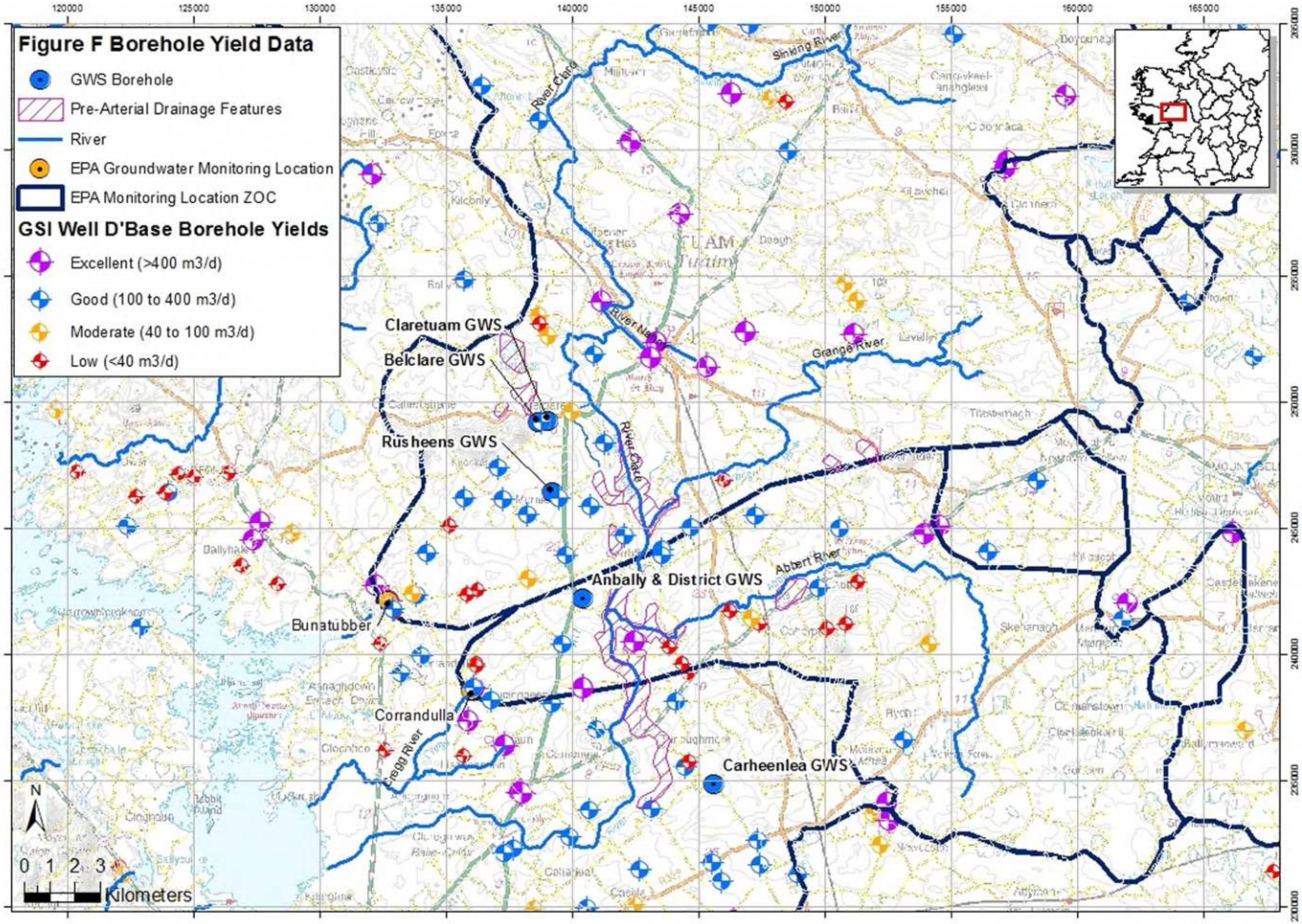


Figure F Borehole Yield Data
GWS Borehole
Pre-Arterial Drainage Features
River
EPA Groundwater Monitoring Location
EPA Monitoring Location ZOC
GSI Well D'Base Borehole Yields
Excellent (>400 m3/d)
Good (100 to 400 m3/d)
Moderate (40 to 100 m3/d)
Low (<40 m3/d)
Claretuam GWS
Belclare GWS
Rusheens GWS
Anbally & District GWS
Bunatubber
Corrandulla
Carheenlea GWS
River Clare
River Nanny
Sinking River
Grange River
Abbert River
Clegg River
N
0 1 2 3
Kilometers
120000
125000
130000
135000
140000
145000
150000
155000
160000
165000

