Establishment of Groundwater Zones of Contribution

Kildallan Group Water Scheme, Co. Cavan

December 2015

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The National Federation of Group Water Schemes

Acknowledgements

Carried out with the assistance of Tadgh Murphy of Kildallan GWS, Brian Brady of EPS, Jean Rosney of NFGWS, and any other scheme members who provided data and/or assistance during site visits.

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Document control information

Revision	Date	Author	Checked	Approved
A	14.10.15	Colin O'Reilly	24.11.15	NHW
B	13.01.16	Colin O'Reilly	05.02.16	NHW
Draft Final	05.02.16			NHW
Final				

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 Kildallan 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.

Kildallan GWS (CN22) is supplied by groundwater that flows through conduits in a regionally important karstified limestone aquifer. The GWS abstracts 438 m^3/d from a pair of boreholes.

[1] Geological Survey of Ireland, 2000.

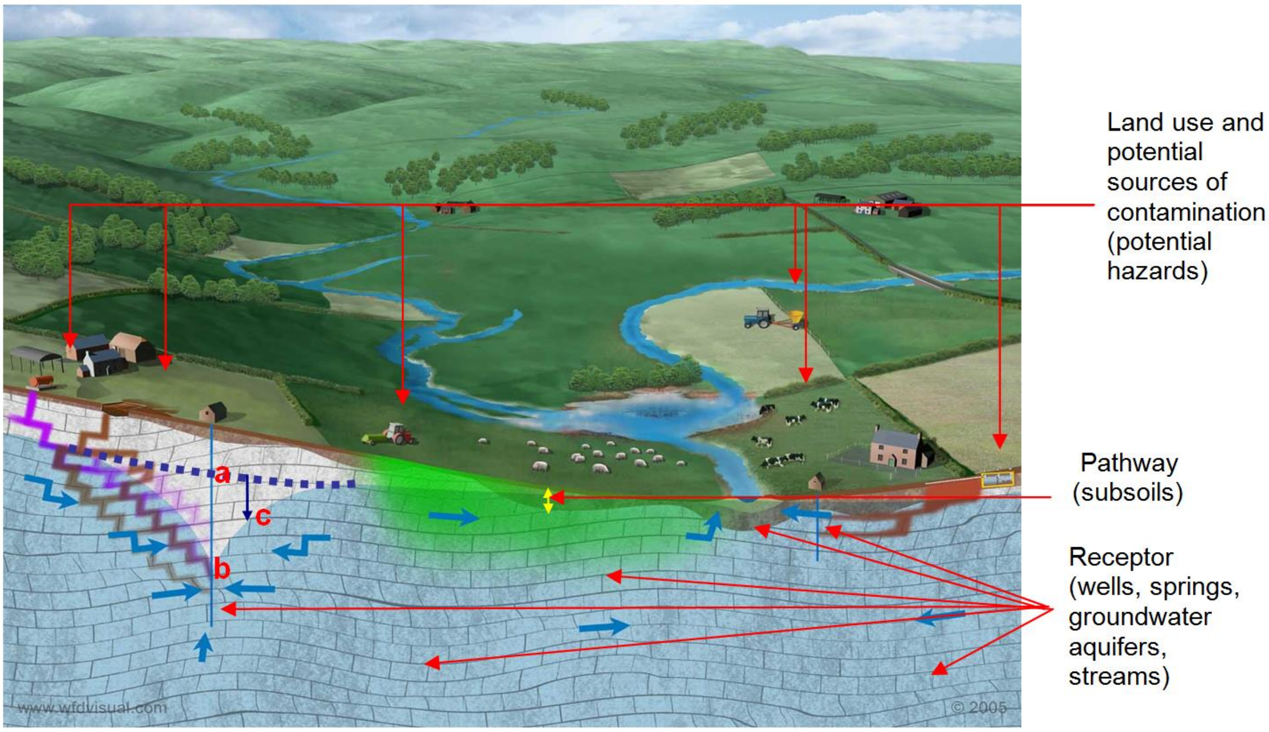


Diagram 1. Rural Landscape Highlighting the Interaction between Surface Water, Groundwater and Potential Land Use Hazards

2 Location, Site Description, Supply Details and Wellhead Protection

The zone of contribution (ZOC) for the Kildallan 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.

Between 1979 and 1996 Kildallan GWS obtained raw water from a lake abstraction. The lake abstraction has ceased and Kildallan GWS is now supplied from two boreholes located in Burren, approximately 8 km southwest of Ballyconnell (**Figure 1**). The boreholes are located in a small area of forestry clearing, to the rear of the water treatment plant (**Diagram 2, Photograph 1**).

The scheme serves 410 customers (500 connections in total to 280 houses, 130 farms and several schools), with a reported average usage of approximately 418 m^3/d. The network has reportedly been upgraded to deal with leaks[3].

The two boreholes are pumped alternately on a fortnightly cycle. The instantaneous pumping rate is 31 m^3/h and the daily abstraction is 438 m^3/d. This implies the borehole is being pumped for about 14 hours per day. Raw water is pumped to the on-site treatment plant before being transferred to a 1000 m^3 reservoir at Mullaghmore (3 km northeast) from which it feeds into the distribution network by gravity.

[2] DELG/EPA/GSI, 1999

[3] Personal communication with Tadgh Murphy

Suspended solids are removed by sand filtration. The sand filters are backwashed three times daily, which accounts for up to 20 m^3/d. Backwash water is collected in a wastewater tank, from which the settled sludge is disposed of every two months by a licensed contractor, with excess water disposed of via a percolation area. Disinfection consists of chlorination.

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

Diagram 2. Aerial photo showing location of GWS abstraction points

Photo 1: Borehole pad

Photo 2: Borehole cover (PW1)

Photo 3: Wellhead arrangement

Photo 4: Treatment plant

Table 1. Water Supply Details

NFGWS No. CN22	PW1	PW2
Grid reference	Irish Grid: E 223222 N 311106	Irish Grid: E 223216 N 311102
Townland	Burren	Burren
Source type	Borehole	Borehole
Drilled	May 2001	May 2001
Drilling Contractor	Dunnes Drilling	Dunnes Drilling
Owner	Kildallan GWS	Kildallan GWS
Elevation in metres above Ordnance Datum	Ground level = 85.02 mOD Top of casing = 84.26 mOD	Ground level = 84.71 mOD Top of casing = 83.79 mOD
Total depth (m)	~ 81 m (265 ft)	Assumed as per PW1
Construction details	300 mm outer steel casing installed from surface to 6 m. 200 mm steel casing installed from surface to 18.3 m. 150 mm steel casing installed from surface to 66.5 m 150 mm open hole below base of casing to completed depth of borehole.	No construction details available for PW2. Construction assumed to be as per PW1. There are no details of grouting in the construction logs. It is assumed the boreholes are not grouted.
Depth to rock in metres below ground level	Limestone (soft) at 18 m bgl Black rock (dark limestone?) at 67 mgl	Assumed as per PW1
Inflow zones (water strikes) mbgl	68 m bgl and 76 m bgl	Assumed as per PW1
Static water level (SWL) (m bgl) (start of pumping test June 2001)	33.50 m bgl	
Pumping water level (PWL) (m bgl)	Site visit (21/08/15) = 33.86 m bgl (PW2 pumping only) Pumping test (1584 m^3/d) = 35.63 mbgl	Site visit (21/08/15) = 33.58 m bgl (PW2 pumping only at 30.7 m^3/h)
Pump intake depth (m bgl)	49 m bgl	Assumed as per PW1
Current abstraction rate (GWS)	Assumed to be as per PW2	Hourly rate = 30.7 m^3/hr Daily rate = 438 m^3/day (based on information provided by live and bulk meter readings on 21/08/15).
Number of Connections	500	
Reported yield (m^3/d)	980 m^3/d estimated during drilling (drill log records); 1584 m^3/d during pumping test	Assumed as per PW1
Specific Capacity (m^3/d/m)	744	744
Transmissivity (m^2/d)	807	807

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 boreholes are located on a drumlin ridge top. High density of drumlins in the area which generally peak between 80 – 100 mOD, and have valley floors at 50 – 70 mOD. Slieve Rushen (400 mOD) peaks 10 km to the north.
Land use		Predominantly grassland supporting low to moderate intensity cattle and sheep grazing, with pockets of forestry throughout. Small cluster of one-off housing 500 m to south but otherwise density is low. Low density of farmyards in area. Large timber-treatment facility and piggery 1.5 km east of source.
Surface Hydrology (**Figure 1 & Figure 2**)		A series of interconnected streams and lakes occupy local hollows and valleys. Derrycassan Lough is part of a local lake system (including Garadice, Ballymagauran and Cooologe) and comes to within 400 m west of the source. These collect water from Cuilcagh Mountains and surrounding drumlins and drain in a northeasterly direction to the Woodford River, which flows into Upper Lough Erne 17 km to the northeast.
Topsoil http://gis.epa.ie/envision		Deep, poorly drained soils.
Subsoil (**Figure 3**) www.gsi.ie/mapping		Low permeability chert and sandstone till ('boulder clay'). Peats form in low-lying pockets on ground prone to waterlogging.
Groundwater Vulnerability (**Figure 4**) www.gsi.ie/mapping		'Low' (see **Appendix 1**). Areas of 'Extreme' to east of source.
Geology (**Figure 5**) www.gsi.ie/mapping		The water supply boreholes are located in pure limestone bedrock. Drill logs (**Appendix 5**) show a transition from soft white limestone to harder black rock at 70 m below surface. Shales come to the surface to the northwest and south. Geological faulting (large, linear breaks in the rock) shown 2 km south and 2.5 km east of the source.
Aquifer Classification (**Figure 6**) www.gsi.ie/mapping		The pure limestone bedrock is classified as a Regionally important karstified aquifer (**Rk_c**), dominated by conduit flow. The nearby shales are classified as a locally important aquifer, moderately productive only in local zones (**Ll**).
Groundwater Body (GWB) www.wfdireland.ie		The source is located in the Newton-Ballyconnell groundwater body, which is categorised as having "good" status. (www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)
Recharge Coefficient (**Appendix 2**)	7.5 – 25 %	Low recharge rates (5-10%) occur in a Low 'vulnerability' setting where low permeability subsoils are present. The regionally important aquifer is likely to be recharged on 'Extreme' and 'High' vulnerability areas where subsoils are thinner and more permeable. The bulk recharge coefficient for the ZOC area is between 7.5 and 25%.
Recharge (mm/yr) www.gsi.ie/mapping	60 – 195 mm	

