Establishment of Groundwater Zones of Contribution

Kiltiernan Group Water Scheme, Co. Galway

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Project description

Since the 1980s, the Geological Survey of Ireland (GSI) has undertaken a considerable amount of work developing Groundwater Protection Schemes throughout the country. Groundwater Source Protection Zones are the surface and subsurface areas surrounding a groundwater source, i.e. a well, wellfield or spring, in which water and contaminants may enter groundwater and move towards the source. Knowledge of where the water is coming from is critical when trying to interpret water quality data at the groundwater source. The ‘Zone of Contribution’ (ZOC) also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

This report has been prepared for the Kiltiernan 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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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[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.

Kiltiernan GWS (NFGWS No. G194) is supplied by one borehole abstracting groundwater that flows through epikarst, fissures and conduits in a regionally important karstified limestone aquifer.

[1] Geological Survey of Ireland, 2000.

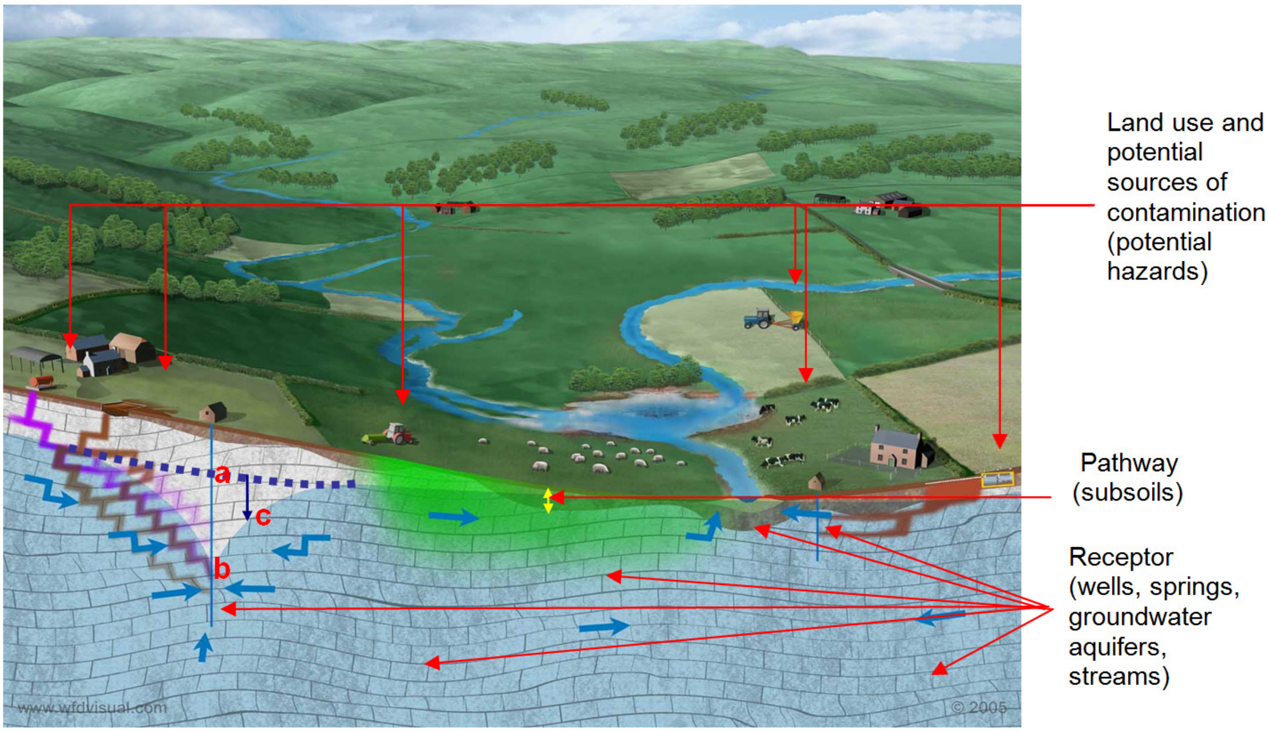

Diagram 1. Rural Landscape Highlighting the Interaction between Surface Water, Groundwater and Potential Land Use Hazards

2 LOCATION, SITE DESCRIPTION, SUPPLY DETAILS AND WELLHEAD PROTECTION

The zone of contribution (ZOC) for the Kiltiernan Group Water Scheme (GWS) has been delineated according to the principles and methodologies set out in 'Groundwater Protection Schemes'[2] and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

Kiltiernan GWS is supplied from one borehole located in Kiltiernan West, approximately 6 km south of Clarinbridge and 6 km north east of Kinvarra, Co. Galway (**Figure 1**). The supply borehole (BH1) is located in a chamber. A second, currently unused borehole (BH2) is located 12 m to the north east of the current abstraction borehole, also within a chamber. The supply borehole (BH1) and the adjacent pump house are located within a locked, and gravelled compound, surrounded by a palisade fence. BH2 is partially fenced. Both boreholes are within 10 m of an adjacent 'other' class road. The system reservoir is located approximately 100 m to the south east of BH1 (**Diagram 2, Photograph 1**).

Average daily usage in 2016 to date is 332 m^3/day. The maximum daily usage in 2016 to date was 480 m^3/day, the minimum was 210 m^3/day. (Glan Agua, DBO Operator Monthly Status Reports). The scheme currently serves a total of 595 connections. The connections comprise 293 house only, 65 house and land, 227 land only, 9 site/unfinished house and land and 1 school. The network is metered and has been upgraded to reduce leaks[3].

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[2] DELG/EPA/GSI, 1999

[3] GWS committee member

Pumping and treatment is managed by Glan Agua Ltd. under a DBO contract with the group water scheme. The borehole pump switches on in response to a float switch in the post treatment reservoir, which has a storage capacity of 1208 m^3. There are three level sensors in the supply borehole. The pump cuts out when the water level falls below the 30 m sensor and will not restart until the water level reaches 29 m b.g.l.. Pumping rates are managed and rates are varied through the year in order to minimise colour and turbidity in the raw water and also to prevent pump cut-out during periods of increased drawdown in the borehole. Pumping rates have varied from approximately 62 m^3/hr to 25 m^3/hr over the period September 2013 to present. Treated water is pumped into the network from the reservoir.

The treatment sequence comprises pre-chlorination, sand and carbon filtration, ultra violet disinfection and residual chlorination, prior to storage in the reservoir. The design capacity of the treatment system 1135 m^3/day.

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

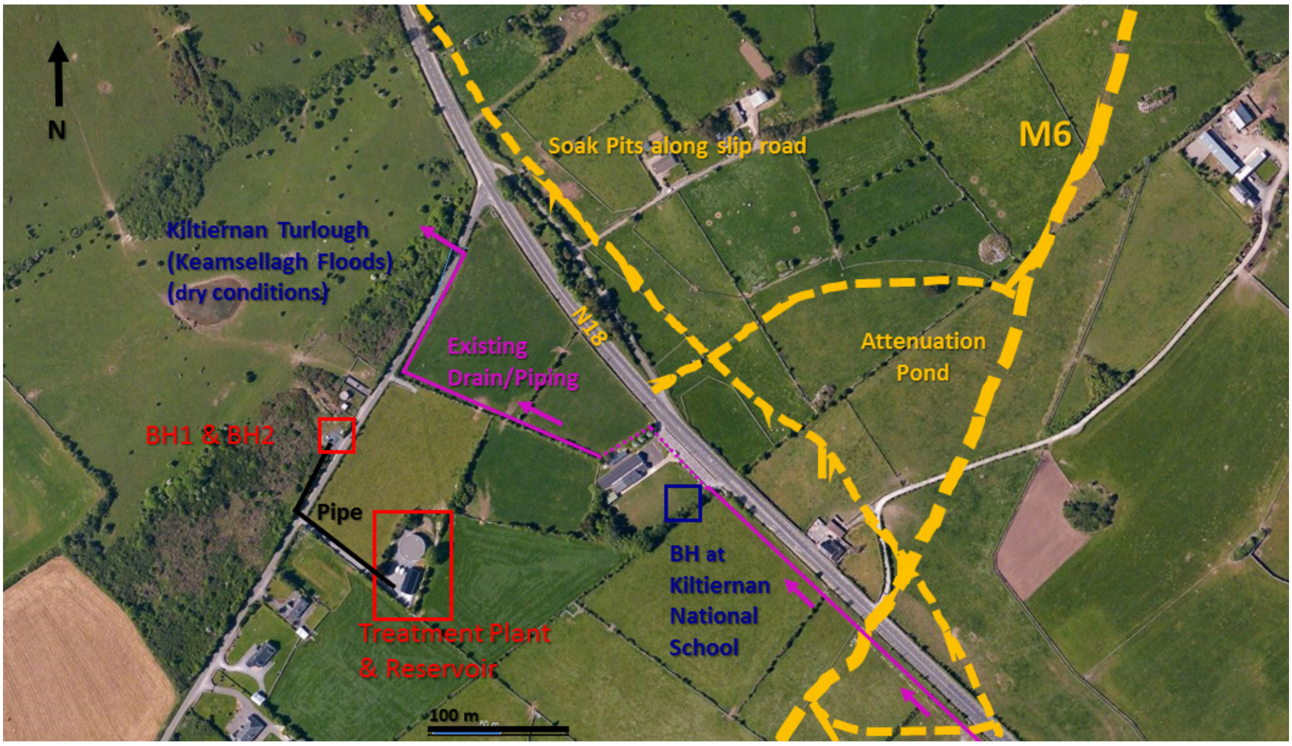


Diagram 2. Aerial photo showing location of Kiltiernan GWS and surrounds

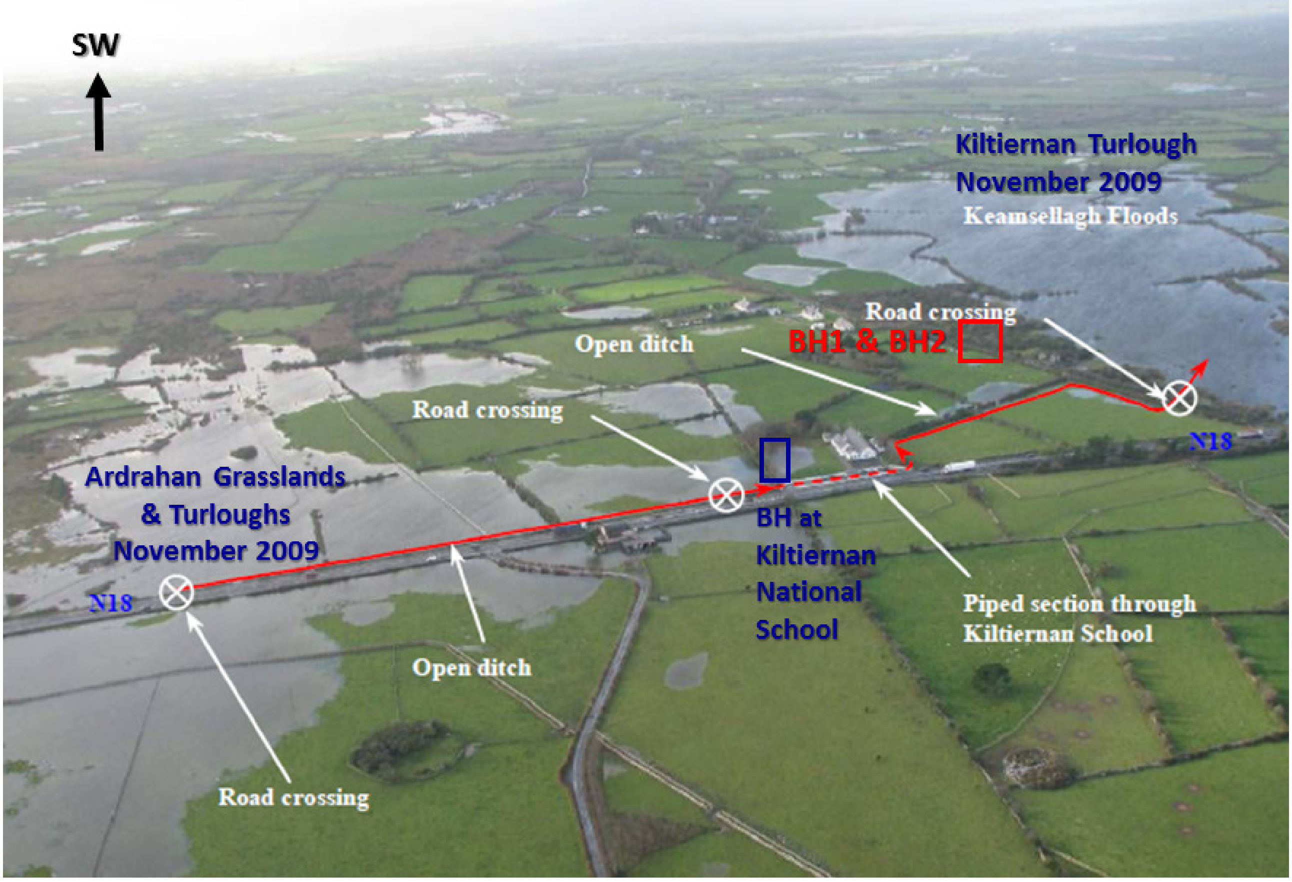


Diagram 3. Aerial photo showing 2009 flood extents in the vicinity or Kiltiernan (modified from Fig 3.3 OPW, 2010)

Photo 1. BH1 pump and rising main in pump chamber

Photo 2. BH2 below ground level in chamber.

