Establishment of Groundwater Zones of Contribution

Danganbeg Spring
Killeigh, Killurin and Cloneygowan
Group Water Scheme , Co. Offaly

March 2017

and

Killeigh Group Water Scheme
Danganbeg Spring (Tobernanoge)

Groundwater Source Protection Zones

April 2001

‘Note:
Since the Danganbeg Spring report was published (2001), the Source Protection Area and, possibly, other component maps have been updated based on improved geoscientific evidence and hydrogeological knowledge.
The most up-to-date version of the Source Protection areas (SPAs) and other maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).’

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Update Report 2016

Danganbeg Spring

Killeigh, Killurin and Cloneygowan Group Water Scheme

March 2017

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Killeigh, Killurin and Cloneygowan GWS

The National Federation of Group Water Schemes

Acknowledgements

Joe Arnold, Paudge Brady, John Arnold of the Killeigh, Killurin and Cloneygowan Group Water Scheme

The National Federation of Group Water Schemes

Joe Gallagher, Barry Deane

Document control information

Revision	Date	Author	Checked	Approved
I	07.08.2016	KLI	12.08.16	NHW
II	24.08.2016	KLI	29.09.16	NHW
Draft Final	01.11.2016	KLI		
Final	10.03.2017	KLI	10.03.2017	ML

Project description

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

This report has been prepared for Danganbeg Spring Source (sometimes known as Tobernanoge spring) of the Killeigh, Killurin and Cloneygowan 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 GSI previously delineated Groundwater Source Protection Zones for the Danganbeg Spring in 2001. However since this time the available scientific understanding and knowledge has evolved and this current report has revisited the original 2001 report and updated it to include new data.

The report has been prepared in the format developed during an earlier pilot project "Establishment of Zones of Contribution" which was undertaken by the Geological Survey of Ireland (GSI), in collaboration with the National Federation of Group Water Schemes (NFGWS), and with support from the National Rural Water Services Committee (NRWSC).

The methodology undertaken by the GSI included: liaising with the GWS and NFGWS to facilitate data collection, a desk study, a site visit to inspect the supply, the local area, and to record groundwater level(s). The data was then analysed and interpreted in order to delineate the ZOC.

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

The report and maps are hosted on the GSI website (www.gsi.ie).

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1 Overview: Groundwater, groundwater protection and groundwater supplies

Groundwater is an important natural resource in Ireland. It originates from rainfall that soaks into the ground. If the ground is permeable, the rainfall will filter down until it reaches the main body of groundwater, which is usually within either the bedrock, or a sand/gravel deposit. If the bedrock or sand/gravel deposit can hold enough groundwater and allow enough flow to supply a useful abstraction, it is referred to as an aquifer.

In Irish bedrock aquifers, groundwater predominantly flows through interconnected fractures, fissures, joints and bedding planes, which can be envisaged as a 'pipe network', of various sizes, with varying degrees of interconnectivity. The speed of flow through this network is relatively fast, delivering groundwater, and a large proportion of any 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 overlying soil and subsoil protects the aquifers; thick, impermeable clay soil and subsoil provide good protection while thin, very permeable gravel will provide limited protection. Therefore, variations in subsoil type and thickness are important when characterising the 'vulnerability' of groundwater to contamination.

The karst limestone aquifers provide significant and important groundwater supplies in Ireland. Karst landscapes develop in rocks that are readily dissolved by water *e.g.* limestone (composed of calcium carbonate). Consequently, conduit, fissure and cave systems develop underground[1]. Groundwater typically travels very fast in karst aquifers, which has a significant impact on the water quality; neither filtration nor pathogen die-off are associated with these aquifers.

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

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

The Killeigh, Killurin and Cloneygowan GWS is supplied by four individual sources, one of which is the Danganbeg Spring (which is sometimes known as Tobernanoge Spring). The spring emerges from fractured 'Calp' limestone bedrock classified as a Locally Important Aquifer that is generally moderately productive only in local zones (Ll). The abstraction rate is 330 m^3/d.

[1] Geological Survey of Ireland, 2000.

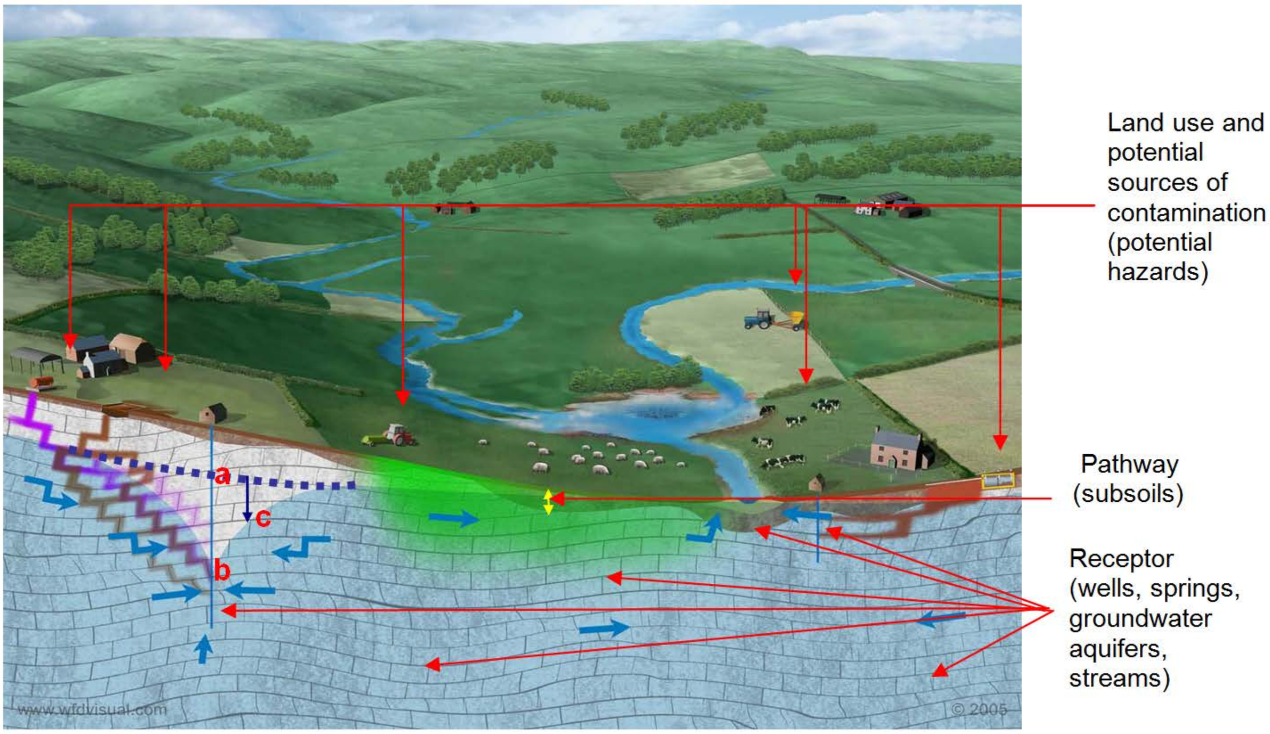

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Killeigh, Killurin and Cloneygowan Group Water Scheme (GWS) is currently supplied by four separate sources:

- Danganbeg Spring (sometimes known as Tobernanoge Spring);
- Toberfin Springs at Newtown;
- Two wells at Clonyquin;
- 'Moat Well' Spring at Killurin.

A previous report was prepared by the Geological Survey of Ireland for Danganbeg Spring[2]. This current report updates the existing 2001 report, as the hydrogeological data and understanding has evolved since that time. The Zone of Contribution (ZOC) of the 'Moat Well' Spring was delineated in 2013[3]. A ZOC report for the two wells at Clonyquin is also being produced as part of this current 2016 project and an update report for the Toberfin Spring is also being produced.

The Killeigh, Killurin and Cloneygowan Group Water Scheme (GWS) was started in 1962. The GWS started using Danganbeg Spring in 1965. The GWS currently supplies 1,300 domestic connections and around 250 farm connections, making it a very large scheme. The Danganbeg Spring currently contributes 330 m^3/d to the scheme's overall usage of 1,766 m^3/d, but it is likely that the spring's output fluctuates seasonally. The water abstracted from Danganbeg is pumped to two 60,000 gallon (273 m^3) reservoirs at Ard.

[2] Kelly, C. (2001). Killeigh Group Water Scheme; Danganbeg Spring (Tobernanoge); Groundwater Source Protection Zones. Geological Survey of Ireland.

[3] Meehan, R., 2013. Establishment of Groundwater Zones of Contribution; Killeigh, Killurin and Cloneygowan Group Water Scheme; The 'Moat Well' Spring. An Talamh/National Federation of Group Water Schemes/Geological Survey of Ireland

Danganbeg Spring is located 3 km east of Killeigh village in Co. Offaly, but less than 1 km from the border with Co. Laois. The spring is located on the southern side of a small third class road that runs from Killeigh in the west to Cloneygowan in the east (**Figure 1**).

The spring is housed within a new steel shed inside a small fenced compound (**Photo 1**). The steel shed also houses the treatment unit which consists of chlorination. It was reported that the scheme are considering upgrading their treatment to include a UV treatment unit within the next year or so. The spring comprises a large rectangular sump covered with concrete (**Photo 1**). The site is surrounded by agricultural land with some houses and farm yards dotted around the area.

Photo 1 –Danganbeg Spring, note concrete sump on left of image

It was reported by the scheme caretaker that the discharge from the Danganbeg Spring fluctuates particularly in response to dry or very wet weather conditions e.g. the dry summer of 1995 resulted in a drop in water level at the spring for a period of a few months. A dry period in 1984 resulted in discharge from the spring dropping to around 100 m^3/d (or 22,000 gallons per day).

The 2001 GSI report stated the abstraction from the spring was 110 m^3/d at that time. The flow meter records from January to early May 2016 were obtained from the caretaker (**Appendix 1**). These records confirm that over a 113 day period a total of 37,440 m^3 were abstracted, equivalent to a daily average total of 331 m^3/d. This indicates an increased abstraction from the spring in the order of 200% in a 15 year period since the previous GSI report was published (at least in the winter/spring months).

Photo 2 – Internal view of pump house at Danganbeg

Table 1 provides a summary of all known information about the wells, including estimates of hydraulic parameters.

Table 1. Supply Details

	Danganbeg Spring
Grid reference	ING E 240146 N 218412
Townland	Danganbeg
Source type	Spring
Constructed	1965
Constructed By	Unknown
Owner	Killeigh, Killurin and Cloneygowan GWS
Elevation (m aOD)	116 maOD
Total depth (m)	Sump is 3 m deep
Construction details	Concrete Sump is 3 m deep x 6 m wide
Depth to rock (metres below ground level), m bgl	2.8 m (GSI 2001). The 2001 GSI report [2] on the spring included a drilling programme to ascertain depth to bedrock in the area. Five drill holes indicated that the depth to bedrock varies from 2 – 4 m.
Static water level (m bgl)	Not possible to measure water level. Water level reported to fluctuate a lot (maximum of 3 m possible, i.e. spring chamber depth)
Pump intake depth	Unknown
Current abstraction rate (GWS)	Jan – May 2016: 331 m^3/d (over a 113 day period a total of 37,440 m^3 were abstracted) Summer/early autumn abstraction rate likely to be lower.
Reported yield (m^3/d)	Unknown. GSI 2001 states that one estimate of the total yield was made in July 1999 at 110 m^3/d and that according to the caretaker there had not been an overflow at that time since the winter months of 1997/1998, of which there is no estimate. It is probable that the discharge is considerably higher in winter.
Number of connections	1,300 domestic, 250 farm connections approx. *Note: GWS also abstracts from three other sources, Toberfin Springs at Newtown, the 'Moat Well' Spring at Killurin and two wells at Clonyquin, all of which are the subject of separate reports*
Estimated specific capacity (m^3/d/m)	Unknown
Estimated transmissivity (m^2/d)	Unknown

3 Physical Characteristics and Hydrogeological Considerations

3.1 Physical characteristics of the area

A summary of the relevant information on rainfall, land use, topography, hydrology and geology for the area is provided in **Table 2**.

