Establishment of Groundwater Zones of Contribution
Ballinagar Group Water Scheme, Co. Offaly
March 2017

and

Geashill Public Supply
Groundwater Source Protection Zones
April 2001

'Note:
Since the Geashill Public Supply report was published, the Ballinagar Group Water Scheme established the Groundwater Zone of Contribution. Both supplies are sharing this same groundwater catchment as they are very close to each other.
Based on available information the Source Protection Area has been updated to include both supplies. The most up-to-date version of the Source Protection Areas (SPAs) for both schemes and other maps can be found on the Geological Survey Ireland website (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx).'

Legend

- BALLINAGAR ABSTRACTION POINTS
- GEASHILL ABSTRACTION POINT
- BALLINAGAR GWS ZOC (2017)
- GEASHILL PUBLIC SUPPLY SPZ (2001)

Legend

- BALLINAGAR ABSTRACTION POINTS
- GEASHILL ABSTRACTION POINT
- BALLINAGAR GWS and GEASHILL PUBLIC SUPPLY SPZ (2018)

Establishment of Groundwater Zones of Contribution

Ballinagar Group Water Scheme, Co. Offaly

March 2017

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Project description

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

This report has been prepared for Ballinagar Group Water Scheme as part of the Rural Water Programme funding initiative of grants towards specific source protection works on Group Water Schemes (DECLG Circular L5/13 and Explanatory Memorandum).

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

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

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

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

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1 Overview: Groundwater, groundwater protection and groundwater supplies

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

In Irish bedrock aquifers, groundwater predominantly flows through interconnected fractures, fissures, joints and bedding planes, which can be envisaged as a 'pipe network', of various sizes, with varying degrees of interconnectivity. The speed of flow through this network is relatively fast, delivering groundwater, and a large proportion of 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.

Ballinagar GWS is supplied by three shallow dug wells that exploit groundwater at the boundary between peat and sand and gravel deposits, which overlie limestone bedrock classified as a Locally Important Aquifer that is generally moderately productive only in local zones (LI).

[1] Geological Survey of Ireland, 2000.

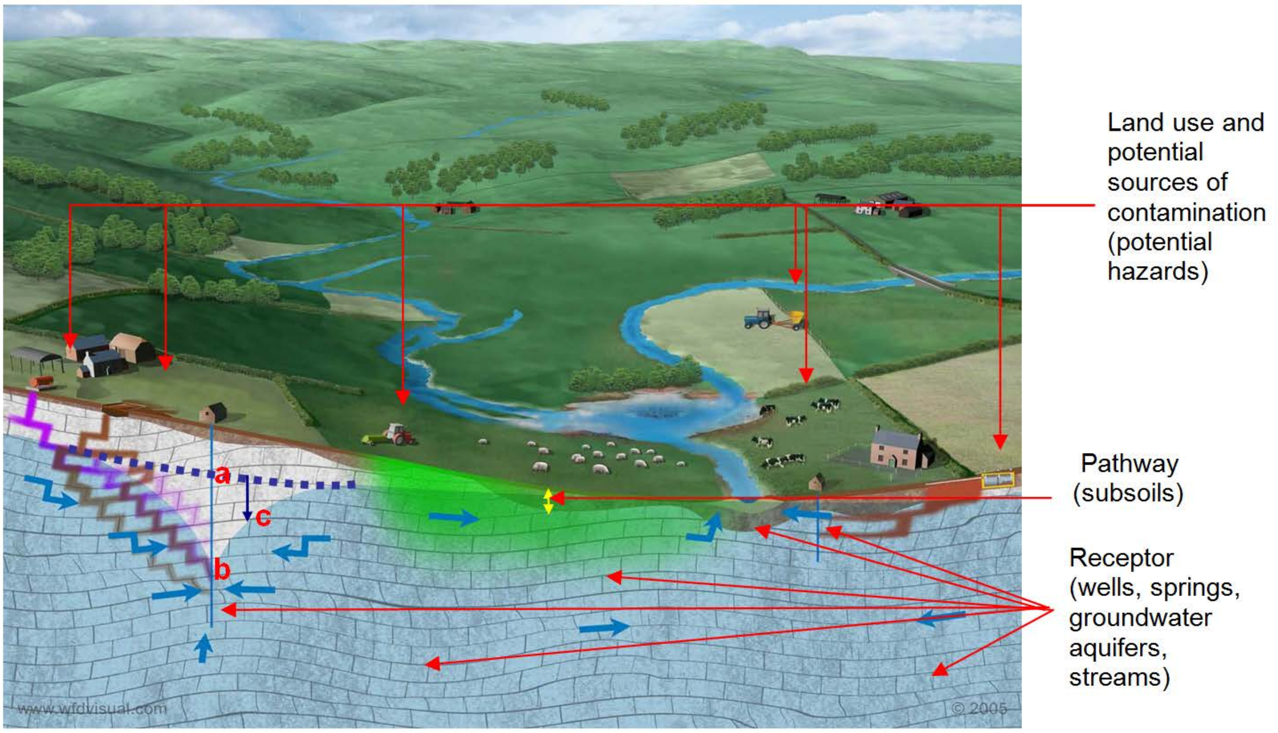

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

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

The Ballinagar Group Water Scheme (GWS) is currently supplied by three dug wells in the townland of Dalgan, Co. Offaly. The site is located approximately 1 km north of Geashill village and 2.2 km south of Ballinagar village. The GWS was founded in 1965 and at that time was supplied by one spring that was shared with the Geashill Public Water Supply. The Geashill Public Supply is located about 150 m to the south of the Ballinagar GWS (**Diagram 2**). In August 1998, Ballinagar GWS purchased a site adjacent to the Geashill Public Supply and excavated three shallow dug wells which now supply the GWS. Given the similar location and construction of both supplies, the Geashill Public Supply Source Protection Report (2001) has been reviewed and referred to as part of this study[2]. Where available, more recent and site specific information has been incorporated to update the Ballinagar GWS report.

The Ballinagar GWS shallow well are located on the western side of the third class road that runs from Geashill in the south to Ballinagar in the north (**Figure 1**). The pump house (**Photo 1**) and all infrastructure is located within a small fenced compound slightly set back from the road.

A small pump house (**Photo 2**) is located adjacent to the source. The discharge from the three wells is gravity fed into the sump at the rear of the pump house (**Photo 3**). The treatment unit, consisting of chlorination and ultra-violet treatment is located at the site of the reservoir. An old dump, which has not been in use for decades, is believed to be located to the east of the wells (**Diagram 2**).

[2] Kelly, C. (2001). Geashill Public Supply Groundwater Source Protection Zones. Geological Survey of Ireland.

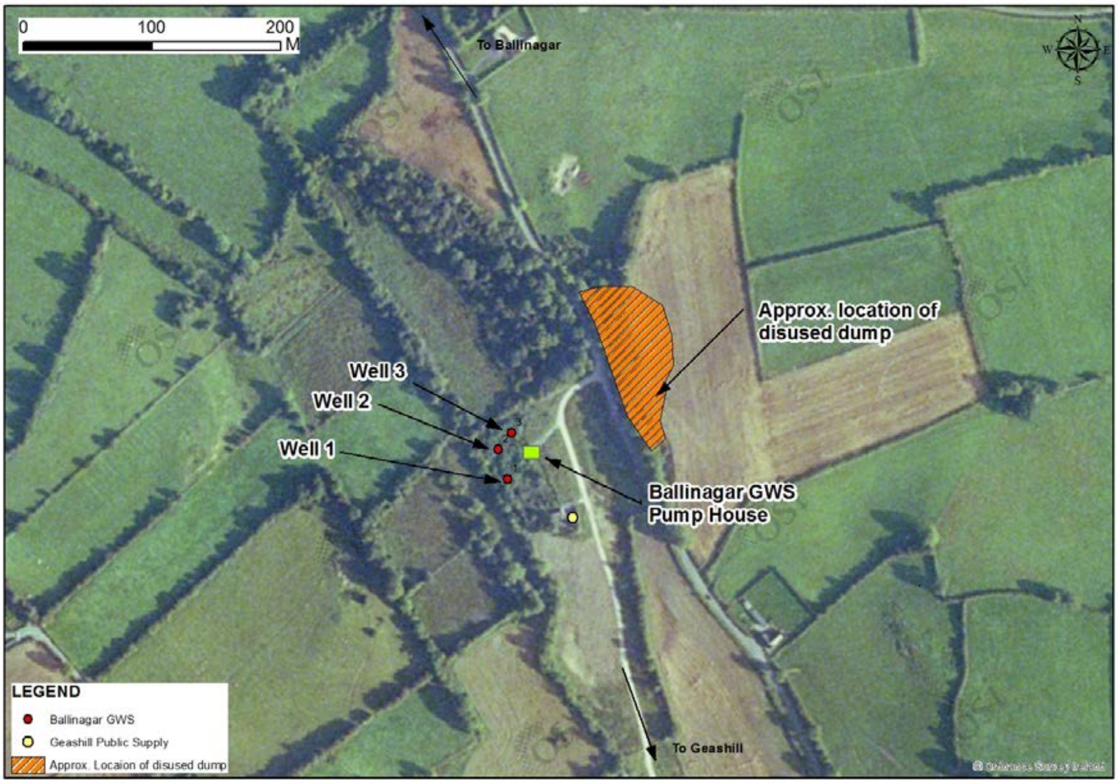

Diagram 2. Relative locations of Ballinagar GWS and Geashill Public Supply

Photo 1 – Ballinagar GWS pump house

Photo 2 – Internal view of pump house

Photo 3 – Sump at rear of pump house

The scheme currently has 570 domestic connections, 63 domestic and farm connections, 7 land only connections and 11 other connections, which include the Irish Water Sewage Works at Ballingar, the Irish Wheelchair Association, Ballinagar Hall, RTE Mast at Cappanageeragh, Cappancur GAA, Cappancur Hall, Ballinagar National School, the Dog Pound at Cappancur, Waterways Ireland, Ballinagar GAA and Ballinagar cemetery. The average daily usage is currently in the order of 350 m^3/d. Significant efforts have been made by the committee to achieve this usage figure, which around 10 years ago was in excess of 1,200 m^3/d. The scheme has a storage reservoir located a few kilometres away.

The three shallow dug wells are located to the rear of the pump house, about 15 m east of the small tributary of the Tullamore River. Each well is held open by a 1.2 m diameter concrete rings and all are at similar depths: Well No. 1 is 4.23 m deep, Well No. 2 is 4.30 m deep and Well No. 3 is 4.27 m deep (**Photos 4 and 5**). The concrete rings stick up above ground level and are covered with secure metal lids. The pump house contains two pumps which are pumped on alternate nights for a period of 6.5 – 7 hours per night.

Photo 4 – Well No's 1 and 2

Photo 5 – Well No. 3

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

Table 1. Supply Details

	Well No. 1	Well No. 2	Well No. 3
Grid reference	ING E245003 N221750	ING E245032 N221771	ING E245008 N221780
Townland	Dalgan	Dalgan	Dalgan
Source type	Shallow dug well	Shallow dug well	Shallow dug well
Constructed	1998	1998	1998
Constructed By	Ballinagar GWS	Ballinagar GWS	Ballinagar GWS
Owner	Ballinagar GWS	Ballinagar GWS	Ballinagar GWS
Elevation (m aOD)	74.2 maOD	75.0 maOD	74.4 maOD
Total depth (m)	4.23 m	4.30 m	4.27 m
Construction details	1.2 m diameter concrete rings	1.2 m diameter concrete rings	1.2 m diameter concrete rings
Depth to rock (metres below ground level, m bgl)	Specific depth to bedrock at the three wells is unknown. There is no bedrock outcrop in the area. However, it is reported that the depth to bedrock at the Geashill Public Supply (150 m to the south) varies between 5 m – 10 m [3].		
Static water level (m bgl)	0.98 m bgl	0.75 m bgl	0.40 m bgl
Pump intake depth	Unknown	Unknown	Unknown
Current abstraction rate (GWS)	350 m^3/d		
Reported yield (m^3/d)	Unknown	Unknown	Unknown
Number of connections	651		
Estimated specific capacity ($m^3/d/m$)	Unknown	Unknown	Unknown
Estimated transmissivity (m^2/d)	Unknown	Unknown	Unknown

[3] Geological Survey of Ireland, 2001. Geashill Public Supply Groundwater Source Protection Zones.