Photo 3. BH1 fenced compound and pump chamber

Photo 4. BH2 chamber and adjacent road

Photo 5. Open borehole, below ground level in Kiltiernan national school grounds**.**

Photo 6. Infiltration trenches along N18 interchange, north east of Kiltiernan N.S.

Table 1. Water Supply Details

NFGWS No. G194	Kiltiernan BH1
Grid reference	Irish Grid: E143630 N214470
Townland	Kiltiernan West
Source type	Borehole
Drilled	10/02/2011. BH1 is a re-drilling, at a wider diameter and extension of a 42 m depth trial well at this location drilled in 2007 by Mulcairs.
Drilling Contractor	Patrick Briody and Sons Ltd.
Owner	Kiltiernan GWS
Elevation in metres above Ordnance Datum	c. 25 m O.D. (Estimated from OSI 1:50,000 Scale Map)
Total depth (m)	52
Construction details (See **Appendix 5)**	Cement grouting to 5.5 m b.t.o.h.'[4] 200 mm OD PVC solid casing to 10 m b.t.o.h. 200 mm OD PVC 3mm slotted screen to 25 m b.t.o.h. 200 mm OD PVC solid casing to 30 m b.t.o.h. 200 mm OD PVC 3 mm slotted casing to 40 m b.t.o.h. 200 mm OD PVC solid casing to 52 m b.t.o.h.
Depth to rock in metres below ground level	3 m
Inflow zones (water strikes) mbgl	14 m, 22 m, 36 m
Static water level (SWL) (m bgl) (Pump test of Mulcairs 5/3/2007 trial well, (See **Appendix 6)**	4.57 m b.g.l.
Pumping water level (PWL) (m bgl) (During monitoring period 20/6/2014 – 24/9/2014 and based on pump cut-out 2013, 2014. (See **Appendix 6)**	Range 11.4 m b.g.l to 30 m b.g.l
Pump intake depth (m bgl)	>31 m b.g.l.
Current abstraction rate (GWS)	210 m^3/day to 480 m^3/day (Based on Glan Agua Monthly Status reports 2016 to date)).
No. of connections	595
Reported yield (m^3/d)	No yield test for BH1 as constructed above. 72 hr continuous discharge pump test of Mulcairs trial borehole TW1) on 5/3/2007 at 60 m^3/hour (1440 m^3/day) resulted 5.09 m drawdown.
Specific Capacity (m^3/d/m)	Not available
Transmissivity (m^2/d) (See **Appendix 6**)	Ranges 3550 m^3/day to 58 m^3/day

[4] Below top of borehole at drilling i.e. approximately below current ground level

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

	Description/Comments
Topography (**Figure 1 & Figure 2**)	The borehole is located at a height of approximately 25 m O.D. in a low lying area. The topography is gently undulating, with an east north-east, west south-west lineation. It falls towards the coast c. 7 km to the west and rises eastward to a height of 40 m O.D. at a distance of 3 km. Cashlaundrumlahan (358 m OD) 18 km south east, is the closest significant topographic height.
Land use	Land use is dominated by grassland for cattle rearing and some dairy farming. Land spreading and silage production and occur. Unsewered domestic houses and farmyards occur in the area. 6 farmyards occur within 1 km and a cattle crush area occurs within 40 m of BH1. At Kiltiernan N.S. c. 200 m from BH1, there is an open borehole, OSWWTS and a percolation area. A quarry at Tonroe, with an active planning application is located 1.5 km to the south east. An interchange of the N18 road with the extension of the M6 motorway is under construction within 200 m of BH1.
Surface Hydrology (**Figure 1 & Figure 2**)	There are no natural surface watercourses draining run-off. Surface water percolates rapidly to become groundwater, including via discrete points at swallow holes and enclosed depressions. All bodies of water are an emergence of the groundwater at the surface. This occurs seasonally to form turloughs, such as the adjacent Kiltiernan Turlough (SAC 001285) known locally as Keamsellagh floods, Carraunavoodan Turlough (SAC 000242) 1.8 km north east, Tullynafrankagh and Derreen turloughs (SAC 000606) 0.8 km north west and Ardrahan Grasslands and turloughs (SAC 002244) 0.8km to the south east. Groundwater also occurs seasonally in smaller enclosed depressions and in the quarry 1.6 km to the east south-east. Local and OPW arterial drainage schemes link areas which flood seasonally, by open drains and a pipe network. Flood waters from Ardrahan grassland are drained north westwards, via open drain (along the N18) and piping, through Kiltiernan NS grounds to Kiltiernan turlough. At high flood levels, water flows in a pipe from Kiltiernan to Tullynafrankagh and westwards to Lough Fingall via open channel and pipework. Sections of this network are very flat, resulting in backflows (OPW 2010). During extreme flood events, such as 2009, flood waters extend from Ardrahan grasslands, through the N.S. grounds, across the area of the N18 interchange and are drained to Kiltiernan Turlough (See **Diagram 3**).
Topsoil http://gis.epa.ie/envision	Shallow, well drained soils dominate the area, with areas of deeper soil also present. There are pockets of poorly drained peaty soils and pockets of lacustrine soils around turloughs.
Subsoil (**Figure 3**) www.gsi.ie/mapping	Karstified bedrock outcrop and subcrop dominate the area. 'Moderately' permeable limestone tills ('boulder clays') are also present in the area, predominantly in the north east and also immediately surrounding the borehole.
Groundwater Vulnerability (**Figure 4**) gsi.ie/mapping	BH1 drilling log indicates c. 3 m of till, indicating Extreme vulnerability. The area surrounding BH1 is mapped as 'Extreme – Rock near surface or karst'. The majority of the area has this or 'Extreme' vulnerability. 'High' vulnerability is also present in the north east. (**Appendix 1**).
Geology (**Figure 5**) www.gsi.ie/mapping	The bedrock comprises karstified Dinantian Pure Bedded Limestones, which are overlain by Dinantian Upper Impure Limestones to the north east and east. Numerous karst features (turloughs, swallow holes, enclosed depressions etc.) occur in the karstified limestones.
Aquifers (**Figure 6**) www.gsi.ie/mapping	The karstified pure bedded limestones are classified as a Regionally Important Karst Aquifer dominated by conduit flow (**Rk$_c$**). The impure limestones are classified as Locally Important Aquifers which is moderately productive only in local zones (**Ll**).

<table>
<tr><td>Groundwater Body (GWB) www.wfdireland.ie</td><td colspan="2">BH1 is in the GWDTE-Kiltiernan Turlough GWB which is a sub-body of the Clarinbridge GWB. www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)</td></tr>
<tr><td>Recharge Coefficient (%) (Appendix 3) www.gsi.ie/mapping</td><td>60-85</td><td rowspan="2">High recharge rates (85%) occur where bedrock outcrop and subcrop occur. A rate of 60% occurs where well drained soil and ‘moderately’ permeable subsoils overly the Rk$_c$ aquifer. In areas of impure limestone (LI aquifer) recharge is capped at 200 mm.</td></tr>
<tr><td>Recharge (mm)</td><td>200-551</td></tr>
</table>

3.2 Hydrochemistry and water quality

Glan Agua on-site monitored average daily data (2013, 2014 and 2016), circa monthly sample data (1/9/2011 – 12/9/2016) and GWS sample data (20/2/2012 – 31/5/2016) were used to assess the hydrochemistry and water quality for Kiltiernan GWS. All available water quality data are presented in **Appendix 3**.

The data are summarised in **Table 3**, 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 2. Key Hydrochemistry and Water Quality values in untreated water samples

Parameter	No. of samples	Min	Max	Average*	Drinking Water Limit (DWL) or Threshold Value (TV)
Total Hardness (mg/l as $CaCO_3$)	10	304	378	334	[-]
Electrical Conductivity (µS/cm) (laboratory samples)	11	541	704	600	800 (TV), 2,500 (DWL)
Turbidity	72	<0.5	21.2	3.07	[-]
Colour	72	2.1	112	3.6	[-]
Total Coliforms (MPN[5]/100 ml)	3	1	**261**	2 exceedances (<100 counts) 1 exceedance (>100 counts)	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	3	1	**7**	3 exceedances (<100 counts)	0 (DWL)
Clostridium Perfrigens (CFU/100 ml)	2	0	0	0 exceedances	0 (Indicator)
Nitrate (mg/l NO_3)	75	2	**52.7**	15.23	50 (DWL) 37.5 (TV)
Chloride (mg/l)	8	21	**42**	30.13	250 (DWL), 24 (TV)
Ammonium (mg/l N)	64	0.01	**0.27**	0.03	0.3 (DWL) [0.23 as N], 0.225 [0.175 as N] (TV)
Iron (Total, µg/l)	76	7.2	**4880**	97.72	200 (DWL)
Manganese (Total, µg/l)	76	0.5	**624**	37.16	50 (DWL)
Aluminium (Total, µg/l)	76	5	842	60	200 (DWL), 150 (TV)
Potassium:sodium ratio	10	0.21	0.47	0.33	0.4 (indicator)

*values below detection limits, set as detection limit value for purposes of averaging.

[5] MPN is most probable number

Data indicate that the water is ‘hard’, which is typical of limestone aquifers, since the limestone dissolves readily into the groundwater. The average field pH is approximately neutral. Electrical conductivity is high and variable reflecting the variability in the source of groundwater at different groundwater level conditions.

Iron and manganese drinking water limits have been exceeded on 7 and 11 occasions respectively. Elevated and/or exceeding levels always occur at the same time as each other. Aluminium levels in exceedance of the drinking water limits have accompanied the Iron and Manganese exceedances on 4 occasions. Turbidity and/or colour has been very high on the occasions of each aluminium exceedance. Very high turbidity and/or colour levels accompany almost all exceedances and relative increases in Iron and Manganese levels. With one exception, all of these exceedance events have occurred in late summer - autumn. Where data is available these can be correlated with a significant increase in drawdown in the borehole and also with pump shut-off. (See **Appendix 6**). The exceedances are considered to result from the pumping of water from deeper karst conduits intercepted in the borehole, when water levels have dropped below the higher epikarst zone, which predominantly supplies the borehole during periods of higher water level. Increased Aluminium, Iron, Manganese and turbidity levels occurring in the same sample may result from mobilisation of sediments in the conduits. Increased iron and manganese may arise from the sinking of water derived from impure limestones to the north east and/or east into the conduit system which supplies the borehole during these periods.