Table 2. Physical Characteristics of the Area of Interest

	GWS Well	Description/Comments
Annual Rainfall (mm)	948	Met Éireann average annual rainfall data 2013 - 2016
Annual Evapotranspiration Losses (mm)	484	Met Éireann (www.met.ie)
Annual Effective Rainfall (mm)	464	National Groundwater Recharge Data (www.gsi.ie)
Topography	Danganbeg Spring emerges from the ground at an elevation of 116 m aOD close to the bottom of a hill that slopes down from the south (at a maximum elevation of 143 m aOD) towards the north. The surrounding land is generally more low-lying and the hill from which the spring emerges forms an east to west trending small ridge in the landscape.	
Land use	Agricultural land surrounds the site with grazing and grassland the predominant activities. A number of houses and farm yards are dotted around the area.	
Surface Hydrology	The land around the spring generally appears to be well drained with not many surface water features present. There is another smaller spring about 0.5 km to the southwest of Danganbeg Spring. There are a number of small drainage ditches locally while the closest stream is rises about 300 m west of the spring and flows northwards where it forms a tributary of the Toberfin River. The Toberfin River in turn is a tributary of the Tullamore River which is the main drainage feature in the area.	
Topsoil	The Danganbeg Spring emerges from the ground at the boundary between two different types of topsoil. Mineral alluvium is mapped to the west and peaty gleys are mapped to the east. (Teagasc 2006). The surrounding area is underlain by grey brown podzolics classified as till.	
Subsoil (**Figure 2**)	Two different subsoil types again meet at this location – undifferentiated alluvium to the west and limestone till to the east (Teagasc 2006). Augering carried out by the GSI in 2001 indicated that the subsoils encountered very close to the spring were classified as sandy silt with clay and gravel; to the west of the spring the subsoils were classified as peaty silt with clay and frequent stones and were classified as sandy silt with gravel to the east. On the higher ground to the south deposits of clayey sand with gravel or sandy gravel with clay were encountered (**Appendix 2 and Figure 2**).	
Groundwater Vulnerability (**Figure 3**)	High (H) groundwater vulnerability over most of the area, with Extreme (E) vulnerability around the spring and Extreme (E and X) vulnerability in the south of the ZOC (See **Appendix 3**).	
Geology (**Figure 4**)	The bedrock type underlying this area is classified as the Lucan Formation, commonly known as 'the Calp'. This limestone is part of the Dinantian Upper Impure Limestones rock unit group. It is a fine grained, dark muddy limestone interbedded with layers of shale. Bedrock layers ('beds') dip north-westwards at a low angle. Two major fault sets are present, trending NE-SW and SE-NW. The joint pattern is likely to have similar orientations. There are faults mapped in the region and it is likely that others are present but have not been identified due to lack of bedrock outcrop.	
Aquifer (**Figure 5**)	**Locally Important Fractured Bedrock Aquifer – that is generally moderately productive only in local zones (LI).** Groundwater flow occurs along fractures, joints and major faults. Limited karstification has occurred in the Upper Impure Limestones. Groundwater flow paths are short and flow towards surface water bodies or springs, and are controlled by local topography. The 2001 GSI report [2] indicates that the muddy nature of this limestone means that it has poor potential for water storage and abstraction but that localised zones of higher permeability do exist. It is likely that the Calp in this area is cleaner and less muddy that normal.	
Groundwater Body	Geashill GWB. Categorised as 'possibly at risk of not achieving good status' (www.epa.ie)	
Recharge Coefficient (**Appendix 4**)	22.5 %	Moderate permeability subsoil overlain by poorly drained (gley) soil overlying a Locally Important (LI) Aquifer with a High (H) vulnerability. Hydrogeological setting 2.vi (see **Appendix 4**).
Average Recharge (mm/yr)	104	

3.2 Hydrochemistry and water quality

During the site visit to Danganbeg on 09/05/2016 pH, electrical conductivity and temperature measurements were taken. The results are presented in **Table 3** below.

Table 3. Summary of field measurements of physico-chemical parameters

Parameter	Danganbeg Spring
pH (pH units)	7.11
Conductivity @ 20°C (µS/cm)	812
Temperature (deg C)	10.7

There are no historical data available for the raw water quality at the spring. Offaly County Council carry out check and audit monitoring around the supply network. The check and audit monitoring data for 2014 and 2015 were made available for this report but, as the samples were collected from around the supply network, they represent a blend of the water from several of the scheme's individual supplies rather than the water from one single source. Therefore these data are not considered in this report.

The 2001 GSI report [2] on the spring indicated that, based on a limited dataset, the spring water is very hard and was occasionally contaminated with organic wastes and faecal bacteria. This was based on a hardness value of >350 mg/l $CaCO_3$, nitrate levels of 26 – 32 mg/l, chloride levels of 20 – 25 mg/l and a sodium to potassium ratio of around 0.3, with one very high ratio of 0.86 in May 1999. Faecal bacteria were present in two samples in 1995.

As part of this current project, the National Federation of Group Water Schemes (NFGWS) collected a raw (untreated) water sample from the spring in June 2016. The analytical data are presented in **Appendix 5** with summary information below in **Table 4**. The analytical results have been compared to the drinking water limits from the Drinking Water Regulations (SI No. 122 of 2014), and/or the Threshold Values from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010), whichever is the lower.

The chemical parameters analysed for were all within acceptable limits. The water remains very hard, but nitrate is lower than in 2001. The total coliform count was recorded at 53.1 cfu/100/ml, above the limit of 0 cfu/100ml, indicating some bacteriological contamination is present in the spring. The ratio of potassium to sodium was very high, indicting that there is organic contamination present in the groundwater, most likely from farm yard waste.

Table 4. Summary Raw Water Quality Data

Parameter	Danganbeg Spring	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
Conductivity @ 20C	695	µS/cm	800 (TV)
Sodium	7.28	mg/l	150 (TV)
Chloride	18.47	mg/l	24
Potassium	6.54	mg/l	
Ammonium NH_4	0.03	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	13.82	mg/l	37.5 (TV)
Nitrite as NO_2	<0.03	mg/l	0.5 (TV)
Total Hardness (Kone)	397.8	mg/l $CaCO_3$	
Iron	<20	µg/l	200 (DWL)
Manganese	<5	µg/l	<50 (DWL)
E Coli	<1.0	cfu/100ml	0
Total Coliforms	**53.1**	cfu/100ml	0
Potassium:Sodium	**0.89**		>0.4 indicates contamination from plant organic matter

4 Zone of Contribution

4.1 Conceptual model

The current understanding of the geological and hydrogeological setting is given as follows (see cross section **Diagram 2)**.

Groundwater is replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. The subsoils here are moderately permeable, but they are overlain by less well draining topsoils. This means that a high proportion of the rain falling over the land surface will run off to streams and ditches. The subsoils overlie fractured muddy limestone (Calp) classified as a Locally Important Aquifer that is generally moderately productive only in local zones (Ll). The remaining portion of rainfall that percolates downwards (rather than running off to surface water) will enter the limestone bedrock through its upper weathered zone which is likely to have a well developed network of fractures and fissures. The deeper limestone will contain some fractures and fissures which will act as conduits for groundwater flow. It is considered likely that the bedrock faulting mapped in the area (NE-SW and NW-SE) influences the orientation of the smaller fractures and fissures through which groundwater will move. The groundwater will follow the direction of the topographic gradient (or slope), from the higher ground in the south towards the north. This groundwater will ultimately discharge into the small stream that is a tributary of the Toberfin River.

Augering (shallow drilling) carried out by the GSI in 2001 indicated that close to the spring the subsoils consist of sandy silt with clay and frequent gravel. The subsoils encountered west and east of the spring were classified as peaty silt with clay and frequent stones to the west and sandy silt with gravel to the east. On the higher ground to the south, deposits of clayey sand with gravel or sandy gravel with clay were encountered.

The Danganbeg Spring emerges from the ground towards the base of a hill; a break in slope is often the location where groundwater emerges from the ground to form a spring. However, the break in slope is not particularly dramatic at this location. It is more likely that this spring is emerging as groundwater from the upper layers of the bedrock and then discharging through a zone of permeable subsoils, such as the sandy or gravelly layers identified in the auger holes. There is another spring about half a kilometer to the southwest. Its flow is not known but is considered to be smaller than the spring captured to supply the GWS (Danganbeg). Since it is not possible to apportion groundwater flows to each spring individually, a combined zone of contribution for both springs is considered appropriate.

The discharge from this spring fluctuates, with periods of very little or no overflow reported. This suggests that the fractures in the bedrock feeding the spring respond quickly to changes in rainfall levels, and have low groundwater storage.

The groundwater in the immediate vicinity of the spring is considered to have an Extreme (E) vulnerability to contamination. The area surrounding the spring is primarily classified with a High (H) vulnerability rating, except the higher ground in the south, where thinner subsoils give Extreme (E and X) vulnerability.

Groundwater will flow from south to north, and the Zone of Contribution (ZOC) will extend upgradient (upslope) from the wells in a southerly direction.

The delineation of the zone of contribution boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in flow rates and water levels.

Diagram 2: Schematic vertical cross section through the ground, and conceptual model of groundwater flow

4.2 Boundaries

Given the proximity of the other spring 0.5 km to the southwest of Danganbeg Spring, and the lack of information about this spring, it is difficult to apportion separate groundwater flow regimes and zones of contribution to each spring indiviually. Therefore in order to be conservative the western boundary of the Danganbeg Spring zone of contribution has been enlarged to incorporate the area likely to be supplying the other spring. The boundaries of the area contributing to the source are considered to be as follows (**Figure 6**).

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

The **Northern boundary**, is the 'downgradient' limit', beyond which groundwater will not be drawn back upgradient under the influence of the pump. A conservative 50 m buffer is applied as the downgradient boundary. This area is considered appropriate to incorporate all the land that may possibly be contributing groundwater to the spring from the downgradient direction when the pumped water level in the chamber is at its lowest level (Taly Hunter Williams pers. comm.).

The **Southern Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the water balance for the site and on the local topography. The boundary is defined by the topographic high point in the townland of Parkbeg.

The **Western and Eastern Boundaries** define the width of the ZOC. These boundaries are defined based on a combination of the topography, hydrogeological inferences and a basic water balance exercise completed for the spring. There is a degree of uncertainty associated with these boundaries but conservative assumptions used in the water balance (**Section 4.3** below) mitigates against these uncertainties and ensures that a conservative approach is adopted throughout. As indicated above the western boundary has been enlarged to incorporate the other spring around half a kilometer to the southwest.

The delineation of the boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

4.3 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 abstracted by the source.

The current abstraction rate (based on four months of data from early 2016) for the Danganbeg Spring is 330 m^3/d. In order to account for seasonal fluctuations in abstraction volumes plus uncertainities in the groundwater flow direction, a conservative approach is adopted and therefore the water balance has been calculated based on a daily abstraction rate of 400 m^3/d.

The available recharge is estimated at 104 mm/yr across the majority of the ZOC (see **Table 2**). There are small portions where groundwater recharge is 200 mm/yr, but the lower amount is used. The minimum geographical area required to sustain an abstraction of 400 m^3/d (or 146,000 m^3/yr) based on the minimum available recharge of 104 mm/yr (or 0.104 m/yr) is 1.4 km^2 (140 ha or 346 acres). The delineated ZOC measures 2.2 km^2.

