Establishment of Groundwater Zones of Contribution

Mount Lucas Group Water Scheme, Co. Offaly

March 2017

and

Mount Lucas Group Water Scheme

Groundwater Source Protection Zones

August 1996

‘Note:

Since the Mount Lucas Group Water Scheme Groundwater Source Protection Zones report was published (1996), the spring was replaced by a borehole. The Mount Lucas Group Water Scheme established the Groundwater Zone of Contribution for the borehole in 2017.

The most up-to-date version of the Zone of Contribution (ZOC) for the scheme and other maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).’

Establishment of Groundwater Zones of Contribution

Update Report 2016

Mount Lucas Group Water Scheme, Co. Offaly

March 2017

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and

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Mount Lucas GWS

The National Federation of Group Water Schemes

Acknowledgements

Frank Slattery, Mount Lucas GWS

The National Federation of Group Water Schemes

Joe Gallagher, Barry Deane

Document control information

Revision	Date	Author	Checked	Approved
I	28.06.2016	KLI	22.07.2016	Monica Lee
II	25.07.2016	KLI	30.08.2016	Monica Lee
Final Draft	09.09.2016	KLI	13.09.2016	Monica Lee
Final	07.03.2017	KLI	07.03.2017	Monica Lee

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 Mount Lucas 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 Mount Lucas Group Water Scheme in 1996 (Hudson, M. (1996). Mount Lucas Group Water Scheme, Groundwater Source Protection Zones. Geological Survey of Ireland).

However since this time the available scientific understanding and knowledge has evolved and this current report has revisited the original 1996 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.

Mount Lucas GWS is supplied by a well abstracting groundwater from limestone bedrock that is categorised as a Locally Important Aquifer that is generally moderately productive (Lm).

[1] Geological Survey of Ireland, 2000.

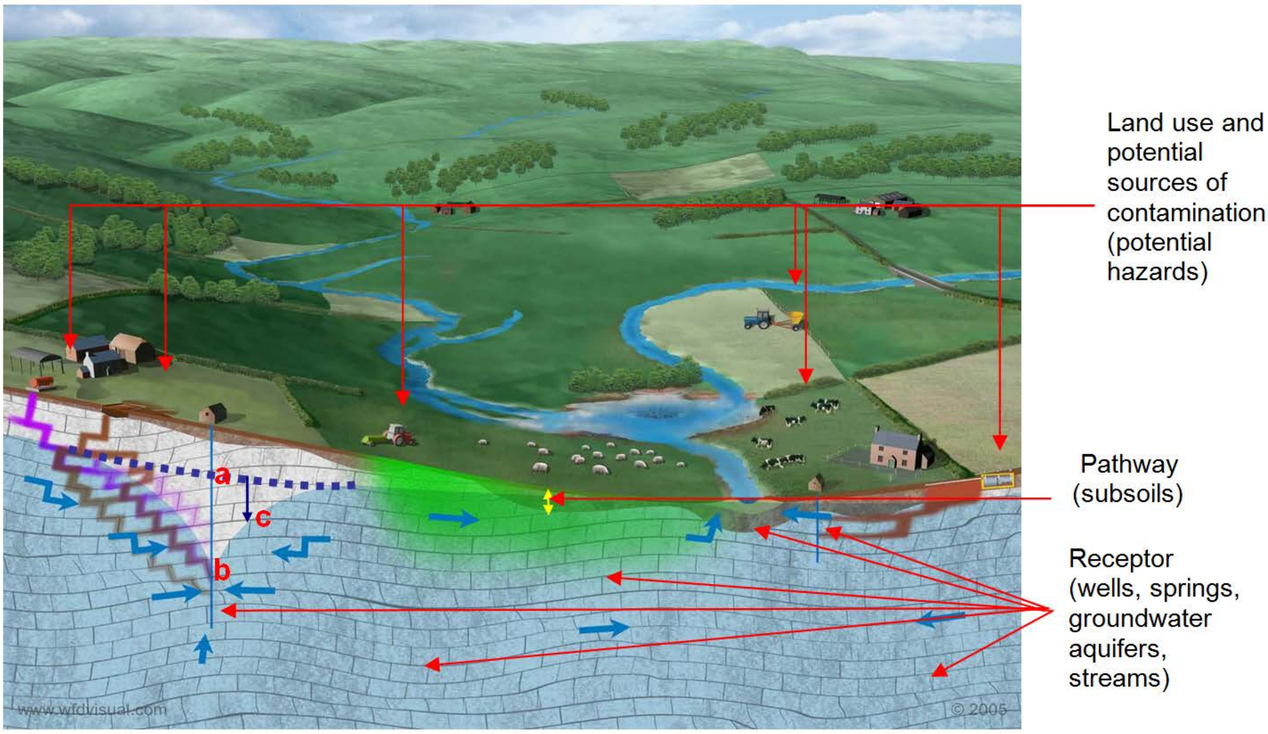

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Mount Lucas Group Water Scheme (GWS) is currently supplied by one well in the townland of Riverlyons, Co. Offaly (Figure 1). The site is located approximately 3 km east of Daingean village and approximately 500 m south of the R402 which is the main Daingean to Edenderry road. The well is located 200 m south of the Philipstown River. The land slopes gently down from the south towards the river in the north.

The GWS was originally supplied by a shallow spring at the same location, this spring was deemed highly vulnerable to contamination and so was replaced by a borehole approximately 15 years ago. The well head is located within small fenced compound that also contains the pump house (Photo 1) and a third party, neighbours well. The GWS currently supplies 144 connections, which includes approximately 10 farms.

The well is housed within a subsurface concrete sump, covered by a metal manhole lid that is flush with the ground. The manhole cover is surrounded by a concrete apron that slopes away from the well head (Photos 2 and 3). The pump house contains the treatment unit consisting of chlorination.

The well is pumped for 8 hours per day at a rate of 14 – 15 m^3/hr, which is equivalent to around 120 m^3/d. The GWS have a 454 m^3 (100,000 gallon) reservoir which is normally filled to hold about 400 m^3.

Photo 1 – Mount Lucas GWS Pump House

Photo 2 – View of well head from the pump house

Photo 3 – Internal view of Well Head

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

Table 1. Supply Details

	Mount Lucas GWS Well
Grid reference	250094 226962
Townland	Riverlyons
Source type	Borehole
Constructed	Approx. 2000 - 2001
Constructed By	Unknown
Owner	Mount Lucas GWS
Elevation (m aOD)	76 m
Total depth (m)	106 m
Construction details	250 mm steel casing, depth of casing unknown
Depth to rock (metres below ground level, m bgl)	3 – 5 m [2]
Static water level (m bgl)	1.75 m bgl – 09/05/2016
Pump intake depth	Unknown
Current abstraction rate (GWS)	120 m^3/d
Reported yield (m^3/d)	Unknown
Number of connections	144
Estimated specific capacity (m^3/d/m)	Unknown
Estimated transmissivity (m^2/d)	Unknown

[2] Hudson, M. (1996). Mount Lucas Group Water Scheme Groundwater Source Protection Zones. Geological Survey of Ireland.

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)	850	Met Eireann average annual rainfall data 2012 - 2015
Annual Evapotranspiration Losses (mm)	437	Met Eireann (www.met.ie)
Annual Effective Rainfall (mm)	413	National Groundwater Recharge Data (www.gsi.ie)
Topography	The site is at an elevation of 76 m aOD. The land slopes gently downhill from south to north towards the Philipstown River. There are a number of small local high points around the area.	
Land use	Agricultural land surrounds the site with low intensity grazing and grassland the predominant activities. A number of houses and farm yards are located within 300 m of the well. The Mount Lucas Wind Farm is located to the east of the GWS site approximately 1.5 km away.	
Surface Hydrology	The well is located 200 m south of the Philipstown River. A number of small unnamed streams drain the area towards the river. The overflow from the spring at the site, once used by the GWS, forms a small stream that flows northwards into the Philipstown River.	
Topsoil	The well is underlain by topsoils classified as surface water gleys (Teagasc 2006).	
Subsoil (**Figure 2**)	Subsoils underlying the site are classified as Till derived from limestone (Teagasc 2006). Trial pits dug in the area (Hudson 1996) indicate that the till is composed predominantly of fine sand (approx. 70%) with sub-rounded to sub-angular clasts of limestone up to 400 mm in size. Silt was also present within the till together with a small percentage of clay. Large areas of peat surround the site and some small areas where subsoil is absent (rock is close to or at the surface) on the higher ground to the north at Killoneen Hill.	
Groundwater Vulnerability (**Figure 3**)	Extreme (E) at the well and on the higher ground at Killoneen to the north (See **Appendix 1**). High in the surrounding areas with areas rated as Moderate (M) or Low (L) further to the east and west (see **Appendix 1**).	
Geology (**Figure 4**)	The bedrock in this area is classified as the Edenderry Oolite Member which is part of the Dinantian Pure bedded Limestones rock unit group. This is a pale grey-light blue limestone (composed of small spherical grains).	
Aquifer (**Figure 5**)	**Locally Important (Lm) – Bedrock which is generally moderately productive.** The GWB description: the Bog of Allen peat is the main strata overlying the limestone aquifer in this groundwater body. As the limestones are pure, relatively high permeabilities could be expected. However, evidence suggests that this is not always the case perhaps because of poorly developed bedding. The permeability is estimated at 10 – 20 m/d and the porosity at 0.02 (Hudson 1996). Regionally flow systems are unlikely as this is not a regionally karstified aquifer. The aquifer is likely to be permeable to depths of 30 m.	
Groundwater Body	Rhode GWB. Categorised as ‘at risk of not achieving good status’ (www.epa.ie)	
Recharge Coefficient (**Appendix 2**)	60%	Moderate permeability subsoil overlain by ‘poorly drained’ (gley) soil – overlying a Locally Important Bedrock Aquifer which is generally moderately productive (Lm), High (H) vulnerability.
Average Recharge (mm/yr)	248	

A very short duration pumping test was conducted on 09/05/2016. The length of time the pump was switched off prior to the monitoring period is unknown so it is uncertain if the start water level is a true static (non-pumping) water level. Water levels were monitored for a period of 12 minutes, during which time the drawdown in the water level was 5.01 m (from start water level of 1.75 m to 6.76 m below ground level) for an abstraction rate of 120 m^3/d. Once the pump was switched off the water level rose back up the well quickly, rising by 2.2 m within the first minute. The water level recovery was monitored for 15 minutes during which time the water level rose to 1.82 m, which was to within 0.07 m of its original level at the start of the short test. Although the rate of drawdown had slowed down towards the end of the pumping period (12 minutes) steady state conditions had not been achieved.

