

Dunmore-Glenamaddy Water Supply Scheme

Gortgarrow Spring

Groundwater Source Protection Zones Final report

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1 Introduction

There are a number of large springs located in the vicinity of the townland of Gortgarrow in northeast County Galway. The major one, which is known as Gortgarrow Spring, was developed in 1976 and is used to supply the Dunmore-Glenamaddy Water Supply Scheme. As well as this, a Group Scheme Supply also sources water from the spring; this was developed in 1977 and supplies the Boyounagh-Ballyedmond Group Scheme. The other four springs in the immediate vicinity are not used for water supply.

Galway County Council requested a source protection zone report for Gortgarrow Spring in October 2006 and though the other springs in its vicinity are not used as water supply sources, given the complexity of the geology in this area, these four other springs close to the main source are considered together.

The objectives of the report are as follows:

- To delineate source protection zones for the spring(s).
- To outline the principal hydrogeological characteristics of the Gortgarrow area.
- To assist Galway County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the springs. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection and source protection map/report suite for the county (GSI, 2007). The maps produced for the scheme are based largely on the readily available information in the area 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.

2 Location, Site Description and Well Head Protection

The pumphouse and springs are located approximately 2.5 km north of Clonberne Village, which lies southeast of Dunmore and southwest of Glenamaddy in northeast County Galway. The spring source is the largest of five springs in Gortgarrow Townland, all which are within 530m of each other. Their locations are shown in Figure 1.

The largest of these five springs forms the spring source, which supplies both Dunmore and Glenamaddy towns, as well as much of the surrounding rural area. The Boyounagh-Ballyedmond Group Scheme supplies the rural districts around Ballyedmond, Boyounagh North, Boyounagh South and Woodfield.

At the spring, groundwater emerges from the bedrock and filters through esker gravels and peat at NGR 157155 259535 to collect in a rectangular, 0.6m thick solid concrete chamber dug into the peat (approximately 28m by 13m and 2.5m deep) with a galvanised roof. The entire pumphouse site area of c. 2 acres is fenced off with poor quality fencing, and is further surrounded by a narrow belt of young conifer forestry which lies within a pasture area. Cutover peat extends to the northwest (see Figures 1 and 3).

The sump and drainage channel are not fenced off, and the channel is frequently overgrown with weeds, as recorded on a number of site visits and by the caretaker.

The spring source was originally used as the water supply to the Clonberne Creamery in the 1920s. It was first gauged during 1965 and 1966, when a minimum overflow of 14,460m³ per day

(5,250,406m³ per year) was calculated. The proposal was to abstract a maximum amount of 9,463 m³ per day¹.

The scheme was commissioned in 1972 but did not begin until 1977. The groundwater collects in the chamber and is fed by gravity flow *via* a 600mm diameter sump into the pumphouse, which both the Local Authority and Group Schemes supplies draw from. With the Local Authority supply, the water is chlorinated and fluoridated on-site and is then pumped to a reservoir at Monairmore with a storage capacity of approximately 3,785 m³ (1,000,000 gallons), which equates to 2-3 days storage. The chlorination tank and chemicals are stored in the pumphouse and a tap is present for raw water samples.

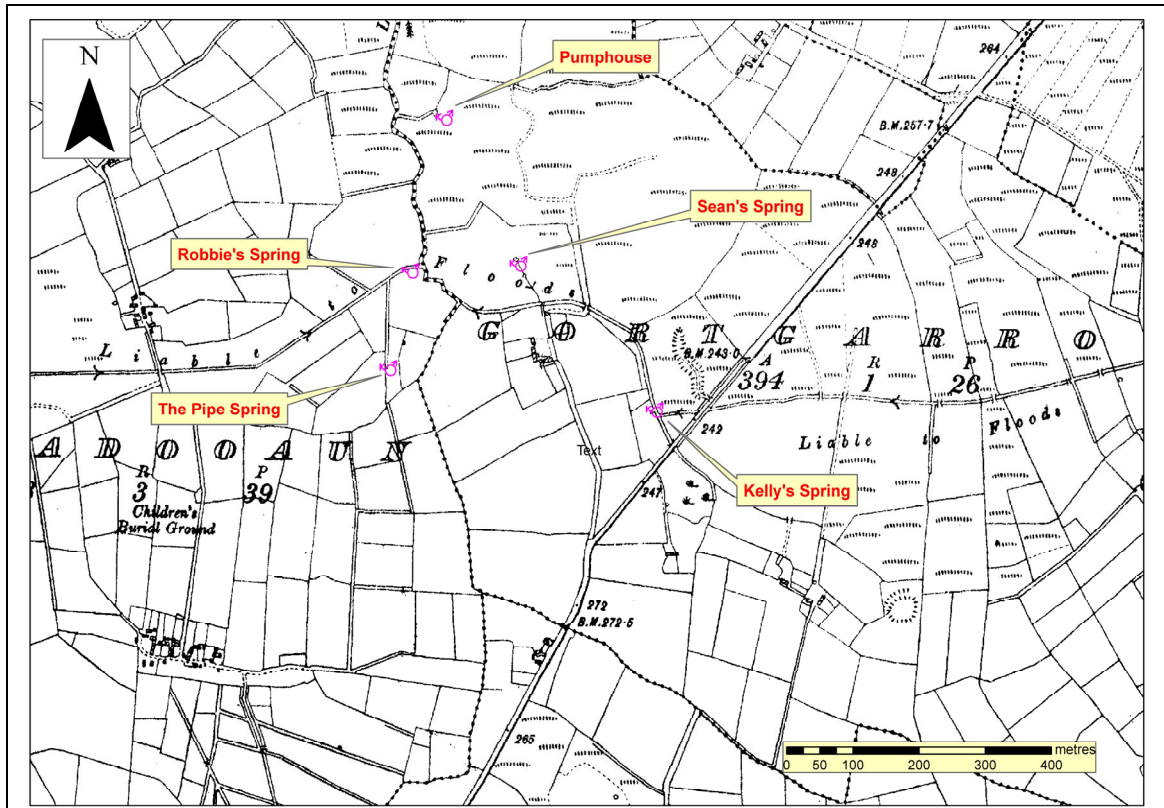


Figure 1: Location of the five springs, delineated by the pink symbols, and the pumphouse at Gortarrow. The underground pipe in the Pipe Spring is depicted with a line.

The other four springs in the immediate vicinity are called Sean's Spring, the Pipe Spring, Robbie's Spring and Kelly's Spring and are located 245m south-southeast, 395m south-southwest, 235m south-southwest and 545m southeast of the source spring respectively. Sean's Spring emerges through gravels; the Pipe Spring is piped into the adjacent stream from permeable till, where it rises; Robbie's Spring emerges through peat; and Kelly's Spring rises through permeable till.

¹ 2.5 million gallons is quoted in historical Local Authority documentation on the spring.