5 Conclusions

The Danganbeg Spring is one of four souces used by the Killeigh, Killurin and Cloneygowan Group Water Scheme that supplies 1,300 domestic and 250 farm connections. The discharge from the spring fluctuates seasonally but was calculated to be on average 330 m^3/d for the first four months of 2016. This indicates an increase of 200% since the last time the spring was assessed by the GSI in 2001 (Kelly 2001), and also reflects the seasonal variation of spring flow, and the significant reduction in flow in dry weather conditions.

The updated information on spring flows and groundwater recharge has resulted in a larger ZOC being delineated than previously (Kelly, 2001). The length of the Inner Protection Area delineated in 2001 (i.e. 750 m upgradient of the spring) is still appropriate. It is shown on **Figure 6**.

The spring emerges from the ground through fractured shaley limestone bedrock known as the Lucan Formation or 'Calp'. This limestone is overlain by a range of different subsoils, which in the region of the spring appear to consist of sand and gravel with a high permeability. This zone of high permeability subsoil is facilitating the spring emerging at the surface. The vulnerability of the groundwater to contamination is Extreme (E) in the region of the spring and High (H) in the surrounding area, although water-logged soils restrict percolation of rainfall down to the water table.

The ZOC is occupied by agricultural land and houses. Potential sources of contamination to the well include septic tanks (in particular old or inefficient tanks that have not been emptied in many years) and agricultural activities e.g. grazing, landspreading, slurry pits or slatted units. Land use activities around the spring will impact on the groundwater quality in the spring. Landspreading immediately around the spring is of particular concern. An arbitrary setback buffer of 200 m is recommended (in the EU Nitrates Directive) as the area around a source within which landspreading should not occur. This distance is arbitrary and it is considered acceptable to specify a more site specific setback distance based on the hydrogeological conditions at a given site. For Danganbeg Spring, it is recommended that landspreading be prohibited within 100 m of the spring.

While the chemical parameters analysed for in the recent raw water sampling are within acceptable limits, there is some evidence of bacteriological contamination entering the spring.

Any landuse changes or planning permissions within the ZOC should be carefully monitored and assessed for likely impacts on the spring. The ZOC (and Inner Protection Area, SI, previously delineated by Kelly, 2001) crosses from Offaly into Laois, and planners in both Local Authorities should be made aware of the ZOC and SI.

6 Recommendations

The recommendations below have been subdivided into higher and lower priority; ideally the higher priority recommendations should be addressed immediately.

Essential:

- Routine monitoring of untreated groundwater should be undertaken for the source for a specified period of time (e.g. monthly/quarterly for a year, to include sampling immediately after at least one rainfall event). The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist. This should include the parameters in Table 4, and should be water taken directly at the spring, and not from the network.

- The yield of the spring should be investigated and clarified to give the GWS some certainty about the security of supply. It would be useful to have a better understanding of how the spring responds to changing rainfall levels in particular, and so a number of seasonal assessments should be made, in conjunction with rainfall data (available from Met Éireann website).

- Any future planning applications made within the ZOC should be assessed for their potential impact on the quality of groundwater (refer to both the Offaly and Laois county development plans and Groundwater Protection Schemes Document, 1999).

- Licensed landspreading must only take place within the context of the guidelines as specified in the document entitled "Groundwater Protection Schemes" published by the Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland in 1999 and 'Landspreading of Organic Wastes' Guidance on Groundwater Vulnerability Assessment of Land, Environmental Protection Agency 2004. As mentioned above, it is recommended that landspreading is prohibited within 100 m of the spring. This measure would contribute significantly to maintaining good water quality by limiting the risk of contamination entering the spring.

Desirable:

- Comprehensive hazard mapping (e.g. septic tanks, slatted units and slurry pits) within the delineated ZOC should be undertaken. This should include septic tank inspections to clarify their condition.
- The GWS spring and its ZOC should be assessed to establish the level of risk, if any, posed by cryptosporidium.
- It is recommended that the scheme's consideration of upgrading the treatment to include UV is implemented.

Other:

- The following EPA guidelines may serve as future useful reference documents for the Killeigh, Killurin and Cloneygowan GWS:
  - EPA Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources. Of particular interest would be Section 4.1 – Step 2 – Hazard Mapping[4].
  - EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans. This document contains checklists for hazards which would assist in hazard mapping within the ZOC[5].
  - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