Field measurements of physio-chemical parameters were taken during the site visit on 09/05/2016. These were as follows: water temperature 13.6 °C, pH 7.5, conductivity 699 µS/cm.

A second site visit was undertaken on 16/05/2016 in order to collect water levels and data from wells in neighbouring houses. Unfortunately it was not possible to make contact with any homeowners on the day.

3.2 Hydrochemistry and water quality

Two sources of water quality data were available for the Mount Lucas GWS:

- Offaly County Council check and audit monitoring records for 2014 – 2015. This data is for treated water samples. It is presented in **Appendix 3**.

- Raw water (untreated) sample dating from June 2016 collected by the National Federation of Group Water Schemes as part of this project. A summary of this data is presented in **Table 3** below with the full analysis presented in **Appendix 3**.

The analytical results have been compared to the Threshold Values from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010); and/or the drinking water limits from the Drinking Water Regulations (SI No. 122 of 2014), whichever is the lower.

The Offaly County Council treated water results demonstrate that the treated water quality is largely in compliance with required standards. A sample collected in May 2014 had elevated concentrations of trihalomethanes at 5.65 µg/l, above the threshold value of 0.075 µg/l. The isolated nature of this elevated result suggests that it may reflect either a sampling or a lab error. The sample collected in May 2015 had a number of elevated parameters; including colour, turbidity, iron, pesticides (mecoprop). Information provided by the GWS suggests that the location from which this sample was collected was compromised and the elevated concentrations recorded simply reflect poor sample integrity rather than the water quality itself.

The bacteriological water quality results for the treated water were all within acceptable limits indicating that the chlorination dosing system was operating efficiently at that time.

The raw water sample collected in June 2016 indicates that the groundwater in the Mount Lucas well is very hard, with a total hardness of 339.2 mg/l $CaCO_{3.}$ Both the chemical and bacteriological water quality are within acceptable limits currently.

Table 3. Summary Raw Water Quality Data

Parameter	Mount Lucas GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
Conductivity @ 20C	591	µS/cm	800 (TV)
Sodium	8.37	mg/l	150 (TV)
Chloride	12.86	mg/l	24
Ammonium NH_4	0.03	mg/l NH_3	0.3 (DWL)
Nitrate as NO_3	16.02	mg/l	37.5 (TV)
Nitrite as NO_2	0.03	mg/l	0.5 (TV)
Total Hardness (Kone)	339.2	mg/l $CaCO_3$	
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	2.58	µg/l	<50 (DWL)
E Coli	<1.0	cfu/100ml	0
Total Coliforms	<1.0	cfu/100ml	0

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 consist of moderate permeability tills overlain by poorly draining topsoils. However to the south of the well in the direction that the ZOC extends the topsoils have higher permeabilities. Although large areas of peat surround the till, meaning a lot of the rainfall falling over the land surface will runoff to streams and ditches, the area of land occupied by the ZOC is underlain by subsoils that are more freely draining. The remaining portion of rainfall that percolates downwards will enter the bedrock through its upper weathered zone which is likely to have a well developed network of fractures and fissures. The deeper bedrock will have less fractures and fissures but some groundwater will access these deeper layers. The groundwater will then move through the bedrock under gravity and therefore downhill, which is likely to be a subdued reflection of the land surface until it reaches a discharge point such as the Philipstown River to the north. The GWS well is intercepting some of this groundwater before it reaches the river.

The Mount Lucas GWS well is abstracting groundwater from the network of fractures and fissures within the limestone bedrock. The 1996 report (Hudson) completed for this source, although a spring was used by the GWS at the time as it was prior to drilling the current well, indicates that the static water level in the spring is higher than the level of the Philipstown River to the north, confirming that groundwater flows northwards towards the river.

The limestone bedrock is classified as a Locally important Aquifer that is generally moderately productive (Lm) and the vulnerability of the aquifer to contamination is Extreme (E) in the region of the wells and High (H) on surrounding land.

The Zone of Contribution (ZOC) will extend upgradient (upslope) from the wells in a southerly direction. Therefore the ZOC occupies an area underlain by a limestone aquifer whose vulnerability to contamination varies from High (H) to Moderate (M).

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.

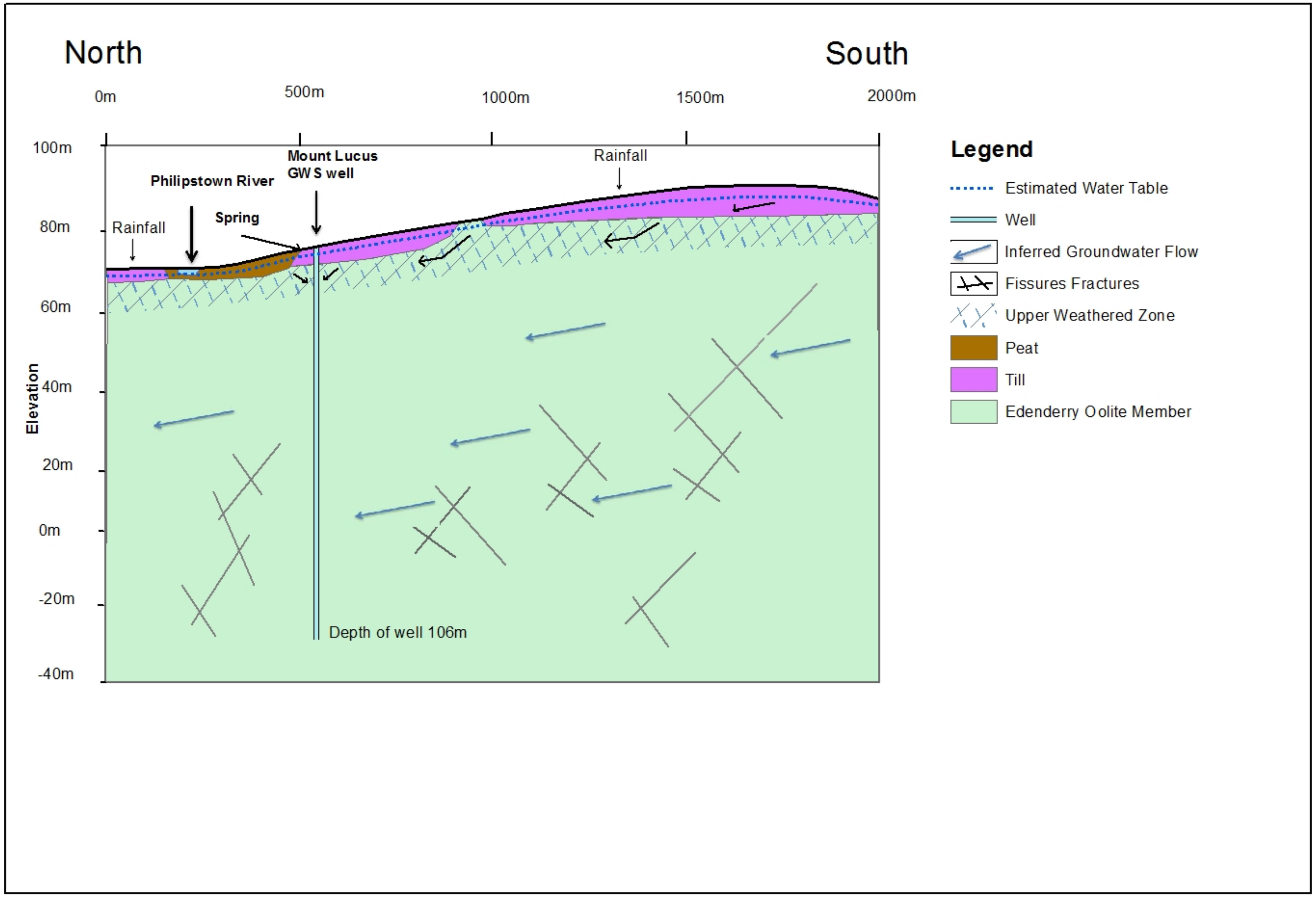

Diagram 2: Schematic Cross Section and Conceptual Model

4.2 Boundaries

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 (**Appendix 5**).

The **Northern boundary**, is the 'downgradient' limit', beyond which groundwater will not be drawn back upgradient under the influence of the pump. It is estimated using the uniform-flow equation (Todd 1980), as 115 m. There is some uncertainty over whether the high ground to the northeast of the well is contributing groundwater to the well. If this is the case then there is a possibility that surface water from the Philipstown River could be drawn into the well. While this is considered unlikely, a conservative approach is adopted here and the upgradient boundary has been extended to to coincide with the Philipstown River.

The **Southern Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the local topography. The boundary extends to the local topographic high point at 92 m aOD to the south of the well.

The **Western and Eastern Boundaries** define the half-width of the ZOC. There is a degree of uncertainty associated with these boundaries but they are generally parallel to the inferred direction of groundwater flow. The uniform flow equation (Todd 1980) was used to estimate the half-width of the ZOC as 360 m, or 720 m for the full-width. There is some uncertainty with the eastern boundary as it is unclear if the higher ground to the northeast of the well is contributing groundwater through a network of subsurface fissures and conduits. In order to be conservative the eastern boundary has been adjusted to take account of the topography and recharge characteristics. The two boundaries meet on the downgradient side of the boreholes at the ‘downgradient limit’.

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

The current abstraction rate from the Mount Lucas GWS well is 120 m^3/d. In order to account for seasonal fluctuations in abstraction volumes plus uncertainties 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 180 m^3/d i.e. 150% of the known current abstraction rate.