Turbidity and colour are very variable and frequently high. Increases in both are considered to be associated with the period of filling of Kiltiernan turlough by the GWS committee.

Ammonia levels have exceeded the drinking water limit on three occasions and the threshold value on two. Two of the drinking water limits and both of the threshold exceedances have occurred during the late summer/autumn period and are associated with increased or above threshold Iron and Manganese levels. One exceedance of the drinking water limit occurred during April. Sources of ammonia in groundwater include farmyard manure, slurry and dirty water or on-site wastewater treatment systems (such as septic tanks or similar). Ammonia is not very mobile in soil or subsoil and elevated concentrations indicate very rapid transport at high groundwater flow rates, possibly in a confined environment, such as would occur during karst conduit flow or else a nearby source of contamination (the April exceedance).

Only three analyses of indicators of microbial contamination, Total Coliforms and E. Coli, are available, all for the winter – spring period. Each of the samples exceeds the drinking water limits, with one of the Total Coliform samples corresponding to gross contamination (>100 MPN/100 ml). Two analyses performed for Clostridium Perfringens had levels below the relevant threshold. Where microbial contamination of karstified aquifers such as that supplying Kiltiernan occurs, it is often characterised by spikes of microbial contamination, which are difficult to identify with small numbers of samples. None of the exceedances were accompanied by increases is ammonium, indicating that the pollutant source in these instances is not nearby to the borehole.

Nitrate levels have exceeded the drinking water limit on one occasion and the threshold value on two occasions, all occurring during the winter - spring period. Average nitrate levels are above the upper bound of the average national background levels (90^{th} %ile 13 mg/l) [6]. Sources of nitrate in groundwater include farmyard manure, slurry and dirty water or on-site wastewater treatment systems (such as septic tanks or similar). Nitrate is very mobile in groundwater, generally indicating sources of contamination which can be at a distance from the source. Ammonium from closer sources may also be oxygenated more rapidly in the shallow, open waters of the turlough, to form nitrate. Turlough waters are assumed to be in connectivity with the groundwater supplying the well.

Chloride levels are variable, but within the range expected for a site within 8 km of the coast, so no conclusion can be drawn as to whether the levels are associated with contamination of groundwater. The potassium:sodium (K:Na) ratio is variable and most frequently below the background potassium:sodium ratio in most Irish groundwater of less than 0.4 and often less than 0.3. (A K:Na ratio of >0.4 can be used to indicate contamination by plant organic matter (e.g. slurry). On the one occasion that a K:Na ratio of >0.4 occurred, no other measured indicator parameters of contamination were elevated.

[6] OCM (2007). Establishing Natural Background Levels for Groundwater in Ireland.

No sample results were available for during the flood events which occurred in 2009 and 2015. The impact of flooding on borehole raw water quality cannot therefore be assessed.

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. Treated water quality of the standard specified in the DBO contract has consistently been achieved.

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**.

Rainfall amounts are high in the area. Across the majority of the area Dinantian Pure Bedded Limestone rock occurs at or very close to the surface. In these areas the majority of the effective[7] rainfall will percolate down to the water table and replenish (recharge) the upper layers of the karst aquifer. Very little rainfall therefore becomes surface water run-off, resulting in no significant surface water drainage courses. In this upper part of the karst aquifer (from the surface to approximately 20 m below the ground surface) a zone of 'epikarst' occurs, in which fissures and fractures are numerous and well connected with one another and with the surface. This zone is highly transmissive of groundwater flow and groundwater flowing in this zone has a high degree of connectivity with the surface.

Recharge of the upper epikarst zone of the pure limestones will occur discontinuously across the surface where sub-soils are thin, via discrete point locations, and also through the overlying impure limestone where it thins out at the boundary between the two bedrock types in the north east and east. Deeper in the aquifer profile, beneath the epikarst, karst conduits and fissures occur. These are less well connected and may not be connected with the overlying epikarst. Recharge enters these fissures and conduits at discrete point recharge locations at the surface and groundwater flow thereafter is constrained within them.

The borehole intersects both the upper epikarst layer and the underlying conduit system, which are probably only connected at this location by the vertical borehole-. Water can flow into the borehole from both the upper epikarst layer and the lower conduit system. During periods of very low groundwater levels, which if they occur, occur during late summer- autumn, water is provided only by the deeper conduit system. The depth of aquifer transmitting water to the borehole reduces to that of the conduit and drawdown in response to pumping increases significantly and very rapidly (over a period of hours). Water levels rebound in the borehole when pumping stops, since the conduit groundwater is under a pressure head (at least partially confined).

During periods of higher water levels, when groundwater levels are up in the overlying epikarst zone and well connected shallower conduits, a greater depth of more connected epikarst aquifer is also transmitting water to the borehole and there is minimal drawdown in response to pumping. Flow from the epikarst zone and shallow well connected conduits is the dominant source of pumped groundwater, in part due to the location of the pump directly below this screened zone. The hydrochemistry of the groundwater (See Section 3.2 above) changes in response to the dominant source.

During periods of high water level, which occur annually in winter-spring, there is insufficient storage in the karst bedrock and groundwater emerges at the surface as flooding in turloughs, enclosed depressions and at springs. Kiltiernan Turlough is assumed to be in hydraulic connectivity with the supply borehole based on estimates of the distance from the borehole of downgradient and lateral influence of the pumping well during high water level conditions, connectivity with BH2 (See **Appendix 6**) and NPWS (NPWS, pers. comm.). This

[7] Effective rainfall is the proportion of rainfall which is not taken up by plants or evaporated and is the amount which is available for recharge of groundwaters and surface water run-off.

emergent groundwater is fully connected with water in the epikarst zone and may also connected with the conduit system at certain locations.

Groundwater flow directions are regionally westwards to the coast (OPW, 1998). In the area surrounding the borehole, groundwater contours indicate seasonally variable, but predominantly south westwards flow towards the borehole (Coxon and Drew, 1986). Flood water levels measured in Caherglassaun and Tullnafrankagh turloughs (Tynan et al, 2007) compared with water levels in BH1, indicate flow is from the north west towards the borehole. However, individual flow pathways are frequently constrained by the geometry and direction of karst conduits and so actual flow directions do not necessarily follow the regional groundwater flow direction. Tracing from Tullnafrankagh turlough indicates groundwater flow directions south west towards Kinvarra and north west towards Kilcolgan (GSI Tracer Database www.gsi.ie/mapping).

Groundwater vulnerability is extreme where karstified limestone bedrock underlies thin or absent subsoils. Vulnerability is increased further where groundwater emerges seasonally as flooding at the surface. These flood waters are vulnerable to contamination and have a high degree of connectivity with groundwater in the underlying karst. The supply borehole is assumed to have connectivity with groundwater emerging in Kiltiernan Turlough. In addition, a drainage channel, predominantly open, collects drainage from Ardrahan grasslands, the N18 and Kiltiernan N.S. grounds which is drained into Kiltiernan turlough. Locations of point recharge to the karst conduit system are also extremely vulnerable to contamination entrained in run-off.

4.2 Pressures

A number of pressures occur within the Kiltiernan GWS Zone of Contribution which have the potential to impact on raw water quality at the supply borehole. They include:

- Run-off from the M6 motorway and its interchange with the N18 road. These cross the existing drainage channel from Ardrahan grasslands to Kiltiernan turlough and the adjacent areas of flooding (See **Diagram 3**). Elements of the road drainage system, under construction in June 2016, such as slip road infiltration trenches, excavated to the top of bed rock (See **Diagram 2** and **Photo 6**) are located in areas which flooded in 2009 and 2015 and were continuous with Kiltiernan Turlough. There is potential for contamination entrained in road run-off to enter the epikarst zone directly, via infiltration trenches within 250 m upgradient of the borehole, to be directed to Kiltiernan Turlough, which is assumed to be connectivity with the supply borehole, via drainage channels or via continuous areas of flooding.

- The quarry at Tonroe, which has an active planning application, has the potential to result in contamination of the groundwater contributing to Kiltiernan Turlough, depending on the activities (if any) permissioned. These potential impacts could be mitigated by an appropriate water management system at the quarry.

- Organic wastes arising from land spreading, waste water, farmyard run-off and on site waste water treatment systems (OSWWTS) located in areas of extreme groundwater vulnerability have the potential to result in contamination at the borehole. Organic wastes entrained in surface waters or shallow groundwater on the Upper Impure Limestones in the north east has the potential to result in contamination at the borehole;

- Flood events such as those which occurred in 2009 and 2015, result in a high degree of connectivity between surface water run-off, emergent groundwater and groundwater in the epikarst zone. Kiltiernan N.S. has been flooded on both occasions and also during less extreme flood events. A borehole of is located in the school grounds at c. 200 m up-gradient of the supply borehole, which is uncapped and below ground level. It therefore provides a direct pathway into groundwater for any contaminants entrained in flood waters. There is also an OSWWTP with a raised percolation area. If the OSWWTP were to be flooded, this would also create potential for contamination of flood waters and therefore of the supply borehole.

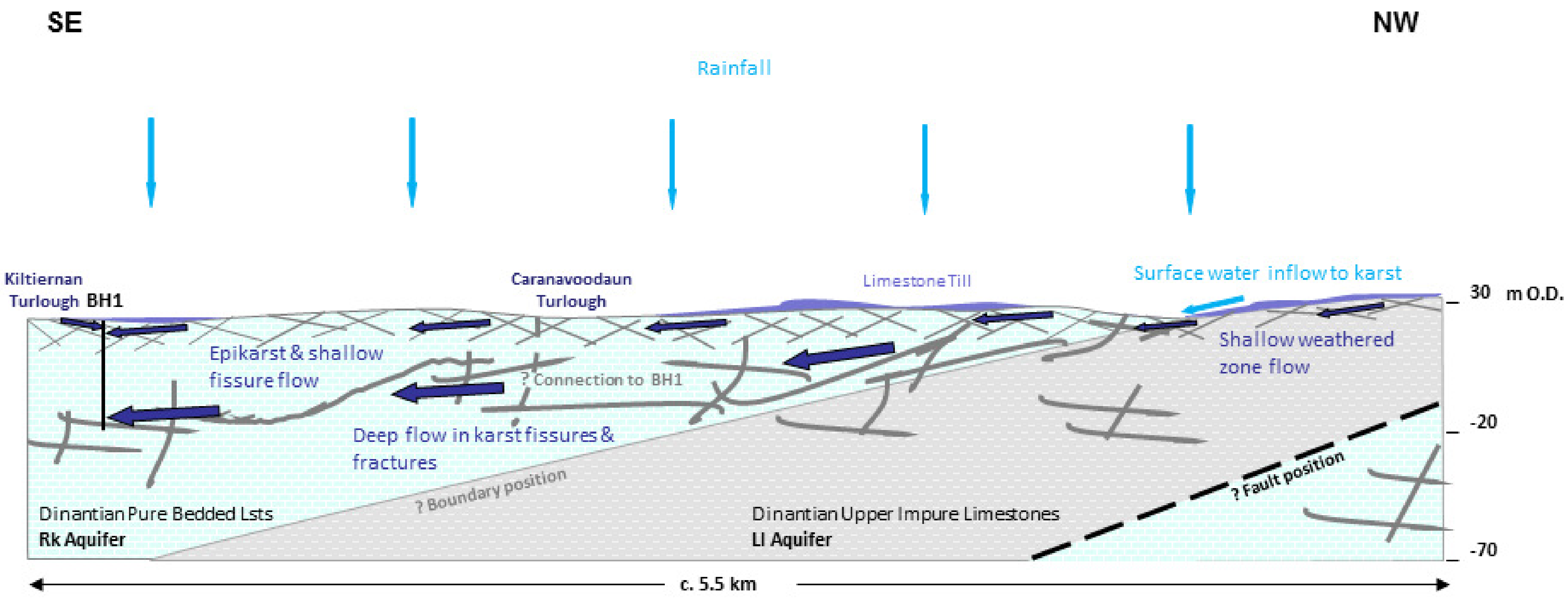


Diagram 3. Conceptual model of groundwater flow (Note exaggeration of vertical scale)

4.3 Boundaries

The Zone of Contribution (ZOC) delineated for Kiltiernan GWS is based on a combination of hydrogeological mapping and inferences, and geological boundaries. The very unpredictable nature of actual flow paths in karst limestone results in a high degree of uncertainty in the delineated ZOC boundaries.