3.2 Hydrochemistry and water quality

GWS monthly status reports for the years 2005 to 2015 were made available. Data for the period January 2013 to June 2015 were used to summarise the hydrochemistry and water quality for Kildallan GWS. Water quality data are presented in **Appendix 3**, which includes graphs showing how key water quality parameters have varied over time.

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 3. 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)
Electrical Conductivity (µS/cm)	31	437	**871**	503	800 (TV), 2,500 (DWL)
Laboratory pH	31	6.9	7.9	7.2	6.5 – 9.5 (DWL)
Turbidity (NTU)	31	1.3	**67**	36	
Total Coliforms (MPN[4]/100 ml)	31	0	<1	<1	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	31	0	<1	<1	0 (DWL)
Clostridium perfringens (MPN/100 ml)	31	0	<1	<1	
Nitrate (mg/l NO_3)	31	<0.44	<8.9	<8.9	50 (DWL) 37.5 (TV)
Ammonium (mg/l NH_4)	31	0.03	**0.7**	0.21	0.3 (DWL), 0.225 [0.175 as N] (TV)
Iron (µg/l)	31	**971**	**4984**	**2958**	200 (DWL)
Manganese (µg/l)	31	**354**	**1070**	**916**	50 (DWL)
Aluminium (µg/l)	31	<2	**297**	<5	200 (DWL)

Raw groundwater abstracted from the Kildallan GWS boreholes has been entirely free of microbial contamination during any of the monthly sampling events over the past two years. Groundwater is well protected by the thick, impermeable subsoil.

Water is ‘hard’, which is typical of limestone aquifers, since the limestone dissolves readily into the groundwater. On occasion pH has been marginally below neutral which may suggest an input from groundwater flowing through fractured shales. Conductivity is relatively stable, with a typical range of 460 – 520 µs/cm.

Nitrates and nitrites were below detection limits for all sampling events. Ammonia is typically in the range 0.17 – 0.22 mg/l. This can indicate contamination from nearby organic sources (e.g. landspreading, septic tanks) but in this case is attributed to geological processes (e.g. conversion of nitrates to ammonia, input from shales, peat runoff).

Iron and manganese are consistently, and significantly, elevated at this source. This indicates that the groundwater environment is lacking in oxygen (known as a ‘confined’ aquifer) and that recharge takes a long time to percolate down to the water table. The elevated iron and manganese coincide with high turbidity. The caretaker describes raw water as being cloudy and smelling slightly of sulphur. These solids are removed efficiently during filtration at the treatment plant.

[4] MPN is most probable number

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**.

Groundwater is replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. Subsoils are very thick and of low permeability and as such these areas will contribute only low recharge, over a long period of time. Most precipitation falling on these areas will flow over land to local streams and lakes. Higher recharge rates are likely to occur where bedrock is closer to surface, i.e. in areas where vulnerability classification is ‘Extreme’.

Drilling logs (**Appendix 5**) show that a significant flow of groundwater enters the borehole at an interface where soft, broken brown/white rock (limestone) sit atop a harder black rock (assumed to be dark limestone). The broken limestone is capable of storing significant volumes of groundwater. Further significant inflows were reported in a cavern at the base of the borehole. Similar cavity features were observed in a trial well that had to be abandoned. These conduits are typical of karstified limestone and are responsible for concentrating groundwater flows and transmitting significant volumes of water underground.

The low drawdown observed during high discharge rate pumping tests confirms the high permeability of the limestone fractures and conduits. The pumping test also shows a low hydraulic gradient is present under pumping conditions.

The regional groundwater flow direction is assumed to be from south to north towards Upper Lough Erne. There may be some localised groundwater flow towards nearby lakes. The lack of any microbial contamination suggests that there is little or no interaction between lake water and the production wells. This good microbial quality is linked with the thick subsoil cover, low groundwater vulnerability rating, good borehole construction, and lack of landuse pressures in the ZOC.

Shale bedrock to the south is of low permeability, and yields limited amounts of groundwater. This was confirmed in the well survey (carried out on 28/09/15 and shown in Figure 2) as wells to the south of the R199 road displayed water tables very close to surface. This is perched water and occurs because the shale bedrock is unable to accept all of the rain falling on it, due to the limited development of fractures.

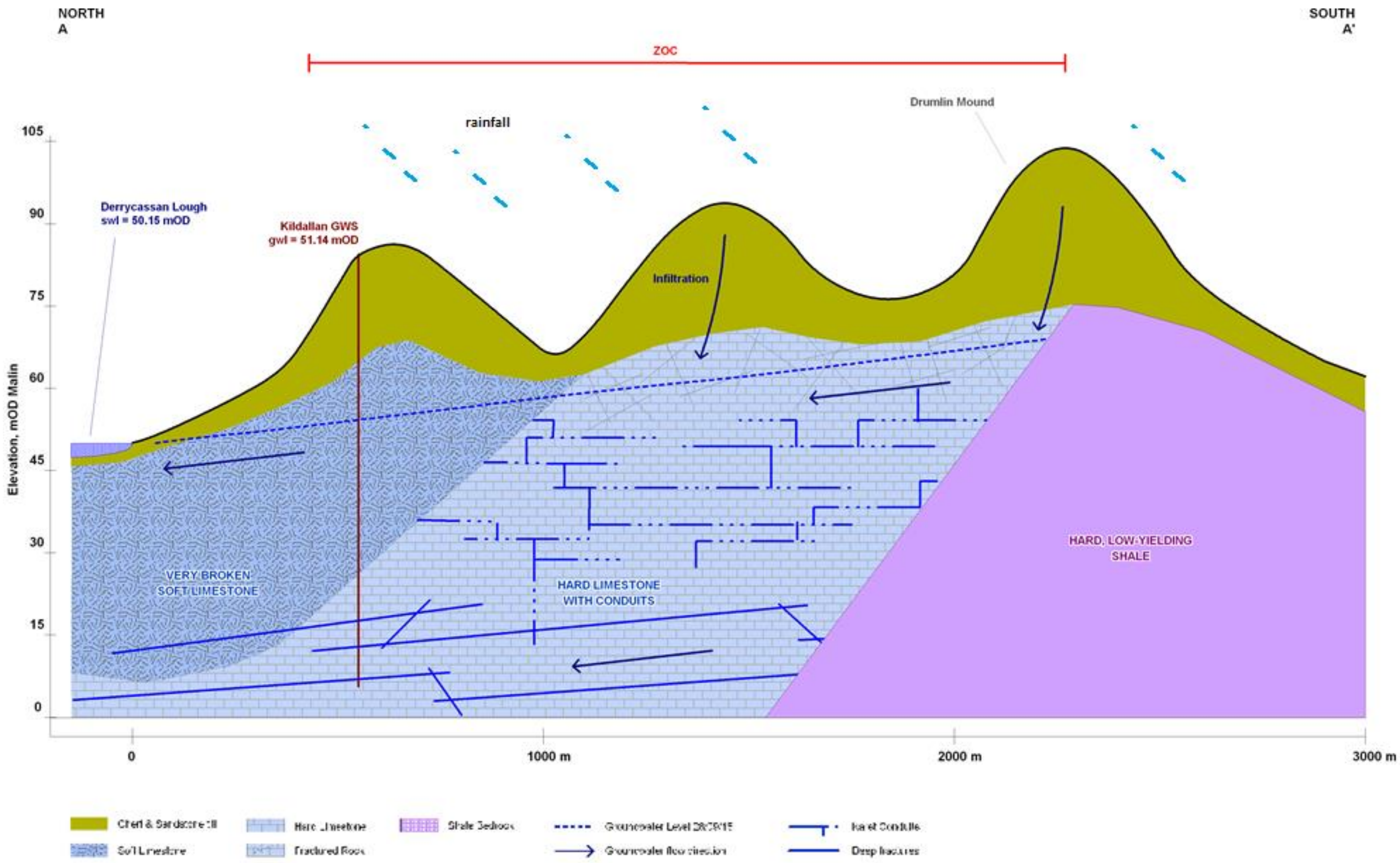


Diagram 3. Conceptual model of groundwater flow shown on a vertical cross-section through the ground

4.2 Boundaries

The Zone of Contribution (ZOC) delineated for Kildallan GWS is based mainly on a combination of hydrogeological mapping and inferences, and geological boundaries. The delineation of the zone of contribution boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

The **southern** boundary is based on a geological boundary, where the pure limestone meets the shale bedrock. Geological maps show this interface to be a geological faultline, which may contribute significant groundwater flow. However, only a limited amount of groundwater is thought to cross into the limestone aquifer from the shale bedrock. To allow for the fact that some groundwater flow will occur from shale to limestone, and for uncertainties in the geological map, a buffer of 100 m has been extended into the shale rock type.