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 Wells	Description/Comments
Annual Rainfall (mm)	825	Met Eireann average annual rainfall data 2012 - 2015
Annual Evapotranspiration Losses (mm)	442	Met Eireann (www.met.ie)
Annual Effective Rainfall (mm)	383	National Groundwater Recharge Data (www.gsi.ie)
Topography	The Ballinagar GWS wells are at an elevation of 74 - 75 m above Ordnance Datum (m AOD). The topography is generally undulating although the GWS site is located within a slightly low-lying area surrounded by higher ground to the east, south and west. Overall, the land slopes gently downwards towards the Tullamore River to the north, although the site itself slopes down slightly towards a small unnamed stream along its western boundary.	
Land use	Agricultural land surrounds the site, with low intensity grazing and grassland the predominant activities. The adjacent field, which lies between the GWS site and the road, was ploughed about a year ago and it was reported locally that this field will remain fallow for the next five years or so. It was also reported locally that landspreading in the area has increased in intensity in recent years due to increasing herd sizes. Geashill village, which is 1 km south of the GWS site, lies within the ZOC.	
Surface Hydrology	The land in the surrounding area appears to be reasonably well drained. The Tullamore River is the main drainage feature and flows to the northwest about 300 m north of the site. A small unnamed tributary of the Tullamore River flows along the western boundary of the site. It is understood that the base of this stream is lined with a 'marl' type deposit which restricts the downward leakage of water through the stream bed.	
Topsoil	The three wells are in a small area of poorly draining peat (Teagasc 2006), which is enclosed by well draining soils to the south, east and west.	
Subsoil (**Figure 2**)	The wells are at the boundary between poorly draining peat subsoils and more freely draining esker sands and gravels, which form a narrow linear body, immediately east of wells (Teagasc 2006). Both the esker sands and gravel and peat subsoils are surrounded by limestone sand and gravel. All three subsoil types are in an approximate northwest-southeast alignment, within a general area of limestone till.	
Groundwater Vulnerability (**Figure 3**)	'Moderate' at the three wells. 'High' in the surrounding areas to the east and west (see **Appendix 1**).	
Geology (**Figure 4**)	The bedrock is classified as Dinantian Upper Impure Limestones (Lucan Formation). This rock type consists of dark, fine grained, muddy limestone with interbedded layers of shale. It is commonly known as 'Calp'. There are a number of faults in the bedrock mapped in the area. They trend in both NE-SW and SE-NW directions. The fractures within the bedrock, though which groundwater moves, are likely to be of similar orientations.	
Aquifer (**Figure 5**)	**Locally Important (LI) – Bedrock which is moderately productive only in local zones.** The GWB description: this GWB is composed generally of low transmissivity and storativity rocks. 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 wells is controlled by local topography.	
Groundwater Body	Geashill GWB. Categorised as 'possibly at risk of not achieving good status' (www.epa.ie)	
Recharge Coefficient (**Appendix 3**)	85 %	High permeability subsoil (sand/gravel) overlain by well drained soil. Hydrogeological setting 2.ii (see **Appendix 2**).
Average Recharge (mm/yr)	325	

3.2 Hydrochemistry and water quality

The water quality interpretation for the Ballinagar GWS is based on the supply's sample results but also takes account of the analyses for the Geashill PWS (Kelly, 2001), due to the high degree in similarity between the types of supply, locations and hydrologeological settings, which suggests that those results are highly likely to be reflective of the conditions at the Ballinagar supply, thus providing additional information.

There are two sources of raw (untreated) water quality data available for the Ballinagar GWS itself:

- Historical raw water data from November 2007 to April 2016. These data were made available by the GWS and were tabulated as part of this report.
- A raw water sample collected by the National Federation of Group Water schemes as part of this project in June 2016.

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. 278 of 2007), whichever is the lower. **Table 3** below provides a summary of the key parameters and all the data are included in **Appendix 3**.

Table 3. Key Hydrochemistry and Water Quality values in untreated (raw) water samples

Parameter	No. of samples	Concentration			Drinking Water Limit (DWL) or Threshold Value (TV)
Electrical Conductivity µS/cm @ 20degC	1	699			800 (TV), 2,500 (DWL)
Sodium, mg/l	1	11.8			150 (TV)
Chloride, mg/l	1	16.7			250 (DWL), 24 (TV)
Ammonium, mg/l NH_4	1	0.05			0.3 (DWL), 0.225 [0.175 as N] (TV)
Nitrite, mg/l	1	<0.03			0.5 (TV)
		Min	**Max**	**Average**	
Total Hardness (mg/l as $CaCO_3$)	92	342	586	394	-
Total Coliforms (MPN[4]/100 ml)	102	0	**89**	22 exceedences	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	102	0	**61**	10 exceedences	0 (DWL)
Nitrate (mg/l NO_3)	82	15.2	31.8	23.9	50 (DWL) 37.5 (TV)
Iron (µg/l)	93	<3	**266.8**	36.68	200 (DWL)
Manganese (µg/l)	92	0.2	**51**	4.1	50 (DWL)

The historical raw water data, which includes analysis for a limited range of parameters; hardness, pH, dissolved solids, iron, manganese, calcium, magnesium, nitrates, coliforms, and E. coli. This data confirms that E. Coli and nitrates pose continuous management issues for the scheme. The presence of bacterial contamination (E. Coli./Faecal coliforms) reflects the vulnerable nature of the shallow dug wells.

The data show that nitrates are, and have been, a potential cause for concern. The nitrate concentrations were greater than 25 mg/l consistently from November 2007 until July 2008. From June 2008 to January 2015 the concentrations fluctuated between 18.8 – 29.4 mg/l, from August 2008 until April 2009, the concentration was consistently below 25 mg/l. Four nitrate analysis were available for 2016, they were around 25 mg/l. **Diagram 3** below shows the nitrate concentrations in the groundwater from 2007 to date.

[4] MPN is most probable number

A GSI (1999) report on the water quality of public and group water schemes in Co. Offaly classified the Geashill Public Water Supply, which at the time included the Ballinagar GWS, as a “Category C” supply with regard to nitrate concentrations. A category C supply has ‘average nitrate levels that exceed 25 mg/l, peaks rarely approach 50 mg/l but give cause for concern’. As a response to this category the report recommended a ‘regular review of data, in particular maintaining, for instance, a graph of nitrate variations with time’. The report also stated that the levels of chloride in the supply and the ratio of potassium to sodium concentrations (K:Na) were close to the GSI threshold level and that one elevated ammonia concentration was reported. The report highlighted the presence of the sewage works in the area and emphasised that careful management of this facility was crucial. However, the zone of contribution (ZOC) as delineated in this report for the current Ballinagar Wells does not include the location of the waste water treatment plant.

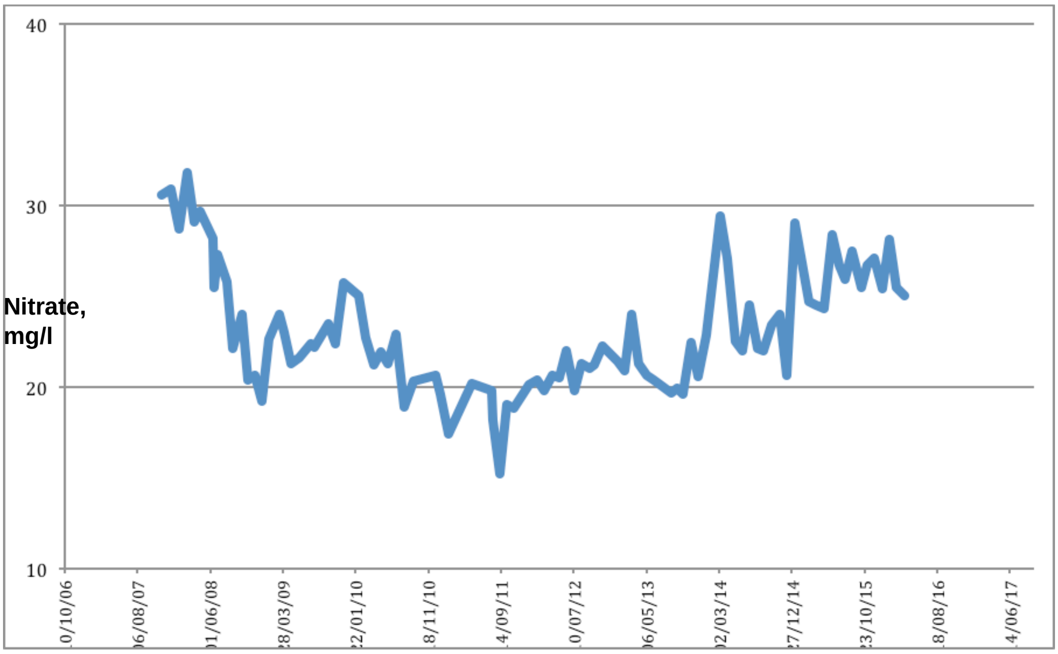

Diagram 3 – Nitrate concentrations over time

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 4)**.

The Ballinagar GWS is supplied by three shallow dug wells that are exploiting an area of shallow, abundant groundwater in a low-lying, predominantly flat area that is surrounded by higher ground to the east, south and west. The presence of the nearby Geashill Spring confirms the presence of a good groundwater resource in the area.

The three shallow dug wells are springs that were excavated by the scheme and held open by 1.2 m diameter concrete rings. They exploit shallow groundwater flowing at the boundary between poorly drained peat and a linear deposit of well draining esker sands and gravels that is mapped immediately to the east. The body of peat is small and is surrounded to the east and west by well draining limestone sands and gravels (which incorporate the esker sands and gravels). The limestone bedrock that underlies the area is classified as a Locally Important Aquifer that is generally moderately productive only in local zones.

In general terms, groundwater is replenished by rainfall percolating diffusely through the soils and subsoils down to the water table in the bedrock. Uphill of the GWS site, the permeability of the subsoils is higher than at the site itself. Therefore within the catchment to the dug wells a good proportion of the rainfall will percolate and move downhill towards the wells through the sands and gravels. When this groundwater then encounters the lower permeability peat its flow is impeded which results in the accumulation of the groundwater which is then forced to the surface thus creating the Ballinagar and Geashill Springs. It is possible that the bedrock is also contributing groundwater to these wells and the Geashill Spring by supplying groundwater to the sands and gravels and, ultimately, flowing into the Tullamore River which is likely to be a groundwater discharge point.

Groundwater will flow from the higher ground in an overall northerly direction towards the Tullamore River. The groundwater that is not intercepted by the GWS (and the Geashill Spring) will continue downhill and discharge into the river. The area supplying groundwater to the GWS (the ZOC) will extend uphill from the wells in the southerly direction. The vulnerability of the aquifer (which describes the ease at which the aquifer may become contaminated) in the region of the wells is rated as Moderate (M). It is rated High (H) on the higher ground to the south, east and west.

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.