3 Summary of Spring Details

Spring Name	Gortgarrow Spring (source)	Sean's Spring	Pipe Spring
GSI No.	1425SEK006	1425SEK007	1425SEK008
Grid reference	157155 259535	157266 259316	157073 259160
Townland	Gortgarrow	Gortgarrow	Timadoodaun
Owner	Galway County Council	Private Ownership	Private Ownership
Well Type	Spring	Spring	Spring
Elevation (ground level)	75.4m OD.	75.7m OD.	76.1m OD.
Static water level	2m below ground level	0.9m below ground level	c. 0.3m below gr. level
Depth to rock	c. 7.5m	7.5m	Unknown
Normal abstraction	1227 m ³ d ⁻¹ (270,000 gallons per day) (Caretaker 9/11/06)	Not applicable.	Not applicable
Maximum abstraction	1227 m ³ d ⁻¹ (270,000 gallons per day) (Caretaker 9/11/06)	Not applicable.	Not applicable
Estimated total discharge (see Section 8.4)	11,398 m ³ d ⁻¹	4,415 m ³ d ⁻¹	363 m ³ d ⁻¹
Hours Pumping	12 hours for L.A. Scheme 24 hours for Group Scheme	Not applicable.	Not applicable
Depth of sump	2.5m	Not applicable.	Not applicable

Spring Name	Robbie's Spring	Kelly's Spring
GSI No.	1425SEK009	1425SEK0010
Grid reference	157105 259309	157472 259100
Townland	Timadoodaun	Gortgarrow
Owner	Private Ownership	Private Ownership
Well Type	Spring	Spring
Elevation (ground level)	75.7m OD.	76.1m OD.
Static water level	0.9m below ground level	c. 0.7m below ground level
Depth to rock	Unknown	5.5m
Normal abstraction	Not applicable	Not applicable
Maximum Abstraction	Not applicable	Not applicable
Estimated Total Discharge (see Section 8.4)	5,925 m ³ d ⁻¹	1,815 m ³ d ⁻¹
Hours Pumping	Not applicable.	Not applicable
Depth of sump	Not applicable.	Not applicable

4 Methodology

Details about the spring source such as date commissioned, historical data and outline abstraction figures were obtained from County Council personnel. As well as this, the data collection process included the following:

- Interview with the caretaker for the County Council Supply, 9/11/2006.
- Interview with the caretaker for the Group Scheme Supply, 5/12/2006.
- A desk study of existing geological and hydrogeological information was completed on 4/12/2006 and 16/3/2007, procured predominantly within the relevant GSI databases and maps.
- Visits to the spring and important surrounding sites in the landscape, with Dr. David Drew of the Geography Department of Trinity College Dublin, were carried out on 29/3/2007 and 19/4/2007.
- The spring was visited by GSI and EPA Staff on 12/4/2007.

- Detailed field survey of the subsoil geology, the hydrogeology and vulnerability to contamination was carried out by walkover stream surveys, logging of outcrops and exposures, and hand augering. This was completed on 20/3, 28/3, 16/4, 17/4 and 19/4, 2007.
- Mapping of swallow holes in the surrounding region of northeast Galway which were seen as possible contributors to the spring was carried out on 3/4, 4/4, 18/4 and 19/4, 2007.
- Rotary core drilling deep into bedrock was carried out at the source between 16/04/2007 and 20/4/2007.
- Auger drilling of sixteen holes was carried out by the GSI to ascertain depth to bedrock and subsoil permeability between 30/04/2007 and 4/5/2007.
- Installation of water level recorders, by the EPA, at the spring source V-notch and in the deep borehole drilled by GSI adjacent to the source, was carried out on 26/4/2007.
- Measurements of hydraulic conductivity and temperature from the main Gortgarrow Spring were carried out daily from 4/4/2007 to 18/07/2007
- Geophysical Mapping of the area, using VLF-Resistivity and 2D-Resistivity techniques, was carried out by Apex Geoservices Limited on 27/4/2007 and 3/5/2007.
- Water tracing of a swallow hole in Tullaghaun Townland, Kilkerrin, was carried out on 24/4/2007, with consequent sampling at the five springs at Gortgarrow and at Marganure Spring, Kilkerrin, between 25/4/2007 and 2/5/2007.
- Analysis of field study results, previously collected data and hydrogeological mapping were used to delineate protection zones around the source.

5 Topography, Surface Hydrology and Land Use

The springs are located in Hydrometric Area 30 of the Western River Basin District. The Sinking River is the main river that drains the area, and is part of the River Clare catchment. The Sinking River is bounded to the southwest by the Grange River Catchment and to the east by the Shiven River Catchment.

The springs are located between 75m and 76m OD (see Section 3 for exact spring elevations) at the boundary between higher, pasture land to the south and the extensive lowlying peat bog to the north (Figure 3). The land rises in a general sense towards the southeast to just over 110m in Derreen Lower townland west of Kilkerrin Village. The area as far as Kilkerrin itself forms an undulating, but high, dry plateau, with a gradual gradient up as far as Kilkerrin. The average topographic gradient from Kilkerrin to the springs is approximately 0.005.

The natural and artificial drainage density in the immediate vicinity of the source area is high owing to the springs being situated in the peat area. To the southeast, however, there are no surface drainage features on the high plateau; streams flow only around its lower slopes, usually in peaty valleys.

Two streams flow through the springs area; one flows from the west and one from the east, and they join just south of the main Gortgarrow Spring (source), with the confluent stream flowing off to the north where it joins the Sinking River at Parkbaun. The Pipe Spring and Robbie's Spring flow into the westernmost stream, which rises 1.46 km southwest of the source at Timadooan (this is not as depicted on the O.S. 1:50,000 Map, Sheet 39²). Kelly's Spring and Sean's Spring flows into the easternmost stream, which rises at Doo Lough 3.76 km southeast of the source spring.

Kiltullagh Lough, a major waterbody which fluctuates markedly in area between winter and summer and which has no outflow stream, is situated 3.2 km east of the springs (Figure 2). Two streams flow into this lake; one at its northeastern shore; the other along its easternmost point.

Dolines (enclosed depressions with a karstic origin) are common just south of Kiltullagh Lough, between there and Kilkerrin (see Figure 2). Here, surface water features are again absent.

At Kilkerrin, two groups of swallow holes occur where short, permanent streams sink underground. These are located 1 km northwest and 1 km east of the village crossroads.

² The point where this stream rises is marked as a continuous stream on the Ordnance Survey 1:50,000 Map, whereas the flow 'splits' from a topographic divide point (depicted in Figure 2).