The **western** and eastern boundaries are based on an assessment of local groundwater flow directions, and are located along interpreted groundwater flow lines. Both localised and regional groundwater in the area west of the ZOC is assumed to flow into Derrycassan Lough.

The **northern** boundary is based on the assumption that the majority of the abstraction is sourced from the soft, broken limestones. This assumption means that some groundwater will be drawn towards the well against what is considered to be the regional groundwater flow direction. The downgradient distance to which drawdown extends has been estimated as 283 m (**Appendix 7**).

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 current demand for the Kildallan GWS is 438 m^3/d. The hourly pumping rate is 30.7 m^3/h (737 m^3/d). The maximum sustainable yield for the borehole is confirmed from a pumping test as being at least 1584 m^3/d. The ZOC is delineated for the daily demand rather than the hourly pumping rate.

The area described above and shown in **Figures 2** and **7** is 3.0 km^2. Recharge to the overall delineated ZOC is 689 m^3/d [5].

For the purpose of the ZOC delineation and water balance a rate of 657 m^3/d is used, which is 150% of the current abstraction rate. The total recharge provided by the delineated ZOC area broadly similar to this actual abstraction rate and therefore deemed to be sufficient to sustain the well.

5 Conclusions

Kildallan GWS is supplied from a pair of boreholes which pump alternately on a fortnightly basis at an hourly rate of 31 m^3/h, and supply 438 m^3/d over 24 hours per day from a karstified aquifer.

Rainfall infiltrates to the groundwater system through a thick layer of boulder clay. The ZOC, which encompasses an area of 3 km^2, is defined by geological boundaries to the north and south, and by groundwater flowlines to the east and west. Groundwater flow direction is generally from south to north, and

[5] Recharge to the 'Low' vulnerability area (2.36 km^2) of the ZOC is estimated as 60 mm/yr (see **Table 2**), which yields 388 m^3/d. Recharge to the 'Extreme' vulnerability area (0.33 km^2) of the ZOC is estimated as 175 mm/yr, which yields 158 m^3/d. Recharge to the 'High vulnerability area (0.27 km^2) of the ZOC is estimated as 195 mm/yr, which yields 143 m^3/d.

locally towards nearby lakes. Groundwater flows freely within fractures in the upper broken limestone bedrock layer, and through conduits within a deeper limestone system.

The available water quality data show that groundwater is well protected from microbial contamination by the thick layer of low permeability subsoils. Groundwater vulnerability across the ZOC is predominantly ‘Low’, although there are minor portions of ‘Extreme’ and ‘High’ vulnerability along the eastern and western perimeters, respectively.

The overall thick subsoil cover and slow infiltration rates mean that groundwater is lacking in oxygen. The aquifer is said to be ‘confined’ and this results in elevated levels of iron and manganese, which readily dissolve in low-oxygen groundwater. Sand filtration is an effective treatment method for the removal of iron and manganese. The lack of oxygen also results in any nitrates being converted to ammonia.

The maps produced are based largely on the readily available information in the area, a field walkover survey, and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

6 Recommendations

Essential:

- Continue monthly monitoring of raw water supply.

Desirable:

- Ensure wellheads are made rodent-proof.
- Install concrete floor in wellhead chambers.
- Consider raising wellhead casings above ground level.
- Consider running the borehole pumps on a continuous 24-hour cycle at a lower pumping rate, in the order of 14.3 m^3/d. This could be trialled for a 6-month period to see if any improvement in iron/manganese results.
- Decommission the on-site trial well. According to drilling logs this well was not completed and serves no purpose. Decommissioning should be done in consultation with a hydrogeologist and recommended drilling contractor.
- Consider installation of a new trial well, which does not penetrate the harder limestones. The well should be installed in accordance with IGI Guidelines. The aim would be to abstract groundwater only from the interface between the soft and hard limestones. This may potentially result in lower iron and manganese concentrations.
- Continue to identify and mitigate against leaks in the network.
- Consider covering the well pad in hardstanding (concrete). Installing a perimeter drain around the pad will ensure no surface runoff from surrounding areas can enter the wellheads.

Other:

- The following EPA guidelines may serve as future useful reference documents for the GWS:
  - EPA Guidance on Landspreading of Organic Waste[6]
  - 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[7].
  - 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[8].
  - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[9]

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

GSI (2008). County Cavan Groundwater Protection Scheme.

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

[6] http://www.epa.ie/pubs/advice/waste/waste/EPA_landspread_organic_waste_guide.pdf
[7]]http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp
[8] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo
[9] http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html#.UpNR8eJ9KEo

Figures

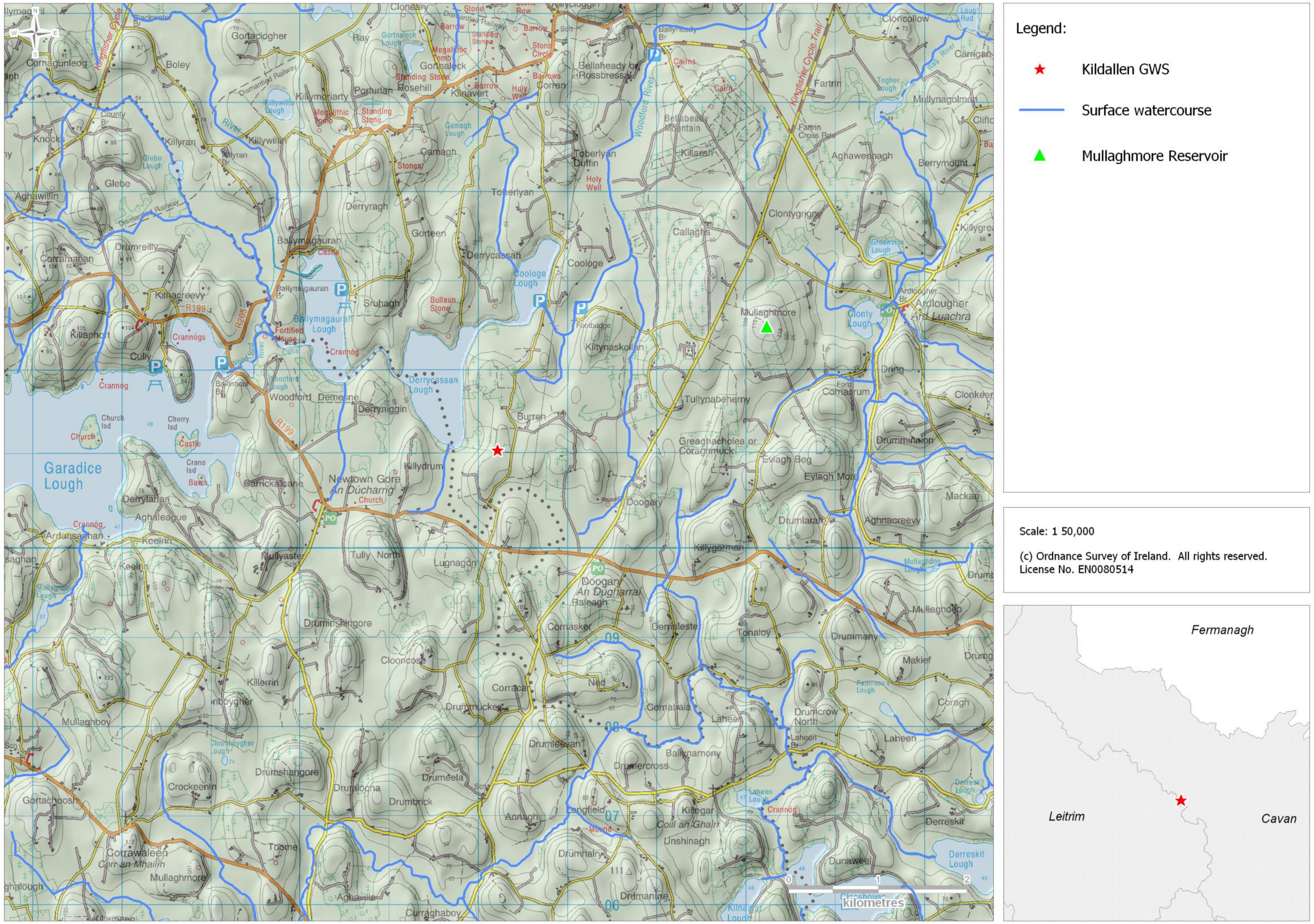


Figure 1 Location Map (OSI 1:50,000 Scale for main map)