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FIGURES

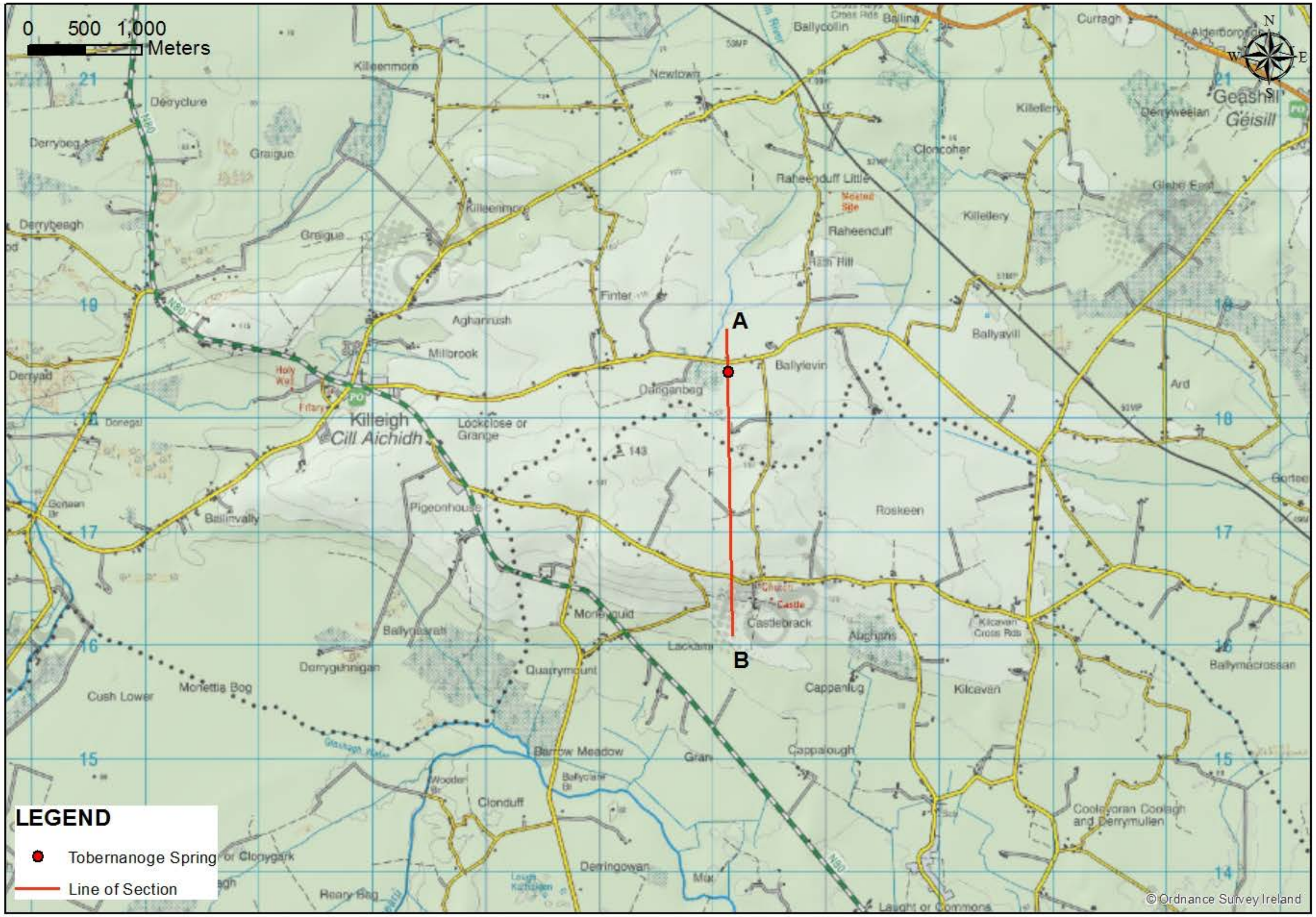

Figure 1. Location Map

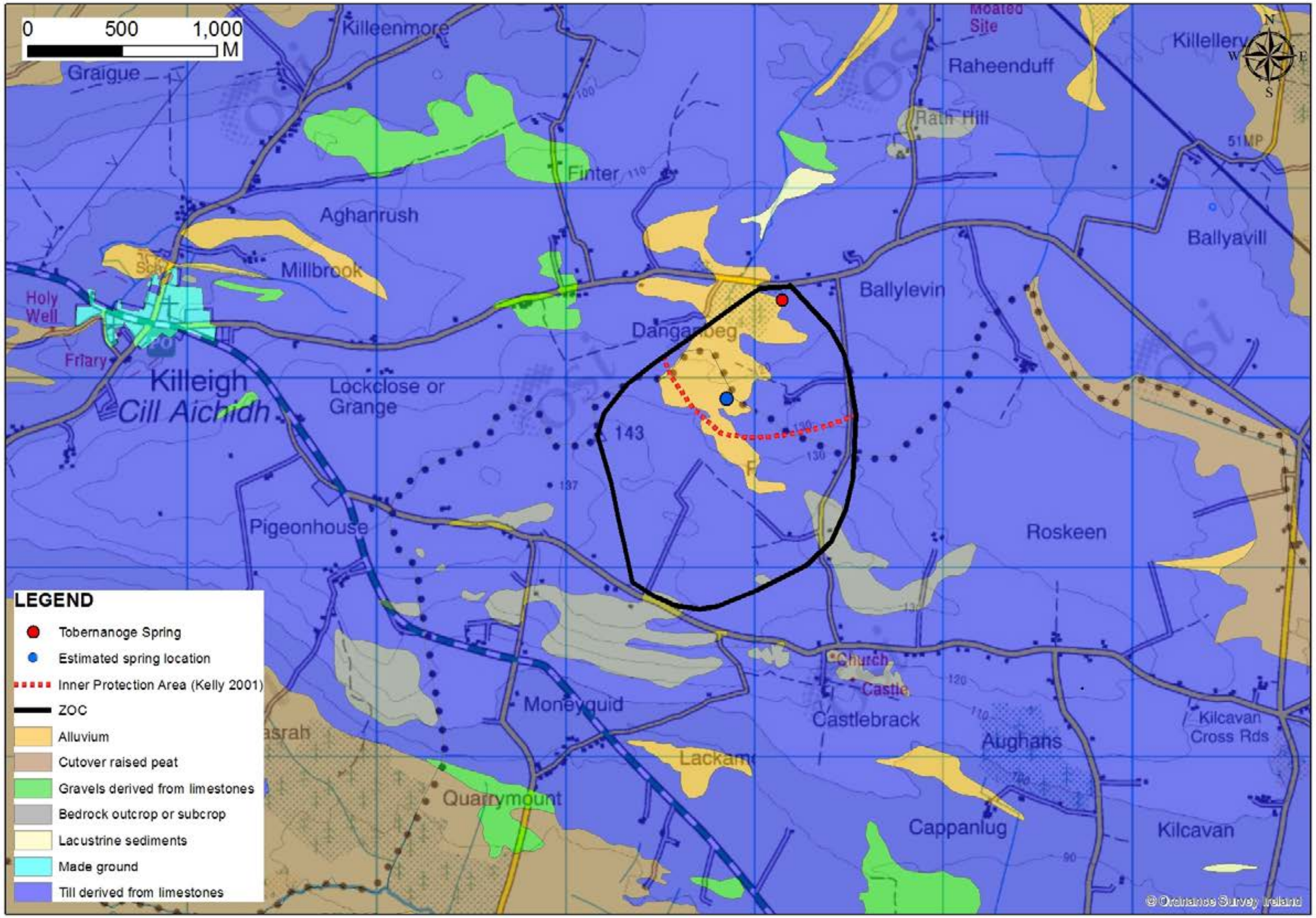

Figure 2. Subsoils Map

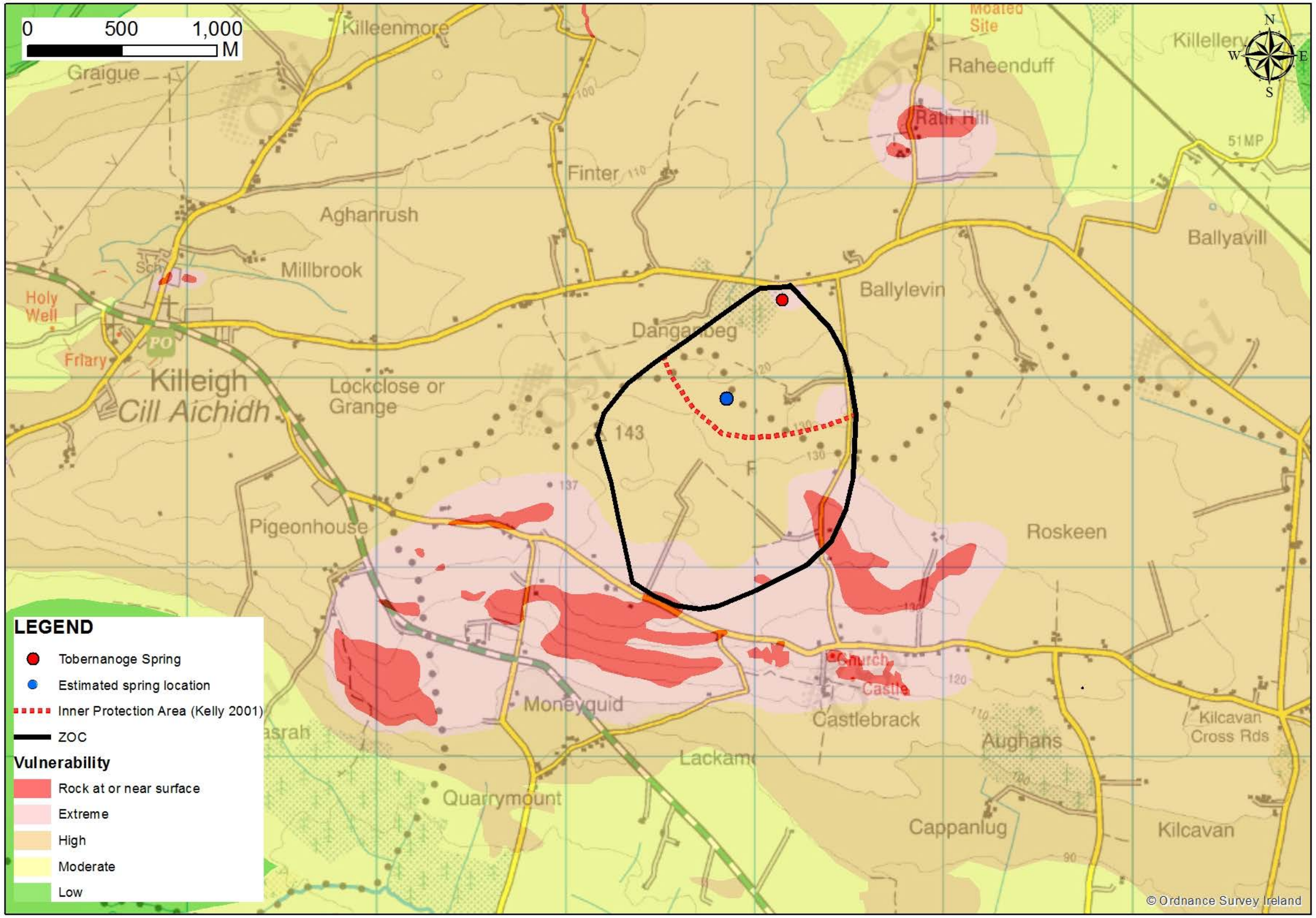

Figure 3. Groundwater Vulnerability Map

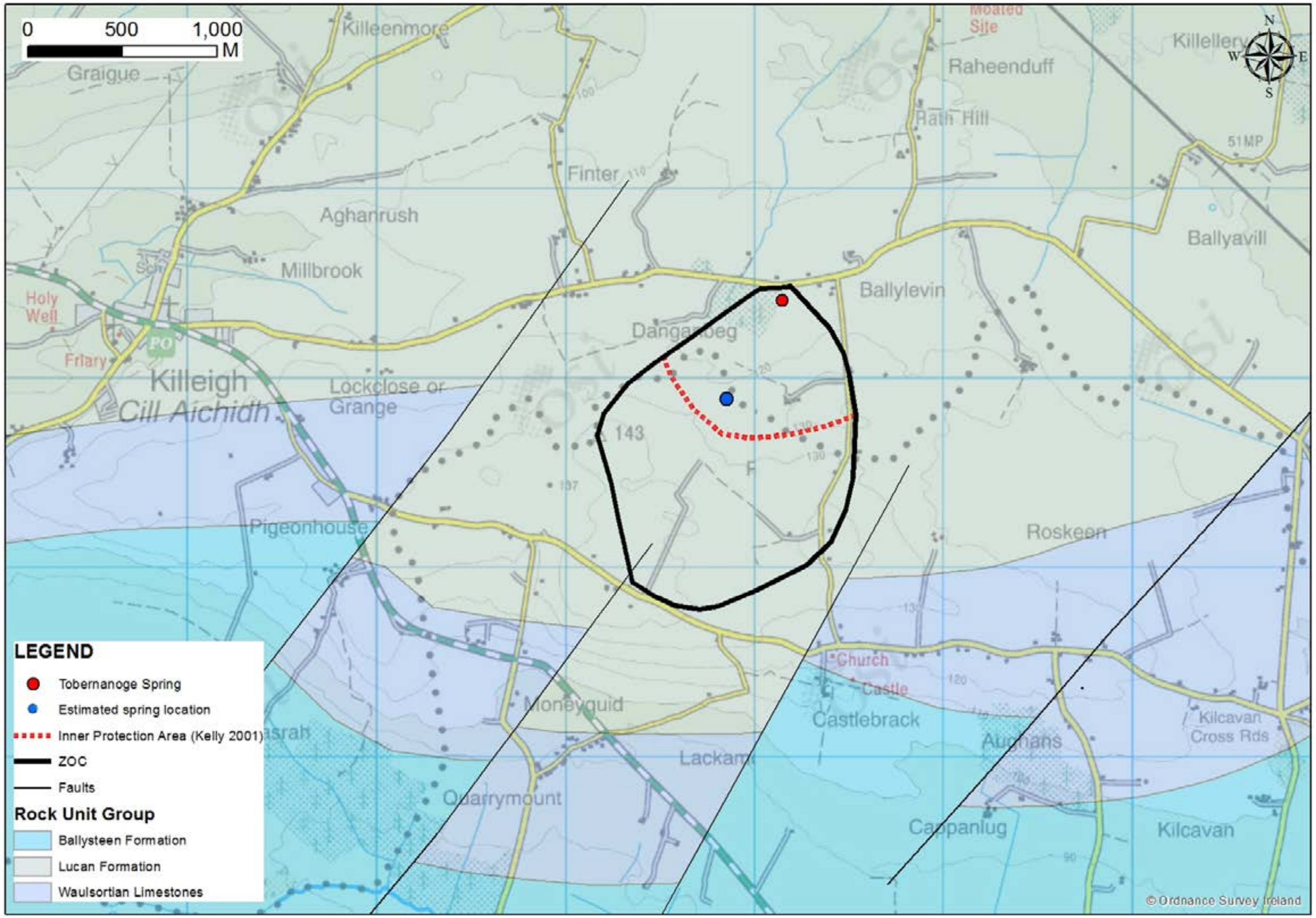

Figure 4. Rock Unit Group Map

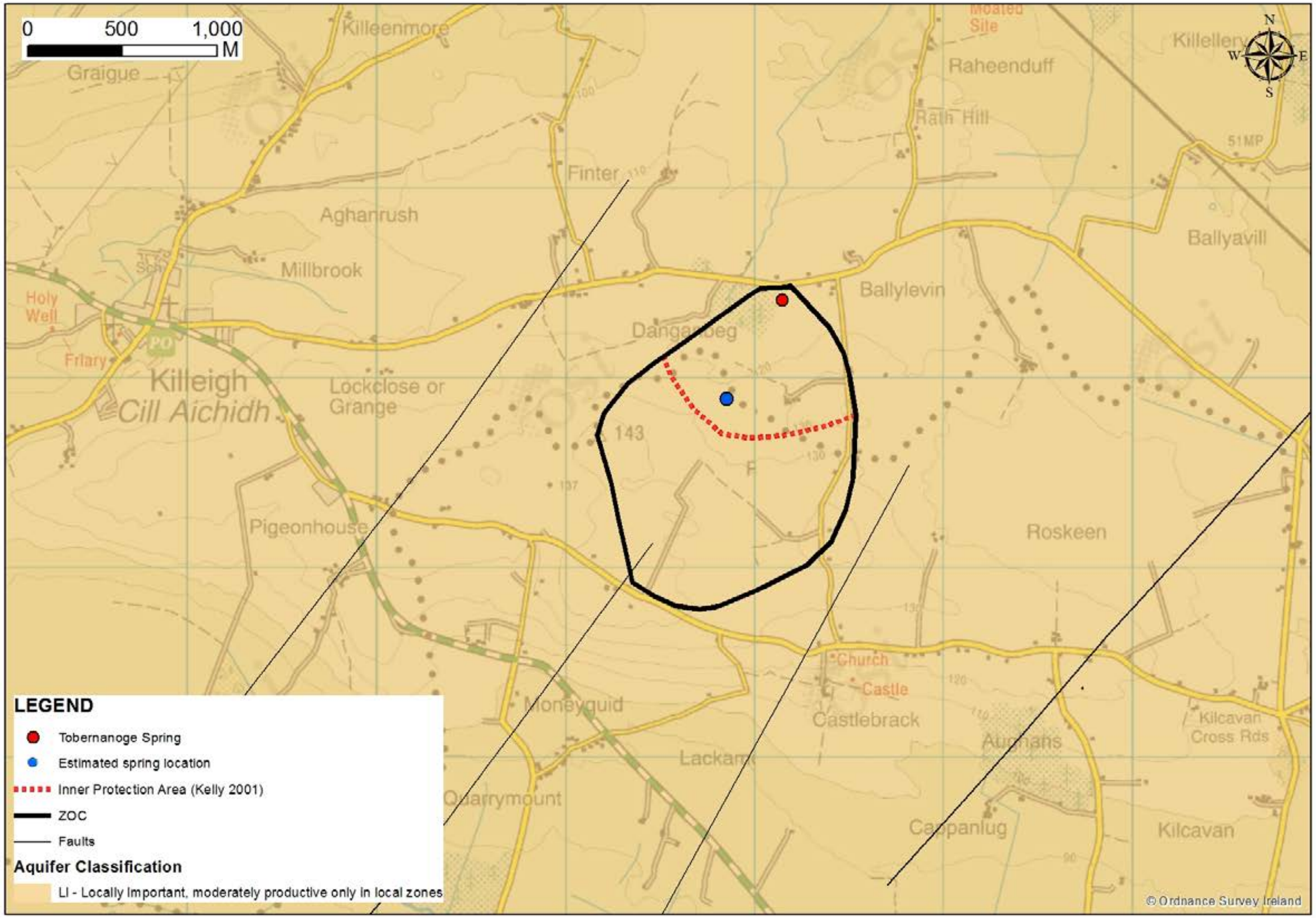

Figure 5. Aquifer Map

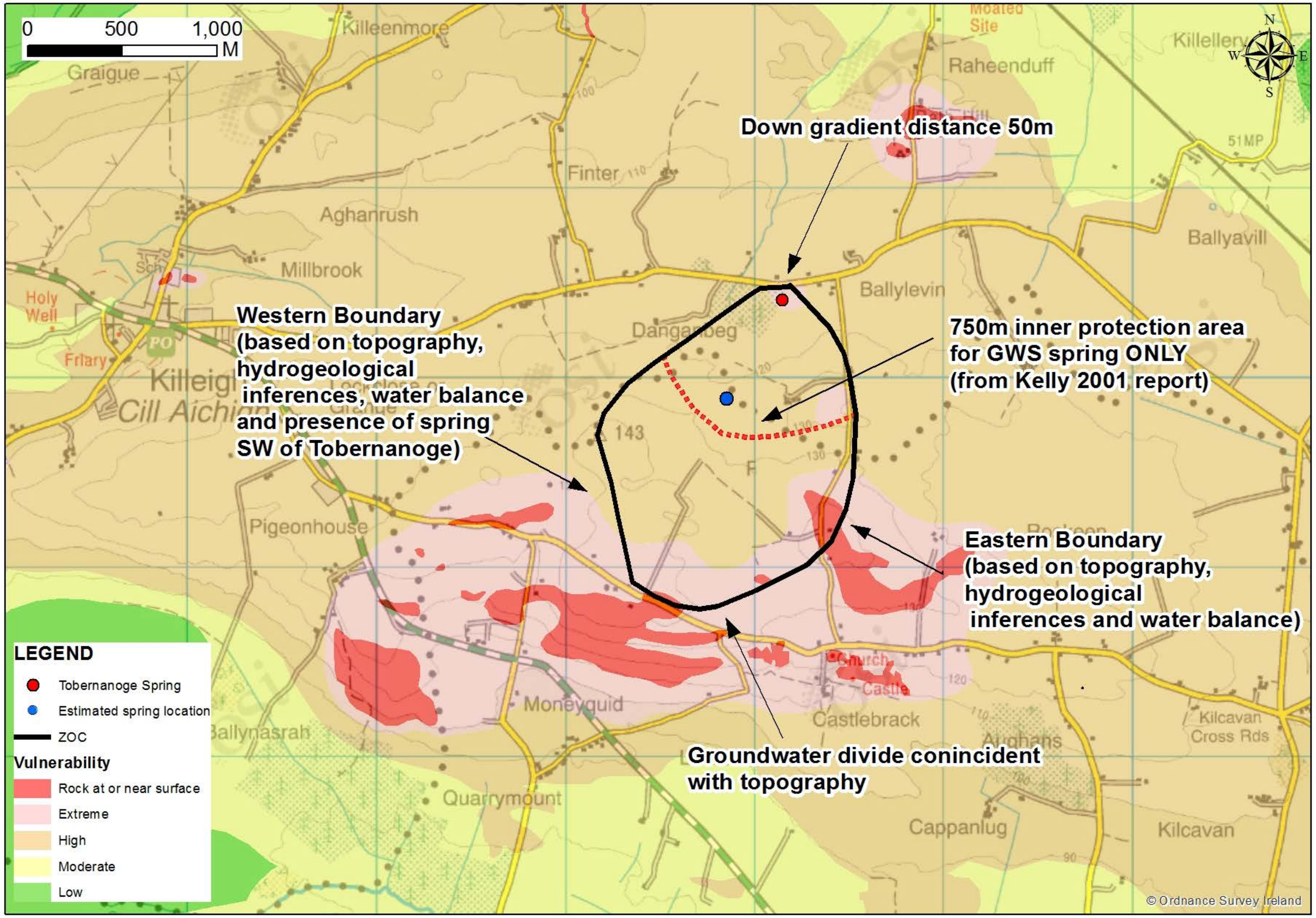

Figure 6. ZOC Boundary Map

Acronyms and glossary of terms

BGL	Below Ground Level
EPA	Environmental Protection Agency
DEHLG	Department of Environment Heritage and Local Government
EQS	Environmental Quality Standard
EU	European Union
GPZ	Groundwater Protection Zone
GSI	Geological Survey of Ireland
GWB	Groundwater Body
GWD	Groundwater Directive (European Union)
GWS	Group Water Scheme
IGI	Institute of Geologist of Ireland
MOD	Metres Ordnance Datum
MRP	Molybdate-Reactive Phosphorus
NRG	National Grid Reference
NRWMC	National Rural Water Monitoring Committee
PVC	Polyvinyl Chloride
SPZ	Source Protection Zones
TOT	Time of Travel
TVs	Threshold Values
UV	Ultra-Violet
ZOC	Zone of Contribution
WFD	Water Framework Directive (European Union)

Glossary of Terms

Aquifer

A subsurface layer or layers of rock, or other geological strata, of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (Groundwater Regulations, 2010).

Attenuation

A decrease in pollutant concentrations, flux, or toxicity as a function of physical, chemical and/or biological processes, individually or in combination, in the subsurface environment.

Borehole

A particular type of well - a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system.

Conceptual Hydrogeological Model

A simplified representation or working description of how a real hydrogeological system is believed to behave on the basis of qualitative analysis of desk study information, field observations and field data.

Confined Aquifer

A confined aquifer occurs where the aquifer is overlain by low permeability "confining" material. Once all the void space in the aquifer is full of water up to the confining layer, the addition of more water to the aquifer causes the stored water to become pressurised and, the additional water is stored by compression, sealed in by the overlying confining layer (the water is added upgradient where the confining layer is absent). Where a borehole punctures the confining layer, the water will rise up into the borehole to equalise the confining pressure.

Diffuse Sources

Diffuse sources of pollution are spread over wider geographical areas rather than at individual point locations. Diffuse sources include general land use activities and landspreading of industrial, municipal wastes and agricultural organic and inorganic fertilisers.

Direct Input

An input to groundwater that bypasses the unsaturated zone (e.g. direct injection through a borehole) or is directly in contact with the groundwater table in an aquifer either year round or seasonally.

Doline

Or enclosed depressions are relatively shallow bowl or funnel shaped depressions that form in karst landscapes, and serve to funnel or concentrate recharge underground. Their presence indicates that subterranean drainage is in operation.

Dolomitisation

Is a process, whereby the calcite crystals in limestone is replaced by magnesium. This results in an increase in the porosity and permeability of the rock. Dolomitised rocks are a highly weathered, yellow/orange/brown colour and are usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery. Dolomitisation often occurs preferentially in both fault zones and purer limestones.

Down-gradient

The direction of decreasing groundwater levels, i.e. flow direction. Opposite of upgradient.

Dry Weather Flow (Receiving Water)

The minimum flow likely to occur in a surface water course during a prolonged drought.

Environmental Quality Standard (EQS)

The concentration of a particular pollutant or group of pollutants in a receiving water which should not be exceeded in order to protect human health and the environment.

Enclosed Depression

See doline

Fissure

A natural crack in rock which allows rapid water movement.

Good Groundwater Status

Achieved when both the quantitative and chemical status of a groundwater body are good and meet all the conditions for good status set out in Groundwater Regulations 2010, regulations 39 to 43.

Groundwater

All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Groundwater Regulations, 2010).

Groundwater Body (GWB)

A volume of groundwater defined as a groundwater management unit for the purposes of reporting to the European Commission under the Water Framework Directive. Groundwater bodies are defined by aquifers capable of providing more than 10 m3/d, on average, or serving more than 50 persons.

Groundwater Protection Scheme (GWPS)

A scheme comprising two principal components: a land surface zoning map which encompasses the hydrogeological elements of risk (of pollution); and a groundwater protection response matrix for different potentially polluting activities (DELG/EPA/GSI, 1999).

Groundwater Protection Responses (GWPR)

Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

Groundwater Protection Zone (GPZ)

A zone delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code, e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important karstified aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

Groundwater Recharge