The available recharge is estimated at 248 mm/yr (see Table 2). The minimum geographical area required to sustain an abstraction of 180 m^3/d (or 65,700 m^3/yr), based on the available recharge of 248 mm/yr (or 0.248 m/yr) is 0.26 km^2 (or 264,919 m^2). The delineated ZOC measures 1.26 km^2 (or 1,266,818 m^2) which is considered more than adequate.

5 Conclusions

The Mount Lucas GWS currently abstracts 120 m^3/d from one well abstracting groundwater from limestone bedrock classified as a Locally Important Aquifer that is generally moderately productive (Lm). The scheme currently has 144 connections, which includes around 10 farms.

The vulnerability of the groundwater supplying the well is High (H) immediately around the well but with some areas of Moderate (M) to Low (L) elsewhere in the ZOC. The ZOC extends to the south of the well and is occupied by agricultural land, farm yards and houses. Potential sources of contamination to the well include septic tanks (in particular old or inefficient tanks that have not been emptied regularly) and agricultural activities e.g. grazing, landspreading, slurry pits or slatted units.

Although the well is reasonably modern (drilled around 2000 – 2001) very little is known of its integrity. The depth of steel casing or the presence of a grout seal is unknown. A lack of grout seal means that the well is vulnerable to contamination arising at or close to the surface particularly in close proximity to the well.

The raw water sample collected in June 2016 indicates that the groundwater in the Mount Lucas well is very hard, with a total hardness of 339.2 mg/l $CaCO_3$. Both the chemical and bacteriological water quality is within acceptable limits currently.

Any landuse changes or planning permissions within the ZOC should be carefully monitored and assessed for likely impacts on the well.

6 Recommendations

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

Essential:

- Routine **untreated** groundwater monitoring 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. Given the vulnerability of the well it is essential that bacteriological parameters are regularly monitored in the raw water.

- The integrity of the well is unknown and information on the depth of casing in the well was not available. The drilling company should be identified and contacted to obtain borehole logs.

- Any future planning applications made within the ZOC should be assessed for their potential impact on the quality of groundwater (refer to the local authority's county development plan and Groundwater Protection Schemes Document, 1999). Similarly any significant changes in land use, such as forestry clearance, should be monitored.

- 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. The Good Agricultural Practice for the Protection of Water Regulations 2014 should also be adhered too.

- The old county council well at the site should be properly decommissioned as, in its current state, it may act as a pathway for contaminants to gain access to the aquifer.

Desirable:

- Comprehensive hazard mapping (e.g. septic tanks, slatted units and slurry pits) within the delineated ZOC should be undertaken. This should ideally include septic tank inspections to clarify their condition and inspections of high risk features in farm yards such as slatted units and slurry pits.

- The GWS borehole and its ZOC should be assessed to establish the level of risk, if any, posed by cryptosporidium.

- Ideally, the well head should be finished above ground in order to provide maximum protection against the ingress of contamination arising at the surface. Currently the concrete apron around the well head slopes outwards but the well head itself is finished at ground level. The elevated pesticides level in one sample may suggest that contaminated runoff in the region of the well may be able to enter it.

- In order to establish if the high ground to the north is contributing flow to the wells, a pumping test should be conducted, with monitoring wells on the northern side of the Philipstown River monitored throughout.

Other:

- The following EPA guidelines may serve as future useful reference documents for the Mount Lucas 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[3].

    - 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[4].

    - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection

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

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

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

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

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FIGURES

Figure 1. Location Map

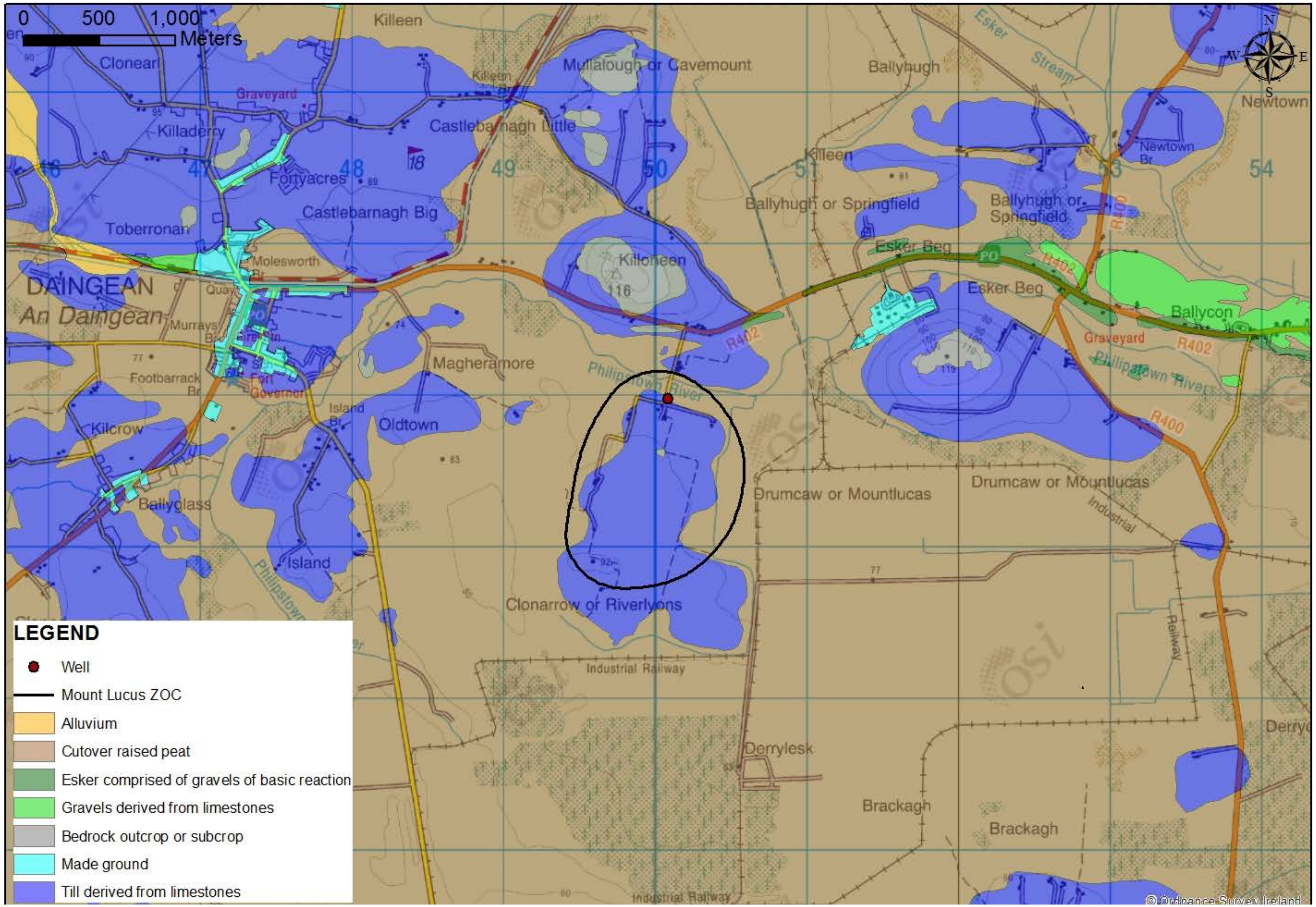


Figure 2. Subsoils Map

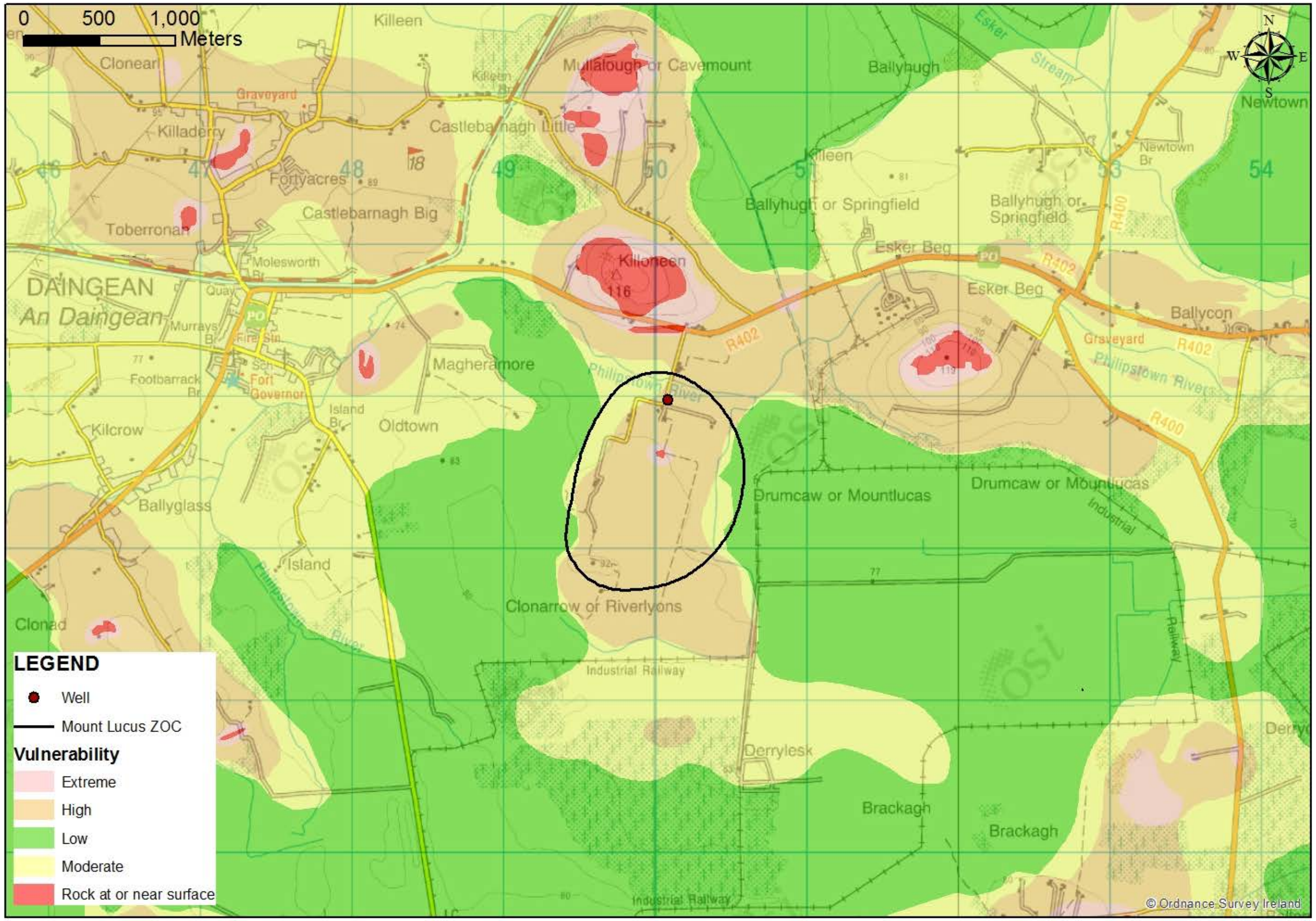


Figure 3. Groundwater Vulnerability Map

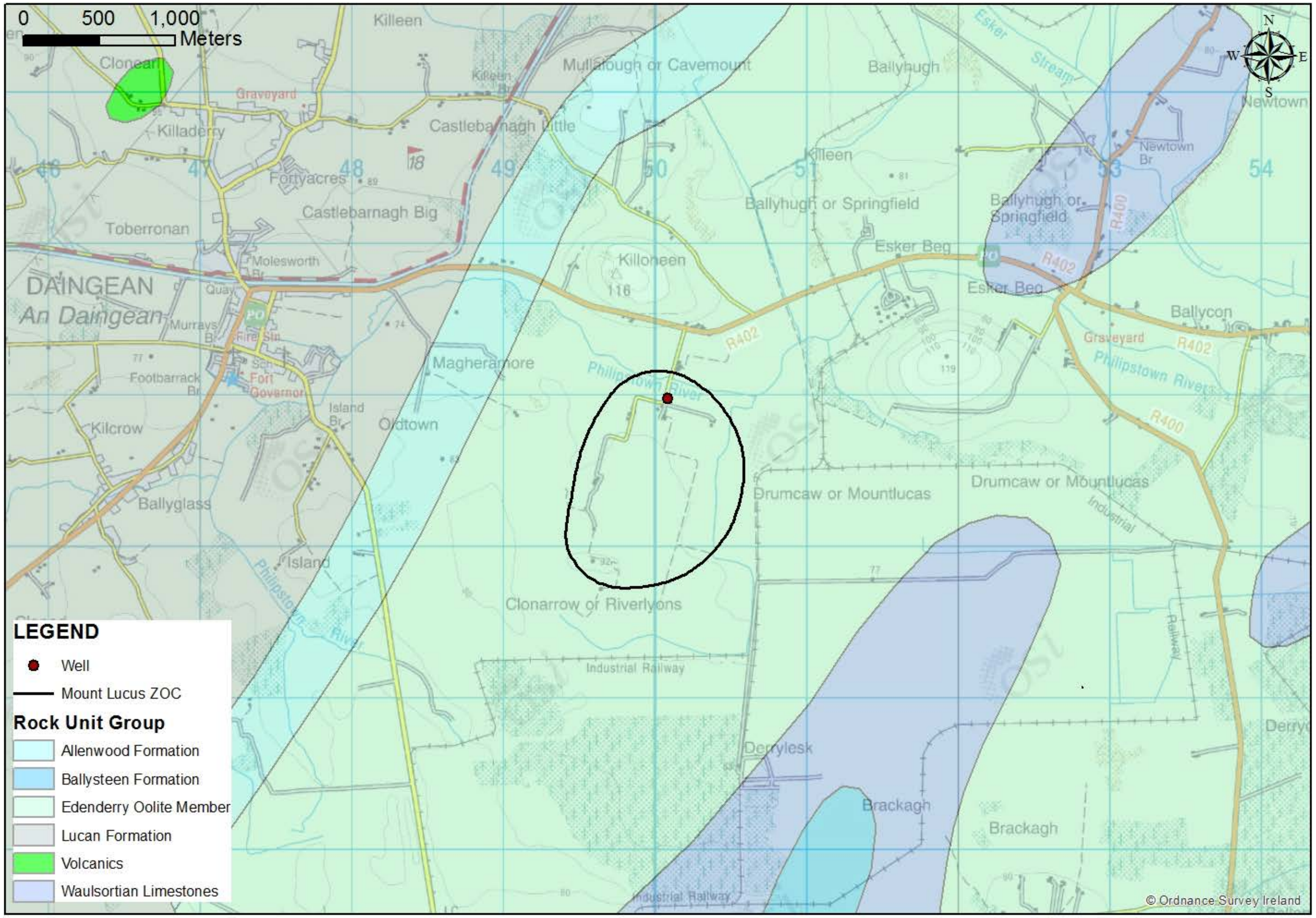


Figure 4. Rock Unit Group Map

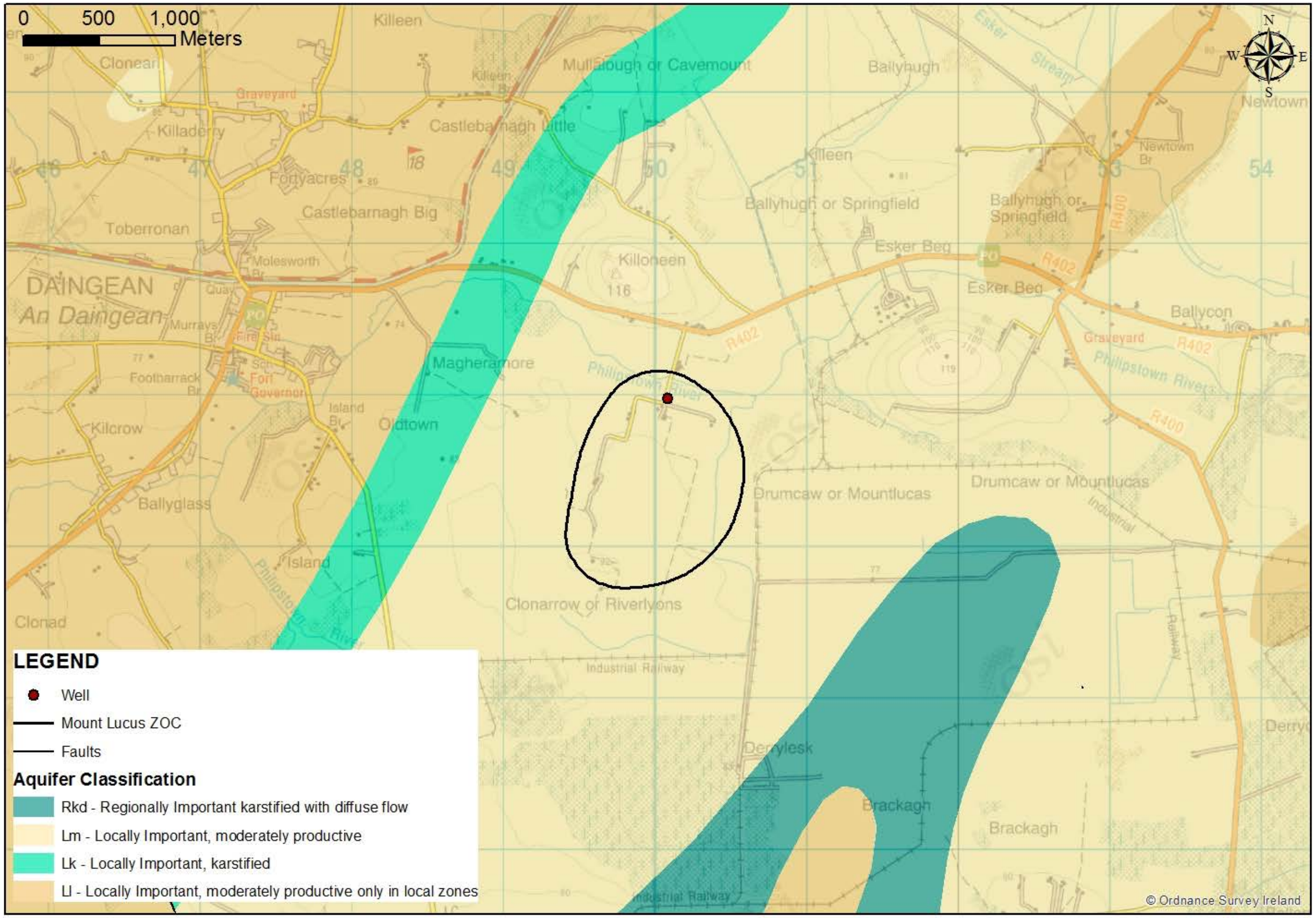


Figure 5. Aquifer Map

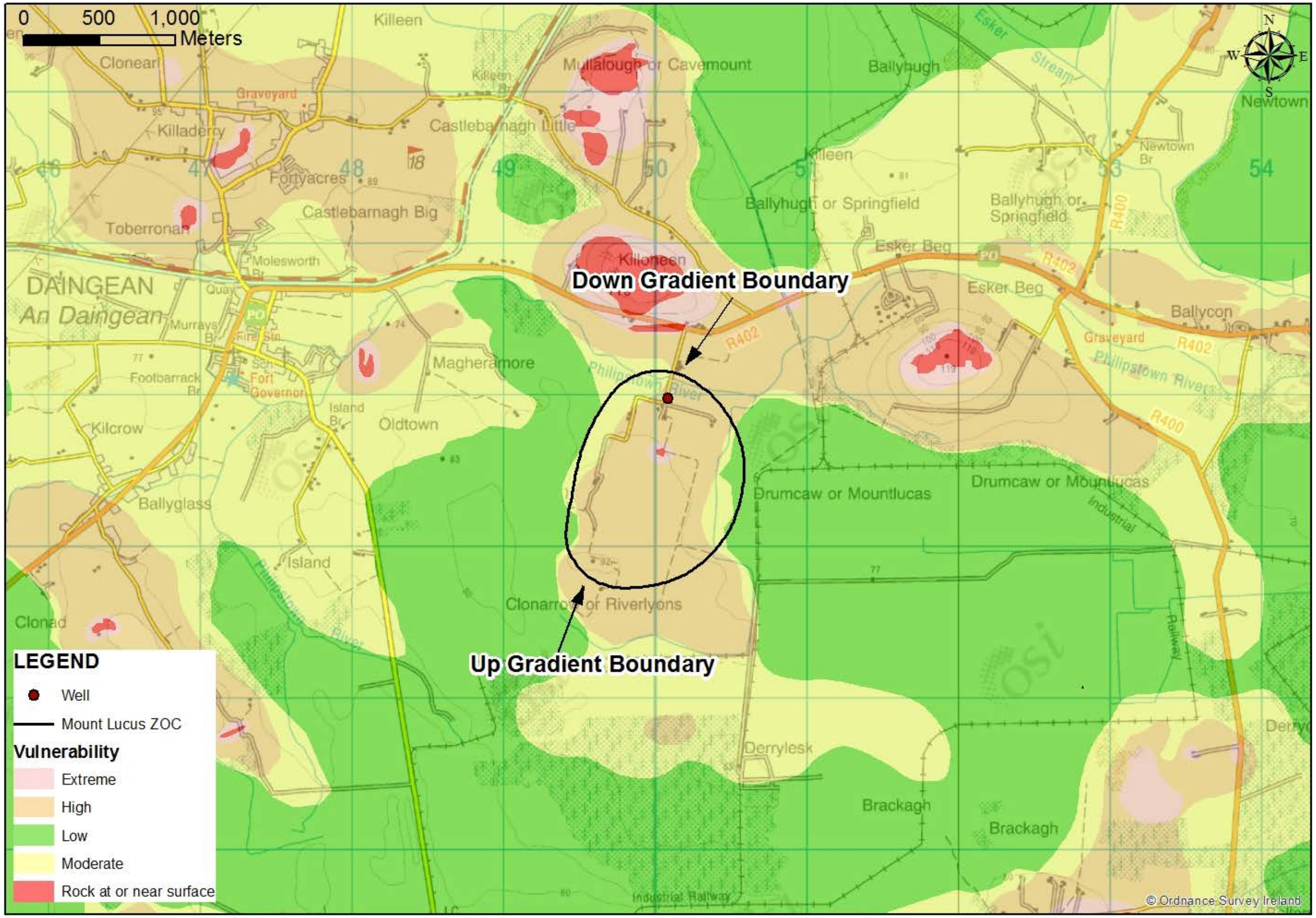


Figure 6. ZOC Boundary Map

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

Groundwater Vulnerability

Introduction

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

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

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

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

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

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

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

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

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

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

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

Sources of Vulnerability Data

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

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

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

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

Thickness of the Unsaturated Zone

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

APPENDIX 2

Groundwater Recharge

Introduction

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

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using Hunter Williams et al (in press) (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
High to Low (HL)	5.i	High predicted permeability subsoils (Sand/gravels)	30	80-90	100
	5.ii	Moderate permeability subsoil overlain by well drained soils	35	50-70	80
	5.iii	Moderate permeability subsoils overlain by poorly drained soils	10	15-30	50
	5.iv	Low permeability subsoil	1	5-10	20
	5.v	Peat	1	5	20

Note: Areas of 'made ground' are assigned a recharge coefficient of 20%. Before full national groundwater vulnerability coverage was achieved in 2012, in unmapped regions the Extreme and 'High to Low' vulnerability categories were used.

APPENDIX 3

Hydrochemistry and Water Quality

Raw Water Data, Mount Lucas GWS, June 2016

Parameter	Mount Lucas GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	<1	mg/l	
Turbidity	0.06	N.T.U.	No abnormal change
pH	7.3	pH units	6.5 – 9.5
Conductivity @ 20C	591	µS/cm	800 (TV)
Alkalinity	309.53	mg/l $CaCO_3$	
Sodium	8.37	mg/l	150 (TV)
Chloride	12.86	mg/l	24
Ammonium NH_4	0.03	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	16.02	mg/l	37.5 (TV)
Nitrite as NO_2	0.03	mg/l	0.5 (TV)
Dissolved Oxygen (%)	8.88	mg/l O_2	
Total Hardness (Kone)	339.2	mg/l $CaCO_3$	
Magnesium, total	23.3	mg/l	50 (DWL)
Colour, apparent	<1.0	mg/l Pt Co	No abnormal change
Silica as SiO_2	7.53	mg/l	
Sulphate	10.63	mg/l	187.5 (TV)
Orthophosphate as PO4-P	0.01	mg/l	
Calcium, total	97.4	mg/l	
Aluminium, dissolved	<20	µg/l	150 (TV)
Iron	<20	µg/l	200 (DWL)