The north eastern boundary comprises the topographic divide, assumed to reflect the groundwater divide, from which surface water and groundwater flows south eastwards on/in the Dinantian Upper Impure Limestones (DUIL). These waters are considered likely to enter the karst flow system via point recharge at a series of enclosed depression and possible swallow holes where the Upper Impure Limestone thins out along its south eastern boundary with the underlying Dinantian Pure Bedded Limestones (DPBL). This boundary is highly uncertain.

The southern boundary and the continuation of this boundary both to the north, then north west and also towards the north and north east, comprises the area contributing groundwater to Kiltiernan Turlough ground water dependent terrestrial ecosystem (GWDTE) as delineated under the Water Framework Directive Characterisation Programme (Water Framework Directive, Article 5). A small part of this boundary comprises the boundary of the extent of the 2009 flooding at Kiltiernan, where it is outside of the GWDTE boundary. The north western and south eastern boundaries are highly uncertain and represent the boundaries of the area within which the karst conduit system which contributes flow to the borehole may occur. The orientation of these boundaries is based on groundwater flow lines which result from groundwater gradient and resulting flow direction from north east to south west. The boundaries allow for the possibility that there is direct input to the karst conduit system from locations other than at the north-eastern boundary of the DUIL and DPBL rocks.

4.4 Recharge and water balance

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 area directly surrounding the borehole which is required to support an annual average abstraction of 480 m^3/day (maximum recorded abstraction 2016) is c. 0.4 km^2 based on mapped annual average recharge rates. This average annual figure assumes that the flow system can store and transmit this volume of water throughout the year. However, this storage does not in fact exist, at least in the epikarst and shallow, well connected conduits. During periods when water levels drop below the epikarst zone, the area providing recharge to support the borehole is potentially up to 7 km north east of the supply borehole.

The ZOC delineated (c. 18.3 km^2) is of a much greater area than required to provide sufficient recharge to support the annual average abstraction. This is in order to take account of the area supplying emergent groundwater at Kiltiernan Turlough which is in connectivity with the supply borehole during seasonal flooding. The area also accounts for input from the karst conduit system from locations at the north-eastern boundary of the DUIL and DPBL rocks.

5 CONCLUSIONS

Kiltiernan GWS is sourced from a borehole, from which an average of 332 m3/day is abstracted from a karstified aquifer.

The borehole intersects an upper epikarst and shallow well connected conduit zone and an underlying (probably confined) conduit system. The supply is abstracted predominantly from the upper epikarst zone, except during periods of very low groundwater levels when groundwater levels drop significantly in response to pumping and during which the lower conduit system alone provides supply.

The area surrounding the borehole is subject to annual seasonal groundwater flooding when the storage capacity of the karst is exceeded. Groundwater flood waters which emerge in Kiltiernan Turlough are assumed to be in hydraulic connectivity with groundwater supplying the borehole. The groundwater supplying the borehole is therefore also in connectivity with water which is drained from surrounding areas to Kiltiernan Turlough via a largely open drainage system. The conduit system receives direct recharge from an area likely to be located to the north east.

The Zone of Contribution (c. 18.3 km^2) has, therefore, been delineated to include:

- The area of epikarst supplying the majority of flow to the borehole, during most of the year,
- The area previously delineated as contributing groundwater to Kiltiernan Turlough GWDTE,
- The extent of the 2009 flooding of the area surrounding Kiltiernan,
- The area to the north east which potentially supplies direct recharge to the karst conduit system and provides flow to the borehole during periods of very low groundwater levels;
- The area between the north eastern area and the other areas.

The available microbial water quality data, coupled with the extreme vulnerability karst setting suggest the borehole is susceptible to microbial contamination. There are annual raw water high levels and/or exceedances of Iron, Manganese and Aluminium drinking water limits, almost exclusively during periods of low groundwater levels, when supply to the borehole is predominantly from the lower karst conduit system. These are associated with significant increases in turbidity and/or colour and occasional exceedances in ammonium. Turbidity and colour are very variable and also frequently high during other times of year.

There are a number of pressures within the ZOC. These include the currently under construction M6 motorway, it's interchange with the N18 and associated drainage system. Run-off from which is a potential contaminant source. Pathways exist via both direct groundwater pathways and via drainage to Kiltiernan Turlough, which is assumed to be in connectivity with groundwater supplying the GWS borehole, during seasonal flooding.

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 Kiltiernan GWS spring with a high degree of confidence, due to the complicated nature of the karst aquifer in this region. It is possible that additional or less area is contributing to the supply borehole. 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 microbial water quality parameters of untreated water that would include coliforms (total and faecal). This survey should incorporate samples taken during periods of groundwater flooding as well as following a variety of wet and dry rainfall conditions in the preceding week. The results should be shared with the GSI. This survey should be taken on a monthly basis for the first year. The need for future monitoring can be determined on the basis of these results, in consultation with a hydrogeologist.

- A regular survey of water quality parameters of untreated water that will act as indicators of contamination from road run-off. Important contaminants associated with road run-off include the heavy metals copper (Cu), Lead (Pb), Cadmium (Cd), the Polycyclic Aromatic Hydrocarbons (PAHs), suspended sediment (SS) and phosphorous (P). The parameters tested should include Cu, Cu Dissolved, Zn, Zn Dissolved, Cd, Pb, Total PAH. PAHs consist of thousands of compounds but the

United States Environmental Protection Agency (USEPA) have chosen 16 to represent the entire range and these have become the standard suite. A lab which is fully certified to carry out these analyses should be chosen. This survey should be taken on a monthly basis for the first year of operation of the M6 and interchange and should incorporate samples taken during periods of groundwater flooding as well as following a variety of wet and dry rainfall conditions in the preceding week. The analysis results should be compared with the threshold values (TV) from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010) and the Drinking Water Regulations (S.I. No. 122 of 2014). The need for future monitoring can be determined on the basis of these results, in consultation with a hydrogeologist. The results should be shared with the GSI. The Group Water Scheme should consider whether responsibility for this regular sampling and assessment of the results could be passed to the DBO operator.

- The GWS should consult with and/or make observations on planning applications in order that appropriate mitigation measures should be conditioned in any planning permission.

- Adherence to the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 and prescriptions arising from GLAS (REPS) schemes by landowners within the ZOC is critical.

- The borehole at Kiltiernan national School should be fully decommissioned or otherwise made impervious to flooding.

- BH2 at the supply borehole compound should be made watertight by raising or closing off the borehole casing or by decommissioned.

Desirable:

- Future work could usefully include investigations for swallow holes close to the north eastern boundary of the ZOC where enclosed depressions are located.

- Tracer testing at any swallow holes close to the north eastern boundary of the ZOC and at Carraunavoodaun Turlough would be useful to test the connection between these areas and the borehole as well as confirm groundwater flow directions. This work is needed to further constrain the boundaries and give a higher confidence to the ZOC

- Tracer testing of the run-off from the M6 motorway and its interchange with the N18 road would be useful if the scheme are concerned or if a deterioration in water quality occurs. Dye could be injected in the infiltration trenches near the borehole.

Other:

- The following NRA document may serve as a future useful reference document for the GWS:
  - Drainage Design for National Road Schemes – Sustainable Drainage Options http://www.tii.ie/tii-library/Standards_Related_Materials/1-Drainage-design-for-national-road-schemes-May-2014.pdf

- The following EPA guidelines may serve as future useful reference documents for the GWS:
  - EPA Guidance on Landspreading of Organic Waste[8]
  - 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[9].

[8] http://www.epa.ie/pubs/advice/waste/waste/EPA_landspread_organic_waste_guide.pdf
[9]]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[10].
- EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[11]

7 REFERENCES

Coxon, C. and Drew, D. P. (1986). Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In: Paterson, K & Sweeting M. (eds), New Directions in Karst, Norwich, 259-280.

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

OPW (1998) An Investigation of the Flooding Problems in the Gort - Ardrahan Area of South Galway – April 1998 Final Report.

OPW (2010) Review of the South Galway Flood Study Report – Assessment of the Existing Kiltiernan/Ballindereen Flood Relief Scheme.

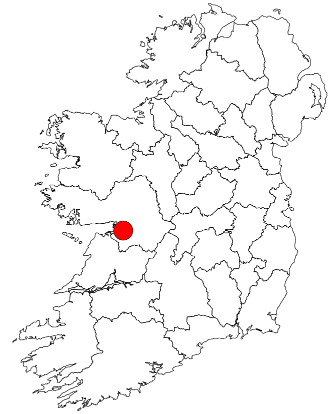
Tynan, S., Johnston, P. and Gill, M. (2007) Development of a methodology for the characterisation of a karstic groundwater body with particular emphasis on the linkage with associated ecosystems such as turlough ecosystems. EPA RTDI Programme Final Report 2002-W-DS-8-M1.

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

Figures

Legend:

- Kiltiernan GWS



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Project:	Zone of Contribution Delineation
Stage:	
Client:	Kiltiernan Group Water Scheme
Scale:	1:40,000 @ A4

surveyed	drawn	checked	date
	ST		27/10/16

Revisions: Rev A

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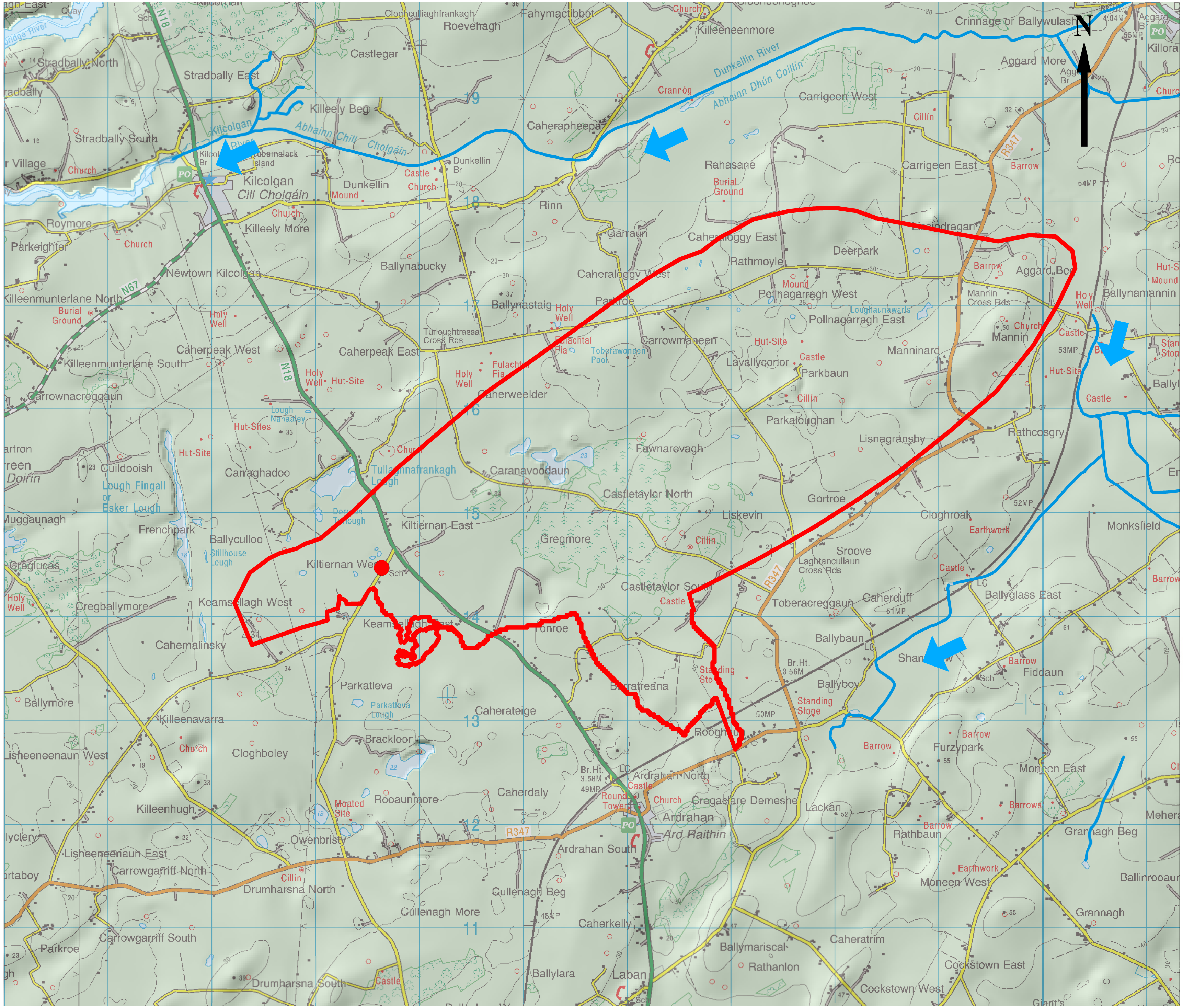
Legend:

- Supply Borehole
- ZOC Boundary
- Surface Watercourse & Flow Direction



Title:
Figure 2 Topography & Regional Drainage

Drawing No: 130_2

Project:
Zone of Contribution Delineation

Stage:

Client:
Kiltiernan Group Water Scheme

Scale: 1:50,000 @ A4

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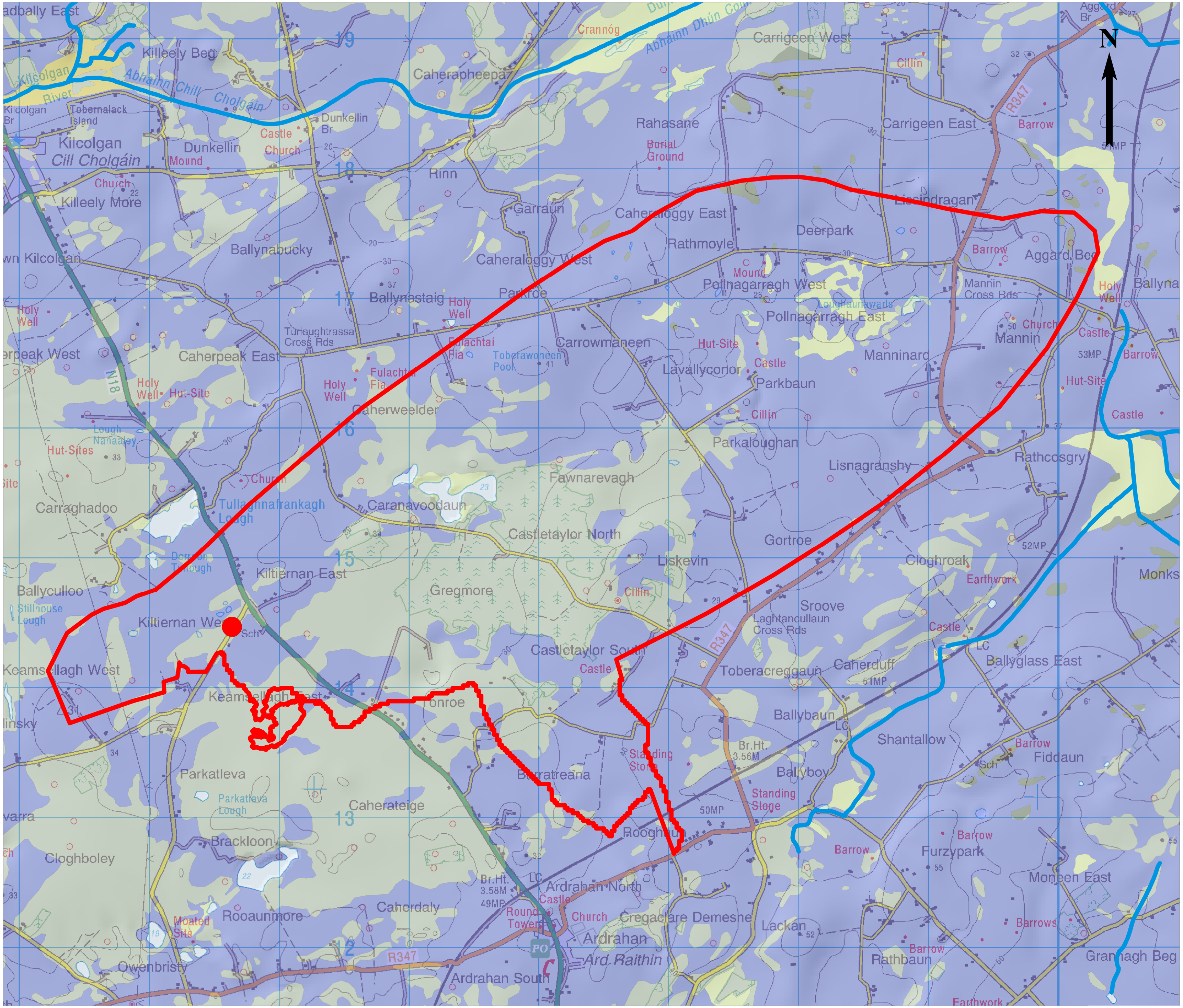

Legend:

- Supply Borehole
- ZOC Boundary

Subsoils

- Karst Rock
- Lake Sediments
- Rock Exposed
- Limestone Till

Title:	Figure 3 Subsoils
Drawing No:	130_3
Project:	Zone of Contribution Delineation
Stage:	
Client:	Kiltiernan Group Water Scheme
Scale:	1:40,000 @ A4
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checked	
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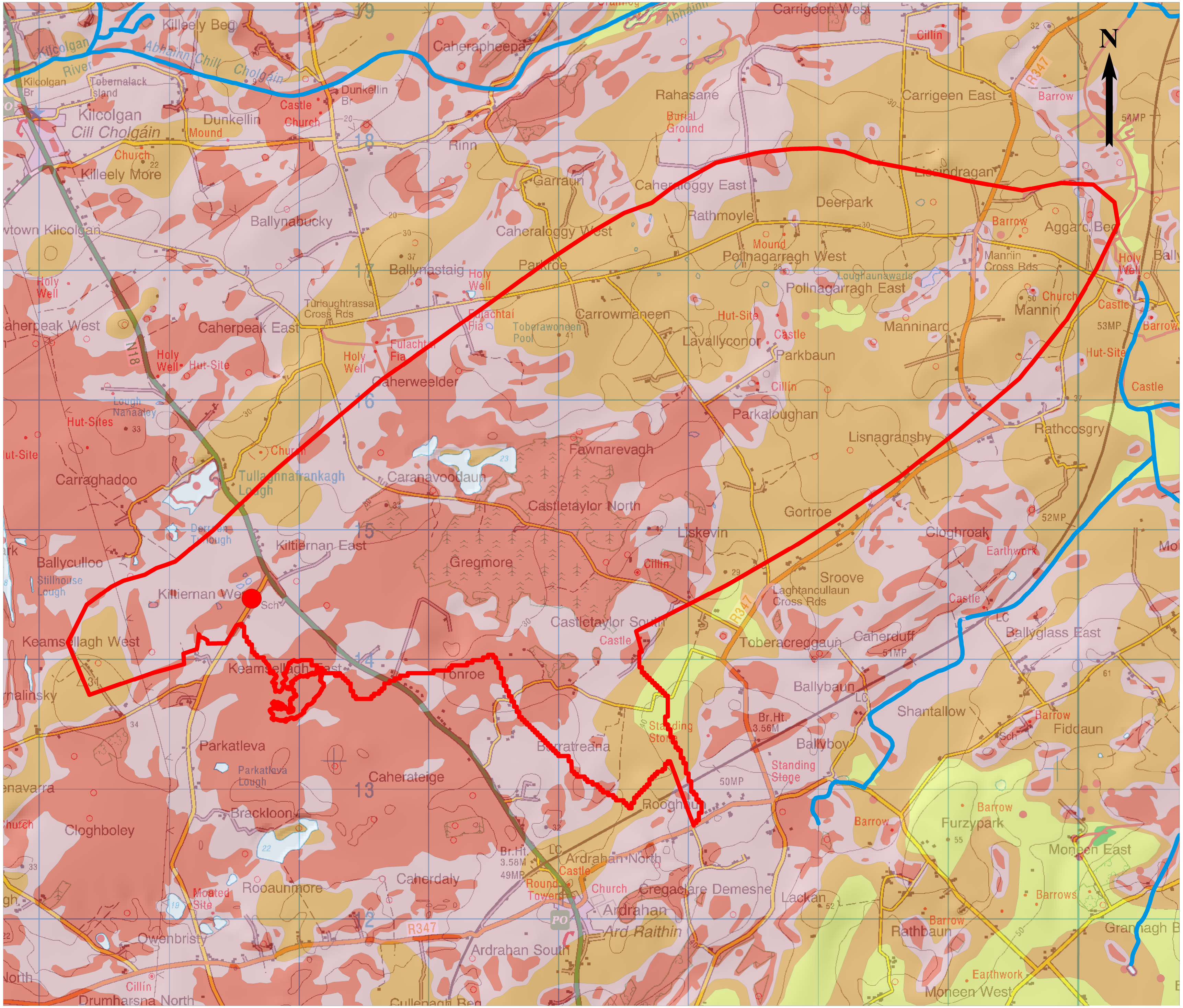

Legend:

- Supply Borehole
- ZOC Boundary

Groundwater Vulnerability

- Rock at or near surface or Karst
- Extreme
- High
- Moderate

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Title:	Figure 4 Groundwater Vulnerability
Drawing No:	130_4
Project:	Zone of Contribution Delineation
Stage:	
Client:	Kiltiernan Group Water Scheme
Scale:	1:40,000 @ A4