Table 2. Karst Features Data

Dataset	Claretuam (CT)	Belclare (BC)	Rusheens (RSH)	Anbally (ANB)	Carheenlea (CHL)
OSi Hist	Map of surface water courses from late 1700s in Ryan Hanley (2010) shows a large lake in Monivea (north of Corofin); A huge turlough at Turloughmore which has no outflow, i.e. no Clare River south of the Turloughmore; no Abbert River west of Ballyglunin (i.e. it sinks and doesn't link to the Turloughmore). Rivers rise again along spring line east of Lough Corrib, e.g. Bunatubber and Corrandulla. 6" Hist map shows extensive "liable to flooding" east of Claretuam & Rusheens (Cloonmore, Clonkeen Lough) down to Corofin. Numerous turlough & karst townlands: CT & BC – Turloughnaroyer, Pollaturk (Newgarden), Polldarragh; RSH & ANB – Turloughour, Turloughcartron, Turloughmartin, Turloughrevagh; CHL – Turloughmore. No Abbert River in area south of Corofin and modern Clare River not constructed yet 25" map provides similar picture to 6" map. More individual turloughs delineated – these have been picked up by the GSI karst database. Modern Courses or Clare and Abbert Rivers in place.				
	6" map shows main path of R. Clare flows along the now redundant watercourse through Cloonmore, past Lackagh BH, and discharges into mid west boundary of Clonkeen Lough. By 25" map R. Clare created, Clonkeen Lough drained and old Cloonmore channel reduced to a drain. 25" flow arrows show drain flows south (arrow at Rusheens North) towards Lackagh BH area, to 3 dead end channels.				
GSI Karst Dbase	CT & BC – Turloughnaroyer.		Turloughour 2.8km SE, Tobernamucka Sp 2 km SSW; Cave 1.5km South; (they are all about the same distances but North from Anbally). Numerous Turloughs and springs to SW at Bunatubber.	9 turloughs to SE @1.3 to 4km distance – Pollakilleen, Meelick, Pollnacloya, Cloghdo, Turloughnarevagh + 4 unnamed. 3 Springs – Pollabullaun, Betty's Hole + 1 unnamed. BallygluninCave & Swallow holes ~5km E. Auclogeen SP to WSW.	Tobar Suibne Sp 2.7km West; Turloughmore Common 2.8km NW; 3 EncDep 3km East & 8 Enc Dep 2 to 3 km NE. Claregalway GWS SP & Intermediate Sp to WSW at Claregalway.
OPW	Large swathes of land on either side of Clare River in the vicinity of these sources mapped as benefitting lands (BL) - following flood plains of Clare River plus tributaries. For Claretuam and Belclare the BL extends around to the north and northwest and includes				Benefitting Lands immediately adjacent to source (at Flood ID

Dataset	Claretuam (CT)	Belclare (BC)	Rusheens (RSH)	Anbally (ANB)	Carheenlea (CHL)
	Turloughnaroyer, Pollaturk and Polldarragh. The BL is typically 0.4 to 1km distant. For Rusheens the most significant BL is the sinking distributary (original channel of Clare River) & former Clonkeen Lough area in the Rusheens/Cloonmore townland areas 1 km east of the source. This area is also less than 1 km east of Claretuam. At Anbally the former full extent of Turloughmore extends north to Corofin and sits approximately 1 km east of the source. Karst related flood points (Flood ID) include: CT & BC: Pollaturk (575); Turloughnaroyer (968); N17 Headford Tuam Rd/Claretuam (1808); Carrowbeg (1826); Headford Road Jn (1853);. RSH: Cummer Turlough (628); Turloughour (1017); Curry Eighter (1807); Ballybanagher Corofin (10801) ANB: Pollakilleen Turlough (1005); Meelick Turlough (1006); Pollnacloya Turlough (1007); Cloghdo Turlough (1008); Tonmace Turlough (1012); Corrandrum Turlough (1013); Turloughrevagh (1014); Turlough – Common (1015); Ballaun Turlough (1016); Ballyglooneen area Recurring (1803); Clare Corbally Recurring (1806); Flooding at Ardskeaghmore, Corofin Co. Galway Nov2009 (10800); Flooding at Ballyglunin Corofin Co Galway November 2009 (10802); Flooding at Annagh Corofin Co Galway in November 2009 (10803); Flooding at Bullaun Corofin Co Galway Nov 2009 (10804).				1878). Clare River BL approx 2.5 to 3km West. Karst related flood points (Flood ID) include: Lackagh Beg (630); Turloughmore Common (1009); Ballynasheoge Recurring (1877); Rathlee Recurring (1878). Rathlee (1878) – Floods every year after heavy rain. The water flows off high land. Large area can be flooded to an estimated depth of 6 to 8 feet. (GWS identified this as a Turlough).