Manganese, dissolved	2.58	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	19	µg/l	
Barium, dissolved	24	µg/l	
Total Organic Carbon	1.5	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	193	µg/l	
E Coli	<1.0	cfu/100ml	0
Total Coliforms	<1.0	cfu/100ml	0
Fluoride	0.09	mg/l	0.8 (DWL)

Local Authority Compliance Monitoring Data – treated water – 2014 - 2015

Parameter	**Units**	**Drinking Water Limit (DWL) or Threshold Value (TV)**	**20.01.14**	**19.05.14**	**09.06.14**	**11.08.14**	**01.09.14**	**13.10.14**	**23.02.15**	**20.04.15**	**25.05.15**	**08.06.15**	**24.08.15**	**19.10.15**
1,1,1-Trichloroethane	µg/l										<0.04			
1,2-Dichloroethane	µg/l	2.25 (TV)		<0.07							<0.07			
2,3,6-TBA Trichlorobenzoic Acid	µg/l			<0.025							<0.007			
2,4-D Acid Herbicide	µg/l			<0.003							<0.006			
Aluminium, dissolved	µg/l	150 (TV)	<0.9	1.3	1.4	<0.9	<0.9	0.9	0.9	3.8	93.2	1.3	3.8	1.9
Ametryn	µg/l			<0.002							<0.01			
Ammonium	mg/l	65 – 175 (TV)	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	0.251	0.021	<0.015	<0.015
Antimony	µg/l	5 (DWL)		<0.033							0.151			
Arsenic, dissolved	µg/l	7.5 (TV)		0.26							0.45			
Atrazine	µg/l	0.075 (TV)		<0.001							<0.002			
Benzene	µg/l	0.75 (TV)		<0.02							<0.02			
Benzo(a)pyrene	µg/l	7.5 (TV)		0							<0.002			
Boron	mg/l	0.75		<0.021							0.006			
Bromate	µg/l			0.5							<0.1			
Bromoxynil	µg/l			<0.003							<0.003			
Cadmium, dissolved	µg/l	3.75 (TV)		0.016							0.267			

Parameter	Units	Drinking Water Limit (DWL) or Threshold Value (TV)	20.01.14	19.05.14	09.06.14	11.08.14	01.09.14	13.10.14	23.02.15	20.04.15	25.05.15	08.06.15	24.08.15	19.10.15
Chloride	mg/l	24		21							3.7			
Chromium, dissolved	µg/l	37.5 (TV)		2.68							0.39			
Clopyralid	µg/l			<0.011										
Clostridium Perfringens	cfu/100ml	0	0	0	0	0	0	0	0	0	0	0		
Coliform Bacteria	MPN/100ml	0	0	0	0	0	0	0	0	0	0	0		
Colony Count @ 22degC	no./ml	No abnormal change		0							0			
Colour, apparent	mg/l Pt Co	No abnormal change							<0.5	<0.7	**15.3**	<0.5		
Conductivity @ 20C	µS/cm	800 (TV)	591	591	608	591	589	593	557	593	42	583		
Copper, dissolved	µg/l	1500 (TV)		0.003							1.19			
Cyanide	µg/l	37.5 (TV)		<0.5							<0.5			
Dicamba	µg/l			<0.008							<0.001			
Dichlobenil	µg/l			<0.001										
Diuron	µg/l	0.075 (TV)		<0.003							<0.003			

Parameter	**Units**	**Drinking Water Limit (DWL) or Threshold Value (TV)**	**20.01.14**	**19.05.14**	**09.06.14**	**11.08.14**	**01.09.14**	**13.10.14**	**23.02.15**	**20.04.15**	**25.05.15**	**08.06.15**	**24.08.15**	**19.10.15**
E Coli	cfu/100ml	0	0	0	0	0	0	0	0	0	0	0		
Enterococci	cfu/100ml	0		0							0			
Fluoride	mg/l	0.8 (DWL)		0.11							0.03			
Iron	µg/l	200 (DWL)	<3.6	5.1	<3.6	<3.6	<3.6	<3.6	<3.6	<3.6	**694**	<3.6		
Lead, dissolved	µg/l	18.75 (TV)		0.21							4.78			
Malathion	µg/l			<0.002							<0.01			
Manganese, dissolved	µg/l	<50 (DWL)		<2.6							17.5			
MCPA	µg/l	0.075 (TV)		<0.005							0.007			
Mecoprop Total	µg/l	0.075 (TV)		<0.002							**2.955**			
Mercury	µg/l	0.75 (TV)		<0.02							<0.02			
Metazachlor	µg/l			<0.002							<0.002			
Nickel, dissolved	µg/l	15 (TV)		2.16							0.76			
Nitrate as NO_3	mg/l	37.5 (TV)		20.4							0.55			
Nitrite as NO_2	mg/l	0.5	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	0.015	<0.009	<0.009	<0.009
Odour	Odour units		0	0	0	0	0	0	0	0	0	0	0	0
PAHs	µg/l	0.075 (TV)		0							0.01			
Permethrin cis	µg/l			<0.002							<0.002			
Permethrin trans	µg/l			<0.001							<0.001			