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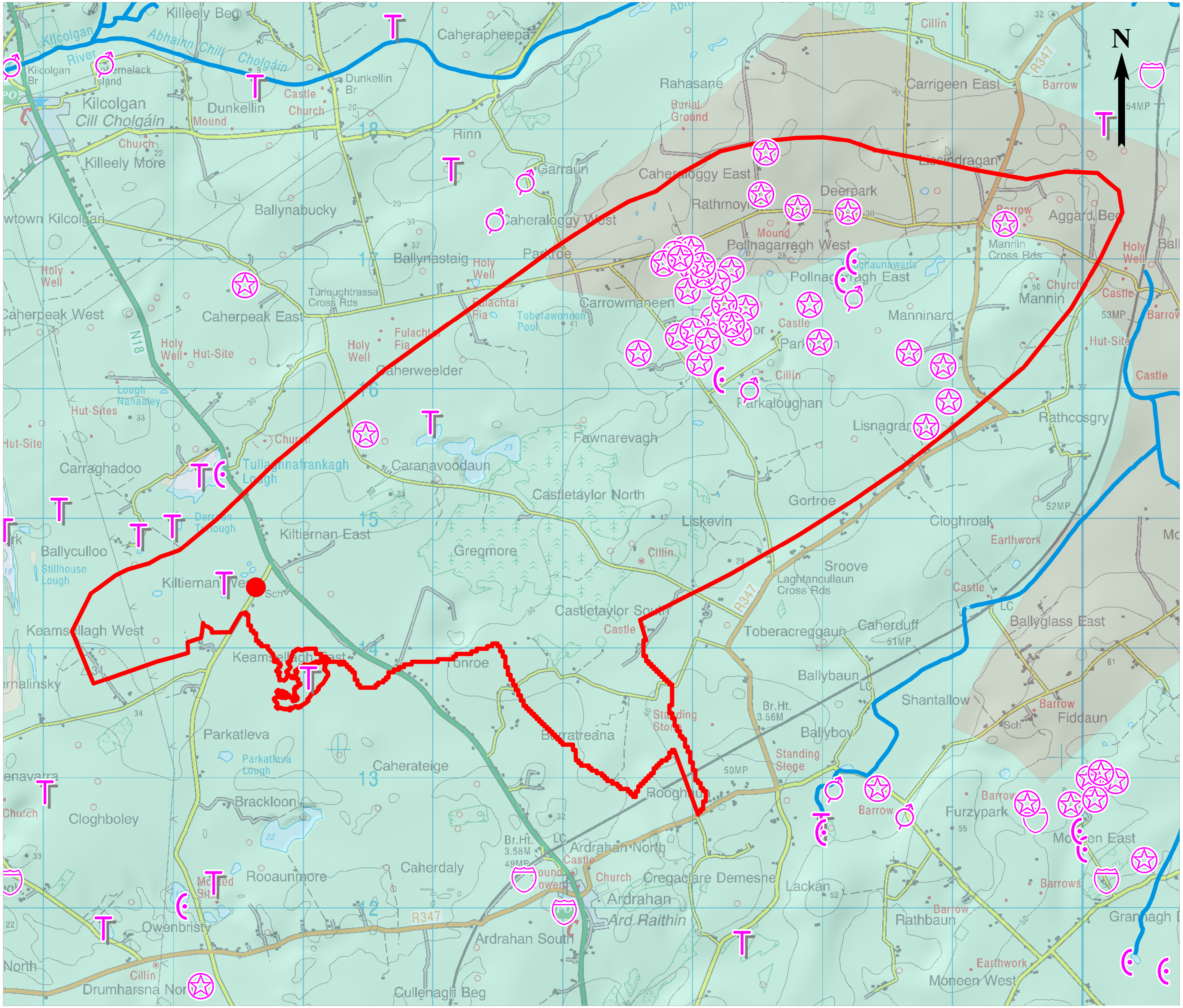

Legend:

- Supply Borehole
- ZOC Boundary

Geological Rock Units

- Dinantian Pure Bedded Limestones
- Dinantian Upper Impure Limestones
- Bedrock Faults

Karst Feature Types

- Cave
- Enclosed depression
- Spring
- Swallow hole
- Turlough

Title:	Figure 5 Bedrock Geology & Karst Features
Drawing No:	130_5
Project:	Zone of Contribution Delineation
Stage:	
Client:	Kiltiernan Group Water Scheme
Scale:	1:40,000 @ A4
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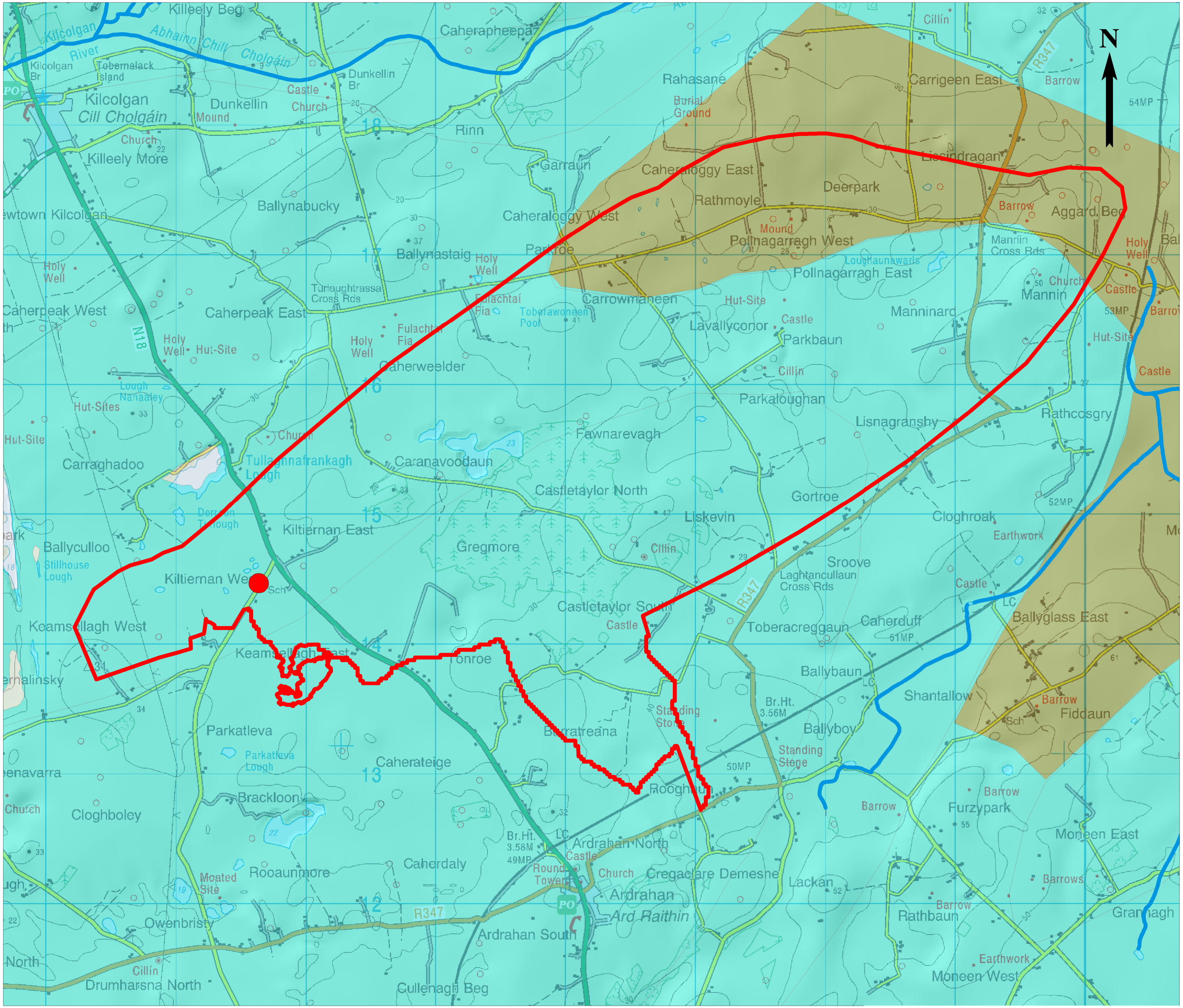

Legend:

- Supply Borehole
- ZOC Boundary

Bedrock Aquifer Type & Productivity

- Locally Import - Mod. Prod. in Local Zones
- Regionally Important - Karstified (conduit)

Title:	Figure 6 Bedrock Aquifer Type
Drawing No:	130_6
Project:	Zone of Contribution Delineation
Stage:	
Client:	Kiltiernan Group Water Scheme
Scale:	1:40,000 @ A4

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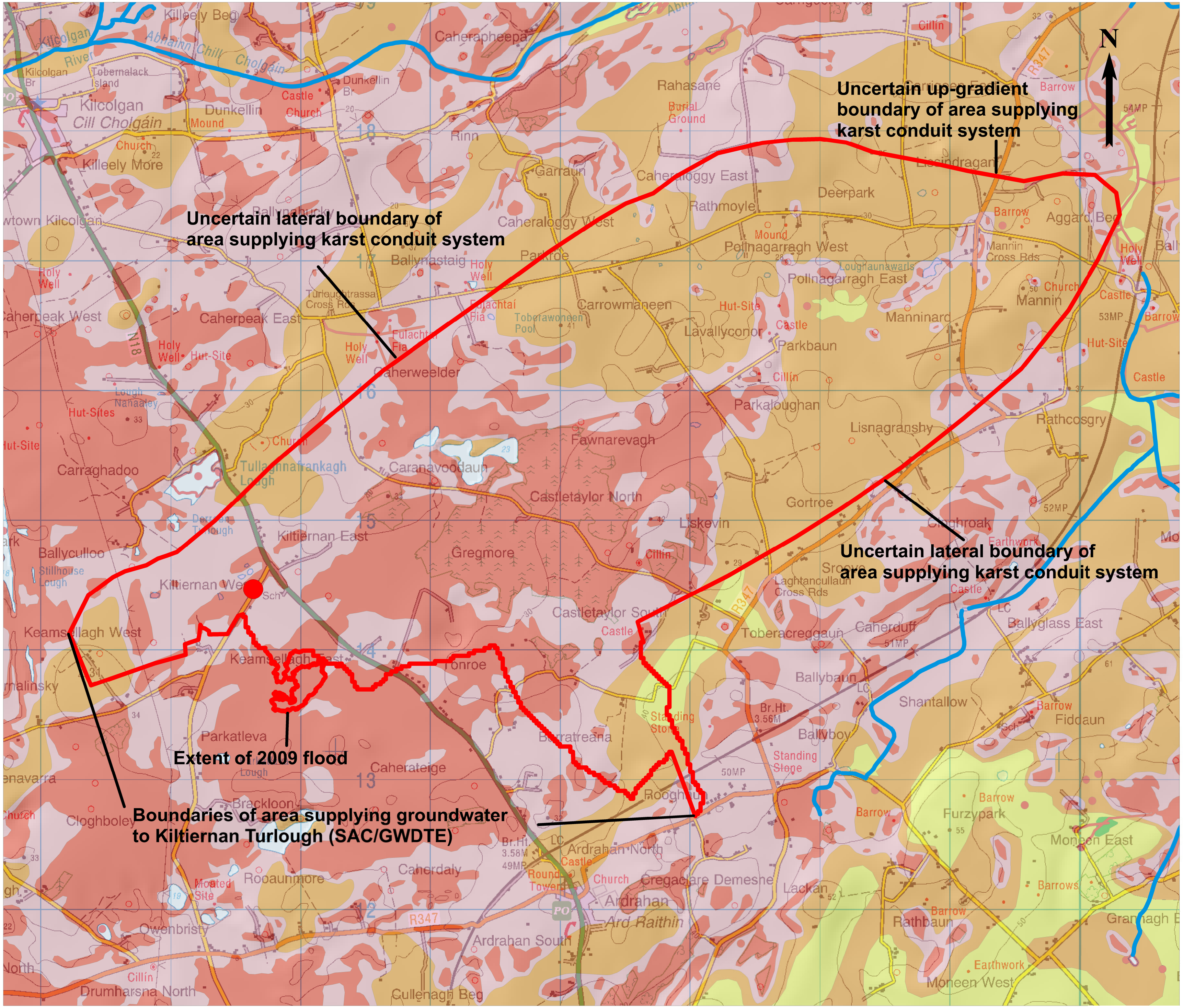

Legend:

- Supply Borehole
- ZOC Boundary

Groundwater Vulnerability

- Rock at or near surface or Karst
- Extreme
- High
- Moderate

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Title: Figure 7 ZOC Boundaries

Drawing No: 130_7

Project: Zone of Contribution Delineation

Stage:

Client: Kiltiernan Group Water Scheme

Scale: 1:40,000 @ A4

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Appendix 1
Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown 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 LI aquifers (200 mm/yr) and PI and PuI aquifers (100 mm/yr). Made ground has recharge coefficient of 20%.