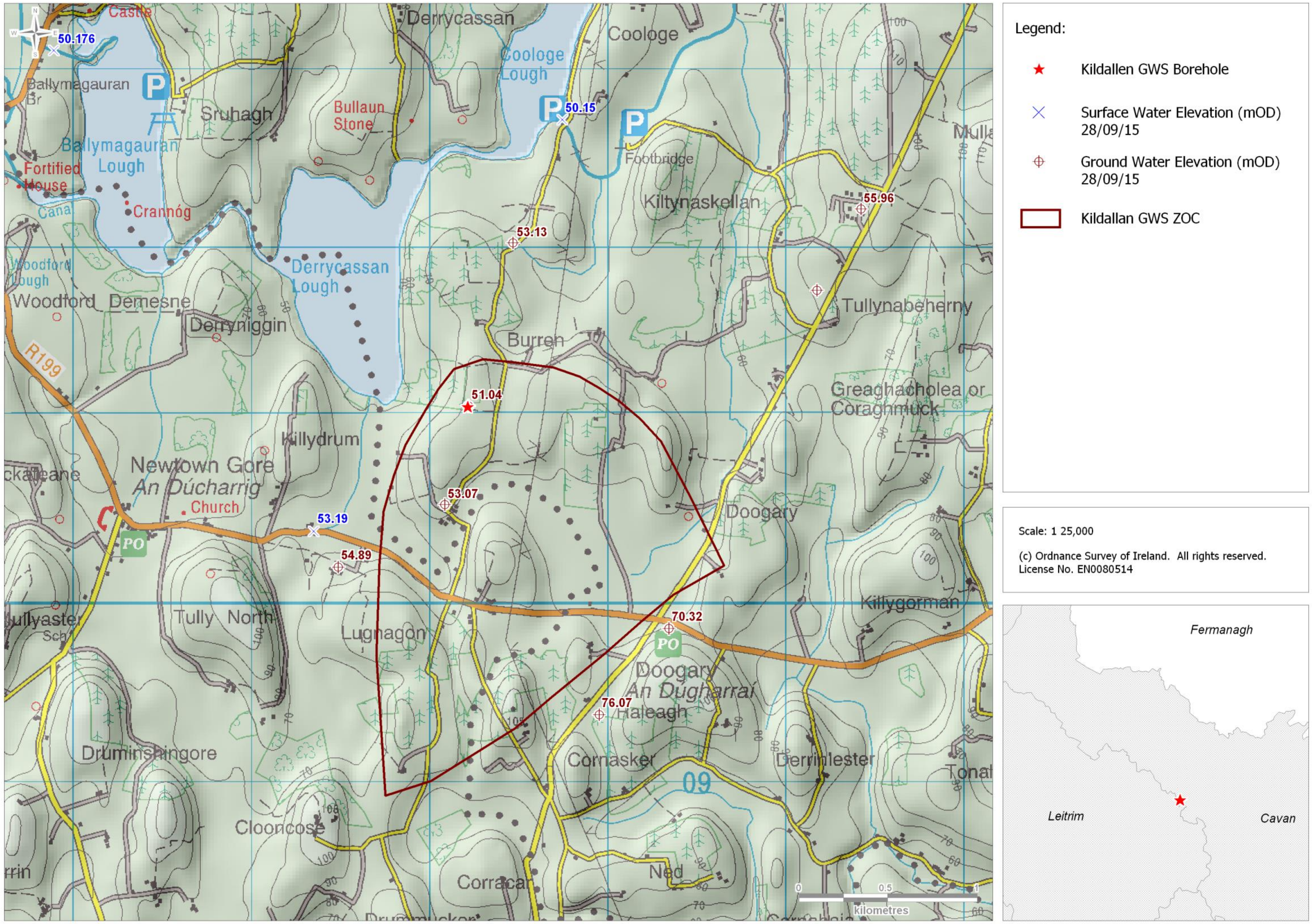


Figure 2 Topography, hydrology and karst features

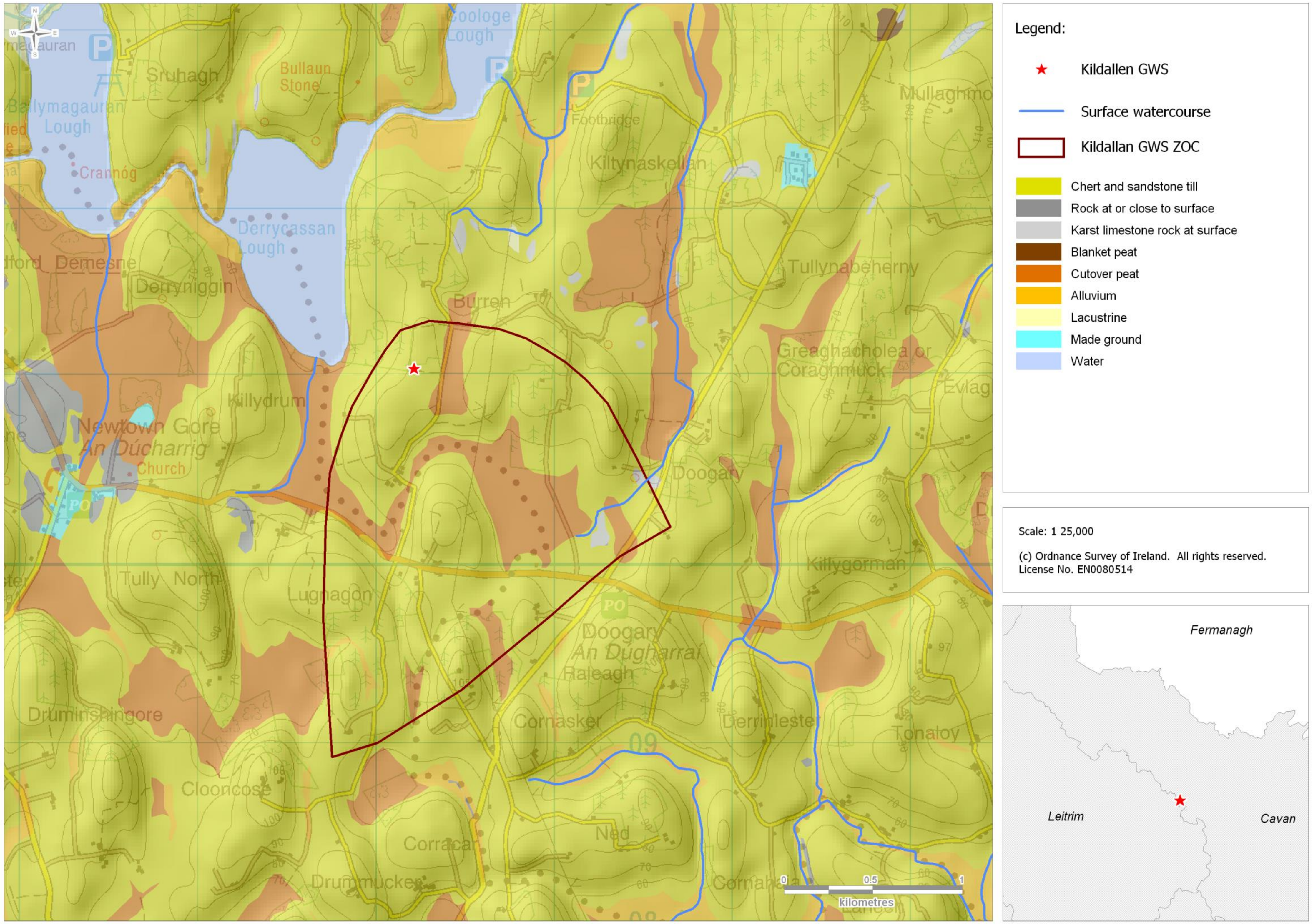


Figure 3 Subsoils

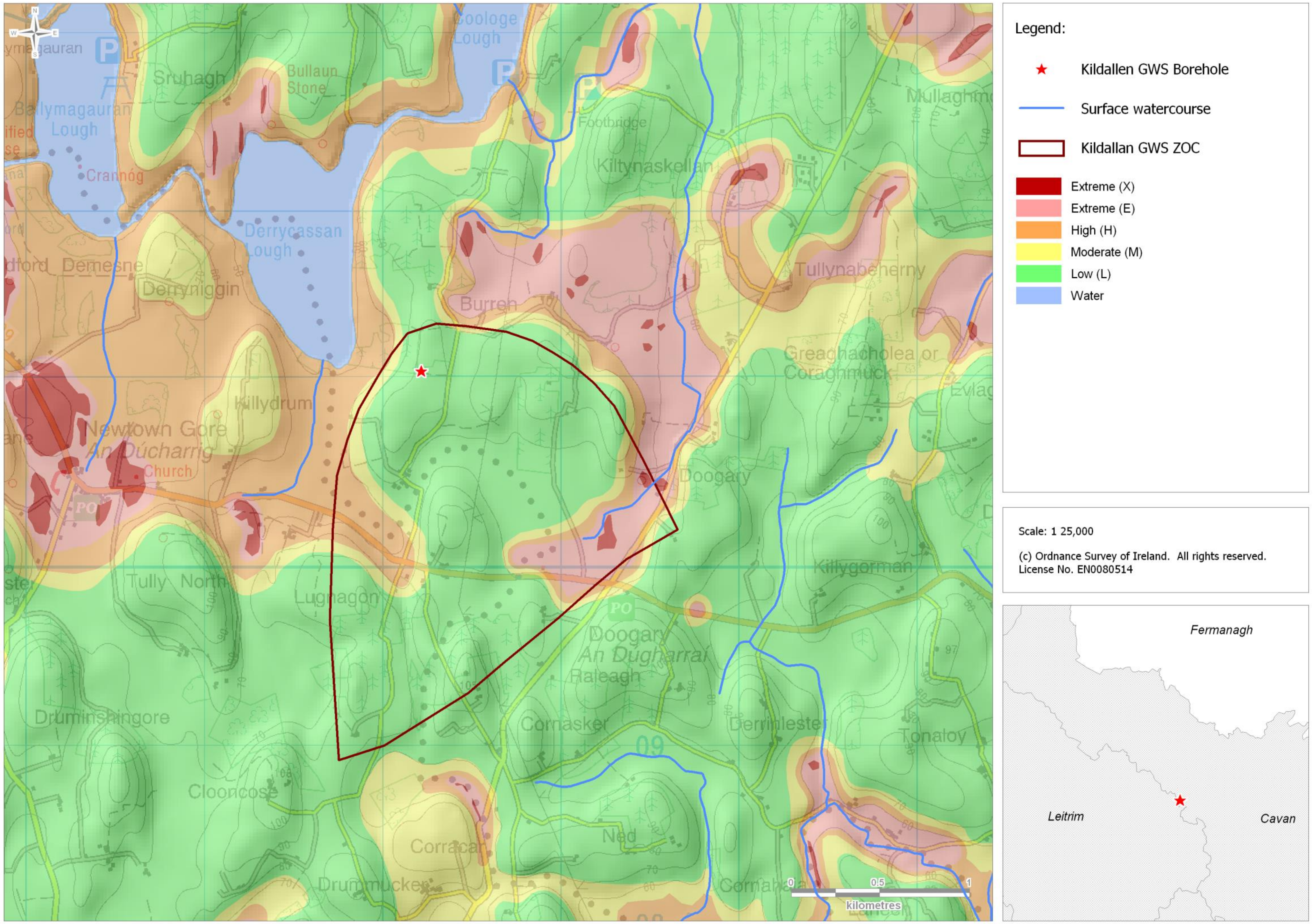


Figure 4 Groundwater Vulnerability Map

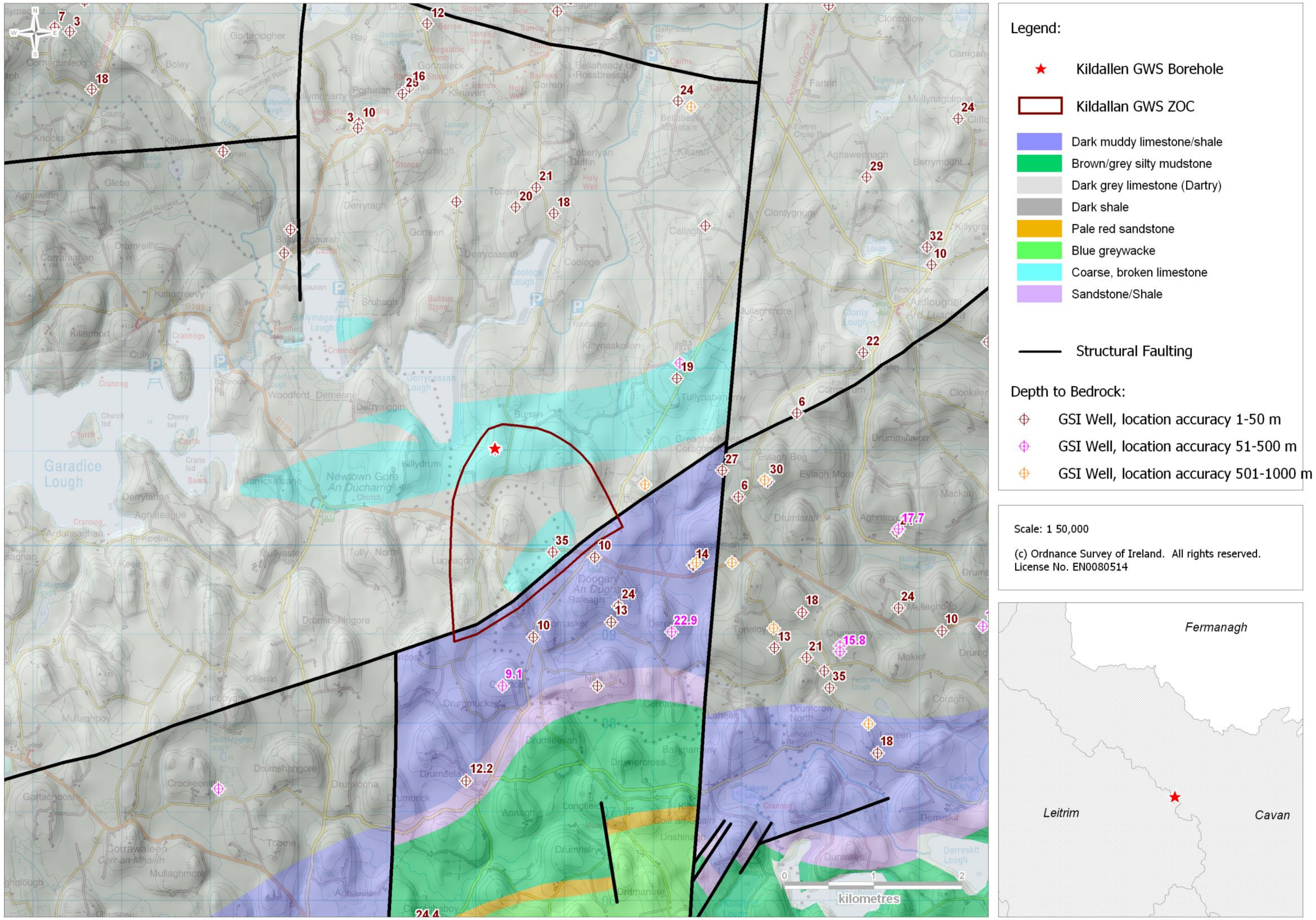