Parameter	Units	Drinking Water Limit (DWL) or Threshold Value (TV)	20.01.14	19.05.14	09.06.14	11.08.14	01.09.14	13.10.14	23.02.15	20.04.15	25.05.15	08.06.15	24.08.15	19.10.15
Pesticides total	µg/l	0.375 (TV)		0.025							**2.96**			
pH	pH units	6.5 – 9.5	7.3	7.61	7.48	7.52	7.47	7.65	7.43	7.46	6.65	7.5	7.46	7.61
Propazine	µg/l			<0.002							<0.01			
Selenium	µg/l	10 (DWL)		0.77							<0.31			
Simazine	µg/l	0.075 (TV)		<0.001							<0.003			
Sodium	mg/l	150 (TV)		8.9							2.3			
Sulphate	mg/l	187.5 (TV)		10.2							4.13			
Taste	Taste units	No abnormal change	0	0	0	0	0	0	0	0		0	0	0
Tecnazene	µg/l			<0.001							<0.003			
Tetrachloroethane & Trichloroethane	µg/l	7.5 (TV)		<0.1							<0.1			
Total indicative dose	mSv/year	0.10 (DWL)		<0.1										
Total Organic Carbon	mg/l	No abnormal change		0.42							5			
Triclopyr	µg/l			<0.007							<0.006			
Trihalomethanes (total)	µg/l	0.075 (TV)		**5.65**							0			
Tritium	Bq/L	100 (DWL)		<5										
Turbidity	N.T.U.	No abnormal change	0.06	0.22	0.11	<0.03	<0.04	<0.03	<0.04	0.04	**2.31**	<0.04	0.09	<0.08

APPENDIX 4

ZOC Boundaries

Boundaries

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. It is estimated using the uniform-flow equation (Todd 1980), which is;

Down-gradient distance = $Q / 2\pi Ti$,

Where;

Q = the daily discharge rate (120 m^3/d – which is increased by 50% to 180 m^3/d in order to be conservative)

Π = 3.14

T = the transmissivity (25 m^2/d) - estimate

i = the non-pumping groundwater gradient (assuming the groundwater gradient is parallel to the topographic gradient), 0.01

The 'down-gradient limit' is therefore estimated as 115 m. This boundary is extended to coincide with the Philipstown River.

The **Southern Boundary**, represents the upgradient boundary of the zone of contribution. This is based on the local topography. The boundary extends to the local topographic high point at 92 m aOD to the south of the well.

The **Western and Eastern Boundaries** define the half-width of the ZOC. There is a degree of uncertainty associated with these boundaries but they are generally parallel to the inferred direction of groundwater flow. The uniform flow equation (Todd 1980) was used to estimate the half-width of the ZOC, as follows;

$y_L = Q/2Ti$,

Where;

Q = the daily discharge rate (120 m^3/d - which is increased by 50% to 180 m^3/d in order to be conservative)

T = the transmissivity (25 m^2/d)

i = the non-pumping groundwater gradient (assuming the groundwater gradient is parallel to the topographic gradient), 0.01

This estimates the half-width of the ZOC as 360 m., or 720 m for the full width. This boundary is adjusted to take account of the topography and recharge characteristics. The two boundaries meet on the downgradient side of the boreholes at the 'downgradient limit'.

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.

MOUNTLUCAS GROUP WATER SCHEME

GROUNDWATER SOURCE PROTECTION ZONES

Matthew Hudson

Groundwater Section

Geological Survey of Ireland

August 1996

MOUNTLUCAS GROUP WATER SCHEME

1. SUMMARY OF WELL DETAILS

GSI no.	:	2321NEW003
Grid ref.	:	25014 22716
Owner	:	Mount Lucas Group Water Scheme
Well type	:	Dug
Elevation (top of casing/surface)	:	Approx. 76.2 m OD (Poolbeg).
Depth	:	2.04 m
Diameter	:	0.9 m
Depth-to-rock	:	3-5 m (to the south of the well)
Static water level : Winter	:	(At surface) 76.2 m O.D.
: Summer	:	Approximately 1 metre below ground level (75.2 m O.D.)
Pumping water level	:	74.72 m O.D. (1.48 m below top of casing on 31/7/96)
Drawdown	:	Approximately 0.5 m
Abstraction rate	:	110 m^3/d (1000 gal/hr)
Normal consumption (Summer)	:	110 m^3/d (approx. 24,000 gal/d on average, over approximately 24 hours)
(Winter)	:	90 m^3/d (approx. 20,000 gal/d on average, over approximately 20 hours)
Specific capacity	:	220 m^3/d/m (this is an approximate value from general pumping data)
Pumping test summary:	:	No pumping test was carried out.

2. METHODOLOGY

There were three stages involved in assessing the area, a detailed desk study, site visits and fieldwork, and analysis of the data. The desk study was conducted in the Geological Survey where the subsoil and bedrock geologies were compiled from the original 6" field sheets and more recent geological maps at 1:100,000 scale. Well details were obtained from a member of the group water scheme and several chemical analyses were obtained from Offaly County Council (Sanitary Services Section).

The second stage comprised site visits and fieldwork in the surrounding area. This included a walkover survey in order to further investigate the subsoils, geology, hydrogeology and vulnerability to contamination of the area around the source.

Stage three, the assessment stage, utilised analytical equations and hydrogeological mapping to delineate protection zones.

3. WELL LOCATION AND SITE DESCRIPTION

The well is located approximately 3 kilometres east of Daingean, off the main Edenderry to Daingean road (see Figure 1.). The well is protected by a steel cover at ground level and is located in a small pumphouse which is fenced off.

4. TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE

The well is located 200 metres to the south of the Philipstown River. The land slopes gently upwards to the south of the well to a height of 95 metres. This higher ground is well drained and is used as pasture and arable land. Areas of peat bog lie to the west and east of the well drained land, these areas are poorly drained, as is the area of land immediately bordering the river (this area is liable to flooding in winter). Two small seasonal streams are marked on 1/2" scale topographic maps, at the margins of the bog areas, these streams are shown on Figure 1.

5. GEOLOGY

5.1 Bedrock geology

The underlying geology of the area is the Edenderry Limestone (as shown in Figure 1). This is a pale grey-light blue oolitic limestone (composed of small spherical grains). The limestone is poorly exposed in the area, however where visible it is well jointed, the larger joints being vertical rather than horizontal. The beds dip approximately 10° to the west.

5.2 Quaternary (subsoils) geology

The subsoils are shown in Figure 2. A large area of sandy till covers the limestone immediately to the south of the well, coinciding with an area of well drained land. The till was exposed in the trial pits excavated 130 metres SSE of the well as part of a planning application. In addition other smaller sections, mainly in ditches and embankments were exposed around the fields south of the well. The till is composed predominantly of fine sand (approx 70%) with subrounded to subangular clasts of limestone up to 400 mm in size. Silt was also present within the till together with a small percent of clay.

5.3 Depth-to-rock

The deepest trial pit within the till reached a depth of 3.3 metres, when bedrock was reached (according to the landowner). Other sections in the till greater than 1 metre were not present in the area south of the well, however it is probable that the hill is rock cored, with a thin (3-5m) cover of till. The depth of the peat either side of the till is unknown, as is the presence of any underlying subsoil. Rock outcrops occur to the north of the river on top of the hill.

Due to the absence of data, depth to bedrock contours have not been drawn.

6. HYDROGEOLOGY

6.1 Data availability

Hydrogeological data for the Mountlucas area are very poor, including the area around the group water scheme. A well survey was conducted during the site visit on the 31/7/96, two shallow handpump wells were found and dipped, the location of these wells is shown on Figure 1.

6.2 Groundwater levels

Although groundwater level data for the area are poor, certain observations can be made. The water table is close to the surface in the immediate vicinity of the well, (less than 2 metres at the well), and at the ground surface during winter (there is a significant overflow from the well in winter). The pumping water level in the well was estimated at 74.72 m O.D. (1.48 m below the top of the casing) on 31/7/96. The trial pit (3.3 m deep) and the handpump well 80 metres SSE of the well (4.7m deep) were both dry on the 31/7/96, indicating that the till is unsaturated during the summer months and therefore that most of groundwater flow to the well is within the underlying limestone. The sandy till is likely to be saturated for part of the winter months.

6.3 Groundwater flow directions and gradients

The water table is likely to be a subdued reflection of topography in general, with groundwater flowing NNE towards the Philipstown River. Groundwater flow directions will vary between winter and summer months.

During the winter months, water levels will be relatively high and a recharge mound is likely to coincide with the topographic rise to the south of the well. Although a major component of flow will be towards the river, groundwater flow will also radiate outwards from the recharge mound and discharge into the seasonal streams to the east and west of the topographic rise. The dry streams during the summer and the dry handpump well SSW of the GWS allow the calculation of a approximate summer groundwater gradient. This gradient is estimated to be 0.005.

During the summer months groundwater levels drop, the seasonal streams are dry and groundwater flow is likely to be northwards towards the Philipstown River.

6.4 Meteorology and recharge

Rainfall data for the area are taken from a contoured rainfall map of Offaly (Burns, 1993) based on data from the Meteorological Service. For the years 1951 - 1980 the mean annual rainfall for the area was 850 mm. Evaporation data for the area are taken from a national contoured map as recorded by the Meteorological Service. Potential evapotranspiration (P.E.) is estimated as 475 mm/yr. Actual evapotranspiration (A.E.) is then calculated by taking 95% of the potential figure, to allow for soil moisture deficits for part of the year, so A.E. is estimated as 450 mm/yr. Using these figures the effective rainfall (E.R.) is taken to be approximately 400 mm/yr.

The presence of thin free draining soils, permeable till and rock close to surface over the area suggests that a high proportion of effective rainfall is infiltrating to the water table. Although the proportion of effective rainfall infiltrating to the water table is not known with certainty, it is assumed that 90% is a realistic figure and that actual annual recharge in the area is therefore approx. 360 mm.