Appendix 3
Water quality results

BH1 Analyses by CLS Ltd. on behalf of Kiltiernan GWS 31/5/2016

Michael J. Murphy Kiltiernan Group Water Scheme Caheradoo Kilcolgan Co. Galway	
Report No. :	297045
Date of Receipt :	31/05/2016
Start Date of Analysis :	31/05/2016
Date of Report :	04/07/2016
Sample taken by :	CLS
Order number:	678752

Test	Units	Kiltiernan GWS main source, 31/05/2016
BOD	mg/l	<1
COD	mg/l	<10
Turbidity	N.T.U.	0.3
pH	pH Units	6.8
Conductivity @20C	uS/cm	621
Nitrite as N	mg/l	<0.005
Sodium, total	mg/l	13
Chloride	mg/l	21.1
Ammonium as NH4	mg/l	<0.01
Nitrate as NO3	mg/l	5.02
Dissolved Oxygen (%)	%Sat	98
Iron, total	ug/l	<10
Potassium, total	mg/l	5
Total Hardness (Kone)	mg/l CaCO3	343
Magnesium, total	mg/l	9 mg/l
Colour, apparent	mg/l Pt Co	<4
Silica as Si O2 (reactive)	mg/l	2.87
Sulphate	mg/l	13.4
Orthophosphate as PO4-P	mg/l	0.071
Manganese, total	ug/l	<5
Calcium, total	mg/l	119
Aluminium, dissolved	ug/l	<2
Copper, dissolved	ug/l	2
Lead, dissolved	ug/l	<0.5
Chromium, dissolved	ug/l	<0.5
Nickel, dissolved	ug/l	<0.5
Cadmium, dissolved	ug/l	<0.5
Arsenic, dissolved	ug/l	0.6
Zinc, dissolved	ug/l	<5
Barium, dissolved	ug/l	13
TOC	mg/l	1.66 mg/L
PAH total	ng/l	16
Clostridium Perfringens in Water	cfu/100ml	0
Strontium, dissolved	ug/l	171
E coli (Filtration) (Environmental Wate	cfu/100ml	4
Total Coliforms (Filtration) (Environme	cfu/100ml	4
Fluoride by IC	mg/l	<0.2
TPH (>C5 - C44) by GC-FID	ug/l	323
Alkalinity Total by Autotitration	mg/l CaCO3	361

BH1 Analyses carried out on behalf of Glan Agua (DBO Contractor) 2011-2016

Date	Color (Pt Co)	TOC (mg/l)	Turbidity (NTU)	pH	Al (µg/l)	Fe (µg/l)	Mn (µg/l)	Ammonia (mg/l N)	Nitrate (mg/l NO_3)	Nitrite (mg/l NO_2)	C. Perf. (cfu/100 ml)	E. Coli (MPN/100 ml)	T. Coli (MPN/100 ml)	K (mg/l)	Na (mg/l)	Hardness (mg/l $CaCO_3$)	Alkalinity (mg/l $CaCO_3$)
12/09/2016	43	1.72	9.75	6.77	12	238	625	<0.010	10.62	<0.066							
08/08/2016	<5.00	2.33	<0.50	6.96	5	16	108	0.03	10.49	<0.066							
11/07/2016	10	2.10	<0.50	7.05	14	19	13	0.09	10.87	<0.066							
13/06/2016	<5.00	0.92	0.58	6.85	18	178	70	0.02	12.03	<0.066							
11/05/2016	<5.00	1.48	<0.50	6.98	7	28	11	0.05	<8.900	<0.066							
11/04/2016	<5.00	0.90	0.90	6.98	12	209	137	<0.010	<8.900	<0.066							
07/03/2016	<5.00	1.43	<0.50	7.06	8	<7.20	6	0.02	9.08	<0.066							
08/02/2016	<5.0	2.13	<0.50	7.12	22	36	23	<0.010	<8.900	<0.066							
11/01/2016	10	2.41	<0.5	7.38	8	9	4	0.03	10.92	<0.066							
08/12/2015	10	2.66	0.72	6.89	10	9	4	0.018	11.261	<0.066							
12/11/2015	<5.00	1.82	0.5	6.87	8	11	2	0.035	20.631	<0.066							
08/10/2015	7	1.67	<0.50	6.62	8	16	6	0.037	20.834	<0.066							
14/09/2015	<5	1.84	<0.5	6.73	8	198	16	0.21	24.14	0.13							
28/08/2015	<5	1.49	<0.5	6.81	13	<7.2	4	0.27	12.36	<0.016							
13/08/2015	112	2.00	9.84	6.93	44	3232	300	<0.01	18.07	0.03							
09/07/2015	<5	5.25	<0.5	6.84	15	176	6	0.04	16.75	<0.016							
11/06/2015	<5	2.18	<0.5	7.03	10	10	7	<0.01	11.61	<0.016							
15/05/2015	<5	<3	<0.5	6.91	6	8	1	0.02	20.07	<0.016							
09/04/2015	<5	1.61	<0.5	7.06	<5	<7.2	1	0.03	18.21	<0.016							
12/03/2015	<5	2.19	<0.5	7.08	12	167	1	<0.01	43.77	<0.016							
12/02/2015	<5	1.83	<0.5	7.33	<5	<7.2	1	0.02	16.08	0.03							
15/01/2015	<5	2.41	<0.5	7.14	11	35	11	<0.01	52.72	<0.016							
11/12/2014	<5	2.67	<0.5	6.97	8	20	4	<0.01	13.47	0.03							
13/11/2014	<5	2.72	<0.5	7.41	<5	9	1	0.02	49.79	<0.016							
16/10/2014	<5	0.70	0.60	6.84	10	29	10	<0.01	10.90	<0.016							
11/09/2014	<5	0.83	1.10	6.93	33	59	25	<0.01	<8.9	0.03							
14/08/2014	63	<3	3.02	6.85	15	25	184	<0.01	9.88	<0.016							
10/07/2014	<5	1.78	0.72	6.70	<5	90	23	0.02	15.02	<0.016							
12/06/2014	<5	<0.5	<0.5	6.67	6	11	6	<0.01	11.61	<0.016							
08/05/2014	<5	2.67	<0.5	6.37	6	<7.2	9	0.05	10.23	0.07							

17/04/2014	<5	3.15	<0.5	7.04	<5	<7.2	4	<0.01	<8.9	<0.016							
13/03/2014	<5	2.05	<0.5	7.29	<5	<7.2	2	<0.01	14.93	0.07							
20/02/2014	<5	1.65	<0.5	7.56	54	<7.2	19	<0.01	15.11	<0.016							
16/01/2014	<5	3.02	<0.5	7.33	6	<7.2	2	<0.01	24.81	<0.016							
12/12/2013	<5	2.10	<0.5	7.16	105	16	33	<0.01	22.42	<0.016							
18/11/2013	<5	2.10	<0.5	7.18	10	12	4	<0.01	30.39	<0.016							
10/10/2013	7	2.12	15.60	7.03	211	242	34	<0.01	13.02	0.03							
11/09/2013	12	0.79	0.60	7.02	82	24	16	0.03	14.09	<0.016							
13/08/2013	19	2.00	1.70	7. 07	257	55	54	0.01	11.87	<0.016							
17/07/2013	88	1.32	9.58	7.10	842	406	158	<0.03	13.11	<0.016							
11/06/2013	<5	2.04	<0.5	6.76	74	31	17	<0.01	12.49	<0.016							
14/05/2013	<5	1.13	<0.5	7.01	26	12	8	<0.01	11.47	<0.016							
16/04/2013	<5	1.41	<0.5	7.24	50	12	23	0.02	10.99	<0.016							
12/03/2013	<5	<0.5	<0.5	7.12	76	<7.2	8	0.16	<8.9	0.03							
12/02/2013	<5	2.10	<0.5	7.14	11	26	2	0.04	<8.9	<0.016							
17/01/2013	<5	2.20	<0.5	7.07	5	<7.2	1	0.02	<2	<0.005							
11/12/2012	<5	2.20	<0.5	7.06	5	<7.2	<0.7	0.02	2.27	<0.005							
08/11/2012	7	3.20	<0.5	6.80	14	<7.2	2	<0.01	22.24	0.07							
18/10/2012	7	2.10	<0.5	6.93	56	10	12	<0.01	2.94	<0.005							
06/09/2012	<5	2.10	<0.5	7.02	13	8	10	0.02									
21/08/2012	<5	2.40	<0.5	6.84	10	<7.2	2	0.03	15.24	<0.016							
12/07/2012	<5	2.20	<0.5	7.02	<5	<7.2	2	0.02	2.92	<0.005							
21/06/2012	<5	1.70	<0.5	7.02	8	16	8	0.02	11.56	<0.016							
16/05/2012	5	2.50	<0.5	7.18	8	<7.2	9	<0.01	16.92	0.03							
24/04/2012	6	0.92	<0.5	<0.5	10	42	24	<0.01	22.37	0.01	0	7	261	4.70	13.00		
07/03/2012	5	2.50	<0.5	7.20	20	<20	<5	<0.01	9.21	<0.07							
23/02/2012	7	2.10	<0.5	7.37	<20	<20	6	<0.01	<8.77	<0.07							
25/01/2012	<5	2.20	<0.5	7.30	39	<20	9	<0.1	9.75	<0.07							
14/12/2011	38	3.60	1.64	7.21	654	246	168	<0.01	33.31	<0.07							
17/11/2011	<5	1.90	<0.5	7.09	<20	27	9	<0.01	14.66	<0.07							
20/10/2011	<5	2.10	<0.5	7.04	<20	<20	<0.5	<0.01	17.54	<0.07							
20/09/2011	<5	1.99	<0.5		<20	<20	9	<0.1	14.93	<0.07						400.80	446.00
15/09/2011	<5	2.70	0.77		120	73	120	<0.1	18.21	0.72						437.00	362.00
07/09/2011	<5	2.03	<0.5		<20	<20	<5	<0.1	11.52	<0.07						382.94	443.00
01/09/2011	<5	1.69	<0.5		<20	<20	10		10.01	<0.07						431.79	490.00

BH1 Analyses carried out on behalf of Kiltiernan GWS 2012 - 2016

Date	Ref	Color	Turbidity	pH	E.C. (µS/cm)	Al (µg/l)	Nitrate (mg/l NO_3)	Nitrite (mg/l NO_2)	Ammonium (mg/l NH_4)	Fe (µg/l)	Mn (µg/l)	Cu (µg/l)	Sb (µg/l)	Cd (µg/l)	Pb (µg/l)	As (µg/l)	Cr (µg/l)	Ni (µg/l)	Se (µg/l)
25/04/2016	W2255-2016	3.8	0.4	7.2	599	20	4.2	<0.02	0.3	36	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
28/01/2016	W436-2016	4.5	0.3	7.3	541	<20	6.7	<0.02	<0.03	<20	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
24/11/2015	W6432-2015	4.8	0.4	7.2	637	<20	23.9	<0.02	0.04	<20	<20	<0.04	<1	<1	<4	<4	<4	5.3	<4
13/08/2015	W4286-2015	<2	0.3	7.3	614	<20	15.2	0.02	0.03	<20	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
24/04/2015	W2086-2015	6.6	0.8	7.2	561	<20	14	<0.02	<0.03	20	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
30/10/2014	W5812-2014	2.1	0.8	7.3	563	20	10.3	<0.02	0.05	<20	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
11/08/2014	W4046-2014	2.3	21.2	7.3	704	107	9.4	0.1	0.3	4880	158	<0.04	<1	<1	<4	6.30	<4	6.30	<4
11/03/2014	W1024-2014	4.9	0.3	7.2	608	<20	13.6	<0.02	<0.03	20	<20	<0.04		<1	<4	<4	<4	<4	<4
29/05/2013	W2835-2013	3.1	0.6	7.1	602	119	6.6	<0.02	<0.03	26	<20	<0.04	<1	<1	<4	<4	<4	<4	<4
20/02/2012	W691-2012	3.3	0.3	7.4	567	53	7.9	<0.02	<0.04	<20	<20	<0.04	<1	<1	<4	<4	<4	<4	<4

Date	***Ref***	***B (µg/l)***	***Zn (µg/l)***	***Hardness (mg/l $CaCO_3$)***	***Alkalinity (mg/l $CaCO_3$)***	***Cl^- (mg/l)***	***SO_4 (mg/l)***	***K (mg/l)***	***Na (mg/l)***	***PO_4-P (mg/l)***	***T. Colis (MPN/100 ml)***	***E. Coli (MPN/100 ml)***
25/04/2016	W2255-2016	0.02	<0.04	315	303	23	<20	13	4			
28/01/2016	W436-2016	<0.02	<0.04	317	306	21	<20	12	4			
24/11/2015	W6432-2015	0.02	<0.04	354	337	29	<20	17	8			
13/08/2015	W4286-2015	0.02	<0.04	333	315	32	<20	15	5			
24/04/2015	W2086-2015	0.02	<0.04	304	272	32	<20	14	4	<.05		
30/10/2014	W5812-2014	0.02	<0.04	317	292	26	<20	14	3	0.05		
11/08/2014	W4046-2014	0.02	<0.04	378	345	36	<20	15	5			
11/03/2014	W1024-2014	<0.02	<0.04	313	280	42	<20	15	6	0.06		
29/05/2013	W2835-2013	<0.02	<0.04	368	344							
20/02/2012	W691-2012	0.02	<0.04	344	317						3	1

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
Borehole Log

Patrick Briody & Sons Ltd.