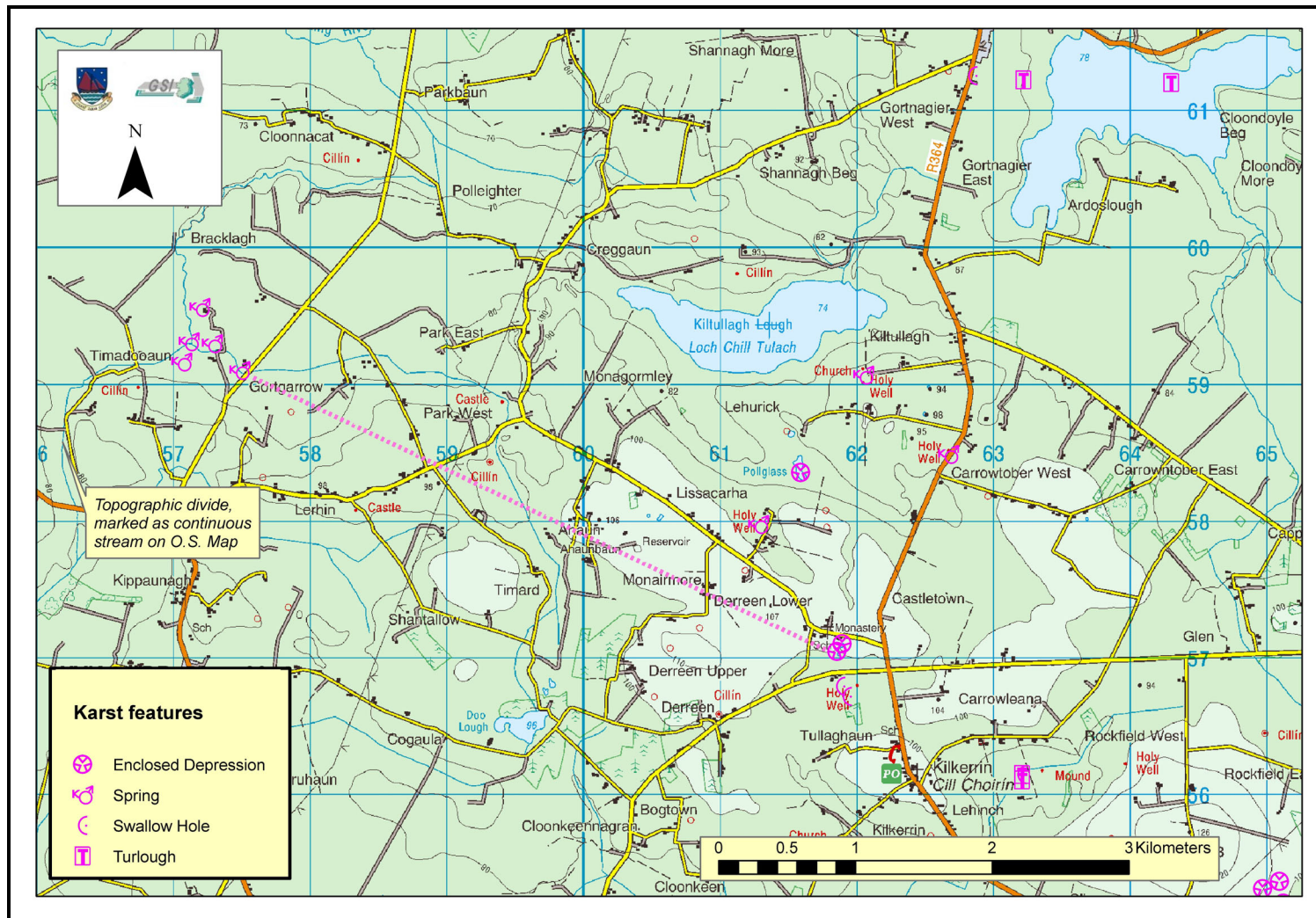


Figure 2: Topography of the area around and southeast of Gortgarrow. The higher plateau between there and Kilkerrin is clearly seen, as are the main hydrological features. Karst features are included, with the tracer test-proven connection between the swallow hole and spring also shown.



Figure 3: Land use around the five springs. See the cutover peat bog (partially reclaimed) extending towards the northwest, with the springs occurring at the junction of this peat with the higher ground underlain by mineral soils and subsoils and hosting well drained pasture, which extends towards the south and southeast.

The land in the vicinity of the source is split between two land uses; agricultural and basin peat. South of the springs, and for several kilometres south, southeast and southwest, the land is primarily agricultural, dominated by dairying, sheep and cattle rearing. North, northwest and northeast of the springs, extensive intact (though drained) raised and cutover peat is in evidence. Immediately north of and around the source spring, the peat has been reclaimed to grassland and young conifer forestry.

Clonberne Village is located 2.5 km to the south of the springs, with Kilkerrin Village 6 km to the southeast. There are a number of new housing estates in both villages, as well many farmyards across the plateau area in Lerhin, Park West and Monairmore Townlands. There are also a number of farmyards in the relatively lowlying area underlain by mineral soil and subsoil immediately south of the springs. A disused sand/gravel pit is located approximately 2.3 km to the east of the springs. There are Petrol Stations in Lerhin townland and Kilkerrin Village.

6 Geology

6.1 Introduction.

This section briefly describes the relevant characteristics of the geological materials that underlie the Gortgarrow source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. Geological information was initially taken from a desk-based survey of available data, which comprised the following:

- McConnell, B., MacDermot, C.V. and Long, C.B., 2002. Geology of South Mayo: A geological description of South Mayo, and adjacent parts of Galway and Roscommon to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 11, South Mayo.
- Morris, J.H., Somerville, I.D. and MacDermot, C.V., 2003. Geology of Longford-Roscommon: A geological description of Longford-Roscommon, and adjoining parts of Cavan, Leitrim and Galway to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 12, Longford-Roscommon.
- The Groundwater Vulnerability Map of County Galway, drawn up within the remit of the current project.
- Roscommon Groundwater Protection Scheme (Lee and Daly, 2002).
- Information from geological mapping in the nineteenth century (on record at the GSI).
- Information from Mineral Exploration Open Files, also held by the GSI.
- Data from the EPA/Teagasc Subsoils Map for County Galway.
- Data from the Teagasc Preliminary Reconnaissance Soil Map of County Galway.

As well as this, detailed field survey of the geology was carried out in the area around the springs by walkover stream surveys, logging of outcrops and exposures, and hand augering. This was completed in March-April 2007. Mapping of swallow holes in the surrounding region of northeast Galway which were seen as possible contributors to the spring was carried out in April 2007.

Rotary core drilling was carried out at the source between 16/04/2007 and 20/4/2007 and involved drilling a borehole to 100m depth immediately adjacent to the Gortgarrow Source Spring.

Auger drilling of sixteen holes was carried out by the GSI to ascertain depth to bedrock and subsoil permeability between 30/04/2007 and 4/5/2007.

Geophysical Mapping of the area, using VLF-Resistivity and 2D-Resistivity techniques, was carried out by Apex Geoservices Limited on 27/4/2007 and 3/5/2007.

6.2 Bedrock Geology.

According to the 1:100,000 bedrock sheets of the region (McConnell *et al.*, 2002 and Morris *et al.*, 2003), the area around the springs is underlain by Undifferentiated Visean limestones (Pure Bedded limestones).

The Undifferentiated Visean limestones (Pure Bedded limestone) have not been subdivided into discrete facies units as detailed mapping of the bedrock has not been carried out in the area. The limestone rock in this part of County Galway is however generally described as pale grey, clean, medium to coarse grained, and bedded.

During the current investigation into the bedrock geology around the source, a deep borehole (GSI-07-06) was drilled to 100m depth at NGR 157231 259521. This was drilled 74.5m west of the spring chamber at the base of the western extreme of the small esker ridge. This borehole encountered 9.5m of glaciofluvial and glacial sediments overlying bedrock (see section 6.3) with the water table at 2.4m bgl.

The bedrock sequence in this borehole was logged by Dr. Markus Pracht of the GSI on 16/5/2007. Thirteen samples of the bedrock core were collected, which will be studied by experts for micropalaeontological analysis. A preliminary stratigraphic interpretation shows karstified bioclastic fossiliferous limestone of the Knockmaa Formation to 23m bgl, with the predominantly cherty bioclastic limestones of the Corranellistrum Formation below that to 99.5m depth. A detailed log of the borehole is shown in Table 1.

Faulting has occurred in the general region around the source, but no faults have currently been delineated in the source locality.

Small areas of bedrock outcrop along the stream behind the creamery in Clonberne, along the stream that runs alongside the esker in Ahaun, and along both the northern and southern shores of Kiltullagh Lough.