These calculations are summarised below:

Average annual rainfall	850 mm
Estimated P.E.	475 mm
Estimated A.E. (93% P.E.)	450 mm
Effective rainfall	400 mm
Recharge (90% E.R.)	360 mm

6.5 Hydrochemistry and water quality

Samples of groundwater from the public supply are analysed regularly by the County Council at various private residences supplied by the group water scheme and at the well. Seven smples are available for analyses. from 1992 to 1995, one of these is a comprehensive analyses. This water supply is not chlorinated.

The chemical analysis at Mountlucas indicates a **slightly hard** (101 - 150 mg/l $CaCO_3$) to **moderately hard** water (151-250 mg/l $CaCO_3$), with a moderate alkalinity (168 mg/l). Conductivity values are typical of groundwater from limestones and limestone tills (570 - 740 µS/cm), as are the pH values (7.1 - 7.4). Chloride levels are slightly elevated (20-25 mg/l) and may be indicative of contamination (up to 38 mg/l on the 10/11/92). From a total of 18 water samples tested for faecal coliforms, between 19/5/93 and 28/5/96, 8 were polluted. Concentrations of ammonia, nitrates and potassium are all normal and there are no iron problems at this well. The analyses suggest that the well is occasionally polluted by organic waste, probably from farmyard or a septic tank.

6.6 Aquifer coefficients

Hydrogeological data on the nature of the limestone (and the till) around the source is poor. In the absence of data the permeability of the upper few metres of weathered limestone is estimated to be in the range 10-20 m/d. The effective porosity of the limestone is also estimated, at 0.02 (2%).

6.7 Conceptual Model

The aquifer feeding the Mountlucas source is the Edenderry Limestone. Groundwater flow is likely to be concentrated in the upper few metres of fissured and weathered limestone. The limestone is overlain to the south by approximately 3-5 metres of sandy till, therefore the aquifer can be considered to be unconfined. The available groundwater level data suggests that the till is predominantly unsaturated during the summer months.

Although data is poor, the water table is expected to be a subdued reflection of topography, higher in the south and decreasing towards the river. The static water level in the well is higher than the Philipstown River to the north, also suggesting groundwater flows northwards towards the river.

A recharge mound is assumed to coincide with the topographic rise to the south of the well during the winter, with a component of groundwater flowing into the seasonal streams to the SW and SE of the source. In addition groundwater levels are at the surface in the vicinity of the well during the winter. Consequently, the water discharging from the well is derived from an area to the south.

During the summer months the water table drops, the seasonal streams are dry and groundwater flow is predominantly northwards, towards the Philipstown River.

A topographic divide is present approximately 1 km to the south of the well. In the absence of data a groundwater divide is assumed to coincide with this feature.

The till has a sandy matrix suggesting that this deposit is moderately permeable. Water levels are at the surface at the well during the winter and the well overflows considerably. It is likely that the till south of the well is saturated to some degree during the winter months and during this time may contribute to the well discharge.

6.8 Aquifer category

This limestone is classified as a **locally important aquifer** which is **generally moderately productive**.

7. VULNERABILITY

The source at Mountlucas is regarded as being highly vulnerable to pollution. Areas where rock is less than 3 m below surface are mapped as having a 'probably extreme vulnerability'. The available evidence suggests that the till is slightly thicker than 3 m, resulting in a 'probably high' vulnerability.

According to the local caretaker overflow from the well responds quickly to rainfall events. This suggests that groundwater throughflow to the well is relatively quick and that the source is vulnerable.

Although the till is very sandy, a permeability test (conforming to SR6 guidelines) produced a 'T' value = 12.6. This figure, and the presence of silt in the till, suggest that this subsoil has a moderate permeability. Consequently the groundwater in the area to the south of the well is given the vulnerability classification of 'probably high'.

The vulnerability zones are shown on Figure 3.

8. DELINEATION OF SOURCE PROTECTION AREAS

The source protection area is delineated for a higher output than is currently abstracted, to take into account the overflow from the source during the winter months. Having spoken to the local GWS caretaker the best estimate of winter overflow is a rate of approximately 3000 gph (330 m^3/d) for 10 weeks during the winter. Ideally more accurate measurements of the overflow would be required in order to delineate the ZOC. The estimated overflow from the well has been combined with the well yield to produce an average well discharge of 165 m^3/d.

8.1 Outer Protection Area

The Outer Protection Area (SO) includes the complete catchment area to the source, i.e. the zone of contribution (ZOC), and it is delineated as the area required to support an abstraction from long-term recharge (see Figure 4).

The most accurate zone of contribution for the Mountlucas GWS is derived from hydrogeological mapping techniques and is controlled primarily by the proposed recharge mound to the south of the supply and by the groundwater flow direction to the Philipstown River. The size of the zone of contribution is based largely on the Recharge Equation.

Taking the average annual recharge to be 360 mm as previously indicated, the area required to supply the estimated average well discharge of 165 m^3/d, is calculated to be 0.167 km^2 ; this is equivalent to a circular area with a radius of 230 m.

Based on the conceptual model outlined above, the groundwater discharging from the well during the winter months is derived from an area to the south of the well. However, groundwater levels are drawn down slightly by the well during the summer, consequently the ZOC is enlarged slightly to take in an area immediately north of the well. The boundaries of the ZOC are a best estimate based on the data available.

A buffer (safety margin) is included in the zone of contribution by incorporating a ±20% error margin in the estimated groundwater flow direction. The zone of contribution is shown in Figure 5.

Although the proposed ZOC is larger than the area required this allows for the expansion of the ZOC during dry periods, and for uncertainties such as; the estimation of water overflow from the well, and the general lack of hydrogeological data.

8.2 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel from a point below the water table 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 from microbial contamination.

A range of values for permeability, between 10 and 20 m/d, were used to estimate the 100 day time of travel zone distance to the well. Using an effective porosity = 0.02, and a groundwater gradient = 0.005, the 100 day time of travel distance to the well is estimated at between 250 and 500 m. The more conservative distance is taken (see Figure 4). It is emphasised, however, that there are no data to enable the aquifer coefficients to be calculated for this source, consequently the boundary to this zone is uncertain.

8.3 Source Site

In addition to the Inner and Outer Areas there is a third protection area, the Source Site (SS), which is delineated as the area in the immediate vicinity of the source (minimum 10 m radius) in order to maintain good wellhead sanitary protection. The fenced off enclosure around the source at Mountlucas is designated the Source Site Area.

9. GROUNDWATER PROTECTION SCHEME

Combining the Source Protection Areas, as described above, with the vulnerability ratings produces three groundwater protection zones for the source at Mountlucas. These zones are listed here and are shown in Figure 5 (with the exception of the Source Site):

- Source Site / High
- Inner Protection Area / High
- Outer Protection Area / High

It is not within the scope of this report to delineate the protection zones in the surrounding area and this is dealt with at the regional resource protection scale.

The accompanying code of practice imposing restrictions on developments will follow when discussions as to the degree of restriction necessary in each protection zone have been carried out between the Council, the EPA and the GSI.

10. POTENTIAL POLLUTION SOURCES

Several potential sources of pollution exist within a a short distance upgradient of the well. A farmyard 50 m to the south of the well is used to store sillage and hay and there may also be a cattle pen in the yard. The house immediately south of the well has a septic tank nearby and two new houses south of Clonarrow House also have septic tanks. Some of the fields to the south of the well are used as arable land which usually involves the application of fertilizers.

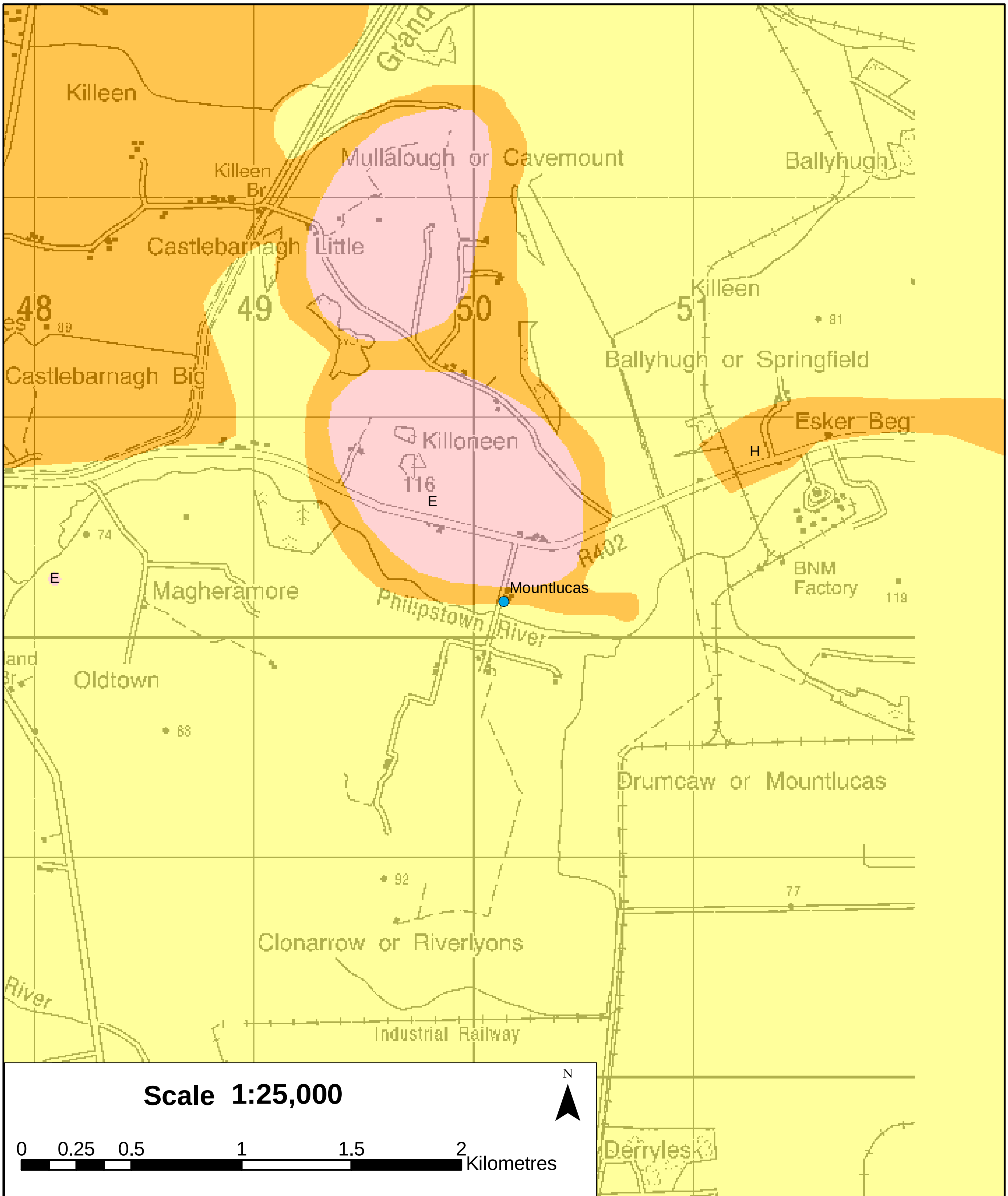
11. CONCLUSIONS AND RECOMMENDATIONS

Overall the source at Mountlucas is a moderately good yielding well which may support an increased yield (particularly during the winter months). The supply is highly vulnerable to pollution due to; the thickness and permeability of the subsoils in the immediate vicinity of the supply, the proximity of the water table to the surface near the well and the apparent rapid throughflow to the well.