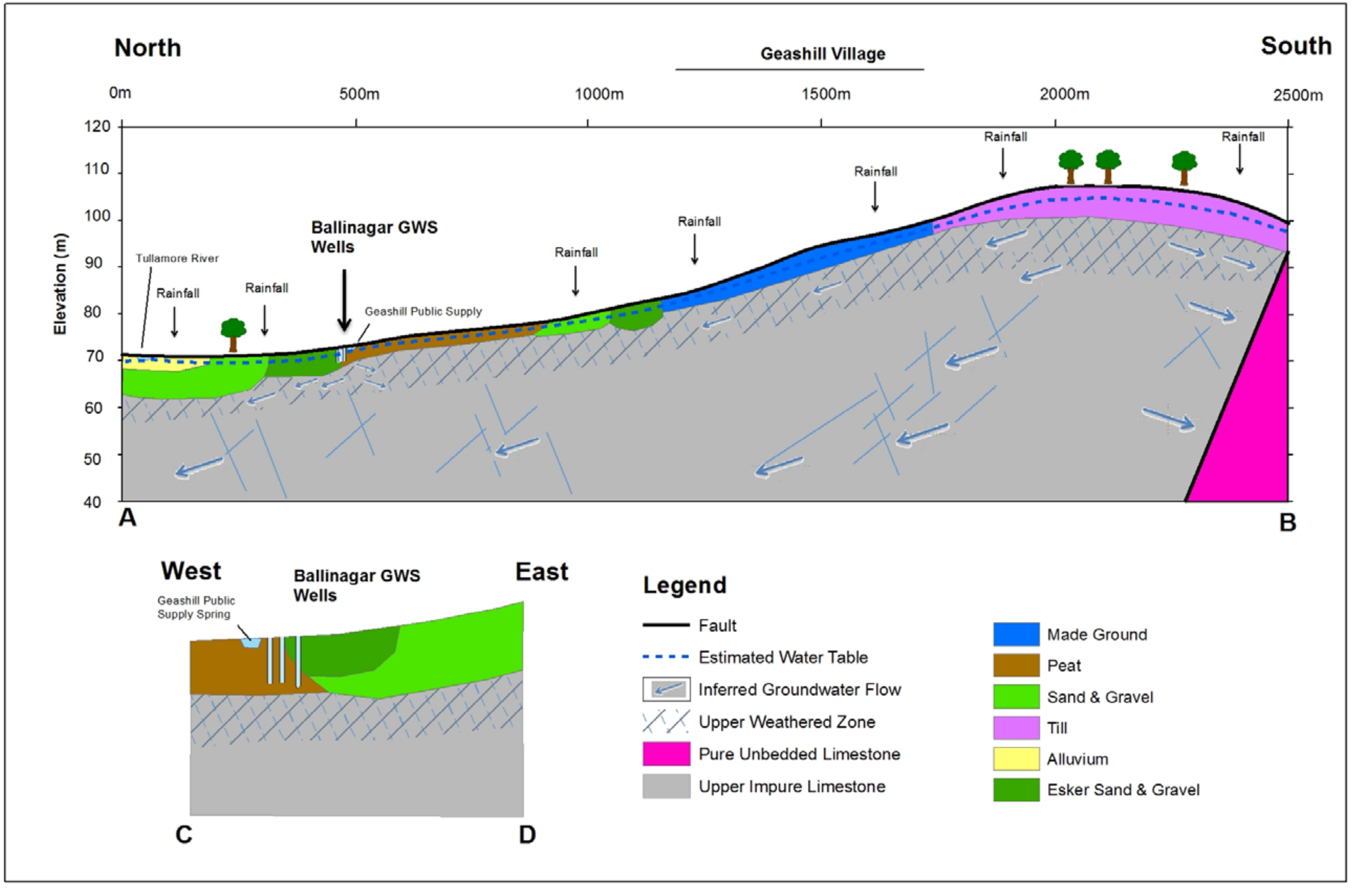

Diagram 4: Schematic Cross Section and Conceptual Model

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 4**).

The **Northern Boundary**, is the 'downgradient' (downhill) limit'. Groundwater will not flow back uphill towards the wells, however, conservative arbitary 30 m buffer is applied here to highlight the possibly issues around the well head itself.

The **Southern Boundary**, represents the upgradient (uphill) boundary of the zone of contribution (ZOC). This is based on interpretation of groundwater flow, which is excepted to be strongly influenced by the local topography. The boundary is defined by the topographic high point (107 m aOD) located to the south of Geashill village.

The **Western and Eastern Boundaries** define the 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. These boundaries have been delineated based on local topography, geological conditions and the water balance exercise. The two boundaries meet on the downgradient side of the wells at the ‘downgradient limit’.

The ZOC, as delineated on Figure 6, incorporates the entire village of Geashill and the agricultural land surrounding the site.

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 abstraction rate from the Ballinagar GWS is 350 m^3/d. However, the groundwater exploited by the three shallow wells is part of an overall groundwater resource that is also supplying the nearby Geashill Spring. Therefore the discharge from that spring, 910 m^3/d is included in water balance calculations for the Ballinagar GWS wells.

In order to account for seasonal fluctuations in abstraction volumes plus uncertainties in the groundwater flow direction a conservative approach is adopted. Therefore the combined abstraction rate of 1,260 m^3/d, is increased to 1,890 m^3/d i.e. 150% of the known current abstraction rate of both Ballinagar GWS and Geashill Spring.

The available recharge is estimated at 325 mm/yr (see Table 2). The minimum geographical area required to sustain an abstraction of 1,890 m^3/d (or 689,850 m^3/yr) based on the available recharge of 325 mm/yr (or 0.325 m/yr) is 2.1 km^2 (2,122,615 m^2). The delineated ZOC measures 1.8 km^2 (1,867,608 m^2). Although this seems to fall short of the recharge required to meet the discharge of all of the wells, it is acknowledged that this is conservative estimate, using 150% of the abstraction. It does, however, indicate that future, planned increases in abstraction should be thoroughly investigated and tested before being implemented to determine if the aquifer in this area can support additional abstraction.

5 Conclusions

The Ballinagar GWS currently abstracts 350 m^3/d from three shallow dug wells located immediately to the west of a small unnamed tributary of the Tullamore River. The wells exploit shallow groundwater that is accumulating in a low lying area overlying the boundary between poorly draining peat and more freely draining sands and gravels. The nearby Geashill public supply spring is fed by the same groundwater system. The underlying limestone bedrock, which is likely to be contributing groundwater flow to the wells (or supplying the sand and gravel that are supplying the wells), is classified as a Locally Important Aquifer that is generally moderately productive only in local zones (Ll). The scheme supplies 651 connections.

The vulnerability of the groundwater in the area is considered Moderate (M) at the GWS site. Elsewhere within the zone of contribution it is High (H). The ZOC is occupied by agricultural land, houses, farms and Geashill village. 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. Any potentially contaminating activities within the village may also potentially impact the groundwater quality at the wells. The nitrate concentrations appear to have gradually risen over the last number of years, perhaps reflecting an intensification of agricultural activities, in particular landspreading, in the area. The recent raw water sampling undertaken in June 2016 confirms that the nitrate concentrations are within acceptable limits at present.

The three shallow dug wells are housed within secure watertight concrete chambers that provide protection from contamination arising immediately adjacent to them. The historical water quality data demonstrates numerous occasions when there was bacteriological contamination in the groundwater. The recent raw water sample indicated that some bacteriological contamination is present. However providing the treatment systems are operating efficiently this should not pose an issue to human health.

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

6 Recommendations

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

Essential:

- A regular survey of water quality parameters of **untreated** water should be carried out. The survey should include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. Of particular importance for Ballinagar GWS are bacteriological parameters (E. Coli, total coliforms) and nitrates. This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The results should be shared with the GSI. The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist.

- Any future planning applications made within the ZOC (both in the rural areas and within Geashill village) 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).

- Any future excavation, drainage or pipeline works should be assessed by a professional hydrogeologist for their potential impact on the quality and quantity of groundwater before breaking ground.

- 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.

Desirable:

- Comprehensive hazard mapping (e.g. septic tanks, slatted units and slurry pits, activities within the village) within the delineated ZOC should be undertaken. This should ideally include septic tank inspections to clarify their condition, including the sewage works at Geashill. Any old disused tanks within the commercial buildings within Geashill village should also be included.

- A pumping test would halp clarify the available sustainable yield for the GWS. A network of monitoring wells throughout the area should be identified and incorporated into a pumping test in order to allow for further delineation of the ZOC boundaries. A pumping test would also allow for investigation into any connection between the adjacent stream and the wells.

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

Other:

- The following EPA guidelines may serve as future useful reference documents for the Ballinagar 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[5].

    - 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[6].