Two definitions: a) the process of rainwater or surface water infiltrating to the groundwater table; b) the volume (amount) of water added to a groundwater system.

Groundwater Resource

An aquifer capable of providing a groundwater supply of more than 10 m3/d as an average or serving more than 50 persons.

Hydraulic Conductivity

The rate at which water can move through a unit volume of geological medium under a potential unit hydraulic gradient. The hydraulic conductivity can be influenced by the properties of the fluid, including its density, viscosity and temperature, as well as by the properties of the soil or rock.

Hydraulic Gradient

The change in total head of water with distance; the slope of the groundwater table or the piezometric surface.

Igneous

Igneous rock is formed through the cooling and solidification of magma or lava.

Indirect Input

An input to groundwater where the pollutants infiltrate through soil, subsoil and/or bedrock to the groundwater table.

Input

The direct or indirect introduction of pollutants into groundwater as a result of human activity.

Karst

A distinctive landform characterised by features such as surface collapses, sinking streams, swallow holes, caves, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits.

Karstification

Karstification is the process whereby limestones are slowly dissolved by acidic waters moving through them. This results in the development of an uneven distribution of permeability with the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones. Karstification results in the progressive development of distinctive karst landforms such as caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime. It is an important feature of Irish hydrogeology.

Pathway

The route which a particle of water and/or chemical or biological substance takes through the environment from a source to a receptor location. Pathways are determined by natural hydrogeological characteristics and the nature of the contaminant, but can also be influenced by the presence of features resulting from human activities (e.g., abandoned ungrouted boreholes which can direct surface water and associated pollutants preferentially to groundwater).

Permeability

A measure of a soil or rock‘s ability or capacity to transmit water under a potential hydraulic gradient (synonymous with hydraulic conductivity).

Point Source

Any discernible, confined or discrete conveyance from which pollutants are or may be discharged. These may exist in the form of pipes, ditches, channels, tunnels, conduits, containers, and sheds, or may exist as distinct percolation areas, integrated constructed wetlands, or other surface application of pollutants at individual locations. Examples are discharges from waste water works and effluent discharges from industry.

Pollution

The direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment (Groundwater Regulations, 2010).

Poorly Productive Aquifers (PPAs)

Low-yielding bedrock aquifers that are generally not regarded as important sources of water for public water supply but that nonetheless may be important in terms of providing domestic and small community water supplies and of delivering water and associated pollutants to rivers and lakes via shallow groundwater pathways.

Preferential Flow

A generic term used to describe water movement along favoured pathways through a geological medium, bypassing other parts of the medium. Examples include pores formed by soil fauna, plant root channels, weathering cracks, fissures and/or fractures.

Saturated Zone
The zone below the water table in an aquifer in which all pores and fissures and fractures are filled with water at a pressure that is greater than atmospheric.

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

Source Protection Area
The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO). The SI is designed to protect the source against the effects of human activities that may have an immediate effect on the source, particularly in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source. The SO covers the remainder of the zone of contribution of the groundwater source.

Specific Yield
The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table.

Spring
A spring is a natural feature where groundwater emerges at the surface. Springs usually occur where the rate of flow of groundwater is too great to remain underground. The position of a springs usually reflects a change in soil or rocktype or a change in slope.

Subsoil
Unlithified (uncemented) geological strata or materials beneath the topsoil and above bedrock.

Surface Water
An element of water on the land‘s surface such as a lake, reservoir, stream, river or canal. Can also be part of transitional or coastal waters. (Surface Waters Regulations, 2009.).

Swallow Hole
The point where concentrated inflows of water sink underground. They are found in karst environments.

Threshold Values (TVs)
Chemical concentration values for substances listed in Schedule 5 of the Groundwater Regulations (2010), which are used for the purpose of chemical status classification of groundwater bodies.

Till
Unsorted glacial Sediment deposited directly by the glacier. It is the most common Quaternary deposit in Ireland. Its components may vary from gravel, sands and clays.

Transmissivity
Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer.

Unsaturated Zone
The zone between the land surface and the water table, in which pores, fractures and fissures are only partially filled with water. Also known as the vadose zone.