6.2.1. Karst Features.

Karst feature mapping was undertaken in the region around Gortgarrow in Spring 2007. As shown in Figures 2 and 3, the mapping identified many swallow holes, springs, dolines and turloughs. Some of these had been previously recorded in the GSI Karst Database, but many new features were surveyed and recorded for the first time. Karstified strata were also found in the deep borehole drilled at the source to 23m depth.

<i>Depth (m)</i>	<i>Description</i>	<i>Structural Features</i>	<i>Stratigraphic Interpretation</i>
0-9.5	Overburden		Overburden
9.4-23	bioclastic limestone (80%) with minor argillaceous limestone (20%) bioclasts: crinoids, corals, shell fragments,	karstified, core fractured, stylolites, 19.3 to 20.0m steep calcite vein,	Knockmaa Formation (or equivalent)
23-41.6	cherty bioclastic limestone. Chert in irregular patches. bioclasts: shells, crinoids, corals. other clasts are intraclasts. There are more argillaceous intervals usually confined to fracture zones and stylolite seams.	stylolites and fractures	Corranellistrum Formation (or equivalent)
41.6-49.5	bioclastic limestone with more argillaceous material, less chert and more bioclasts than unit above		Corranellistrum Formation
49.5-99.5 (e.o.h.)	cherty bioclastic limestone.	stylolites and fractures	Corranellistrum Formation

Table 1: Summary log of borehole GSI-07-06 with preliminary stratigraphic interpretation assigned. The sequence shows 9.5m of overburden, karstified limestone to 23m depth, with more argillaceous and cherty limestone below this.

The mapping initially concentrated on ascertaining the elevation of swallow hole features to examine which were potential contributors to the springs at Gortgarrow. The elevation of each was recorded with GPS; only those features on the upland area around Kilkerrin, at the base of Kiltullagh Lough and immediately south of Glenamaddy Town were sufficiently high above the Gortgarrow Spring to potentially contribute to the spring flow at Gortgarrow.

6.3 Subsoil Geology.

Subsoils mapping was carried out by the author in 2002 while working at Teagasc on the EPA /Teagasc Soil and Subsoil Mapping Project. Refined mapping of subsoils was carried out throughout Galway for the current Groundwater Protection Project. This information forms the basis for subsoil permeability assessments of the county, also carried out for the current project. Further information was gathered from GSI boreholes drilled around the source in April and May 2007.

The subsoils comprise a mixture of coarse- and fine-grained materials. Sand/gravel, limestone tills and peat are the dominant subsoils in the area, with more restricted areas of sandstone/shale till, lake clays and alluvium occurring (Figure 4).

- ‘Till’ or ‘Boulder clay’ is an unsorted mixture of coarse and fine materials laid down by ice. Till is the dominant subsoil type south, southwest and southeast of the source. All of the 16 boreholes drilled through the soft sediments around the source encountered till at some point along their depths; even where peat or lake clays occur at the surface, they are generally underlain by till. The tills are limestone dominated and of moderate permeability, and were described using BS 5930 as gravelly SILT or silty GRAVEL in the majority of cases; CLAY occurred in only two of the boreholes.
- The depth to bedrock in the areas where till occurs is generally greater than 5m, and up to 12m.
- To the north, northeast and northwest of the source, for a distance of 3-5 kilometres, an extensive peat bog occupies the low-lying area. In places, protruding ‘islands’ of low permeability drumlinised till derived from sandstone and shale occur, which is generally a low permeability CLAY till.
- The peat is between 0.4m and 2.5m deep where encountered. However, it must be remembered that, in the area where the boreholes were drilled, the peat had usually been cutover and reclaimed.
- Short, narrow esker ridges protrude through the peat cover in places, including at the water supply spring source itself. The borehole drilled through the esker immediately adjacent to the source shows 4m depth of sandy GRAVEL within the esker, with 4.5m of silty SAND (till) between this and bedrock. It seems that the esker forms a pocket of sand/gravel protruding through the peat where the main Gortgarrow spring is located. At the other springs, sands and gravels or moderate permeability till occur.
- In addition, sand/gravel occupies a small area 200 m to the northeast of Gortgarrow Spring, where 7m of sands and gravels overlie 5m of till. Between the springs and Kiltullagh Lough, in Park West, Park East and Monagormley Townlands, a long, narrow, deep, north-south trending belt of sands and gravels and esker ridges occurs.
- This has been excavated historically and the disused pit faces show up to 10m depth of sand and gravels, which extend to bedrock in the area.
- On the high ridge at Monairmore-Kilkerrin, depths to bedrock in gravelly SILT and silty GRAVEL subsoils are 4m-6m in general. Given that there are no surface streams here, a very high percentage of the effective rainfall must be recharging to the groundwater.

Geophysical mapping in the area shows highly variable depths to bedrock. Bedrock is modelled as being over 10m from the ground surface along much of the esker ridge immediately east of the Gortgarrow Source Spring, with depths to bedrock of 7-8m through most of the peat area. It is seen that the shallowest depths to bedrock in the area are at the Gortgarrow Spring, Sean’s Spring and Robbie’s Spring: here bedrock is within 5m of the surface. Therefore it seems that these are the points where confinement of the groundwater by subsoils is lowest, thus allowing the easiest escape route for groundwater through (relatively) thin, permeable overlying sediments.

7 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater ‘target’. This means that vulnerability relates to the thickness of the unsaturated zone in the sand/gravel aquifer, and the permeability and thickness of the subsoil in areas where the sand/gravel aquifer is absent. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons, 2003).

- The groundwater supply source is the water table emerging at the springs. For the purposes of vulnerability mapping in the immediate vicinity around the springs, the “**water table**” is the target, as this lies above the top of the bedrock. Further southeast, toward Kilkerrin, where the subsoil is till of moderate permeability at an elevation higher than that of the water table and than that at the

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springs, then the “**top of the rock**” is the target³.

- Southeast, south and southwest of the springs, the permeability of the till and alluvium subsoil is interpreted to be “**moderate**”, the permeability of the esker material and the other sand/gravel subsoil is “**high**” and the permeability of the peat subsoil is “**low**” (see Figure 4 for the pattern of subsoils in these areas). North of the springs, the permeability of the till and alluvium subsoil is interpreted to be “**low**”, the permeability of the esker sand/gravel subsoil is “**high**” and the permeability of the peat subsoil is “**low**” (see Figure 4).
- Depth to bedrock varies from being greater than 12 m in pockets close to the source to zero where the rock outcrops occur along the stream beds at Clonberne and Ahaun, and around Kiltullagh Lough.
- At subsoil thickness of less than 3m, as indicated by the outcrop, subcrop and drilling data, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites). This is because infiltration is more likely to occur through ‘bypass flow’ mechanisms such as cracks in the subsoil. Based on the general depth to bedrock, a vulnerability classification of “**extreme**” has been assigned in these areas of shallower subsoil.
- Where subsoil thickness is greater than 3m, the vulnerability classification ranges from “**low**” to “**high**”, depending on the specific combination of permeability and subsoil thickness.
- As the water table at the springs exits either in a chamber with no protective sediment cover, or subaerially (at the surface), the vulnerability to contamination at the springs is classed as “**extreme**”. The extent of the extreme vulnerability is estimated to extend for 30 m around the springs, over the surface area of the flanking till/peat/sand and gravel.
- Several types of karst feature (*e.g.* dolines, swallow holes) provide locations of point recharge, where surface water can infiltrate directly to the bedrock, by-passing any attenuation capacity of the subsoil. These locations are therefore classified as “**extreme**” vulnerability also, which includes a buffer of 30m.