Figure 5 Rock Unit Group Map with karst features

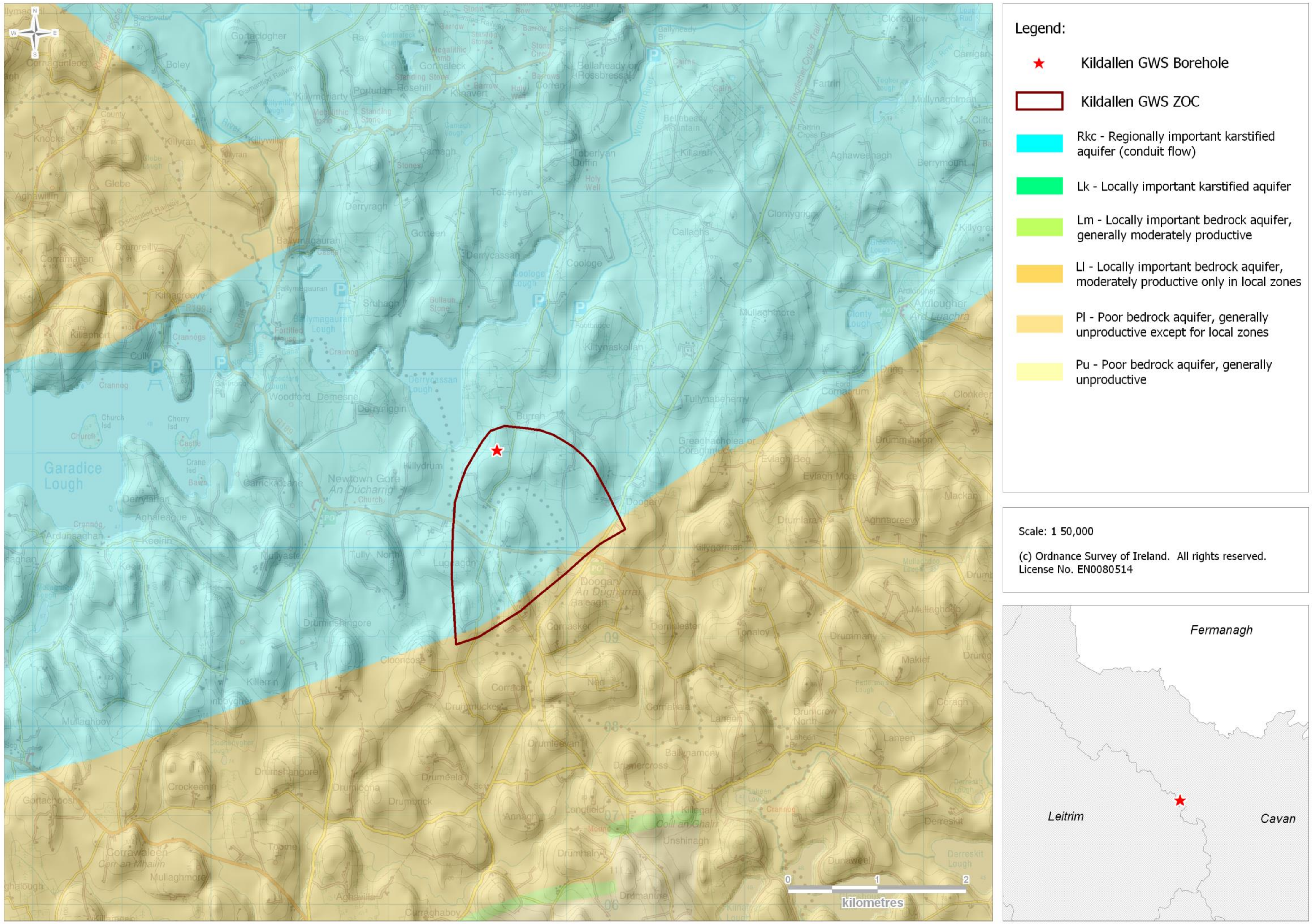


Figure 6 Aquifer Map

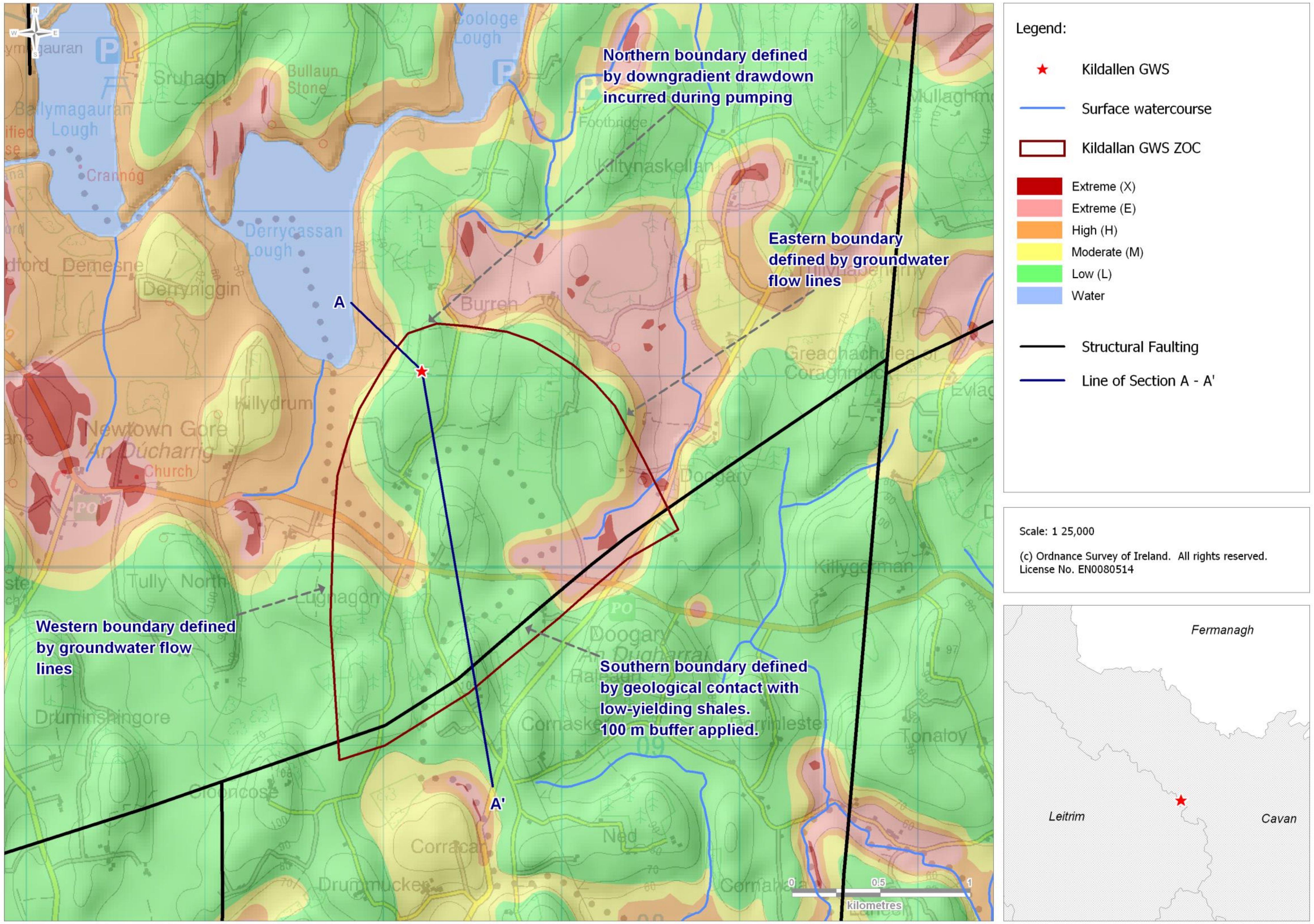


Figure 7 ZOC boundaries

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.

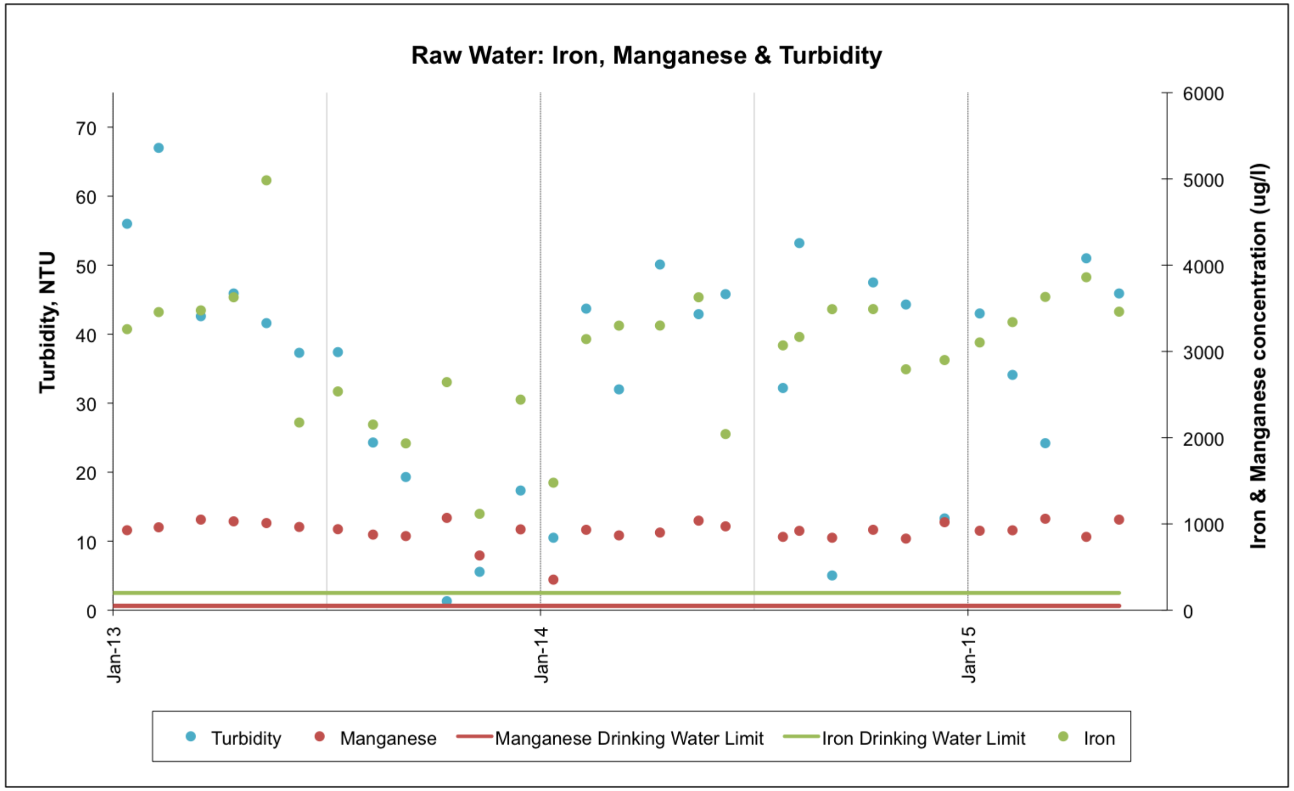
Groundwater vulnerability category	**Hydrogeological setting**		**Recharge coefficient (RC)**		
			Min (%)	*Inner Range*	*Max (%)*
Extreme	1.i	Areas where rock is at ground surface	30	80-90	100
(X or E)	1.ii	Sand/gravel overlain by 'well drained' soil	50	80-90	100
	1.iii	Sand/gravel overlain by 'poorly 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