Vulnerability
The intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (Fitzsimmons et al, 2003).

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

Weathering

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

Zone of Contribution (ZOC)

The area surrounding a pumped well or spring that encompasses all areas or features that supply groundwater to the well or spring. It is defined as the area required to support an abstraction and/or overflow (in the case of springs) from long-term groundwater recharge.

APPENDIX 1

Flow meter records from 2016

Meter reading notes from caretakers notebook, 2016

Date	Meter reading m^3	Equivalent discharge – m^3/d
18/01/16	3436	331.5
22/01/16	4762	329.6666667
25/01/16	5751	312.75
29/01/16	7002	239.5
01/02/16	7960	374.6666667
07/02/16	10208	268.6666667
13/02/16	11820	318
15/02/16	12456	372
17/02/16	13200	343.5
19/02/16	13887	311.6666667
22/02/16	14822	462
26/02/16	16208	328.25
01/03/16	17521	330.3333333
04/03/16	18512	340.3333333
07/03/16	19533	355.75
11/03/16	20956	325
14/03/16	21931	338
18/03/16	23283	359
21/03/16	24360	296.5
23/03/16	24953	312.5
25/03/16	25578	315
29/03/16	26838	336.3333333
01/04/16	27847	348
04/04/16	28891	324
08/04/16	30187	350.25
12/04/16	31588	318
15/04/16	32542	372
18/04/16	33658	323.8
23/04/16	35277	355
26/04/16	36342	342.6666667
29/04/16	37370	355
03/05/16	38790	366.3333333
06/05/16	39889	329
09/05/16	40876	331.5
	Total discharge over 113 days	**37,440 m^3**
	Average discharge per day	**331 m^3/d**

APPENDIX 2

Geological Logs of Auger Boreholes from GSI 2001 Report

Geological Logs of Auger Boreholes – sourced from 2001 GSI Report.

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It was assumed that the auger had reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Auger I.D	Subsoil Type	BS 5930 Description	Permeability Category
Danganbeg No. 1 National Grid Reference 23995 21851			
0 – 0.3 m	Topsoil	Peaty SILT with clay and stones	MODERATE
0.3 – 3.5 m	Till	Sandy SILT with clay and frequent stones	MODERATE
Danganbeg No. 2 National Grid Reference 24019 21846			
0 – 2.0 m	Till	Sandy SILT with clay and frequent gravl	MODERATE
2.0 – 2.8 m	Till	Sandy SILT with clay and abundant gravel	MODERATE
Danganbeg No. 3 National Grid Reference 24035 21848			
0 – 0.5 m	Till	Sandy SILT	MODERATE
0.5 – 1.7 m	Till	Sandy SILT with abundant gravel	MODERATE
1.7 – 2.0 m	Till	Sandy GRAVEL with silt	HIGH
2.0 – 3.6 m	Till	Sandy SILT with clay and frequent gravel	MODERATE
Danganbeg No. 4 National Grid Reference 24046 21788			
0 – 2.75 m	Till with gravel	Clayey SAND with gravel	HIGH
Danganbeg No. 5 National Grid Reference 24042 21745			
0 – 2.0 m	Gravel	Sandy GRAVEL with clay	HIGH

APPENDIX 3

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

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

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 4

Groundwater Recharge

Introduction

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using Hunter Williams et al (2013) (see also Guidance Document GW5 Groundwater Working Group 2005; Hunter Williams et al 2011).

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

Note: Areas of 'made ground' are assigned a recharge coefficient of 20%.

APPENDIX 5

Hydrochemistry and Water Quality of Raw Water

Raw Water Data, Danganbeg Spring, June 2016

Parameter	Danganbeg Spring	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	1	mg/l	
Turbidity	0.05	N.T.U.	No abnormal change
pH	7.0	pH units	6.5 – 9.5
Conductivity @ 20C	695	µS/cm	800 (TV)
Alkalinity	366.38	mg/l $CaCO_3$	
Sodium	7.28	mg/l	150 (TV)
Potassium	6.54	mg/l	
Chloride	18.47	mg/l	24
Ammonium NH_4	0.03	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	13.82	mg/l	37.5 (TV)
Nitrite as NO_2	<0.03	mg/l	0.5 (TV)
Dissolved Oxygen (%)	5.08	%Sat	
Total Hardness (Kone)	397.8	mg/l $CaCO_3$	
Magnesium, total	7.64	mg/l	50 (DWL)
Colour, apparent	<1.0	mg/l Pt Co	No abnormal change
Silica as SiO_2	5.53	mg/l	
Sulphate	12.35	mg/l	187.5 (TV)
Orthophosphate	<0.01	mg/l	
Calcium, total	146.7	mg/l	
Aluminium, dissolved	30	µg/l	150 (TV)
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
Copper, dissolved	<10	µg/l	1500 (TV)
Lead, dissolved	<1	µg/l	10 (DWL)
Chromium, dissolved	<5	µg/l	37.5 (TV)
Nickel, dissolved	<2	µg/l	15 (TV)
Cadmium, dissolved	<0.5	µg/l	3.75 (TV)
Arsenic, dissolved	<10	µg/l	7.5 (TV)
Zinc, dissolved	14	µg/l	
Barium, dissolved	52	µg/l	
Total Organic Carbon	1.6	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	440	µg/l	
E Coli	<1.0	cfu/100ml	0
Total Coliforms	**53.1**	cfu/100ml	0
Fluoride	0.07	mg/l	0.8 (DWL)
UV Transmittance	96.0	%T	

Killeigh Group Water Scheme

Danganbeg Spring (Tobernanoge)

Groundwater Source Protection Zones

(April 2001)

Prepared by:
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In collaboration with:

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1. Introduction

The Groundwater Section, Geological Survey of Ireland, have prepared this report at the request of Offaly County Council.

Danganbeg spring supplements the Killeigh Group Water Scheme (KGWS). It is the second source used for the KGWS; Toberfin springs are the main source and is examined in a separate source protection report (Kelly, 1999).

The objectives of the report are as follows:
- To delineate source protection zones for Danganbeg spring.
- To outline the principle hydrogeological characteristics of the Danganbeg area.
- To assist Offaly County Council in protecting the water supply from contamination.

2. Location, Site Description and Well Head Protection

Danganbeg spring is located 3 km east of Killeigh village, in the townland of Danganbeg, close to the boundary with Co. Laois.

Danganbeg spring comprises a large rectangular sump, collecting water that emerges from bedrock at the bottom of the sump.

The site area is closed off with a fence. The sump is covered with concrete. The rest of the site is grassed over.

3. Summary of Well / Spring Details

GSI no.	:	2321SW W0004
Grid ref. (1:25,000)	:	N 2420 2185
Townland	:	Danganbeg
Well type	:	Spring
Owner	:	Killeigh Group Water Scheme (KGWS)
Elevation (ground level)	:	~ 116 m (380 ft)
Depth & Diameter of sumps	:	3 m x 6 m
Depth to rock	:	2.8 m (9.2 ft)
Static water level	:	2 m bgl.
Normal Abstraction	:	110 m^3 d^{-1}

4. Methodology

The assessment involved three stages: (a) a desk study; (b) site visits and fieldwork; and (c) analysis of the data.

The desk study was conducted in the Geological Survey: details about the group scheme and spring such as elevation, and abstraction figures were obtained from GSI records and County Council personnel; geological and hydrogeological information was provided by the Groundwater Protection Scheme (Daly et al, 1998).

The second stage comprised site visits and fieldwork in the Danganbeg area. This included carrying out spring overflow measurements, depth to rock drilling and subsoil sampling. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the spring.

5. Topography, Surface Hydrology and Land Use

Danganbeg spring emerges at 116 m OD, close to the bottom of a hill, the highest point of which is 143 m OD.

There are few surface streams, except at the spring itself, where there are some surface drains.

Agricultural activity dominates the area with most of the land used for grassland. A number of houses and farmyards are present in the vicinity of the spring.

6. Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the Danganbeg spring source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Bedrock information was taken from a desk-based survey of available data, which comprised the following:

- County Offaly Groundwater Protection Scheme (Daly *et al*, 1998)
- Information from geological mapping in the nineteenth century (on record at the GSI).

Subsoils information was taken from the Offaly Groundwater Protection Scheme (Daly *et al*, 1998) and gathered from a drilling programme that was undertaken by GSI personnel to investigate the subsoils of the area.

6.2 Bedrock Geology

The area is underlain by Calp Limestone; a dark grey bedded, fine grained, muddy limestone.

Movements in the earth's crust have caused the rocks to be folded, faulted and jointed. The rock unit has a NE-SW trend or strike and dips either north-westwards at a low angle. Two major fault sets are present — NE-SW and SE-NW. The joint pattern is likely to have similar orientations. There are two mapped faults in the region and there are probably other faults that haven't been noted because of the lack of outcrop in the area.

6.3 Subsoil (Quaternary) Geology

6.3.1 Introduction

The subsoils comprise a mixture of coarse and fine grained materials, namely; tills, tills with gravels and gravels and are influenced by the underlying bedrock, which in the area is primarily the Calp limestone. The muddy, dark nature of this rock type in this part of Offaly could mean that the subsoils will have proportionally higher percentages of fine grained material than subsoils produced over bedrock of a 'cleaner' nature. The gravel sized component (2-60 mm) are dominated by limestone fragments, mostly angular to subangular. The logs of the auger holes drilled are given in Appendix 1.

The characteristics of each category are described briefly below:

6.3.2 Tills

'Till' is an unsorted mixture of coarse and fine materials laid down by ice. Angular limestone fragments are abundant in the tills. Tills dominate the subsoils in the Danganbeg locality. The tills comprise sandy SILT with clay and frequent gravel.

6.3.3 Till with gravels

The matrix is composed mostly of clayey SAND with gravel. The reconnaissance work in Offaly has shown that many of the sand/gravel units are small and are interbedded with tills. In many places it is not possible to map out separately the sand/gravel units and the till units during a reconnaissance mapping project. This has led to the term "till with gravel" being employed to categorise the sediments over relatively large areas (Daly *et al*, 1998).

6.3.4 Gravels

Extensive fluvioglacial sand and gravels are present in County Offaly. The sands and gravels in the area are generally coarse, poorly sorted but often contain lenses of better sorted material (BS5930: sandy GRAVELS with clay). The boulders and cobbles are limestone in composition.

6.3.5 Depth to Bedrock

A drilling programme was carried out to ascertain the depth, thickness and permeability of the subsoils. Using this information and knowledge of sites that have rock cropping out, the depth to rock is estimated across the area. The borehole locations are given in Figure 1. The depth to bedrock varies between 2 and 4 metres.

7. Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the Danganbeg source. The interpretations and conceptualisations of flow are used to delineate source protection zones around the spring.

Hydrogeological and hydrochemical information for the study was obtained from the following sources:

- Offaly Groundwater Protection Scheme (Daly *et al* 1998).
- An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly, (Cronin *et al*, 1999).
- GSI files. Archival Offaly County Council data for the years 1977, 1989, 1991. C1–C2 type parameters.
- Offaly County Council annual drinking water returns 1992–1999 inclusive (C1, C2, C3 and C4 type parameters). Some raw water analyses were also carried out.
- Limited additional fieldwork.

7.2 Meteorology and Recharge

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 generally assumed to consist of an input (i.e. annual rainfall) less water losses 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 it will dictate the size of the zone of contribution (i.e. the outer source protection area).

In areas where point recharge from sinking streams, etc., is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff and are listed as follows:

- Annual rainfall: 825 mm. Rainfall data for the area are taken from a contoured rainfall map of Co. Offaly, which is based on data from Met Éireann.
- Annual evapotranspiration losses: 431 mm. Potential evaporation (P.E.) is estimated to be 454 mm $yr.^{-1}$ (from Met Éireann data). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.
- Potential recharge: 394 mm $yr.^{-1}$. This figure is a calculation based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater, or lateral soil quickflow and overland flow direct to surface water.
- Annual runoff losses: 39.4 mm. This estimation is based on the assumption that 10% of the potential recharge will be lost to overland flow and shallow soil quickflow prior to reaching the main groundwater system.