Depth to rock and depth to the water table interpretations are based on the available data cited here. However, depth to rock can vary significantly over short distances. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. The mapping is intended as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards. More detail can be found in ‘Groundwater Protection Schemes’ (DELG/EPA/GSI, 1999).

8 Hydrogeology

This section presents the current understanding of groundwater flow in the area of the springs and their feeder catchment. The interpretations and conceptualisations of flow are used to delineate source protection zones around the springs.

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

- GSI Databases.
- GSI dye tracer testing.
- Geophysical investigations, carried out by Apex Geoservices Limited.
- Historical Galway County Council hydrochemistry data.
- Historical hydrochemistry data from the Group Water Supply Scheme.
- EPA Groundwater Monitoring Data from Gortgarrow Spring.
- EPA flow measurement data from Gortgarrow Spring.
- Data on temperature and hydraulic conductivity collected by the caretaker between 4/4/2007 and 17/7/2007.
- Hydrogeological and permeability mapping carried out by the author.

³ In areas where the water table is below the top of the bedrock, the thickness of the unsaturated zone within the bedrock is not taken into consideration in vulnerability mapping, as fractured bedrock has high permeability regardless.

- A drilling programme carried out by the GSI to ascertain depth to bedrock and subsoil permeability in April and May 2007.

8.1 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 assumed to consist of input (*i.e.* annual rainfall) less 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 it will dictate the size of the zone of contribution to the source (*i.e.* the outer Source Protection Area).

At Gortgarrow therefore, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient. The recharge is estimated as follows.

Annual rainfall: 1,080 mm.

The contoured data map of rainfall in Ireland (Met Éireann website, data averaged from 1961-1990) show that the springs are located between the 1000 mm and 1200 mm average annual rainfall isohyet. The closest meteorological stations to Gortgarrow are at Glenamaddy (Gortnagier) and Dunmore. These have average annual rainfall of 1057 mm and 1098 mm respectively. Given that the topography between Dunmore, Gortgarrow and Glenamaddy does not have any major upland features and is generally lowlying, we can therefore interpolate between these stations and the springs and use their distances from Gortgarrow to weight the data. From this, annual rainfall is calculated as *c.* 1080 mm for the springs' locality.

Annual evapotranspiration losses: 450 mm.

Potential evapotranspiration (P.E.) is estimated to be 475 mm yr.⁻¹ (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E., to allow for seasonal soil moisture deficits.

Annual Effective Rainfall: 630 mm.

The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 630 mm/year.

Runoff losses: 164 mm.

Runoff losses are assumed to be 38% of potential recharge. This value is based on an assumption of *c.* 20% runoff for 70% of the area⁴ (high or moderate permeability subsoils and soils, no drains or surface streams), and 80% runoff over 30% of the area due to thicker, less permeable subsoil (Irish Working Group on Groundwater, 2004).

The bulk *recharge coefficient* for the area is therefore estimated to be 62%.

These calculations are summarised as follows:

Average annual rainfall (R)	1080 mm
estimated P.E.	475 mm
estimated A.E. (95% of P.E.)	450 mm
effective rainfall	630 mm
potential recharge	630 mm
recharge coefficient for moderate K	80%
recharge coefficient for low K	20%
runoff losses	38%
bulk recharge coefficient	62%
Recharge	391 mm

8.2 Groundwater Levels, Flow Directions and Gradients.

All five springs emerge in flat, lowlying areas: three emerge in and through cutover and reclaimed peat, and two occur at the junction between the reclaimed peat and till scarps. In most of the area around the springs a

⁴ The 'area' here is the expected, or estimated, potential zone of contribution from preliminary assessments of the topography, soils, subsoils and bedrock geology of the area.

high density of artificial drainage is required in order to utilise the land, which is mainly grazed. There is also a high natural drainage density in this lowlying area around Gortgarrow. The emergence of the springs and the high natural and artificial drainage densities generally indicate a shallow water table in the area around the springs (*i.e.* close to the surface).

The GSI undertook tracer testing in Tullaghaun Townland, just northwest of Kilkerrin, in April-May 2007. Dye was injected into one of three adjacent swallow holes located in this higher, plateau area around the village. Six springs were sampled; the five at Gortgarrow, and the one at Marganure on the other side of the plateau, southeast of Kilkerrin.

The results of the tracer tests show that dye from the swallow hole was detected at all five springs at Gortgarrow, but not at Marganure. The five springs therefore emerge from the same groundwater system. The time-of-travel for the dye to the Gortgarrow Spring, Sean's Spring and Kelly's Spring was five days, with the water taking twelve hours longer to reach the Pipe Spring and Robbie's Spring. This gives groundwater flow velocities of 45 m/hr for Gortgarrow Spring, 43 m/hr for Sean's Spring, 40 m/hr for the Pipe Spring and for Robbie's Spring, and 41 m/hr for Kelly's Spring.

The connections established between the springs and the swallow hole(s) suggest that the local-scale direction of groundwater flow is complicated and thus not easy to predict. This is due to the karstic nature of the bedrock, where particular fissures/conduits are likely to locally dictate the flow directions under specific flow conditions. However, we can assume that the general groundwater flow direction under the plateau area, from Kilkerrin to Gortgarrow, is from southeast to northwest.

Dye was not detected at Marganure Spring on the south side of the Kilkerrin plateau. This indicates that the swallow holes at Tullaghaun are not connected with it, and that Kilkerrin Village is on a karstic watershed divide.

As well as the tracing study, the geophysical survey carried out at Gortgarrow shows that the shallowest depths to bedrock in the area are at the Gortgarrow Spring, Sean's Spring and Robbie's Spring: here bedrock is within 5m of the surface. The survey also indicates that the depth to bedrock is highly variable within a relatively small area around Gortgarrow, suggesting that karst solution is in evidence on its surface. The profiles show coherent bedrock underneath fissured, karstified bedrock, which is reflected in the borehole log drilled by the GSI. From this, the existence of relatively large fissures fed by water from the plateau to the southeast is expected in such a setting.

The groundwater gradients from the swallow holes and within the plateau area, towards Gortgarrow are estimated to be approximately 0.0037.

Two other swallow holes close to Gortgarrow are potential contributors to water flow towards the springs. The first is in Gortnagier East, just south of Glenamaddy Town, at NGR 162858 261920. The second is at the base of Kiltullagh Lough, NGR 160426 259673. Time constraints meant that carrying out tracer tests were impossible on these features, as one was dry and the other full of water when the tracing began. It is highly possible that the water sinking beneath Kiltullagh Lough emerges at Gortgarrow.

Though tracing was not carried out on these other swallow holes, temperature and hydraulic conductivity data were sampled on a daily basis from 4th April to 18th July 2007 in order to see if any hypotheses could be tested on a swallow hole at the base of Kiltullagh Lough contributing to the Gortgarrow flow. Kiltullagh Lough is only 3 kilometres due east of Gortgarrow, and it was thought that this may have an effect on the temperature and hydraulic conductivity of the water at Gortgarrow.