The chemical and bacteriological analyses suggest that the well is occasionally polluted by organic waste, probably from a nearby farmyard or septic tank system.

It is recommended that the raw water from the Mountlucas supply should be analysed regularly (chemically and microbiologically) in order to examine the effects of any potentially polluting activities near to the well. In addition it is recommended that the potentially polluting activities and monitor in the delineated groundwater source protection zones should be controlled and monitored.

At present the source is not chlorinated; in view of the likely vulnerability of the area upgradient of the source, the location of potential pollution sources, and the evidence of occasional pollution, it is recommended that the source be disinfected.



Vulnerability Categories

- E - Extreme
- H - High
- M - Moderate
- Spring

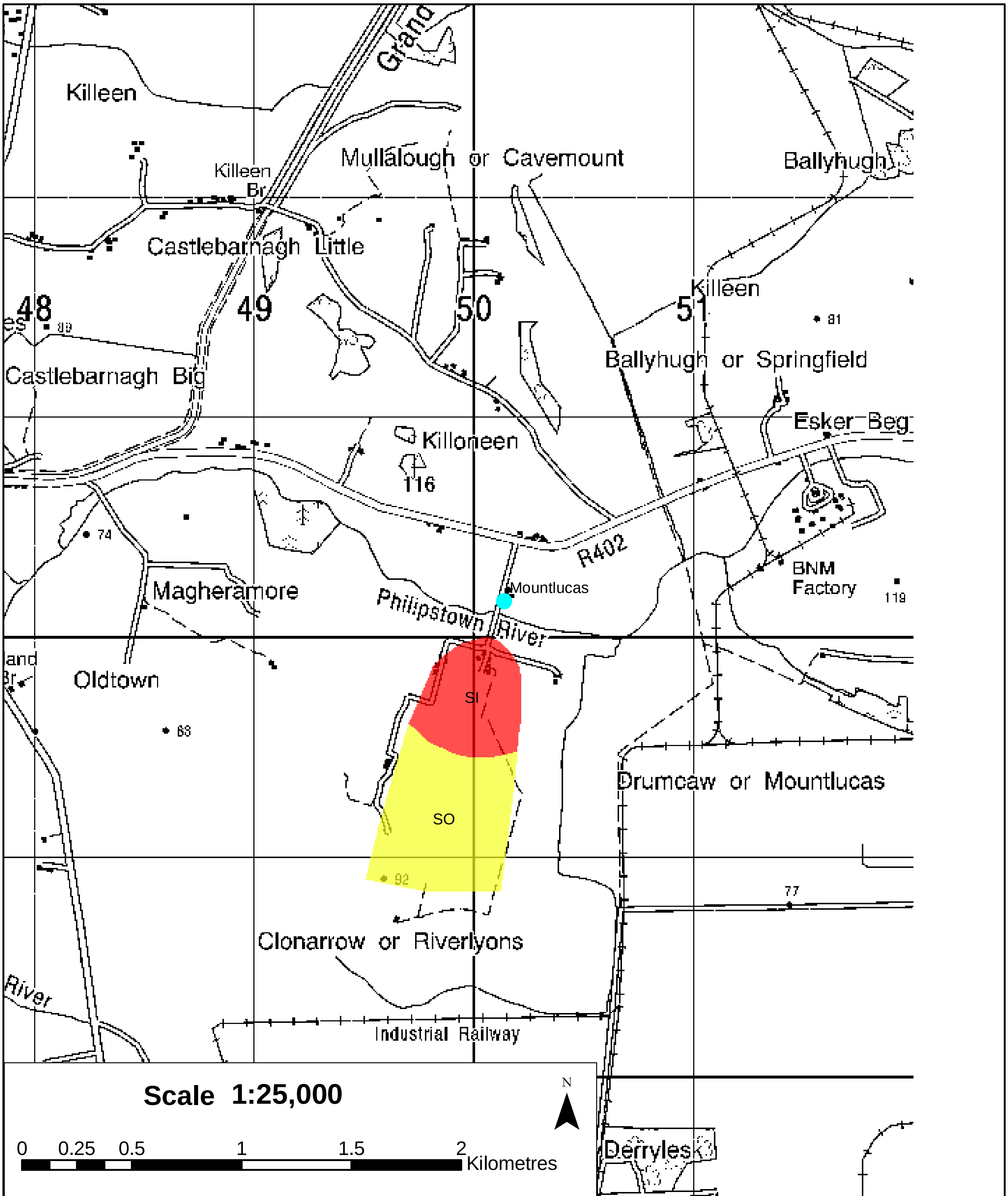
This Source Protection Area map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed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

ESTO FIDELIS

GSI

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



LEGEND

SI Inner Protection Zone

SO Outer Protection Zone

Spring

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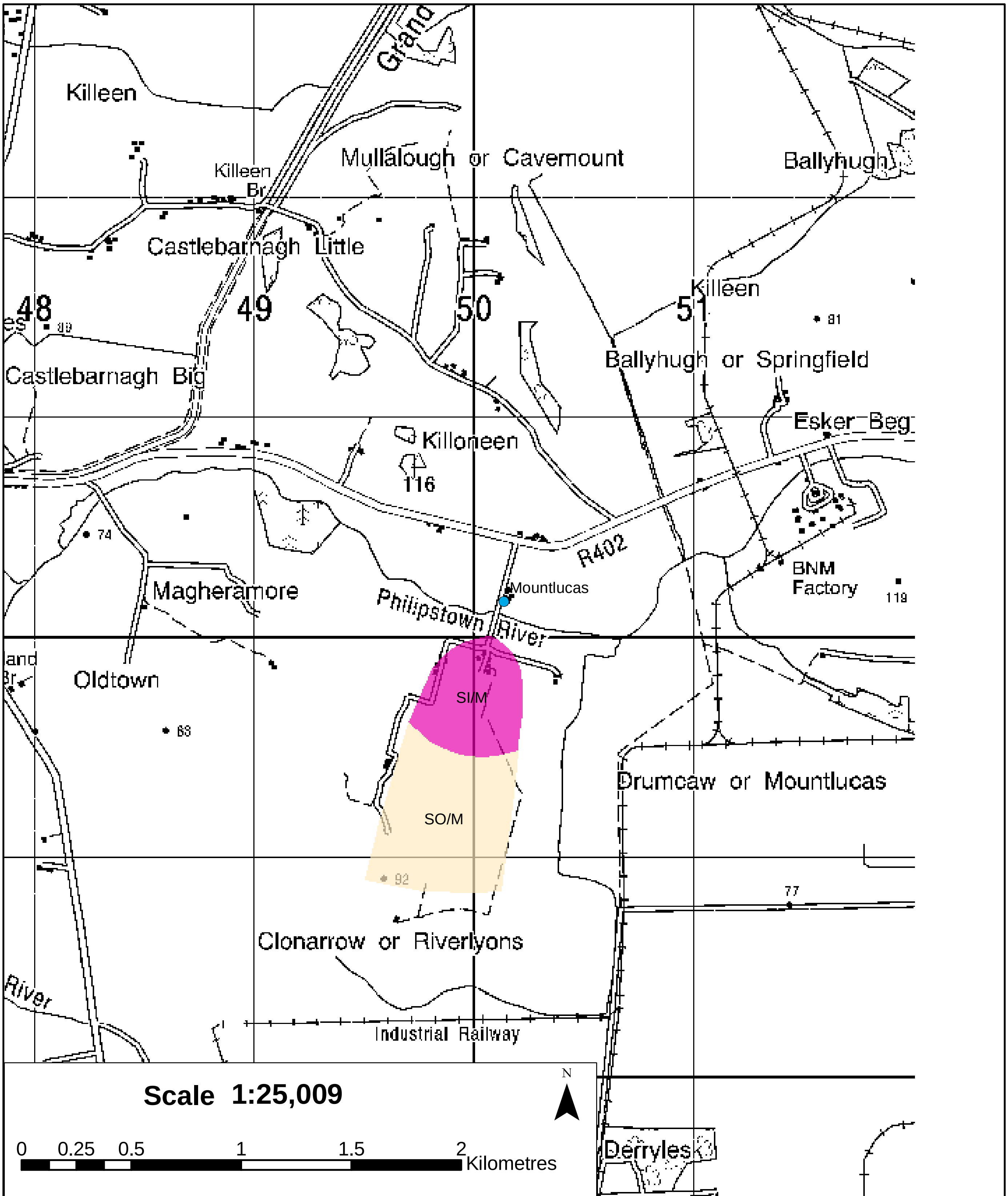

SOURCE PROTECTION ZONES

VULNERABILITY RATING	SOURCE PROTECTION ZONES	
	Inner SI	Outer SI
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	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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