	Aluminium ug/l	Colour, apparent hazen	Manganese ug/l	Iron ug/l	Nitrate as NO3 mg/l	Clostridium perfringens cfu/100ml	coliforms mpn/100ml	e. coli mpn/100ml	Ammonia as NH4 mg/l	Nitrite as NO2 mg/l	Turbidity NTU	Colour, true hazen	Conductivity us/cm	pH
10/01/13	<5	357	963	971	<8.9	<1	<1	<1	0.21	<0.016	56	<5	463	7.36
07/02/13	5	342	927	3258	<8.9	<1	<1	<1	0.17	<0.016	56	<5	566	7.37
06/03/13	<5	369	961	3456	<8.9	<1	<1	<1	0.21	<0.016	67	<5	531	7.25
11/04/13	<5	341	1050	3476	<8.9	<1	<1	<1	0.19	<0.016	42.6	7	686	7.14
09/05/13	<5	221	1030	3628	<8.9	<1	<1	<1	0.21	<0.016	45.9	<5	598	7.27
06/06/13	<5	288	1010	4984	<8.9	<1	<1	<1	<0.0129	<0.016	41.6	<5	871	7.35
04/07/13	<5	185	965	2176	<8.9	<1	<1	<1	0.21	<0.016	37.3	<5	539	7.35
06/08/13	<5	281	939	2536	<8.9	<1	<1	<1	0.03	0.03	37.4	<5	510	7.52
05/09/13	<5	214	876	2152	<8.9	<1	<1	<1	0.17	<0.016	24.3	<5	542	7.35
03/10/13	<5	19	859	1934	<8.9	<1	<1	<1	0.18	<0.016	19.3	<5	506	7.33
07/11/13	<5	81	1070	2644	<8.9	<1	<1	<1	0.7	<0.016	1.31	8	512	7.3
05/12/13	<5	50	634	1117	<8.9	<1	<1	<1	0.14	0.1	5.56	31	467	7.87
09/01/14	12	118	937	2441	<8.9	<1	<1	<1	0.08	0.33	17.34	15	465	7.54
06/02/14	<5	57	354	1478	<8.9	<1	<1	<1	<0.0129	<0.016	10.5	<5	461	7.45
06/03/14	<5	310	932	3143	<8.9	<1	<1	<1	0.18	<0.016	43.7	<5	462	7.32
03/04/14	23	266	867	3299	<8.9	<1	<1	<1	0.18	<0.016	32	<5	464	7.18
08/05/14	<5	386	900	3300	<8.9	<1	<1	<1	0.17	0.07	50.1	<5	463	6.99
10/06/14	<5	321	1038	3628	<8.9	<1	<1	<1	0.25	<0.016	42.9	<5	486	6.95
03/07/14	<5	317	972	2042	<8.9	<1	<1	<1	0.23	<0.016	45.8	<5	486	7.055
21/08/14	56	268	850	3070	<8.9	<1	<1	<1	0.22	<0.016	32.2	6	473	6.89
04/09/14	52	403	920	3168	<8.9	<1	<1	<1	0.25	<0.016	53.2	<5	458	7.01
02/10/14	5	104	840	3490	<8.9	<1	<1	<1	<0.0129	0.03	5.03	<5	469	7.35
06/11/14	297	348	932	3491	<8.9	<1	<1	<1	0.23	<0.016	47.5	<5	443	7.46
04/12/14	<5	303	830	2793	<8.9	<1	<1	<1	0.19	<0.016	44.3	<5	462	7.23
06/01/15	5	114	1020	2900	<8.9	<1	<1	<1	0.19	<0.016	13.3	<5	446	7.19
05/02/15	5	283	921	3104	<8.9	<1	<1	<1	0.19	<0.016	43	<5	454	7.2
05/03/15	6	300	926	3340	<8.9	<1	<1	<1	0.28	<0.016	34.1	<5	443	7.2
02/04/15	7	233	1060	3632	<8.9	<1	<1	<1	0.3	<0.016	24.2	<5	481	7.17
07/05/15	<5	385	850	3860	<8.9	<1	<1	<1	0.13	0.03	51	5	473	6.97
04/06/15	8	318	1050	3461	<8.9	<1	<1	<1	0.3	<0.016	45.9	<5	463	6.87
min	5	19	354	971	<1	<1	<1	<1	0.03	0.03	1.31	5	443	6.87
max	297	403	1070	4984	<1	<1	<1	<1	0.7	0.33	67	31	871	7.87
average	<5	253	916	2932	<1	<1	<1	<1	0.21	0.10	36	12	505	7.2


Raw Water: Iron, Manganese & Turbidity
Turbidity, NTU
Iron & Manganese concentration (ug/l)
0
10
20
30
40
50
60
70
0
1000
2000
3000
4000
5000
6000
Jan-13
Jan-14
Jan-15
Turbidity
Manganese
Manganese Drinking Water Limit
Iron Drinking Water Limit
Iron

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[web] www.cls.ie

CERTIFICATE OF ANALYSIS

Client : Tadhg Murphy
Kiladallan GWS
Mullaghduff
Ballyconnell
Co.Cavan

Report No. : 269323
Date of Receipt : 24/08/2015
Start Date of Analysis : 24/08/2015
Date of Report : 15/09/2015
Order Number :
Sample taken by : CLS

Lab No	Sample Description	Test	*	Result	Units
615222	Kildallan GWS, Mullaghduff, Ballyconnell, Co. Cavan NFGWS Tadhg Murphy @08:30	BOD	R	<1	mg/l
		COD	R	<10	mg/l
		Turbidity	R	53.4	N.T.U.
		pH	R	7.0	pH Units
		Conductivity @20C	R	437	uS/cm
		Alkalinity, total	R	289	mg/l CaCO3
		Nitrite as N	R	<0.005	mg/l
		Sodium, total	R	9	mg/l
		Chloride	R	16	mg/l
		Ammonium as NH4	R	0.203	mg/l
		Nitrate as NO3	R	<0.44	mg/l
		Dissolved Oxygen (%)	R	102	%Sat
		Potassium, total	R	1	mg/l
		Total Hardness (Kone)	R	244	mg/l CaCO3
		Magnesium, total	R	15	mg/l
		Colour, apparent	R	335	mg/l Pt Co
		Silica as Si O2 (reactive)	S	7.15	mg/l
		Sulphate	R	6.56	mg/l
		Fluoride	S	0.22	mg/l
		Orthophosphate as PO4-P	R	0.034	mg/l
		Calcium, total	R	103	mg/l
		Aluminium, dissolved	R	<2	ug/l
		Iron, dissolved	R	3730	ug/l
		Manganese, dissolved	R	921	ug/l
		Copper, dissolved	R	2	ug/l
		Lead, dissolved	R	<0.5	ug/l
		Chromium, dissolved	R	<0.5	ug/l
		Nickel, dissolved	R	6	ug/l
		Cadmium, dissolved	R	<0.5	ug/l
		Arsenic, dissolved	R	9	ug/l
		Zinc, dissolved	R	11	ug/l
		Barium, dissolved	R	103	ug/l
		TOC	R	5.58	mg/L
		Clostridium Perfringens in Water	R	0	cfu/100ml
		Strontium, dissolved	R	206	ug/l
		E coli (Filtration) (Environmental Waters)	R	0	cfu/100ml
		Total Coliforms (Filtration) (Environmental Waters)	R	0	cfu/100ml

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

Approved by: Barbara Lee

Barbara Lee
Environmental Scientist

Complete Laboratory Solutions,
Ros Muc, Connemara,
Co. Galway

Complete Laboratory Solutions,
MedPharma Division,
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Appendix 4

Acronyms & 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

Drilling Log

DUNNES WATER SERVICES LTD

Well Drilling and Horizontal Drilling Engineers

№ 02499

DRILLERS LOG

DUBLIN ROAD,
DROMISKIN,
DUNDALK.
Tel.: (042) 72188

Borehole for CAVAN Co. Col.

at Burren. Coillte Site. TW No 1B
Kildallan G. Pd.

Date	Depth ~~metres~~/ft.	Diam.	Conditions
2/5/01	0 – 10	12"	Clay.
	10 – 20	"	Clay.
	20 – 30	"	Clay, stones.
	30 – 40	"	" " .
	40 – 50	"	Clay – Rock
	50 – 60	"	Rock.
	60 – 80	8"	White Rock.
	80 – 100	"	" "
	100 – 110	"	White Rock – Broken.
	120 – 130	"	" " "

Total Depth of well .... Contd.
Estimated yield ....
Depth to Rock ....
Steel casing installed ....
P.V.C. casing installed ....
Well screen ....
Other remarks ....
....
....
Operator ... Noel Conachy ....

DUNNES WATER SERVICES LTD.

№ · 02500

Well Drilling and Horizontal Drilling Engineers

DRILLERS LOG

DUBLIN ROAD,
DROMISKIN,
DUNDALK.
Tel.: (042) 72188

Borehole for CAVAN County Council.

at Burren — Coillte Site. TW 1 B Control.
Kildallan G. Sch.

Date	Depth ~~metres~~/ft.	Diam.	Conditions
2/5/01	130 — 140	8"	White Rock — broken.
	140 — 150	"	" " very broken.
	150 — 160	"	" " " " .
3/5/01	160 — 180	"	Soft broken Rock.
	180 — 200	6"	Soft broken Brown Rock.
	200 — 220	6"	" " " " .
	220 — 230	"	Lot of water — 4,500 gph. Very hard black Rock.
	230 — 240	"	" " " " .
	240 — 250	"	" " " " .
	250 — 260	"	" " " " 9,000 gph.
	260 — 265	"	Cavern — more water — dirty.

Total Depth of well 265 ft. Drilling stopped.

Estimated yield 9,000 gph plus

Depth to Rock 50 ft

Steel casing installed 218 ft of 6" 60 ft of 8"

P.V.C. casing installed —

Well screen —

Other remarks Water very dirty — silt, mud. Drilling stopped due to water and/or loss of air in cavern.