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

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

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

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FIGURES

Figure 1. Location Map

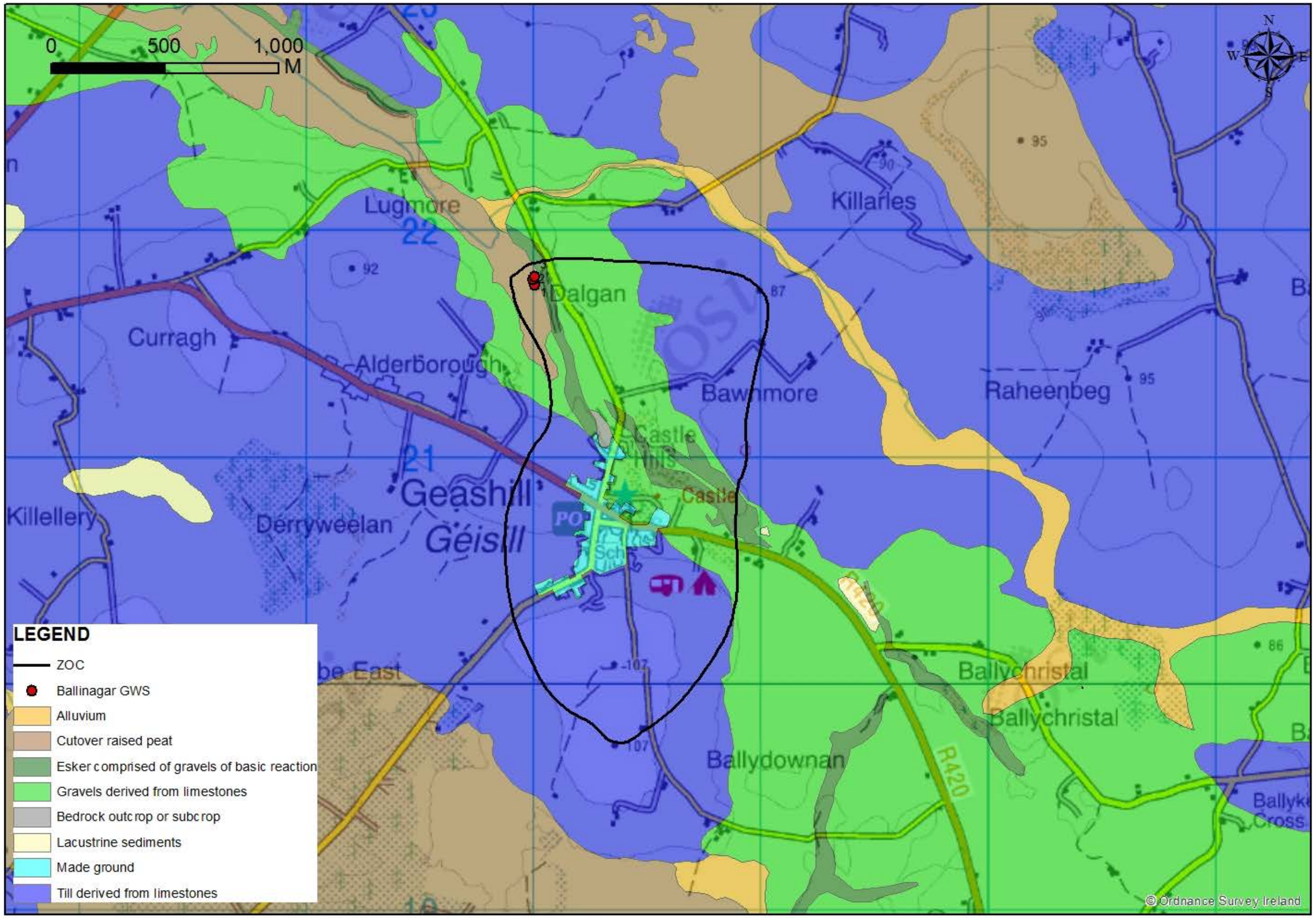

Figure 2. Subsoils Map

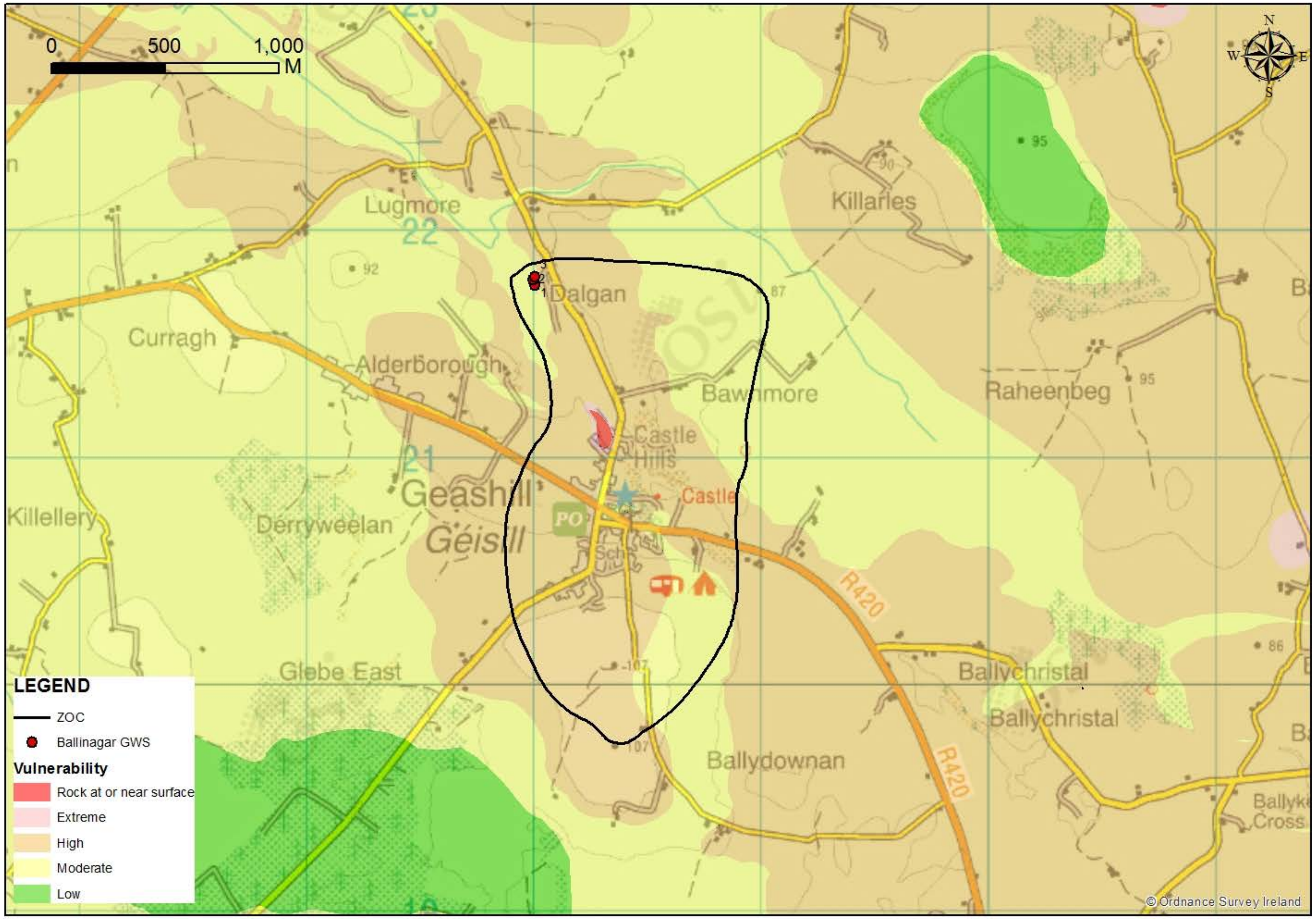

Figure 3. Groundwater Vulnerability Map

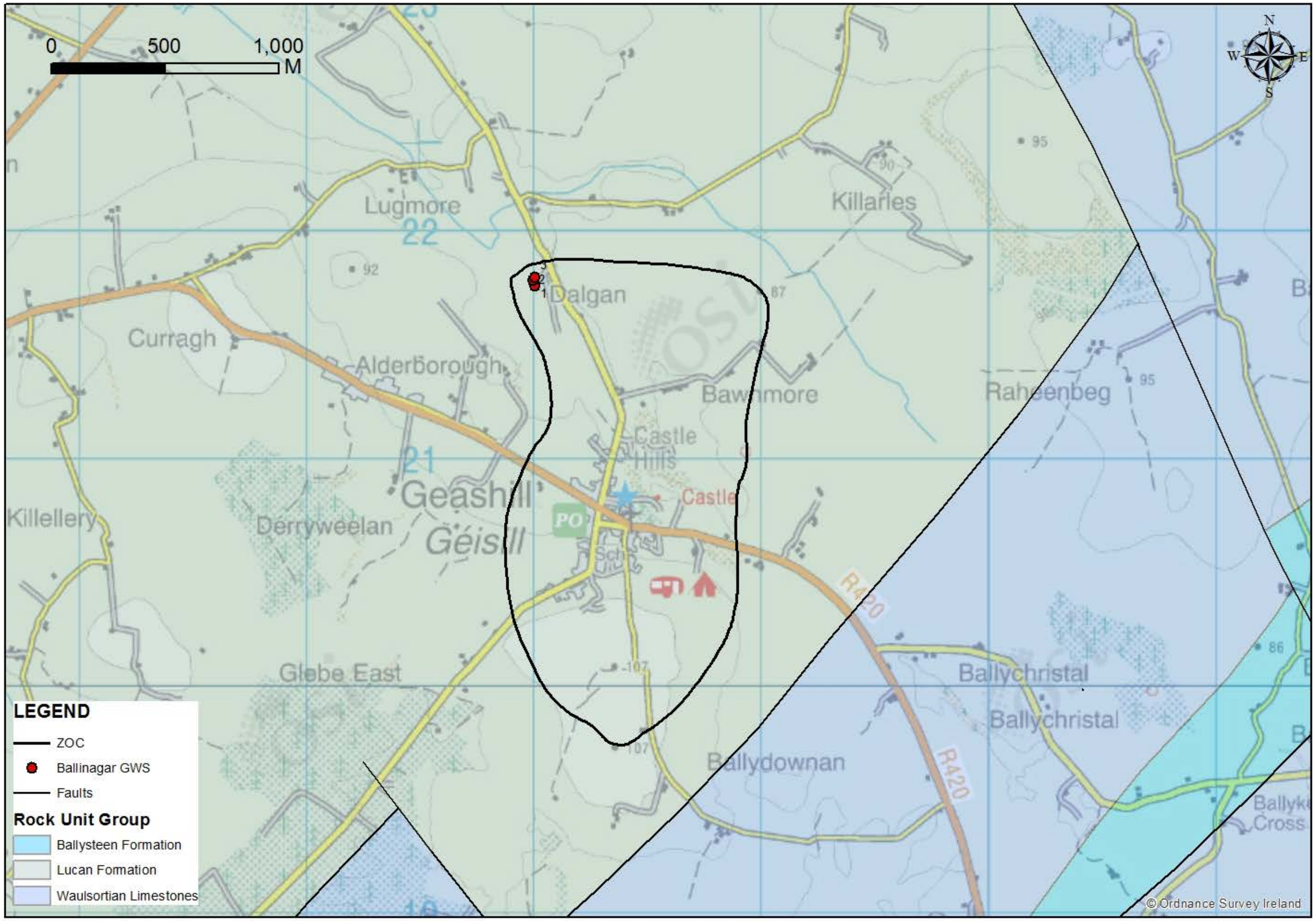

Figure 4. Rock Unit Group Map

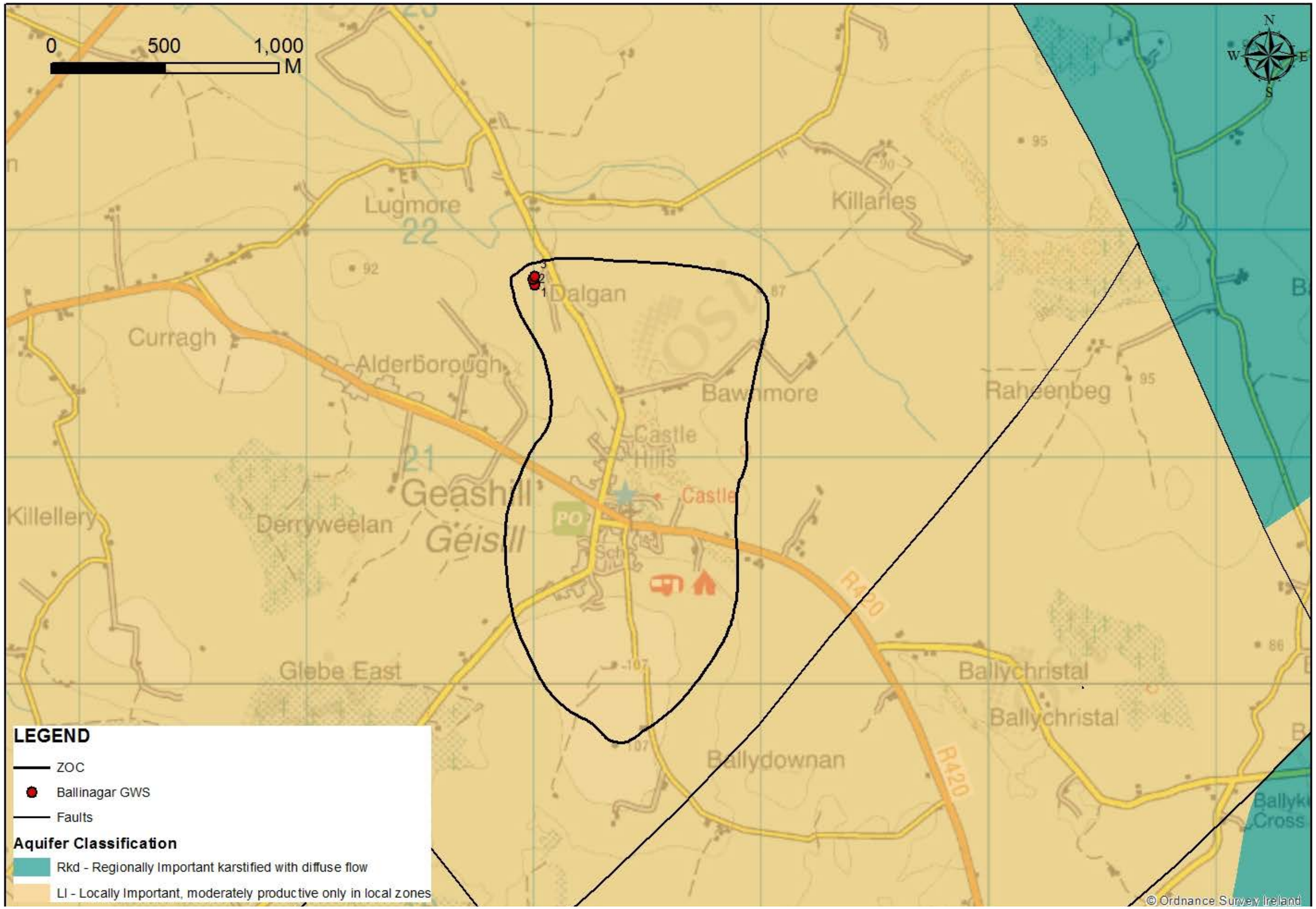

Figure 5. Aquifer Map

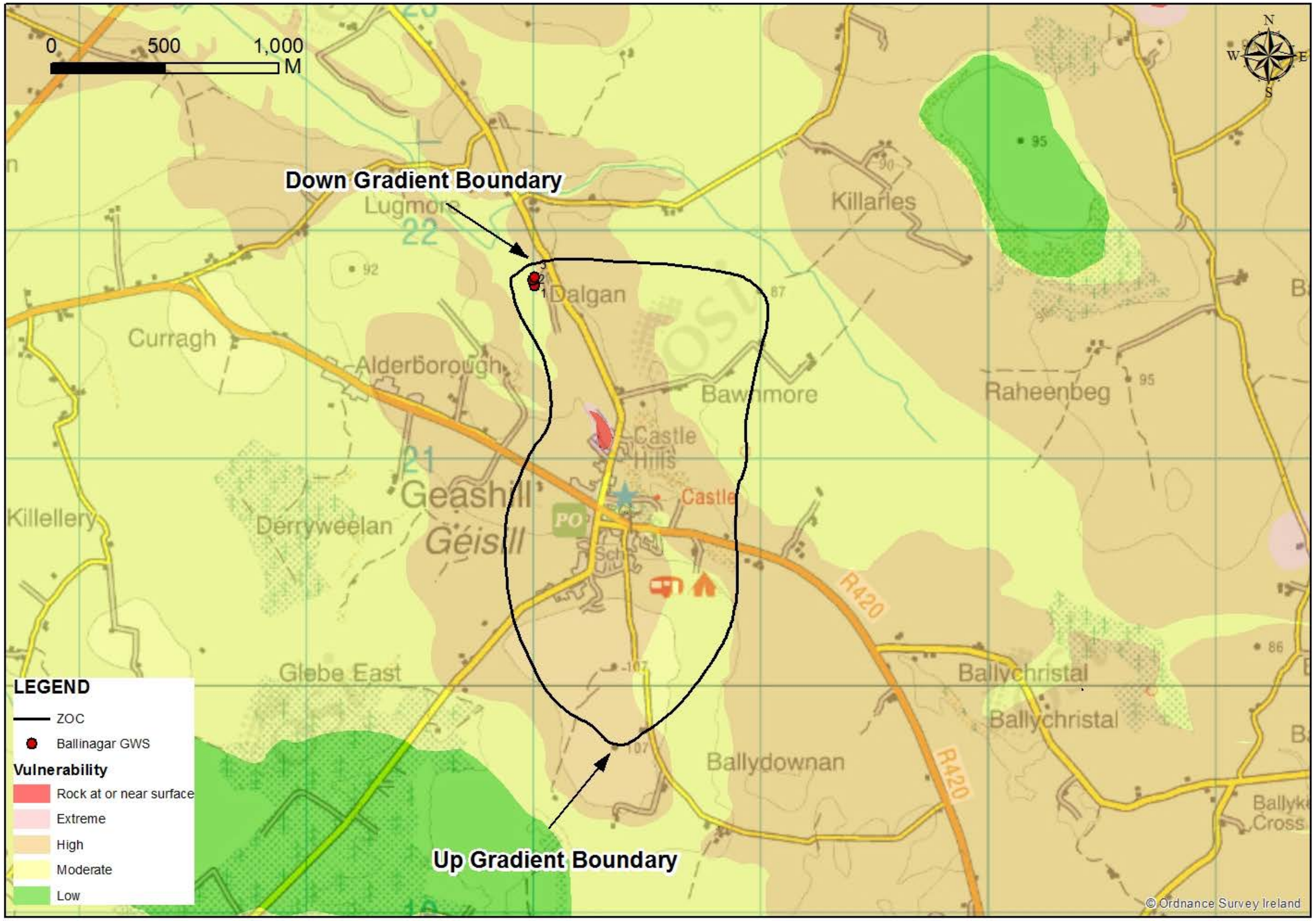

Figure 6. ZOC Boundary Map

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 of Raw Water

Raw Water Data, Ballinagar GWS, June 2016

Parameter	Ballinagar GWS Well	Units	Drinking Water Limit (DWL) or Threshold Value (TV)
BOD	<1	mg/l	
Turbidity	0.04	N.T.U.	No abnormal change
pH	6.9	pH units	6.5 – 9.5
Conductivity @ 20C	699	µS/cm	800 (TV)
Alkalinity	313.65	mg/l $CaCO_3$	
Sodium	11.8	mg/l	150 (TV)
Chloride	16.7	mg/l	24
Ammonium NH_4	0.05	mg/l NH_4	0.3 (DWL)
Nitrate as NO_3	18.52	mg/l	37.5 (TV)
Nitrite as NO_2	<0.03	mg/l	0.5 (TV)
Dissolved Oxygen (%)	5.94	%Sat	
Total Hardness (Kone)	370.6	mg/l $CaCO_3$	
Magnesium, total	11.4	mg/l	50 (DWL)
Colour, apparent	2.1	mg/l Pt Co	No abnormal change
Silica as SiO_2	6.64	mg/l	
Sulphate	14.56	mg/l	187.5 (TV)
Orthophosphate as PO4-P	0.15	mg/l	
Calcium, total	129.6	mg/l	
Aluminium, dissolved	<20	µg/l	150 (TV)
Iron	31	µg/l	200 (DWL)
Manganese, dissolved	<5	µg/l	<50 (DWL)
Copper, dissolved	<10	µg/l	1500 (TV)
Lead, dissolved	1.5	µg/l	18.75 (TV)
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	32	µg/l	
Barium, dissolved	56	µg/l	
Total Organic Carbon	2.1	mg/l	No abnormal change
Clostridium Perfringens	0	cfu/100ml	0
Strontium, dissolved	283	µg/l	
E Coli	**1**	cfu/100ml	0
Total Coliforms	**2**	cfu/100ml	0
Fluoride	0.11	mg/l	0.8 (DWL)

Summary of Historical Water Analysis records, 2007 – to date

Parameter	Units	04.04.2016	02.03.2016	01.02.2016	04.01.2016	01.12.2015	03.11.2015	06.10.2015	02.09.2015	04.08.2015	07.07.2015	Drinking Water Limit (DWL) or Threshold Value
Hardness	mg/l $CaCO_3$	358	342	380	360	378	378	380	414	414	406	-
pH	Units	7.2	7.2	7.2	7.1	7.0	7.0	7.3	7.0	7.2	7.1	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	336	512	220	452	560	492	432	464	480	420	-
Iron, total	µg/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	200 (DWL)
Manganese, total	µg/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	50 (DWL)
Nitrate	mg/l NO_3	25.0	25.5	28.1	25.4	27.1	26.7	25.5	27.5	25.9	26.7	37.5 (TV)
Aerobic colony count 22C	cfu/ml	**12**	**7**	0	0	**22**	-	-	0	**1**	0	0
Aerobic colony count 37C	cfu/ml	**3**	0	0	0	0	-	-	0	0	**2**	0
Escherichia coli	cfu/100ml	0	0	0	**3**	0	-	-	**9**	0	0	0
Coliform bacteria	cfu/100ml	0	0	0	0	0	-	-	0	0	0	0

Parameter	Units	09.06.2015	06.05.2015	02.04.2015	05.03.2015	06.01.2015	02.12.2014	04.11.2014	02.10.2014	01.09.2014	06.08.2014	Drinking Water Limit (DWL) or Threshold Value
Hardness	mg/l $CaCO_3$	400	382	368	386	406	418	398	388	380	382	-
pH	Units	7.2	7.3	7.1	7.2	7.2	7.2	7.0	7.4	7.2	7.2	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	404	424	484	484	410	412	456	434	466	430	-
Iron, total	µg/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	200 (DWL)
Manganese, total	µg/l	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	50 (DWL)
Nitrate	mg/l NO_3	28.4	24.3	24.5	24.7	29.0	20.6	24.0	23.4	22.0	22.1	37.5 (TV)
Aerobic colony count 22C	cfu/ml	0	**40**	**5**	0	0	**4**	**6**	**1**	0	**1**	0
Aerobic colony count 37C	cfu/ml	0	**1**	0	**4**	0	0	0	0	**3**	**17**	0
Escherichia coli	cfu/100ml	0	0	0	0	0	0	0	0	0	**1**	0
Coliform bacteria	cfu/100ml	0	0	0	0	0	0	0	0	**1**	**3**	0

Parameter	Units	01.07.2014	04.06.2014	07.05.2014	02.04.2014	04.03.2014	03.02.2014	07.01.2014	03.12.2013	04.11.2013	03.10.2013	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	414	396	378	384	586	-	400	402	418	408	-
pH	Units	7.1	7.2	7.3	7.3	7.2	-	7.2	7.2	7.2	7.3	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	464	414	424	422	426	-	524	498	474	494	-
Iron, total	µg/l	<50	<50	<50	<50	<50	-	<50	<50	<50	<50	200 (DWL)