DRILLING LOG

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

The Grove,
Rathangan, Co. Kildare.
Tel (045) 524360
Fax (045) 524785
e-mail: info@briodydrilling.com

0773

Consultant/Engineer: Meic

Client: Galway Co. Co.

Borehole Reference No. BH1 Sheet 1 of 3

Borehole Location: Kilterna GWS.

Date of Drilling	Depth (from - to) Mtrs/Ft.	Actual Drilling Diametre	Drilling Conditions / Water Strike
8-2-11	Mobilised	remainder	of equipment
	to site	and	alligned over
	borehole.	dipped	borehole @ 42m.
	Proceeded	to	withdraw PVC
	total length	42m.	all out.
9-2-11	Withdrew	8"	steel casing total 6m
	and	drilled	15" from 0-6m
	bedrock @ 3-4m		
	Installed	6m	x 12" steel.
	then drilled		12" from 6m – 30m
10-2-11	drilled	from	30m – 52m
	Started	airlift	@ 2pm – 5.30pm
11-2-11	"	"	@ 9am – 5.30pm
14-2-11	"	"	@ 10am – 5.30pm
15-2-11	"	"	@ 10am – 2pm

Total Depth of Well……

Estimated Yield……

Depth to Rock……

Steel Casing Installed……

P.V.C. Casing/Screen Installed……

Other Remarks……

……

……

……

Lead Driller…… Drilling Rig……

Engineer Approval……

Schematic View

Patrick Briody & Sons Ltd.

DRILLING LOG

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

The Grove,
Rathangan, Co. Kildare.
Tel (045) 524360
Fax (045) 524785
e-mail: info@briodydrilling.com

Consultant/Engineer: Metc.

Client: Galway Co. Co.

Borehole Reference No. BH 1 Sheet 2 of 3

Borehole Location: Kiltormer GWS

Log 0774

Date of Drilling	Depth (from - to) Mtrs/Ft.	Actual Drilling Diametre	Drilling Conditions / Water Strike
9-2-11	0 - 3	15"	fill or boulder clay
	3 - 4	15"	weathered bedrock
	4 - 6	15"	more competent
	6.5 - 7.5	12"	v weathered no
			hammering
	7.5 - 14	12	competent
	14 - 15	12	weathered small hammering
	15 - 22	12"	competent
	22 - 22.30	12	cavity
10-2-11	22.30 - 36	"	competent
	36 - 36.5	"	cavity
	36.5 - 52	"	competent

Total Depth of Well..........

Estimated Yield..........

Depth to Rock..........

Steel Casing Installed..........

P.V.C. Casing/Screen Installed..........

Other Remarks..........

....

....

....

Lead Driller.......... Drilling Rig..........

Engineer Approval..........

Schematic View

P.V.C Spec.
200 OD × 3mm slot.
solid → 5
Solid → 10
screen → 15
screen → 20
screen → 25
solid → 30
screen → 35
screen → 40
solid → 45
2m solid → 50.

Patrick Briody & Sons Ltd.

DRILLING LOG

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

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0775

Consultant/Engineer: Mc...
Client: Galway Co. Co.
Borehole Reference No: BH 1 Sheet 3 of 3
Borehole Location: Killerrin GVS

Date of Drilling	Depth (from - to) Mtrs/Ft.	Actual Drilling Diameter	Drilling Conditions / Water Strike
15-2-11	Tripped out of		hole and installed
	200mm PVC as		spec to 52m.
16-2-11	Pulled 12" casing out and blocked		
	hole @ 6m		(from 15" - 12") then
	cemented	back	to surface from
	5-½m using		25 bag of cement.
	welded	on	lockable lid on
	2m section of		12" steel and
	kept same	1m	above ground.
	de mobed from		site

Total Depth of Well....................

Estimated Yield....................

Depth to Rock....................

Steel Casing Installed....................

P.V.C. Casing/Screen Installed....................

Other Remarks....................

Lead Driller.................... Drilling Rig....................

Engineer Approval....................

Schematic View

Appendix 6

TW1 Pump Test
PW1 Water Level Monitoring Data
Calculations

Mulcairs

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Drilling Contractors

Monitoring Bores
Houses – Farms - Factories
Pump Sales/Service & Testing
Well Drilling/Divining/Site Investigation

VAT No. 8871119H

KILTERNAN GWS April 2007

BORE 1: Well Number 2 At Kilternan

Test Started: 5/03/2007
Time: 3.30pm
Depth: 42m
Static Water: 4.57m

TEST REPORT

DATE	TIME	STATIC WATER	DRAWDOWN	CHANGE	OUTPUT
5/3/07	3.30pm	4.57m	0.00m	0.00m	0000gph/00.00 m^3 per hour
5/3/07	3.31pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	3.32pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	3.35pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	3.40pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	3.45pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	4.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	4.15pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	4.30pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	6.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	9.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
5/3/07	12.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
6/3/07	6.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
6/3/07	12.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
6/3/07	6.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
6/3/07	12.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
7/3/07	6.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
7/3/07	12.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
7/3/07	6.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
7/3/07	12.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour

Mulcairs

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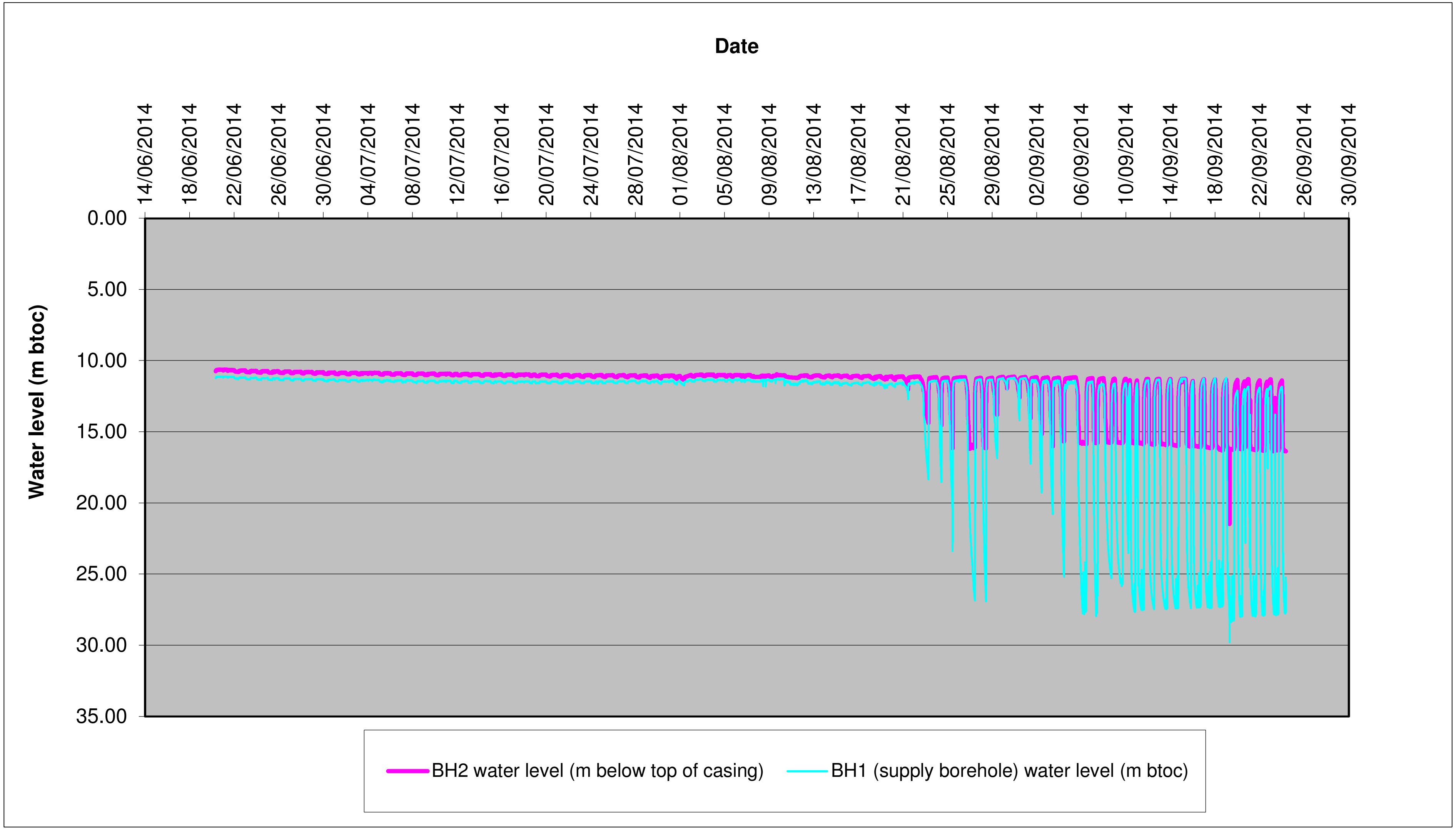
Pump Sales/Service & Testing
Well Drilling/Divining/Site Investigation

VAT No. 8871119H

DATE	TIME	STATIC WATER	DRAWDOWN	CHANGE	OUTPUT
8/3/07	6.00am	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
8/3/07	12.00pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour
8/3/07	3.30pm	4.57m	5.06m	0.49m	13200gph/60.00m^3 per hour

This does not constitute as a guarantee.

Groundwater Level Monitoring Results for BH1 (supply well) and BH2 (un-used well at c. 15 m distance) 20/6/2014 - 24/9/2014.



Transmissivity Calculations and Sensitivity Analysis based on data from BH1 current supply well and trial well at same location

Borehole	Q m3/hr (source Glan Agua MSRs)	Q m3/day	Factor	b (m)	s (m)	s data source	T (1) m2/day (T = 1.22Q/s Confined Logan)	T (2) m2/day (T = 2.43 Qb/(s(2b-s)) Unconfined Logan, after Misstear, 1998 GW Newletter No. 34)	T (2) + Error +10%	T (2) + Error -10%
BH1 trial well Mulcairs	60	1440	1.22	37.43	0.49	05/03/07 Mu	3585	3550	3905	3159
BH1 current	45	1080	1.22	40.69	0.14	01/07/14 Hy	9411	9273	10200	8253
BH1 current	45	406	1.22	40.69	0.14	01/07/14 Hy	3538	3486	3835	3103
BH1 current	32	768	1.22	35.85	16.15	01/07/14 Hy	58	74	81	66
BH1 current	32	768	1.22	27	16.15	01/07/14 Hy	58	81	90	72
BH1 current	32	768	1.22	15	16.15	01/07/14 Hy	58	124	136	110
BH1 current	32	356	1.22	35.85	16.15	01/07/14 Hy	27	34	38	30