Operator Noel Geraghty.

DUNNES WATER SERVICES LTD. № 02497

Well Drilling and Horizontal Drilling Engineers

DRILLERS LOG

DUBLIN ROAD,
DROMISKIN,
DUNDALK.
Tel.: (042) 72188

Borehole for CAVAN COUNTY COUNCIL

at BURREN, Coillte Site. TW No 1A.
Kildallan N. Sch.

Date	Depth ~~metres~~/ft.	Diam.	Conditions
30/4/01	0 — 10'	8"	Sticky Clay
	10 – 20'	"	" "
	20 – 30'	"	Brown clay.
	30 — 40'	"	" "
	40 – 50'	"	Sticky Clay.
	50 – 60'	"	Sticky clay — Rock.
	60 – 70	"	White Rock.
	70 – 80	"	" " .
	80 – 100	6"	White Rock.
	100 – 120	"	" " 1st Water.

Total Depth of well........

Estimated yield........

Depth to Rock........

Steel casing installed........

P.V.C. casing installed........

Well screen........

Other remarks........

Abandoned Bore

Operator........

Contd.

DUNNES WATER SERVICES LTD. Nº 02498

Well Drilling and Horizontal Drilling Engineers

DRILLERS LOG

DUBLIN ROAD,
DROMISKIN,
DUNDALK.
Tel.: (042) 72188

Borehole for Cavan Co. Col.

at Burren. Coillte Site TW No 1A
Kildallan G. Sch.

Date	Depth ~~metres~~/ft.	Diam.	Conditions
	120 — 130	6"	White Rock.
	130 — 140	"	White Rock — very soft.
	140 — 150	"	Very broken — falling in.
	150 — 160	"	" " — collapsing. Drilling stopped due to collapsing.
1/5/01	160 — 180	"	Use foam to drill on. Not possible to drill on due to collapsing.

Abandoned Bore

Total Depth of well 180 ft.

Estimated yield 1300 gph.

Depth to Rock 55 ft.

Steel casing installed 60 ft of 6"

P.V.C. casing installed —

Well screen —

Other remarks Drilling stopped at 160 ft due to collapsing conditions.

Operator Noel Conachy.

Appendix 6

Pumping Test Data

EET No.: 1

rehole location: BURREN KILDALIN Well No: TW-1B Drawdown ✓ Pumping ✓

County: CAVAN Sheet No.: 1 Recovery Observation

Date: 06/06/01 Weather: RAINING Test Conducted by: S. KELLY

Diameter of Well: 150 mm. Distance from Pumping Well: m. Dept of Well: mm.

Dept of Casing: mm. Purchase/Order No: / /

Height of measuring point above g.l. 1.0 m. Distance from pumping well to outfall: 100m

Pump Intake at 49 m. below g.l. Pump type: 18,000GPH SUB Measurement by: SK/LC

Client's Name: CAVAN Co Co. Consultant: B. DUNNE

Time	Elapsed Time - mins	Water Level (m)	Drawdown (m)	Meter Reading	Remarks
	0	33.50	32.76	78010.2	
	0.5	34.39			
	1	34.40			
	1.5	34.40			
	2	34.40			1100 L/m = 14,537 GPH
	2.5	34.44			
	3	34.44			
	3.5	34.47			
	4	34.45			
	4.5	34.47			
	5	34.49			
	6	34.50			
	7	34.53			
	8	34.53			1100 L/m,
	9	34.54			
	10	34.57			
	12	34.60			
	14	34.62			
	16	34.64			
	18	34.66			
	20	34.68			1100 L/m
	22	34.68			
	24	34.70			
	26	34.72			
	28	34.74			
	30	34.76		78045.5	14,537 GPH
	35	34.77			
	40	34.80			
	45	34.82			
	50	34.85			
	55	34.89			
	60	34.89		78077.7	14,537 GPH
	75	34.93			
	90	34.98			
	105	35.00			
	120	35.03		78143.1	
	150	35.07			14,537 GPH
	180	35.12		78210.4	
	210	35.13			
	240	33.16		78277.0	14,537 GPH

ЕET No.: 1

rehole location: BURREN KILDALLAN Well No: T.W - 1B Drawdown ✓ Pumping ✓

County: CAVAN Sheet No.: 2 Recovery Observation

Date: 06/06/01 Weather: RAINING Test Conducted by: S. KELLY

Diameter of Well: 150 mm. Distance from Pumping Well: ----------- m. Dept of Well: ------------- mm.

Dept of Casing: ---------------- mm. Purchase/Order No: -------------/ /-------------.

Height of measuring point above g.l. 1.0 m. Distance from pumping well to outfall: < 100m

Pump Intake at 49 m. below g.l. Pump type: 18,000gph SUB Measurement by: S.K/L.C

Client's Name: CAVAN CoCo Consultant: B. DONNIE

OBS-WELL

Time	Elapsed Time Hours	Elapsed Time Mins	Water Level	Drawdown (m)	Meter Reading	Remarks
	5	300	35.19	33.39	78349.5	14,537 GPH
	6	360	35.24	33.41	78422.1	
	7	420	35.27	33.44	78480.5	
	8	480	35.27	33.47	78539.0	14,537 GPH
	9	540	35.29	33.49	78608.1	
	10	600	35.31	33.51	78677.1	
	12	720	35.33		78805.2	
	14	840	35.35		78933.0	14,537 GPH
	16	960	35.38	33.59	79064.8	
	18	1,080	35.40		79196.3	
	20	1,200	35.43	33.65	79326.7	14,537 GPH
	22	1,320	35.47		79458.6	
	24	1,440	35.50	33.70	79590.9	
	26	1,560	35.52		79731.3	
	28	1,680	35.49	33.75	79853.0	14,537 GPH
	30	1,800	35.52	33.75	79986.5	
	32	1,920	35.53		80120.3	
	34	2,040	35.47		80250.3	1.080G/m = 14,273GPH
	36	2,160	35.50	33.75	80366.2	
	38	2,520	35.50		80496.2	14,273GPH
	40	2,880	35.50		80626.1	
	42	3,240	35.50	33.75	80756.1	14,273 GPH
	44	3,600	35.50		80887.9	
	46	3,960	35.50		81016.3	
	48	4,320	35.53	33.74	81145.2	14,273GPH
	52	4,680	35.56		81401.3	
	56	5,040	35.60		81655.2	
	60	5,400	35.61	33.86	81928.1	14,273 GPH
	64	5,760	35.63		82138.0	
	68	6,120	35.63		82357.1	14,273 GPH
	72	6,480	35.63	33.95	82573.5	
		6,840				
		7,200				
		7,560				
		7,920				
		8,280				
		8,640				

EET·No.: 1 RECOVERY AFTER 72HRS

orehole location: BURREN KILDALLAN Well No: TOWN - 1B Drawdown Pumping

County: CAVAN Sheet No.: 3 Recovery ✓ Observation

Date: 09/06/01 Weather: RAINING Test Conducted by: S. KELLYS

Diameter of Well: 150 mm. Distance from Pumping Well: m. Dept of Well: mm.

Dept of Casing: mm. Purchase/Order No: / /

Height of measuring point above g.l. 1.0 m. Distance from pumping well to outfall: 100m

Pump Intake at 49 m. below g.l. Pump type: 18,000GPH SO3 Measurement by: S.K/L.C

Client's Name: CAVAN CoCo. Consultant: B. DUNNE

Time	Elapsed Time - mins	T.W - 1 Water Level (m)	OBS-WELL Drawdown (m)	Meter Reading	Remarks
	0	35.63	33.95		
	0.5	34.58			
	1	34.66			
	1.5	34.65			
	2	34.63			
	2.5	34.62			
	3	34.60			
	3.5	34.59			
	4	34.58			
	4.5	34.57			
	5	34.57			
	6	34.57			
	7	34.54			
	8	34.54			
	9	34.52			
	10	34.51			
	12	34.49			
	14	34.48			
	16	34.45			
	18	34.43			
	20	34.41			
	22	34.38			
	24	34.37			
	26	34.35			
	28	34.34			
	30	34.33			
	35	34.31			
	40	34.30			
	45	34.30			
	50	34.29			
	55	34.29			
	60	34.28	33.64		
	75				
	90				
	105				
	120				
	150				
	180				
	210				
	240				

Appendix 7

Pumping Test & Boundary Calculations

Transmissivity

Logan Approximation (confined) $T = (1.22 \times Q) / s$

$= (1.22 \times 1584) / 2.13$

$= 907\ m^2 / d$

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

$= (2.3 \times 1584) / (4 \times \pi \times 0.41)$

$= 707\ m^2 / d$

Specific Capacity

Specific capacity $= T / s$

$= 1584\ m^3\ d^{-1} / 2.13\ m$

$= 744\ m^3 / d / m$

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:

Down-gradient distance $= Q / (2\pi \times T \times i)$

$= 1584 / (2\pi \times 807 \times 0.001)$

$= 283\ m$

where

Q	is the pumping test rate: 1584 m^3/d.
T	is Transmissivity
Δ s	is drawdown incurred over 1 log cycle of time
i	is the background non-pumping hydraulic gradient, taken as that between two third party wells and the non-pumping groundwater level at the site (53.17 mOD) = 0.001 m m^{-1}).