Manganese, total	µg/l	<50	<50	<50	<50	<50	-	<50	<50	<50	<50	50 (DWL)
Nitrate	mg/l NO_3	24.5	22.0	22.5	27.1	29.4	-	22.8	20.55	22.44	19.58	37.5 (TV)
Aerobic colony count 22C	cfu/ml	**4**	0	**22**	0	0	0	0	0	0	**6**	0
Aerobic colony count 37C	cfu/ml	0	0	0	0	0	0	0	0	0	0	0
Escherichia coli	cfu/100ml	0	0	0	0	0	0	0	0	0	**17**	0
Coliform bacteria	cfu/100ml	0	0	**6**	**4**	0	0	0	0	0	**28**	0

Parameter	Units	10.09.2013	13.08.2013	05.06.2013	08.05.2013	03.04.2013	05.03.2013	05.02.2013	07.01.2013	03.12.2012	05.11.2012	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	400	378	402	392	404	384	396	436		382	-
pH	Units	7.3	7.0	7.0	7.0	7.1	7.3	7.1	8.0		7.0	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	468	458	448	416	434	496	464	428		484	-
Iron, total	µg/l	<50	<50	<50	<50	<50	<50	**266.8**	<50		73.6	200 (DWL)
Manganese, total	µg/l	<50	<50	<50	<50	<50	<50	<50	<50		<50	50 (DWL)
Nitrate	mg/l NO_3	19.89	19.67	20.37	20.64	21.25	24.01	20.9	21.38		22.26	37.5 (TV)
Aerobic colony count 22C	cfu/ml	0	0	0	0	0	0	**5**	**10**	**34**	0	0
Aerobic colony count 37C	cfu/ml	0	0	0	0	**6**	0	0	0	**2**	**3**	0
Escherichia coli	cfu/100ml	0	0	0	0	0	0	0	0	0	0	0
Coliform bacteria	cfu/100ml	0	0	0	0	0	0	0	**11**	0	0	0

Parameter	Units	01.10.2012	10.09.2012	10.08.2012	10.07.2012	08.06.2012	10.05.2012	11.04.2012	07.03.2012	10.02.2012	06.01.2012	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	394	390	390	377	374	372	378	361	379	394	-
pH	Units	7.1	7.7	7.4	7.5	7.5	7.5	7.3	7.3	7.3	7.2	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	670	502	438	465	448	472	422	452	401	477	-
Iron, total	µg/l	<50	7.1	9.6	11.3	20.8	17	8.2	<3	13.8	21.8	200 (DWL)
Manganese, total	µg/l	<50	0.6	0.5	0.3	0.4	0.5	<0.2	<0.2	0.3	2.6	50 (DWL)
Nitrate	mg/l NO_3	21.21	21.0	21.3	19.8	22.0	20.5	20.6	19.8	20.4	20.1	37.5 (TV)
Calcium	mg/l		136.4	137	132.5	131.1	130.2	132.4	126.9	131.9	138.4	-
Magnesium	mg/l		11.7	11.6	11.1	11.2	11.4	11.5	10.7	11.9	11.6	50 (DWL)
Aerobic colony count 22C	cfu/ml	0	**3**	0	**2**	**26**	0	**110**	**3**	0	**45**	0
Aerobic colony count 37C	cfu/ml	0	0	0	0	**2**	**6**	**14**	0	0	6	0
Escherichia coli	cfu/100ml	0	0	**1**	**1**	**2**	0	0	0	0	0	0
Coliform bacteria	cfu/100ml	0	**12**	**3**	**9**	**89**	0	0	0	**9**	0	0

Parameter	Units	06.12.2011	02.11.2011	06.10.2011	08.09.2011	12.08.2011	03.08.2011	13.05.2011	09.02.2011	06.01.2011	15.12.2010	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	-	382	389	390	375	371	370	382	389	391	-
pH	Units	-	7.3	7.3	7.6	7.3	8.1	7.3	7.3	7.3	7.1	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	-	442	336	469	411	269	416	470	430	441	-
Iron, total	µg/l	-	8.8	18.1	5.9	78.9	7.4	8.6	20.4	51.5	9.76	200 (DWL)
Manganese, total	µg/l	-	0.5	0.9	0.3	1	0.2	0.4	0.6	1.4	0.44	50 (DWL)
Nitrate	mg/l NO_3	-	18.8	19.0	15.2	18.2	19.8	20.2	17.4	19.6	20.6	37.5 (TV)
Calcium	mg/l	-	133	137	137	131	129.8	129	134.3	136.7	137.7	-
Magnesium	mg/l	-	11.9	11.3	11.5	11.5	11.4	11.6	11.2	11.4	11.4	50 (DWL)
Aerobic colony count 22C	cfu/ml	**12**	**11**	**10**	0	**15**	**6**	0	**5**	0	**3**	0
Aerobic colony count 37C	cfu/ml	**5**	**3**	0	0	**2**	0	**14**	0	0	0	0
Escherichia coli	cfu/100ml	0	0	0	0	**61**	0	0	0	0	0	0
Coliform bacteria	cfu/100ml	**20**	**14**	0	0	**61**	**18**	0	**11**	0	**7**	0

-	Units	06.11.2010	15.09.2010	11.08.2010	05.07.2010	02.06.2010	07.05.2010	07.04.2010	02.03.2010	02.02.2010	01.12.2009	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$		379	372	409	404	399	387	404	374	398	-
pH	Units		7.1	7.2	7.3	7.1	7.4	7.2	7.2	7.3	7.4	6.5 – 9.5
Dissolved solids @ 180deg	mg/l		482	453	448	546	466	442	427	472	349	-
Iron, total	µg/l		<25	<25	<25	<25	<25	<25	<25	<25	<25	200 (DWL)
Manganese, total	µg/l		<1	<1	<2	<3	<1	<1	<3	<1	<3	50 (DWL)
Nitrate	mg/l NO_3		20.3	18.9	22.9	21.3	21.9	21.2	22.7	25.0	25.7	37.5 (TV)
Calcium	mg/l		133	130.2	144	144	141	137	144	132	141	-
Magnesium	mg/l		11.2	11.2	12	10.7	11.2	10.8	10.8	10.6	11.1	50 (DWL)
Aerobic colony count 22C	cfu/ml	**2**	**31**	**5**	0	**17**	0	0	0	0	0	0
Aerobic colony count 37C	cfu/ml	**3**	**9**	0	0	**13**	0	0	0	0	0	0
Escherichia coli	cfu/100ml	0	**1**	0	0	0	0	0	0	0	0	0
Coliform bacteria	cfu/100ml	0	**10**	**1**	0	**4**	0	0	0	0	0	0