The data showed interesting results. As would be expected coming into the summer months, the water temperature rose gradually, but steadily, until the weather became more unsettled in mid-June. The conductivity of the water decreased gradually in the same period, also becoming more haphazard from mid-June on. However, the most striking aspect of the data is the response to the extreme rainfall event that occurred on June 14th, when heavy flooding occurred throughout Galway. The conductivity has been falling steadily until that date; but jumped from 490µS/cm to 664µS/cm on June 15th. The temperature decreased from 15.1 °C to 12.8 °C within 48 hours. Both 'jumps' can be seen in Figure 5.

These results suggest that the water is being fed rapidly by a surface water source: a conductivity of 664 μ S/cm is more typical of surface water than groundwater. Also, the one day response time is much quicker than measured in the dye tracing from the swallow holes at Kilkerrin. Therefore, it seems that the lake at Kiltullagh has a high probability of contributing water to Gortgarrow Spring.

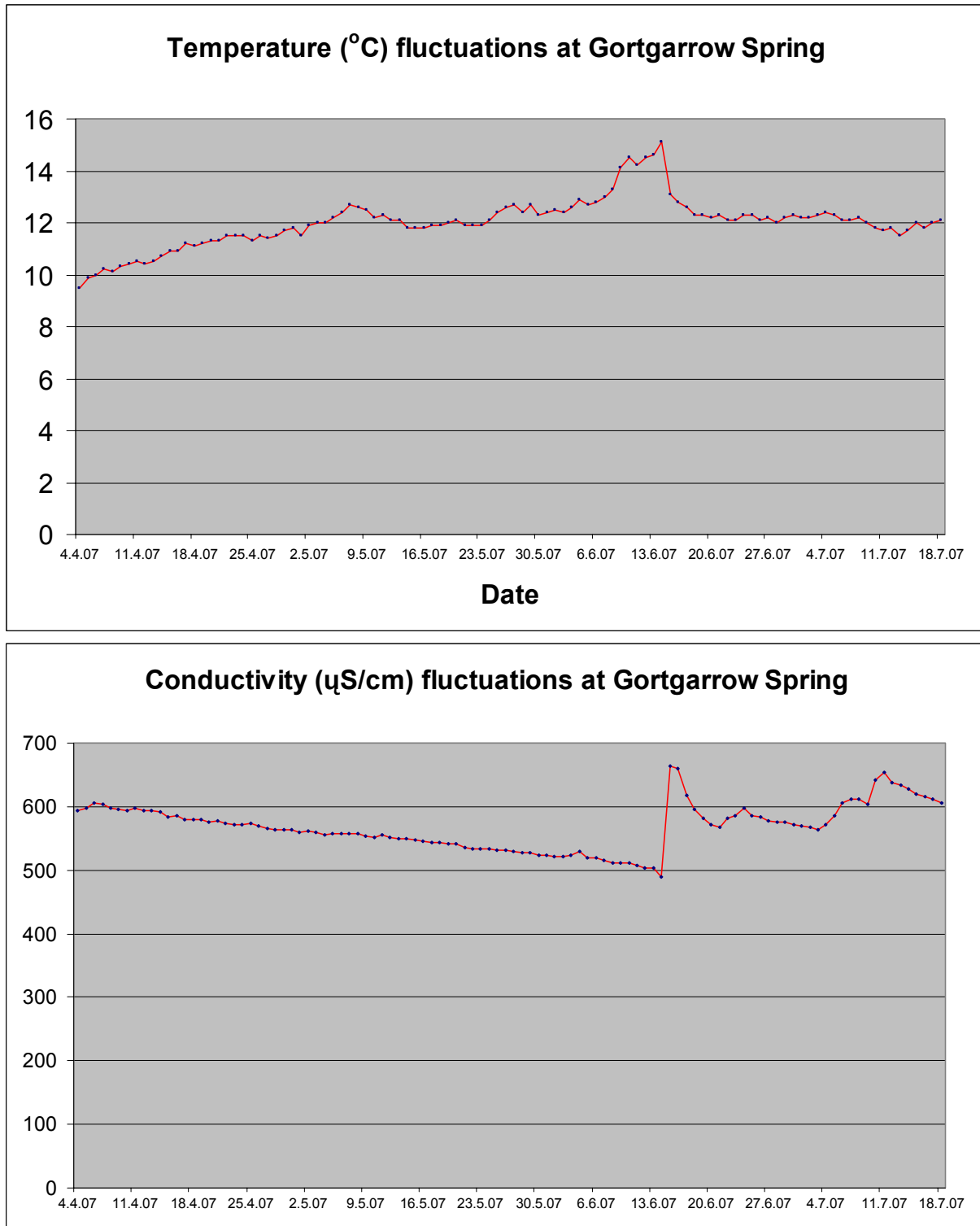


Figure 5: Temperature and conductivity data for Gortgarrow Spring, April-July 2007. Note the ‘jump’ on 15th June following the extreme rainfall event the day before.

8.3 Hydrochemistry and water quality.

The available water quality data for the main Gortgarrow Source Spring is from the EPA bi-annual data, which has been collected at Gortgarrow since 1995. Much of the chemical data, however, is only available from 2000. The data on trends in water quality are summarised graphically in Table 2. The following key points are identified from the data (all samples are from the main source spring).

- The water is generally “very hard” with an average total hardness of *c.* 350 mg l⁻¹ (equivalent CaCO₃) calcium-bicarbonate hydrochemical signature, and electrical conductivity values as sampled by the EPA are of 677-762 µS cm⁻¹. This grade of hardness is often described by analysts as being “excessively hard”. The values are typical of groundwater from limestone, and therefore shows that though the spring emerges through peat, this has little or no effect on its hydrochemical signature.
- Faecal coliforms were present in the water on most occasions sampled. Only three times out of twenty were no faecal coliforms found, and there were greater than 10 faecal coliforms per 100 ml (gross contamination) on seven occasions, although this has reduced markedly in recent years. On 06/09/2005 elevated ammonia (0.19 mg l⁻¹) was recorded, which is greater than the GSI threshold value⁵.
- Nitrate concentrations in available samples since 1995 range from 1.88 mg l⁻¹ to 15.94 mg l⁻¹ (average is 10.36 mg l⁻¹). There are no reported exceedances above the EU Drinking Water Directive maximum admissible concentration of 50 mg l⁻¹, or the GSI threshold value of 25 mg l⁻¹. The area around the springs is relatively sparsely populated, which means that there is a relatively low density of septic tanks. Further from this, it was seen from the geological mapping in the area that depths-to-bedrock are usually not shallow. Little tillage is practiced around the area. Therefore, the relatively low nitrate levels at Gortgarrow are probably due to a combination of the above factors.
- Chloride is a constituent of organic wastes and levels higher than 25 mg l⁻¹ may indicate significant contamination, with levels higher than the 30 mg l⁻¹ usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 16 to 26 mg l⁻¹ (average 20.4 mg l⁻¹), suggesting that contamination from organic wastes has possibly occurred on one occasion (17/01/2006: 26 mg l⁻¹). The data have shown an upward trend in recent years and this chemical signature should be monitored closely in the near future.
- On seven occasions out of 20 potassium was elevated above the GSI threshold value of 4 mg l⁻¹. Again, this has shown an upward trend in recent years with values of 6.3 mg l⁻¹ and 4.4 mg l⁻¹ occurring on the last two occasions sampled (06/09/2005 and 17/01/2006). The potassium:sodium (K/Na) ratio exceeds the GSI threshold of 0.35 on 13 occasions out of 20. These data suggest an organic waste source, and the K/Na ratio suggests farmyard wastes rather than septic tank effluent.
- The levels of iron range from 0.002 to 0.374 mg l⁻¹ at Gortgarrow, with records showing that iron exceeds the maximum admissible concentrations (0.20 mg l⁻¹) four times out of 20. Three of these occasions have been in the last few years (17/09/2003, 21/09/2004 and 06/09/2005). Given that the iron levels have historically been low at Gortgarrow (average before 2001 was 0.065), this also suggests the influence of effluent from organic wastes, which also seem to become more concentrated at the end of the non-recharge period *i.e.* late summer.
- In summary, bacteriological exceedances, commonly elevated potassium and elevated potassium:sodium (K/Na) ratios, recent elevated chloride and high iron suggest contamination from an organic waste source. Given the land use in the area, the most likely source is farmyard wastes.