These calculations are summarised below:

Average annual rainfall (R)	825 mm
Estimated A.E.	431 mm
Potential Recharge (R – A.E.)	394 mm
Runoff losses	39 mm
Estimated Actual Recharge	355 mm

This is an estimation of recharge which allows for surface water outflow, particularly during periods of heavy rainfall.

7.3 Groundwater Levels, Flow Directions and Gradients

There are no water level data for the area south of the spring.

The water table in the area is generally assumed to be a subdued reflection of topography; as the topography slopes northwards, the water table slopes northwards toward the spring. The dominant driving head is the hill to the south of the spring in the townland of Parkbeg. The flow directions are assumed to be perpendicular to the contour lines. In simple terms, rainfall reaching the water table anywhere in the catchment of the spring will flow in a northerly direction toward the spring.

The groundwater gradient is assumed to somewhat less than the topographic gradient, i.e. is estimated as 0.015.

7.4 Aquifer Characteristics

The Calp unit provides the groundwater to the Danganbeg source. The muddy nature of the unit suggests generally poor potential for water storage and abstraction (Offaly Groundwater Protection Scheme, Daly *et al*, 1998), however, localised high permeability zones may be present in the Calp Limestone.

A fracture network probably underlies the source and causes the water to concentrate in this area.

There are no surface streams above 122 m (400 ft), indicating that the land is free draining and the bedrock is probably of a higher permeability. It is possible that the Calp in this locality is cleaner and thus more permeable than normal. In the locality of the spring there are quite a few surface drains and streams, however, the streams and spring occur at the bottom of relatively steep slopes and it would be expected that there would be streams and surface drains present at the bottom of slopes.

Permeability and porosity for the Calp in this locality are based on evaluation of data for the Calp in other areas. Estimates for these parameters are as follows:

Permeability ~ 5 m d^{-1};

Porosity ~ 1 %.

These estimates are lower than at Toberfin Springs in Killeigh (Kelly, 1999), reflecting lower discharge rates at Danganbeg.

7.5 Aquifer Category

The Calp limestone has a wide variation in hydrogeological characteristics across the country. The Calp limestone is described in County Offaly as a Locally Important aquifer which is moderately productive only in local zones **(Ll)** (Daly et al, 1998).

7.6 Hydrochemistry and Water Quality

There are only a few datasets available for analysis and they are for treated water only.

The hydrochemical analyses show that the Danganbeg spring water is a very hard water with total hardness values > 350 mg l^{-1} $CaCO_3$.

Nitrate levels range from 26-32 mg l^{-1} and there is no apparent upward trend in the dataset.

Chlorides range from 20-25 mg l^{-1}, which are higher than typical background levels (12-15 mg l^{-1}). Chloride is a constituent of organic wastes and levels higher than 25 mg l^{-1} may indicate significant contamination.

Sodium (Na) Potassium (K) ratios are about 0.3 with one very high exceedence of 0.86 in May 1999. This exceedence may indicate organic contamination. High Na:K ratios usually indicate contamination from farmyard wastes.

Faecal bacteria is present in two samples taken in 1995, and is the only parameter to exceed the EU Drinking Water Directive maximum admissible concentrations (MAC), indicating pollution of the spring has occurred at least twice.

The limited dataset shows that the spring water is hard, and is occasionally contaminated with organic wastes and faecal bacteria.

7.7 Spring Discharge

There has been only one estimate of the total yield and this was measured in July 1999 to be 110 m^3 d^{-1}. According to the caretaker there has not been overflow since the winter months of 1997/98, of which there is no estimate. It is probable that the discharge is considerably higher in winter.

7.8 Conceptual Model

- The highest measured discharge was 110 m^3 d^{-1}; it is probably greater during wetter weather.
- The available hydrogeological information does not allow a definitive understanding of the hydrogeology. It is considered the bedrock is providing the groundwater to the spring.
- Groundwater flow is present in fractures in the limestone. The discharge indicates relatively high velocities close to the spring.
- It is possible that a fracture system associated with a fault is causing the groundwater to focus in

this area. A “window” in the subsoils, perhaps due to the presence of a localised sand/gravel unit, may have allowed the spring water to emerge from the underground system at the spring. Alternatively, the change in slope that occurs at the spring may also influence the presence of the spring at this location.

8. Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the areas around the spring that are believed to contribute groundwater to the spring, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern, and are presented in Figures 1 and 2.

Two source protection areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution;
- Outer Protection Area (SO), encompassing the zone of contribution (ZOC) of the well.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), and is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by a) the total discharge, b) the groundwater flow direction and gradient, c) the rock permeability and d) the recharge in the area.

Two methods were used to delineate the ZOC for Danganbeg spring and are as follows:

- hydrogeological mapping and
- water balance estimations.

The shape and boundaries of the ZOC were determined using hydrogeological mapping and the conceptual model. The ZOC catchment boundaries are as follows:

1. The **Northern Boundary** is constrained by the location of the spring. Groundwater to the north of the spring cannot flow to the spring as the groundwater is downgradient. An arbitrary buffer of 30 m is placed on the downgradient side of the spring.

2. The **Eastern Boundary** is defined by small topographic ridge which runs north-south from the spring to the highest point in the southern part of the catchment.

3. The **Southern Boundary** is constrained by a watershed divide to south, created by the high ground which lies in the townland of Parkbeg.
4. The **Western Boundary** is topographically constrained. A ridge runs from the highest point in the catchment to the spring. This boundary is uncertain as water in this part of the catchment may be discharging in the streams to the west of the spring rather than to the spring itself.

These boundaries delineate the physical limits within which the ZOC is likely to occur. The area constrained by the hydrogeological mapping is about 1 km^2.

The ZOC straddles the boundary between Co. Offaly and Co. Laois. The county boundary is shown in Figure 1.

If it is assumed that the average daily flow is double the discharge (220 m^3 d^{-1}), the water balance calculation indicates that ZOC of 0.23 km^2 is required to provide enough groundwater to supply the spring. The area constrained by hydrogeological mapping is far greater than the area required by the water balance. However, it is impossible to be more definitive as to what part of the delineated ZOC is providing groundwater to the spring. Therefore the area defined by the hydrogeological mapping is regarded to be the ZOC.

8.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (ToT) to the source and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular microbial contamination. Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling is also used and by using the aquifer parameters for permeability and hydraulic gradient 100 day ToT estimations are made. From Section 7.4 parameters used give velocities of 7.5 m d^{-1}, and so it is assumed that for a 100 day time of travel, groundwater would travel 750 m, using a hydraulic gradient of 0.015. Thus the upgradient extent of the SI zone is 750 m. The SI is presented in Figure 2. Part of the SI zone is falls into Co Laois.

9. Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 1. The subsoils in the ZOC are of high to moderate permeability and are less than 3m thick. Therefore the groundwater in the ZOC is classified 'extremely' vulnerable to contamination.

10. Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an <u>Inner Protection area</u> where the groundwater is <u>highly</u> vulnerable to contamination. There are 2 groundwater protection zones present around the Danganbeg Source as shown in Table 1. The final groundwater protection map is presented in Figure 2.

It is not within the scope of this report to delineate the resource protection zones in the surrounding area and this is dealt with at the regional resource protection scale. For further details refer to Groundwater Protection Scheme for County Offaly (Daly et al, 1998).

Table 1 Matrix of Source Protection Zones for Danganbeg Spring, Killeigh.

VULNERABILITY RATING	**SOURCE PROTECTION**	
	Inner	***Outer***
Extreme (E)	SI/E	SO/E
High (H)	Absent	Absent
Moderate (M)	Absent	Absent
Low (L)	Absent	Absent

11. Potential Pollution Sources

The land in the vicinity of the source is largely grassland-dominated and is primarily used for grazing.

Agriculture is the principal activity in the Danganbeg area. The main potential sources of pollution within the ZOC are farmyards, septic tank systems and landspreading of organic fertilisers. The main potential pollutants are faecal bacteria, viruses, cryptosporidium and nitrogen.

12. Conclusions and Recommendations

- The source at Danganbeg is located in the Calp Limestone, classified a Locally Important aquifer **(Ll)**.

- The area around the supply is extremely vulnerable to contamination.

- It is recommended that:

1) a full **raw** water analysis should be carried out on a regular basis at the spring.
2) particular care should be taken when assessing the location of any activities or developments which might cause contamination at the GWS.
3) the potential hazards in the ZOC should be located and assessed.

- The protection zone delineated in the report is based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.

- A more definitive understanding of the hydrogeology would require a site investigation that would include drilling and geophysics.

13. References

Cronin, C. and Daly, D., 1999. *"An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly"*. Geological Survey Report, 30 pp.

Daly, D., Cronin, C., Coxon, C. and Burns, S.J., 1998. *"County Offaly Groundwater Protection Scheme"*. Geological Survey Report for Offaly County Council, 60 pp.

Kelly, C., 1999. *"Killeigh and Meelaghans Group Water Scheme. Toberfin springs. Groundwater Source Protection Zones"*. Geological Survey Report for Offaly County Council, 16 pp.

APPENDIX 1 GEOLOGICAL LOGS OF THE AUGER BOREHOLES.

All borehole depths are maximum depths drilled by the auger. The depths are the depth at which the auger would not go any further. It assumed that the auger has reached bedrock, the evidence being that in most cases floured bedrock is recovered on the teeth of the auger.

Danganbeg No. 1 **National Grid Reference: N 23995 21851**

Depth (m)	Subsoil Type	BS 5930 Description	Permeability Category
0-0.30	Topsoil	peaty SILT with clay and stones	MODERATE
0.30-3.5	Till	sandy SILT with clay and frequent stones	MODERATE

Danganbeg No. 2 **National Grid Reference: N 24019 21846**

Depth (m)	Subsoil	BS 5930 Description	Permeability Category
0-0-2.0	Till	sandy SILT with clay and frequent gravel	MODERATE
2.0-2.8	Till	sandy SILT with clay and abundant gravel	MODERATE