Parameter	Units	30.10.2009	28.08.2009	30.07.2009	05.08.2009	21.07.2009	02.06.2009	30.04.2009	31.03.2009	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	412			388	386	387	407	389	-
pH	Units	7.4			7.3	7.4	7.4	7.5	7.3	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	464			284	425	398	384	432	-
Iron, total	µg/l	<25			<25	<25	<9	<9	<9	200 (DWL)
Manganese, total	µg/l	<3			<3	<3	<3	<3	<3	50 (DWL)
Nitrate	mg/l NO_3	22.4			22.2	22.4	21.6	21.3	23.0	37.5 (TV)
Calcium	mg/l	145			137	135	137	144	137	-
Magnesium	mg/l	11.9			11	11.8	10.9	11.5	11.2	50 (DWL)
Aerobic colony count 22C	cfu/ml	**3**	0	**2**			0	0	0	0
Aerobic colony count 37C	cfu/ml	**2**	0	0			0	0	0	0
Escherichia coli	cfu/100ml	0	0	0			0	0	0	0
Coliform bacteria	cfu/100ml	**13**	0	0			0	0	0	0

Parameter	Units	12.03.2009	28.01.2009	28.12.2008	01.12.2008	03.11.2008	10.10.2008	26.09.2008	02.09.2008	08.08.2008	22.07.2008	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	424	404	404	382	405	401		414	413	413	-
pH	Units	7.4	7.3	7.4	7.4	7.6	7.8		7.8	7.3	7.3	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	368	410	459	1160	457	400		-	455	-	-
Iron, total	µg/l	<25	<25	<25	<25	<13	17		<13	<13	<13	200 (DWL)
Manganese, total	µg/l	<3	<3	<3	<3	<3	<3		<3	<3	<3	50 (DWL)
Nitrate	mg/l NO_3	24.0	22.6	19.2	20.6	20.4	24.0		22.1	25.8	-	37.5 (TV)
Calcium	mg/l	151	143	143	135	143	141		146	146	146	-
Magnesium	mg/l	11.4	11.4	11.2	10.9	11.5	11.8		11.8	11.7	11.7	50 (DWL)
Aerobic colony count 22C	cfu/ml	0	0	0	0	0		0			0	0
Aerobic colony count 37C	cfu/ml	0	0	0	0	**2**		0			0	0
Escherichia coli	cfu/100ml	0	0	0	0	0		0			0	0
Coliform bacteria	cfu/100ml	0	0	0	0	0		0			0	0

Parameter	Units	01.07.2008	16.06.2008	09.06.2008	19.05.2008	18.04.2008	26.03.2008	25.02.2008	25.01.2008	20.12.2007	12.11.2007	Drinking Water Limit (DWL) or Threshold Value (TV)
Hardness	mg/l $CaCO_3$	409	408	397		397	410	396	414	415	434	-
pH	Units	7.5	7.3	7.5		7.4	7.3	7.3	7.2	7.1	7.4	6.5 – 9.5
Dissolved solids @ 180deg	mg/l	398	444	413		441	450	440	434	387	434	-
Iron, total	µg/l	<13	111	<13		38	<13	40	<13	<25	30	200 (DWL)
Manganese, total	µg/l	<3	51	<3		<3	<3	<3	<3	<3	<3	50 (DWL)
Nitrate	mg/l NO_3	27.3	25.5	28.2		29.7	29.1	31.8	28.7	30.9	30.6	37.5 (TV)
Calcium	mg/l	145	144	140		138	144	140	146	147	155	-
Magnesium	mg/l	11.3	11.7	11.5		12.5	12.2	11.2	11.8	11.6	11.3	50 (DWL)
Aerobic colony count 22C	cfu/ml			0	0	0	0	0	0	0	0	0
Aerobic colony count 37C	cfu/ml			0	0	0	0	0	0	0	0	0
Escherichia coli	cfu/100ml			0	0	0	0	0	0	0	0	0
Coliform bacteria	cfu/100ml			0	0	0	0	0	0	0	0	0

Geashill Public Supply

Groundwater Source Protection Zones

(April 2001)

Prepared by:
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In collaboration with:

Offaly County Council

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1 Introduction

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

The objectives of the report are as follows:

- To delineate source protection zones for Geashill spring.
- To outline the principle hydrogeological characteristics of the Geashill area.
- To assist Offaly County Council in protecting the water supply from contamination.

The report does not take account of the proposal by Ballinagar GWS to abstract water from nearby wells.

2 Location, Site Description and Well Head Protection

The source is one kilometre north of Geashill village, in the townland of Dalgan.

Two large sumps collect the water and an overflow discharges to a nearby stream. A gravel fill has been put in around the sumps. The rest of the site is grassed over.

The site is fenced off and the pumphouse is padlocked. One of the sumps is covered, the other is not fully covered and is thus exposed to birds and animals.

3 Summary of Well / Spring Details

GSI no.	:	2321NE W0001
Grid ref. (1:25,000)	:	N 24510 22160
Townland	:	Dalgan
Well type	:	Spring
Owner	:	Offaly County Council
Elevation (ground level)	:	70.7 m OD (232 feet OD)
Depth & Diameter of sump	:	1m x 3m
Depth to rock	:	10.7m
Static water level	:	Close to ground level, overflowing to stream in high flow periods
Normal Abstraction	:	910 $m^3 d^{-1}$ (~200,200 gal d^{-1})
Estimated Total Discharge	:	910 $m^3 d^{-1}$ to 1170 $m^3 d^{-1}$ (~200,200-257,000 gal 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 schemes and springs such as elevation, and abstraction figures were obtained from GSI records and County Council personnel; and hydrogeological information was provided by the Groundwater Protection Scheme (Daly et al, 1998).

The second stage comprised site visits and fieldwork in the Geashill 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 springs.

5 Topography, Surface Hydrology and Land Use

The spring emerges in a low-lying area at about 70.7 m OD (232 ft). The topography surrounding the springs is generally hilly with higher ground to the east, south and west. The highest point lies to the south of the village at 111m OD (363 ft).

The springs emerge beside a northward flowing tributary of the Tullamore river. In the catchment to the springs there are very few surface streams/drains, reflecting the free draining nature of the land in the area.

Agricultural activity dominates the area with most of the land used for grassland. Geashill village and a number of houses and farmyards are present in the vicinity of the springs. A sewage works lies between the village and the springs.

6 Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the Geashill spring source. This 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

Limestones occupy the whole area and a brief description of the individual rock units in the vicinity of the source is given in Table 6-1. The boundaries are shown in Figure 1.

The springs appear to occur at or close to the Calp - Allenwood boundary. The units are presented in order of increasing age and all are deposited in Carboniferous times.

Table 6-1 The Bedrock Geology of the Geashill area.

Name of Rock Formation	*Rock Material*	*Occurrence*
Calp	Dark well bedded, fine grained, clayey LIMESTONE with calcareous mudstones	Occurs in the western part of the catchment. Source within this unit.
Allenwood	Pale-grey, poorly bedded, medium to coarse grained LIMESTONE	Occurs as a narrow band underlying Geashill village.
Waulsortion	Fossiliferous, pale- grey, poorly bedded fine grained LIMESTONE	Occurs to the east of Geashill village.

Movements in the earth's crust have caused the rocks to be folded, faulted and jointed. The different rock units have a NE-SW trend or strike and they generally dip either north-westwards or south-eastwards 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 is one mapped fault which is close to the springs and possibly intersects the zone of contribution and there are probably other faults that haven't been noted because of the lack of outcrop in the area.

6.3 Subsoil Geology

6.3.1 Introduction

The Groundwater Protection Scheme and a site specific drilling programme carried out by the GSI provided the information on the subsoils. The subsoils comprise a mixture of coarse and fine grained materials, namely; peat, tills with gravels, tills, sand & gravels (eskers) and are directly influenced by the underlying bedrock, which is made up of the Calp, Allenwood and Waulsortion limestones. The muddy, dark nature of the Calp often means that the overlying subsoils will have proportionally higher percentages of fine grained material than subsoils produced over the Allenwood and Waulsortion rock types. The distribution of subsoils is shown in Figure 1, and is based on the Groundwater Protection Scheme (Daly et al, 1998). The geological logs of the auger holes drilled are given in Appendix 1.

The characteristics of each category are described briefly below:

6.3.2 Peat

This material occurs in the low-lying area around the springs themselves. The peat can be seen in stream cuttings next to the springs.

6.3.3 Tills with gravels

This is the dominant subsoil type in the area. The matrix is composed mostly of silty SAND with gravel and/or clay; sandy SILT with clay and clayey SILT with gravels (see appendix 1 for further details). 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 Tills

'Till' is an unsorted mixture of coarse and fine materials laid down by ice. Angular limestone fragments are abundant in the tills. A small area in the north east part of the catchment is made up of this subsoil type.

6.3.5 Sand & Gravels

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

6.3.6 Depth to Bedrock

The depth to rock is known in certain localities from a drilling programme carried out by the GSI to ascertain the thickness and permeability of the subsoils. The locations of the auger holes are given in Figure 1 and the depth of the holes is given in Appendix 1. The depth to bedrock varies between 5 and 10m. The lower lying areas around the spring has the thickest subsoil cover (8-11m) and the higher ground of the catchment has somewhat thinner subsoil cover (6-8m). There is no outcrop in the area.

7 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the Geashill 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: 79 mm. This estimation is based on the assumption that 20% of the potential recharge will be lost to overland flow, stream runoff 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	79 mm
Estimated Actual Recharge	315 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 is no water level data for the area south of the springs.
- At the springs the water level is at ground level and the entire area around the springs is boggy, marshy, quite flat and low lying.
- 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 springs. The dominant driving head are the hills around Geashill village. The flow directions will be perpendicular to the contour lines. In simple terms, rainfall reaching the water table anywhere in the catchment of the springs will flow in a northerly and north-westerly direction toward the springs.

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

7.4 Aquifer Characteristics

The Allenwood limestone has wide range of hydrogeological characteristics; permeability and transmissivity values ranging over several orders of magnitude (Daly et al, 1998). Free draining land overlies the Allenwood in the Geashill area and there are no surface streams, indicating that the Allenwood has good aquifer properties in this area. Permeability and porosity for the Allenwood in this locality are based on evaluation of data for the Allenwood in other areas and of rocks that are generally similar to the Allenwood. Estimates for these parameters are as follows:

Permeability ~ 10 m d^{-1};
Porosity ~ 2 %.

7.5 Aquifer Category

The Allenwood limestone is classed as a **Regionally Important Fissured aquifer (Rf)**. (Daly et al, 1998).

7.6 Hydrochemistry and Water Quality

The hydrochemical analyses show that the Geashill spring water is a hard to a very hard water with alkalinity values of 150-165 mg l^{-1}, total hardness values of 375-412 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 550-770 µS cm^{-1}, indicating that the groundwater has a hydrochemical signature of calcium bicarbonate type water. These values are typical of groundwater from limestone rocks. Table 7-1 gives summary statistics for electrical conductivity. Electrical Conductivity values are high and the current data set shows a unimodal tendency. The coefficient of variation of conductivity is 8.1% which indicates that diffuse recharge is the type of recharge (Doak, 1995).

Table 7-1 Summary Statistics for Electrical Conductivity (EC).

Parameter	*Value (µS cm^{-1})*
Average	670
Max.	770
Min.	550
Standard Deviation	55
Coefficient of variation of St. Dev. of E. C.	8.1%
Sample Number	14

Nitrate concentrations to date have not exceeded the EU Drinking Water Directive maximum admissible concentrations (MAC); values range between 8.8 to 41 mg l^{-1} with a mean of 25.2 mg l^{-1}. Since 1979, there has been a general increase in nitrate levels with two significant peaks in the data set, (Nov. 1990: 41 mg l^{-1}, March 1998: 37 mg l^{-1}). Throughout the 1990's the levels range between 20 and 30 mg l^{-1}. There is no apparent upward trend in recent years from the current data set.

Chloride levels range from 21-31 mg l^{-1}, with a mean of 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. Concentrations higher than the 30 mg l^{-1} usually indicates significant contamination. In July 1979, the level exceeded 30 mg l^{-1}, but in general are about 25 mg l^{-1}.

Sodium levels range between 7-18 mg l^{-1}. The higher recorded values are slightly above the normal range expected for sodium in uncontaminated groundwater.