8.4 Spring Discharge.

There are no long-term discharge data for the springs at Gortgarrow. However, the Local Authority did measure discharge at the source spring for a period of two years between May 1965 and April 1967, as part of the feasibility study on the spring as a water supply. The total average discharge per year was calculated at 10,205,400 m³.

⁵ Levels of ammonia higher than the GSI threshold values were also present commonly before 2001, but similar to the issues with high levels of faecal coliforms, this has diminished in recent years.

Prior to the detailed work carried out on the springs, it had been reported by the Local Authority Supply and the Group Scheme Supply caretakers that the flow had diminished at the spring since 1995, when extensive drainage works had taken place in the fields surrounding the source. In contrast, the flow at Sean's Spring had increased.

The total spring(s) discharge (abstraction quantities and overflow volumes) was not well characterised prior to this project. Apart from the data collected in the 1960's, there were no records of the overflow. According to the caretaker for the Local Authority Scheme, the abstraction is relatively constant, approximately 1,250 m³d⁻¹ consisting of 800 m³d⁻¹ for Glenamaddy and 450 m³d⁻¹ for Dunmore. As well as this, Neptune Laboratories of Galway keep data on the pumping rates for the Group Scheme, which shows that 990 m³d⁻¹ is abstracted by this scheme.

The EPA installed a water level recorder at the spring source V-notch, and in the deep borehole drilled by GSI adjacent to the source, on 26/4/2007. Data from the recorder measuring discharge at the V-notch was calculated for dates between 19/04/2007 and 26/06/2007, a total of 68 days data. This was then used, along with rainfall co-efficients for the rest of the year, to calculate an annual discharge at the V-notch. The total of 504,118.5 m³ for the 68 days equates to 3,342,662 m³ per year, or 9,158 m³d⁻¹.

Sample date	Conductivity µS/cm	Ammonia mg/l N	Chloride mg/l Cl	Iron mg/l Fe	Total coliforms No./100ml	Faecal coliforms No./100ml	Nitrate mg/l NO ₃	Sodium mg/l Na	Potassium mg/l K	Total hardness mg/l CaCO ₃
06/12/95	nm	<0.008	21	0.002	10	8	11.4	9	2.9	282
02/09/96	nm	0.142	21	0.1	27	20	10.99	10.8	3.74	244
12/11/96	nm	<0.008	20	0.1	0	0	18.92	8.5	3.93	159.2
12/11/97	nm	<0.008	19	0.05	42	4	12.71	9	4	178
13/10/98	nm	0.06	20	0.11	174	0	11.39	11	4	364
13/01/99	nm	<0.008	20	0.05	65	52	1.88	12	4	352
22/09/99	nm	0.019	16	0.098	1510	209	9.06	8.56	5.12	328
12/01/00	690	<0.008	22.8	0.0485	57	16	12.97	12	2.2	340
26/09/00	677	0.197	20.2	<0.05	30	20	7.26	11.3	4.1	360
31/01/01	659	<0.1	18	<0.05	18	2	9.74	8	3.4	344
02/10/01	732	0.23	20	0.058	130	2	7.53	5.8	2.8	404
18/02/02	nm	0.01	17	0.175	31	0	12.4	8	3.1	344
18/09/02	nm	0.1	19	0.256	687	4	7.53	5.4	2.5	348
18/02/03	678	<0.03	18	0.22	19	1	9.3	9	2.7	344
17/09/03	762	0.09	18	0.374	171	<1	7.97	10	3.5	400
14/01/04	701	<0.03	23	0.134	154	8	10.62	12	3.4	348
21/09/04	693	<0.03	25	0.263	326	48	9.74	12	3.5	nm
01/03/05	648	<0.03	22	0.183	5	<1	11.51	8	3.6	348
06/09/05	733	0.19	23	0.291	689	9	8.42	9	6.3	364
17/01/06	728	<0.03	26	0.14	115	24	15.94	9	4.4	364

Table 2: Summary hydrochemical data for Gortgarrow Spring, 1995-2006.

Flows from Sean's Spring, the Pipe Spring, Robbie's Spring and Kelly's Spring were measured during a karst mapping programme, which was undertaken by the author in April and May 2007. The estimated discharge values, as well as abstractions, follow.

Gortgarrow Spring (source):	9,158 m ³ d ⁻¹ PLUS 2,240 m ³ d ⁻¹ abstracted = 11,398 m ³ d ⁻¹
Sean's Spring:	4,415 m ³ d ⁻¹
Pipe Spring:	363 m ³ d ⁻¹
Robbie's Spring:	5,925 m ³ d ⁻¹
Kelly's Spring:	1,815 m ³ d ⁻¹

The total discharge from the five springs is therefore **21,676 m³d⁻¹** in the period April-May 2007.

8.5 Aquifer Characteristics.

The Undifferentiated Visean limestones, recently characterised at Gortgarrow as being from the Knockmaa Formation and Corranellistrum Formation by Markus Pracht of GSI, provide the groundwater to the five springs at Gortgarrow. Three of the five are considered to have a high spring yield. They are interconnected (as shown by dye tracing) and no more than 540m from each other.

A large karst network probably underlies the source and the high plateau area southeast of it at least as far as Kilkerrin Village. This causes the water to concentrate in the low lying discharge area. Bedrock is at its closest to the surface at Gortgarrow Spring, Sean's Spring and Robbie's Spring, where it is within 5m of ground level.

Karstification is an important process in Irish hydrogeological systems. It involves the enlargement of rock fissures when groundwater dissolves the fissure walls as it flows through them. The process can result in significantly enhanced permeability and groundwater flow rates. It generally occurs in 'purer' limestones. The large number of densely packed dolines, turloughs and swallow holes (Figure 2) around Kiltullagh and Kilkerrin provide evidence for significant karstification in the Gortgarrow-Kilkerrin area. The results of the tracer test, conductivity and temperature measurements, drilling through bedrock, and geophysical investigations, also indicate a high degree of karstification.

The tracer test recorded minimum groundwater flow velocities of between 40 m/hr and 45 m/hr. These flow rates depend on several factors including topography, rainfall and groundwater levels. However, such high velocities are characteristic of groundwater flow in karstified limestone aquifers.

The bedrock in the Gortgarrow-Kilkerrin area is likely to be characterised by:

- groundwater flow in solutionally-enlarged bedding plane partings, joints, faults and conduits;
- high groundwater velocities, several orders of magnitude greater than in granular (sand/gravel) aquifers;
- concentration of groundwater flow into zones of high permeability;
- a combination of diffuse and point (through swallow holes, dolines) recharge;
- discontinuous or poorly connected water table;
- often extreme vulnerability to contamination due to point recharge by-passing the potential attenuation capability of the subsoil;
- minimal attenuation of contaminants within the aquifer, except by dilution;
- high turbidity, suspended solids and colour after heavy rain, particularly in the autumn;
- short response times when pollution incidents occur.