Danganbeg No. 3 **National Grid Reference: N 24035 21848**

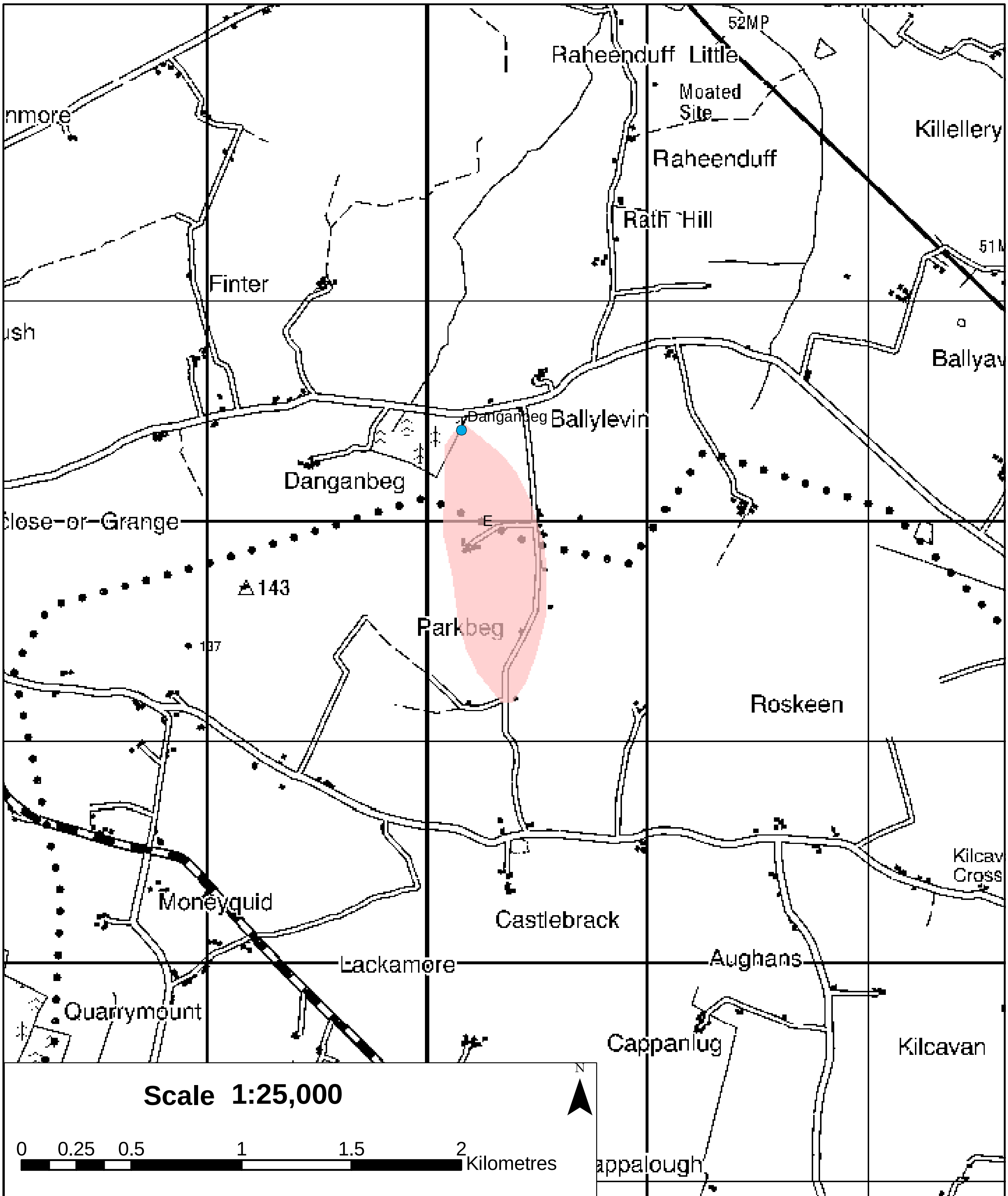
Depth (m)	Subsoil	BS 5930 Description	Permeability Category
0-0.0.50	Till	sandy SILT	MODERATE
0.5-1.7	Till	sandy SILT with abundant gravel	MODERATE
1.7-2.0	Till	sandy GRAVEL with silt	HIGH
2.0-3.6	Till	sandy SILT with clay and frequent gravel	MODERATE

Danganbeg No. 4 **National Grid Reference: N 24046 21788**

Depth (m)	Subsoil	BS 5930 Description	Permeability Category
0-2.75	Till with gravel	clayey SAND with gravel	HIGH

Danganbeg No. 5 **National Grid Reference: N 24042 21745**

Depth (m)	Subsoil	BS 5930 Description	Permeability Category
0-2.0	Gravel	sandy GRAVEL with clay	HIGH



Vulnerability Categories

E - Extreme

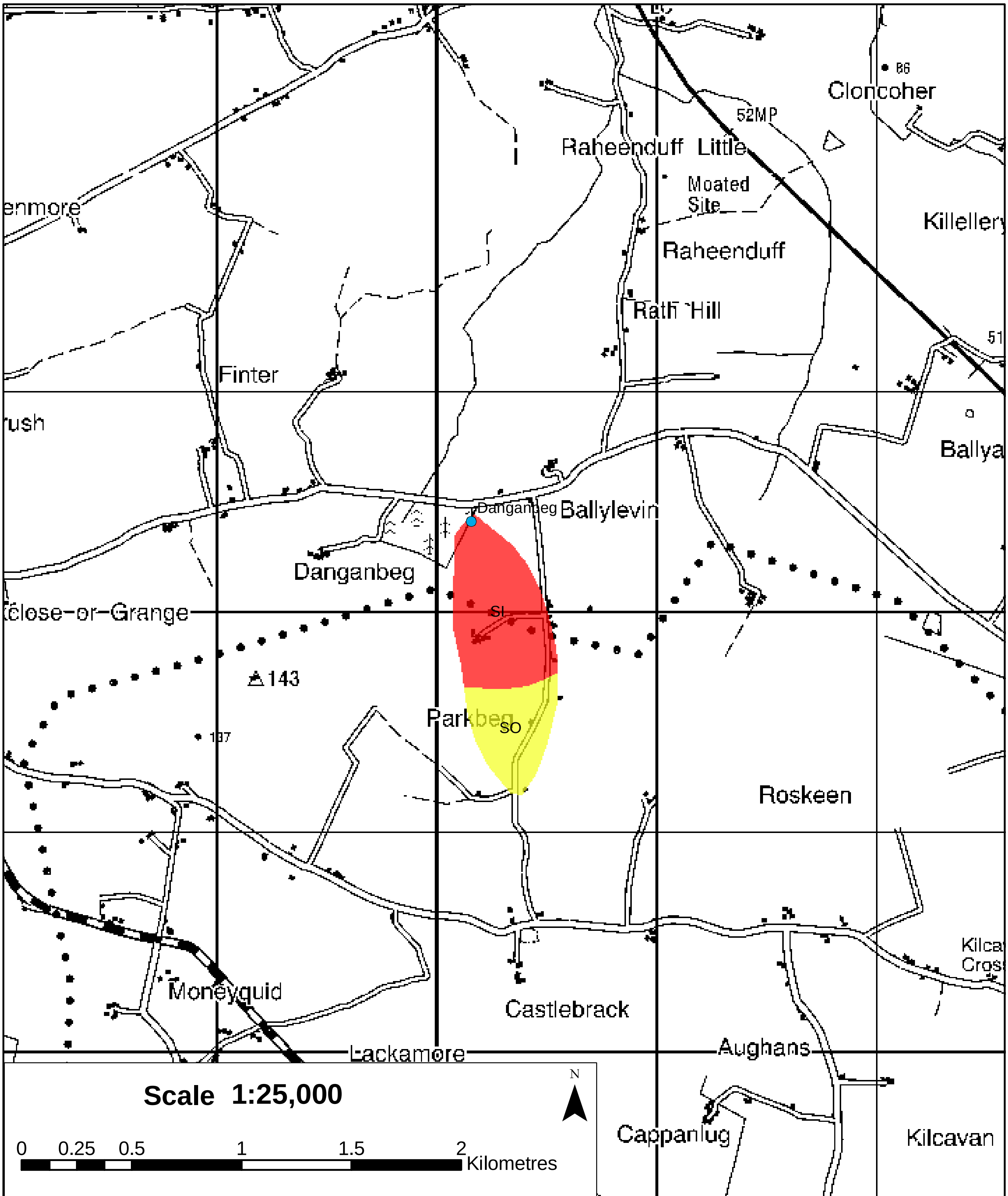
Spring

This Source Protection Area map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessements and will frequently require site investigations to determine the risk to groundwater.

The map is intended for use in conjunction with groundwater protection responses for potentially polluting activities, which lists the degree of acceptability of these activities in each zone and describes the control measures necessary to prevent pollution.

Project Hydrogeologist:	**Coran Kelly**
Project Manager:	**Donal Daly**
Digital Map Production:	**Antonio Manna**

ESTO FIDELIS



LEGEND

SI Inner Protection Zone

SO Outer Protection Zone

Spring

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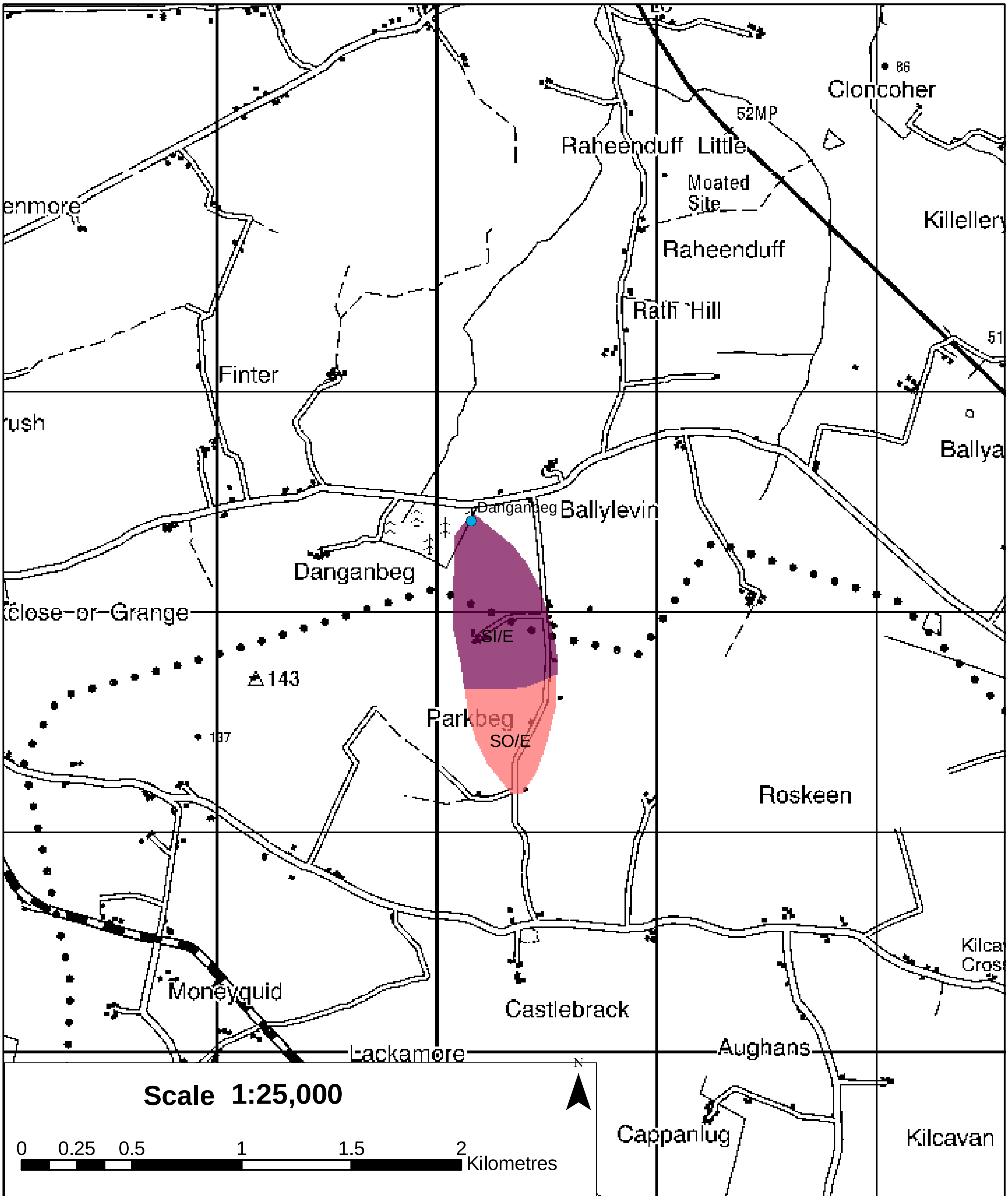

SOURCE PROTECTION ZONES

VULNERABILITY RATING	SOURCE PROTECTION ZONES	
	Inner SI	Outer SI
Extreme (E)	SI/E	SO/E
High (H)	Not Present	Not Present
Moderate (M)	Not Present	Not Present
Low(L)	Not Present	Not Present

Spring

This Source Protection Area map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessements and will frequently require site investigations to determine the risk to groundwater.

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ESTO FIDELIS

GSI