Potassium levels range between 2.4-6.1 mg l^{-1}. On two occasions in 1997 (May and June) the levels were 5.8 and 6.1 mg l^{-1}. These values suggest contamination by an organic waste source.

The ratio of potassium to sodium (K:Na) may indicate contamination if the ratio is > 0.4. On three occasions this ratio has been > 0.4, (Sept'97, May'98 and July'98). The high ratios usually indicate contamination from farmyard wastes. However, chlorides, nitrates and ammonia levels on those dates are well inside the range of values for each these parameters respectively.

The water quality analyses show that the only parameters to have exceeded EU Drinking Water Directive maximum admissible concentrations (MAC) is that of faecal coliforms and turbidity. These exceedances occurred October and September 1997. All the drinking water returns analysed are for treated water.

7.7 Spring Discharge

The total discharge at the springs is difficult to measure accurately. There have been several estimates of the total yield and these are summarised in Table 7-2.

Table 7-2 Estimates of spring discharge at Geashill.

Date	*Source*	*Estimate type (m^3 d^{-1})*	*Discharge*
May 1999	GWS	Abstraction	909 m^3 d^{-1}
July 1999	GSI & GWS	Overflow + abstraction (0+909)	909 m^3 d^{-1}
November 1999	GSI	Overflow + abstraction (260 *(overflow figure)* + 909)	1169 m^3 d^{-1}

The differences in these estimates is that in the first estimate does not take account of the overflow; the second estimate recorded no overflow on the date of measurement and the third estimate is a winter flow measurement during higher flows and the overflow was recorded and measured.

7.8 Conceptual Model

- The highest measured discharge was 1170 m^3 d^{-1}; it is probably greater during wetter weather.
- The groundwater regime in the area is complex and the available hydrogeological information does not allow a definitive understanding of the hydrogeology. While there is insufficient drilling data to be conclusive, it is considered that the source of groundwater is largely due to the bedrock and not to the sand/gravel.
- The spring appears to be emerging at or close to the boundary between the Calp and Allenwood limestones. It is thought that it is likely that the boundary is slightly further north than shown on the bedrock geology map of the area. The Calp generally has a lower permeability and transmissivity than the Allenwood, thus causing an impedance of the general groundwater flow. The presence of the esker gravels may also influence the location as it allows discharge of groundwater at that point.
- The esker probably act as a high permeability "drain" which could take shallow groundwater to the spring.
- There are no surface streams in the catchment to the springs indicating the free draining nature of the subsoil and the relatively high permeabilities of the underlying Allenwood limestone.
- Groundwater flow is likely to flow through two mediums:

1) interconnected, possibly solutionally enlarged fracture zones and along fractures and joints outside the main fracture systems. The discharge indicates high velocities at least close to the springs;
2) via the eskers which may act as a drain or a conduit for groundwater flow from direct recharge through to the eskers or from water drawn in from less permeable tills.

8 Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the areas around the well that are believed to contribute groundwater to the well, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern, as described in Section 7.8 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 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 the 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 0.01. Thus the upgradient extent of the SI zone is 750 m. The SI is presented in Figure 2.

8.3 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.

The shape and boundaries of the ZOC were determined using hydrogeological mapping and the conceptual model. The ZOC catchment boundaries are as follows and illustrated in Figures 1, 2 & 3:

1. The **Northern Boundary**: Groundwater to the north of the springs cannot flow to the springs as the groundwater is downgradient on the northern side of the springs. An arbitrary buffer of 30 m is placed on the downgradient side of the springs. No account has been taken of any future development of the source downgradient of the springs for the Ballinagar GWS.

2. The **Eastern Boundary**: This is defined by the topographic divide that runs north-south subparallel to the road into the village. Groundwater east of this watershed flows eastward toward the Tullamore river. On the western side of this ridge groundwater flows toward the source. The slope toward the Tullamore river is gradual and the slope toward the spring is quite steep.

3. The **Southern Boundary** is marked by a topographic high which acts as a watershed dividing water flowing north and south. It could be argued that water may flow north east and discharge at the Tullamore river. However, in view of the quantity discharging at the springs; the general surface water patterns; the north westerly longitudinal direction of the eskers; the dip and stratigraphy of the bedrock geology - it is likely that groundwater in the southern part of the area flows to the springs.

4. The **Western Boundary** is constrained by a subtle topographic divide to the west of the springs and the village. This boundary roughly coincides with a change in rock units (Allenwood to the Calp). Groundwater to the west of the boundary (overlying the Calp) discharges to the stream which flows past the springs. Groundwater discharges to the spring on the east of this boundary. This idea is strengthened by the fact the head at the springs is higher than the head in the stream (water is unlikely to flow underneath the stream to the springs when it is easier to discharge to the stream). Further evidence is that the Electrical Conductance of the stream has a groundwater signature (Nov. 1999: 728 µS cm^{-1}).

These boundaries delineate the physical limits within which the ZOC is likely to occur. The area constrained by the hydrogeological mapping is 1.5 km^2. A water balance was used to estimate the areal extent of the catchment providing the water to the springs and the resulting area is compared to that delineated by mapping. Table 8-1 shows the results of the water balance and the various estimates of the ZOC according to the discharge. A water balance is carried out by using an estimated recharge value and the discharge estimates.

Table 8-1 Water balance calculations at Geashill Spring.

Discharge (m^3 d^{-1})	Recharge (mm yr.$^{-1}$)	Area (ZOC) (km^2)
1169	315	1.35
909	315	1.05

The water balance indicates that the largest estimated discharge requires an area of 1.35 km^2. The results suggest that the boundaries as defined by the hydrogeological mapping and the conceptualisation processes are slightly conservative, however, the largest discharge recorded is an early winter time record and doesn't accurately reflect the discharge during heavy rainfall periods.

9 Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 1. Most of the catchment is under the high vulnerability classification as it is covered by moderately to highly permeable materials with the depth to bedrock between 5 and 10 metres. Around the source itself where the subsoil cover is greater than 10m, there is highly permeable material overlying moderately permeable material. Where the water table is estimated to be within 3m of the ground surface in the esker, an extreme vulnerable area is delineated.

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 (see the matrix in the Table 10-1 below). 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 Inner Protection area where the groundwater is highly vulnerable to contamination. There are 3 groundwater protection zones present around the Geashill Source as shown in the matrix below. The final groundwater protection map is presented in Figure 2.

Table 10-1 Matrix of Source Protection Zones at Geashill.

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

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).

11 Potential Pollution Sources

The land in the vicinity of the source is largely grassland-dominated and is primarily used for grazing. Agricultural activities and the village are the principal hazards in the area. The main potential sources of pollution within the ZOC are farmyards, septic tank systems, runoff from the roads, the sewage works, leaky sewers and landspreading of organic fertilisers. The main potential pollutants are faecal bacteria, viruses, cryptosporidium and nitrogen. The sewage works is within the zone of contribution to the springs. Also it lies immediately next to the esker which may act as a "drain" leading to the spring. Therefore, it poses a significant threat to the groundwater quality of the spring.

12 Conclusions and Recommendations

- The source at Geashill is an excellent yielding well, which is located at the boundary of the Allenwood and Calp limestones.

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

- The sewage works, runoff from the roads, the garages in the village, houses, farmyards and landspreading pose a threat to the water quality in the spring.

- It is recommended that:

1) A full chemical and bacteriological analysis of the **raw** water should be carried out on a regular basis at the source.
2) particular care should be taken when assessing the location of any activities or developments which might cause contamination at the springs.
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.

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Doak, M., 1995. *The Vulnerability to pollution and hydrochemical variation of eleven springs (catchments) in the karst lowlands of the west of Ireland*. M Sc. Thesis, Sligo RTC, 52 pp.

Thorn, R., 1994. STRIDE project report, DoE.

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.

Geashill No. 9 National Grid Reference: N 24530 22073

Depth (m)	Subsoil	BS 5930	Permeability
0-1.0	Top soil	SILT	MODERATE
1.0-2.5	Till	sandy SILT with gravels	MODERATE
2.5-4.0	Till	clayey SILT with gravels	MODERATE
4.0-6.0	Till	clayey SILT with frequent gravels	MODERATE
6.0-6.15	Till	sandy CLAY with silt	LOW
6.0-6.30	Till	sandy SILT with clay	MODERATE

Geashill No. 8 National Grid Reference: N 24528 22125

Depth (m)	Subsoil	BS 5930	Permeability
0-1.5	Till	sandy GRAVEL	HIGH
1.5-3.0	Till	sandy SILT with frequent gravels	MODERATE
3.0-5.7	Till	sandy SILT with gravels	MODERATE

Geashill No. 2 National Grid Reference: N 24506 22173

Depth (m)	Subsoil	BS 5930	Permeability
0-4.0	Till/Esker	GRAVELS	HIGH
4.0-10.7	Till	sandy SILT with clay	MODERATE

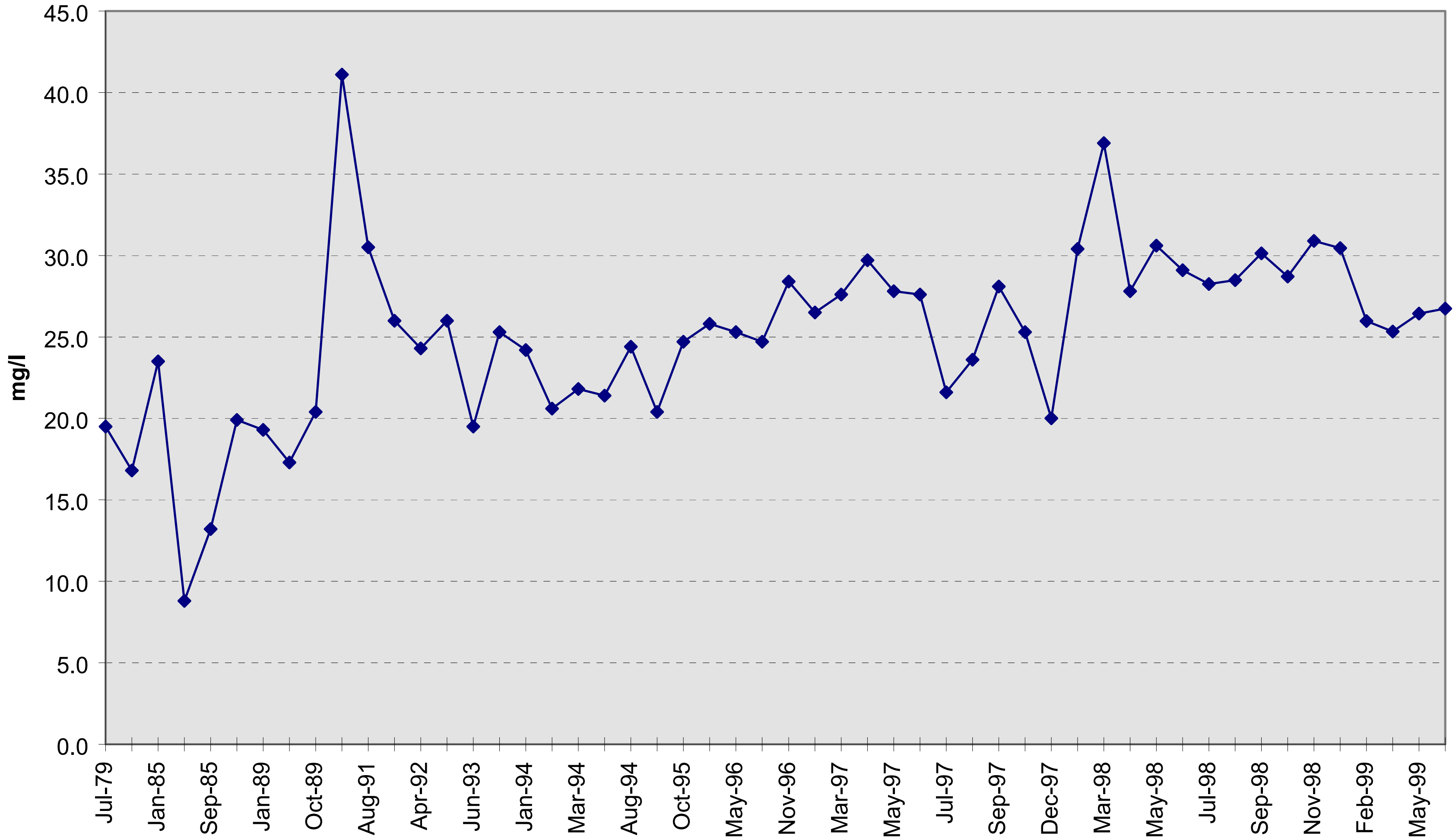
Geashill No. 4 National Grid Reference: N 24513 22162