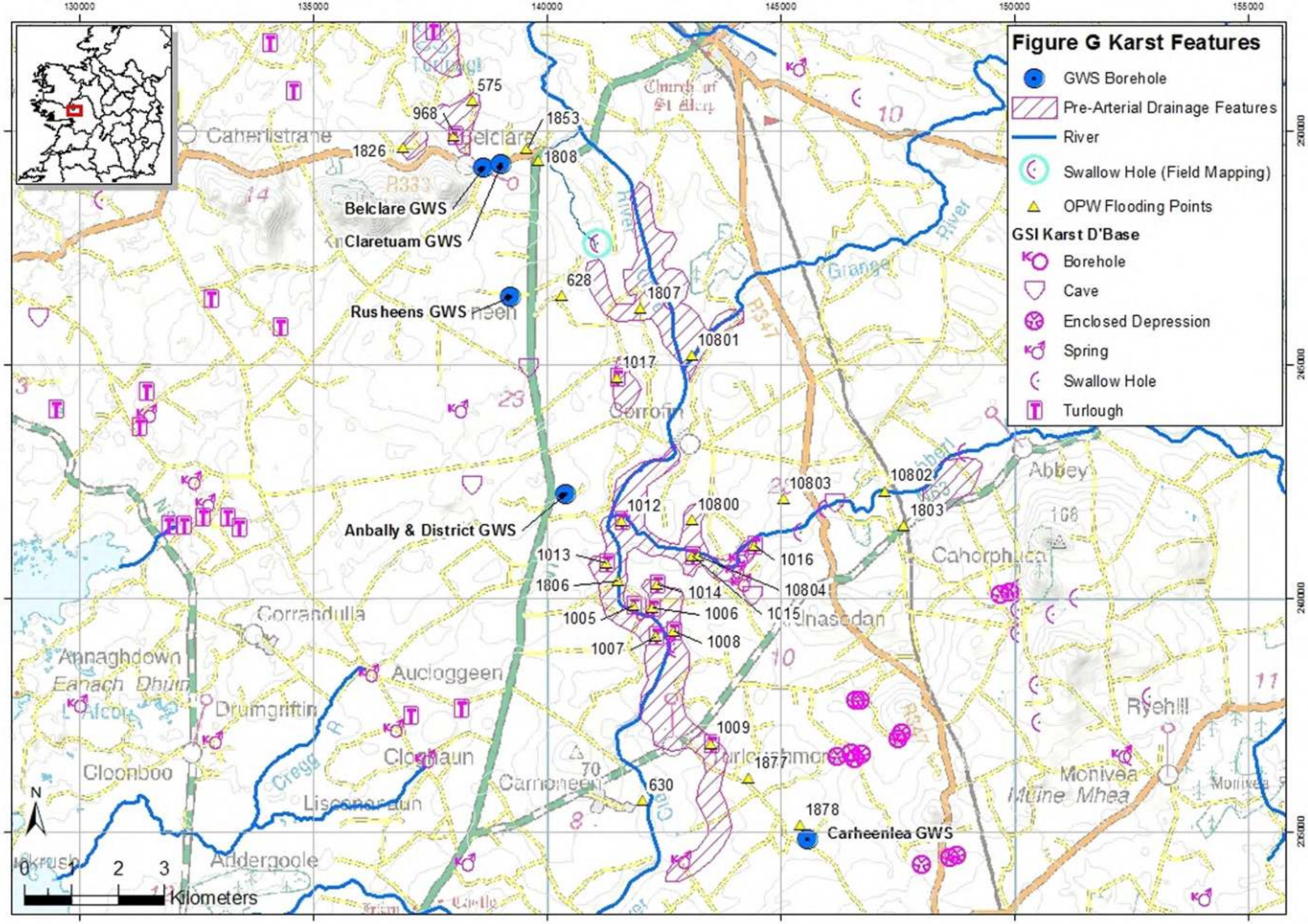


Figure G Karst Features
GWS Borehole
Pre-Arterial Drainage Features
River
Swallow Hole (Field Mapping)
OPW Flooding Points
GSI Karst D'Base
Borehole
Cave
Enclosed Depression
Spring
Swallow Hole
Turlough
Belclare GWS
Claretuam GWS
Rusheens GWS
Anbally & District GWS
Carheenlea GWS
Caherlistrane
Corrandulla
Annaghdown
Eanach Dhúin
Drumgriffin
Aucloggeen
Cloonboo
Abbey
Cahorphuca
Monivea
Muine Mhea
Ryehill
Addergoole
Kilometers
0
1
2
3
N
130000
135000
140000
145000
150000
155000
575
968
1853
1826
1808
628
1807
10801
1017
1012
10800
10803
10802
1803
1013
1806
1014
10804
1016
1005
1006
1015
1007
1008
1009
1877
630
1878

Figure G shows the intensity of major surface karst features in the vicinity of the sources, which is an indication of the subsurface intensity of karst conduits. It is likely that karst conduits operate in the vicinity of each of the GWS source boreholes.

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