Depth (m)	Subsoil	BS 5930	Permeability
0-0.8.5	Till/Esker	sandy SILT with clay and abundant gravels	MODERATE

Geashill No. 7 National Grid Reference: N 24557 22132

Depth (m)	Subsoil	BS 5930	Permeability
0-3.5	Till	sandy SILT with gravels	MODERATE
3.5-4.0	Till	sandy SILT with clay	MODERATE
4.0-7.0	Till	clayey SILT with gravels	MODERATE

Appendix 2 Nitrate levels in Geashill Spring



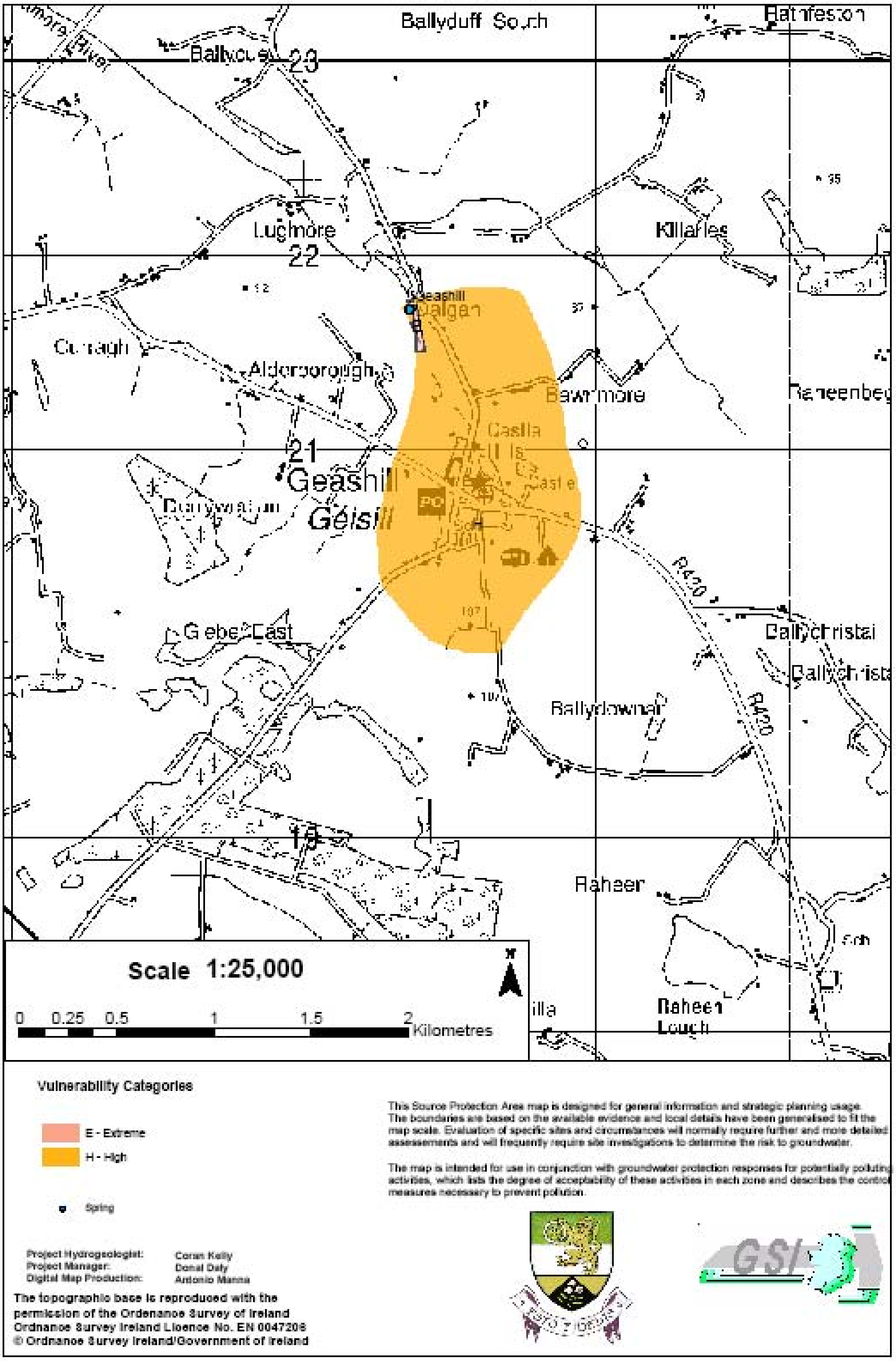


Figure 1 **Groundwater Vulnerability around Geashill**

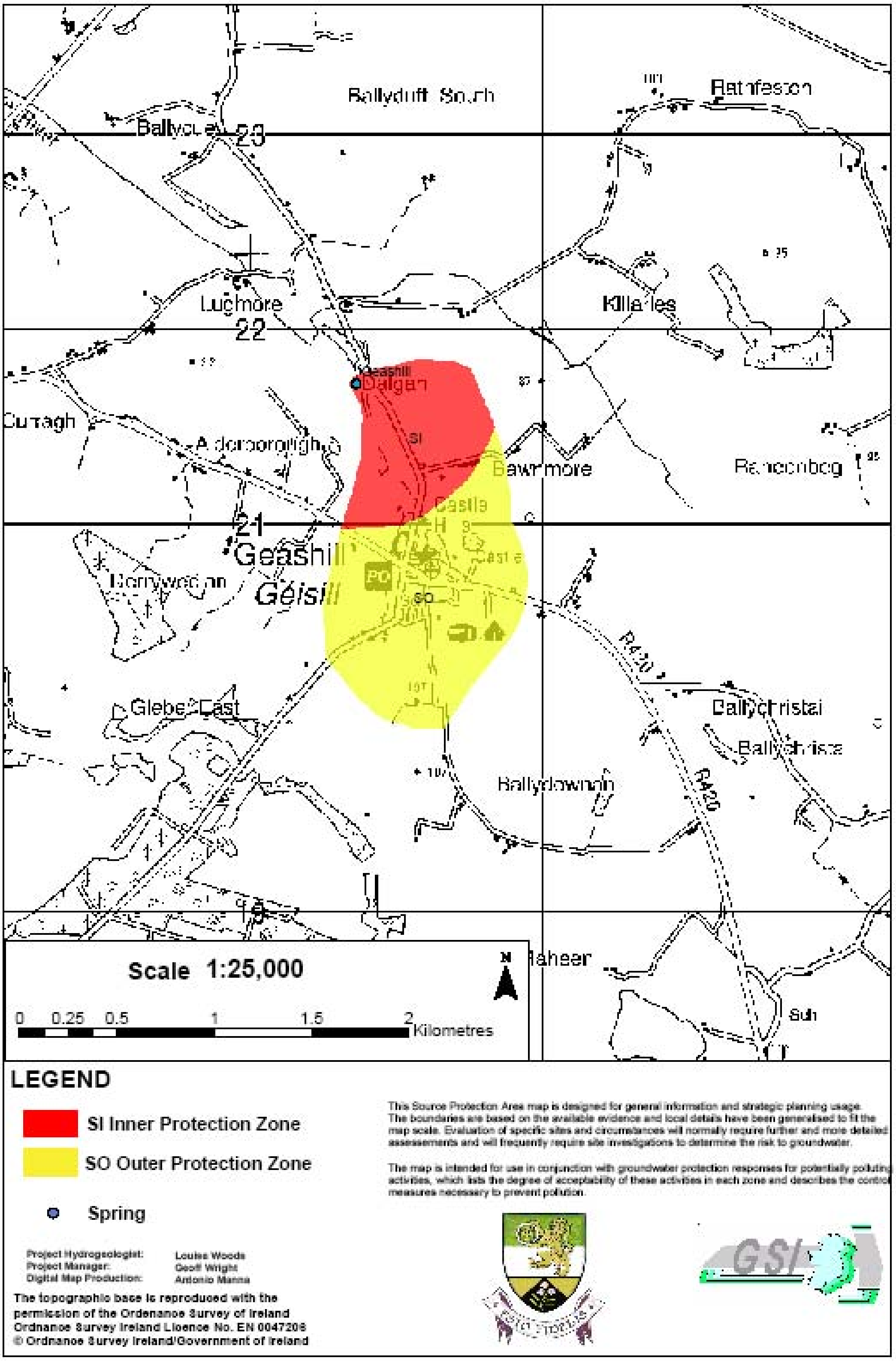


Figure 2 **Groundwater Source Protection Areas for Geashill**

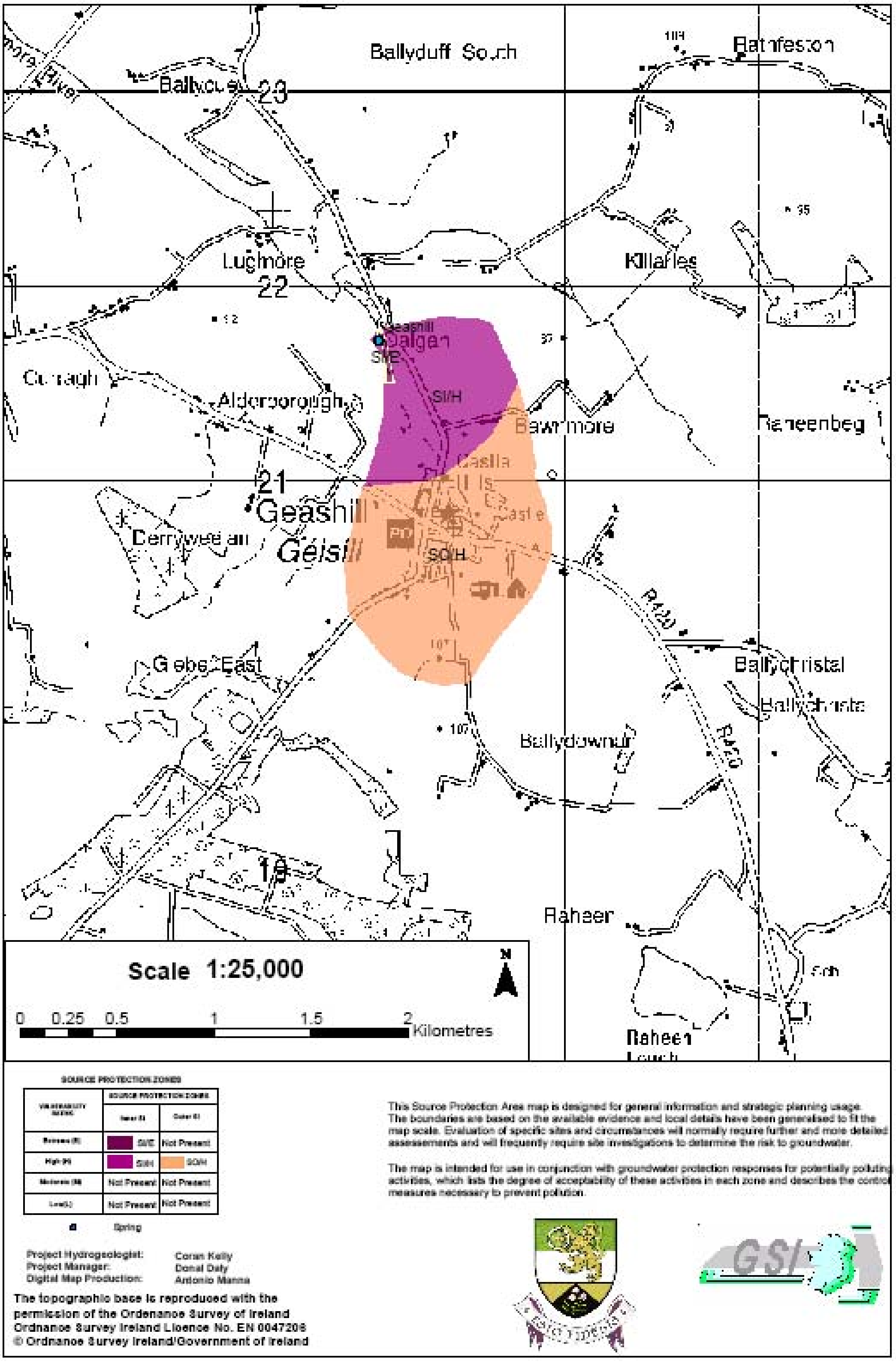


Figure 3 **Groundwater Source Protection Zones for Geashill**