The Knockmaa Formation and Corranellistrum Formation bedrock under the site, and by extension the bedrock around Gortgarrow and Kilkerrin (heretofore mapped as 'Undifferentiated Visean limestone') is classified as a Regionally Important Karstic Aquifer, which is characterised by conduit flow (**Rk^c**).

8.6 Conceptual Model.

- The higher plateau area to the southeast of Gortgarrow is underlain by Visean limestones (of the Knockmaa Formation at Gortgarrow) and has a noted absence of surface streams. The absence of surface drainage suggests that potential recharge readily infiltrates into the groundwater system.

- The pure limestone has undergone significant karstification, shown by the high number of densely packed dolines, swallow holes, springs and dry valleys. Tracer test and drilling results also infer that the karst is well developed.
- The tracer test identified one distinct flow direction: northwestwards from the swallow holes on the plateau at Kilkerrin. A second flow direction from Kiltullagh Lough to the springs (*i.e.* westwards) is suggested by the temperature and conductivity trends at the main Gortgarrow Spring. The general trend is therefore to the west and northwest.
- These results suggest that there is an element of topographic control on the groundwater divide, but not entirely so.
- The springs seem to emerge at Gortgarrow as it is at the base of a regional topographic high, and also seems to have well defined karst conduits. The bedrock is relatively close to the surface in the area of the springs, but the water emerges through permeable till and sand and gravel deposits which act as a 'window' for flow, as well as through peat.
- Given the degree of karstification in the Visean limestone (Knockmaa Formation), groundwater is likely to flow along interconnected, solutionally enlarged fractures and pronounced joints that exist in these rocks. The results of the tracer test and the geophysical investigation possibly reflect some of the larger conduits.
- The precise pathways of groundwater flow, as well as the flow depths, are not known. However, the established connections identified by the tracer test highlight the complexity of potential flow paths through the limestone.
- Groundwater velocities through the karstified Visean limestone are high (minimum of 40m/hr).
- Both diffuse and point recharges occur in this area. Swallow holes and dolines provide the means for point recharge. The subsoil over 70% of the area is moderately permeable and relatively thin (<5m), with much of the area to the immediate east being of high permeability: these materials probably allow a high proportion of recharge to occur through them. Subsoil over the remaining area is slightly thicker and is categorised as 'low' permeability. Thus, a smaller amount of recharge is likely to be occurring through these materials. Diffuse recharge occurs over the catchment and the annual average recharge is estimated to be 391 mm per year.
- The point recharge allows the springs to respond rapidly to rainfall. The tracer test recorded a response time of five to six days for the five springs; the temperature and conductivity measurements suggest a response time of one day.
- Bacteriological exceedances, commonly elevated potassium and elevated potassium:sodium (K/Na) ratios, recent elevated chloride and high iron suggest contamination from an organic waste source. Given the land use in the area, the most likely source is farmyard wastes.

9 Delineation of Source Protection Areas

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, as described in section 8.2 and presented in Figure 6.

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) to the springs.

9.1 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)**, which 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 subsoil and rock permeability and (d) the recharge in the area. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. They are described as follows.

Although relatively good hydrogeological data exists for the Gortgarrow area, the underlying aquifer is karstified. Groundwater flow through karst area is extremely complex and difficult to predict. Flow velocities are relatively fast and variable, both spatially and temporally. Catchment areas are often difficult to define

and they may change seasonally. Consequently, some uncertainty generally exists when delineating boundaries in karst areas.

The ZOC has been defined for all five springs: the reason for this is that the springs share, at least in part, the same catchment area. Given the available data, it is impossible to define the precise zone for each individual spring, and they must be considered together, as one.

The shape and boundaries of the ZOC were determined using hydrogeological mapping, including tracer testing, and the conceptual model. The boundaries and the uncertainties associated with them are as follows:

1. **The eastern boundary** is taken to be the topographic divide at the Lough Lurgeen-Glen Lough Catchment. This catchment includes many swallow holes at and around Glenamaddy, which have been traced to Lettera Spring, which rises 3 kilometres northeast of Gortgarrow. This catchment is assumed to include the small swallow hole at Gortnagier East, just south of Glenamaddy. However, this feature straddles the divide and tracing should confirm where exactly it contributes to flow.
2. **The southeastern boundary** is complicated but is primarily based on the topographic divide on the higher plateau area. The divide separates the topographic catchment contributing to Marganure Spring (which was sampled as part of the dye-tracing for this project, and is not linked to the swallow holes at Tullaghaun), from the Gortgarrow Catchment. The swallow hole east of Kilkerrin Village, at the base of the valley there, is not included in the ZOC to Gortgarrow (it may contribute to Marganure Spring). The stream feeding this is also considered to be in a separate catchment to Gortgarrow.
3. **The southwestern boundary** is defined as the topographic catchment for the tributaries of the Grange River, which all rise along a line between Timadooaun, Clonbern, Doo Lough and Cloonkeen. Doo Lough is taken to be along the boundary, as a stream exits from its' northern shore and flows through Ahaun and Park West to Gortgarrow. The Grange River catchment is effectively bounded along its northeastern edge by the Kilkerrin plateau.
4. **The northeastern boundary** includes the boundary of the Kiltullagh Lough mini-catchment. This lake is fed by two streams to its east and northeast: all three features are included in the ZOC to Gortgarrow.
5. For the **northern boundary** it is assumed that the water down-gradient of the springs will not flow back to contribute to their discharge. Therefore the boundary delineates the groundwater flow down-gradient of the springs, which will be outside the ZOC. It is based on the direction of flow suggested by the tracer test and the general trend of surface water drainage patterns (towards the north in this area). A buffer of 30m down-gradient of the springs is incorporated into this boundary.

The area delineated above is approximately 23.7 km². As a cross check, a water balance was used to estimate recharge area required to supply groundwater to the source. Assuming an annual recharge of 391 mm, a recharge area of approximately 20.3 km² is required to provide enough groundwater to supply 21,676 m³d⁻¹. Thus, there appears to be a relatively good match between the area delineated and the area required to provide water to the springs.

9.2 Inner Protection Area

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial contamination and it is based on the 100-day time of travel (ToT) to the supply.

The tracer tests carried out record rapid groundwater velocities within the Visean limestone (Knockma Formation) which have a minimum value of 40 m/hr. As the Visean limestones underlie the entire ZOC, and given this minimum velocity, the groundwater can possibly reach the springs from any point in the ZOC within 8-9 days.

It is therefore likely that all groundwater within the delineated catchment could reach the source in less than 100 days. These data suggest that the entire ZOC should be incorporated into the Inner Protection Area.

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 Table 3). In practice, this is achieved by superimposing the vulnerability map (Figure 6) 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. All of the hydrogeological settings represented by the zones may not be present around any given source.

Four groundwater protection zones are present around the source as illustrated in Table 3. The final groundwater protection zones are shown in Figure 8.

VULNERABILITY RATING	SOURCE PROTECTION	
	<i>Inner</i>	<i>Outer</i>
<i>Extreme (E)</i>	SI/E	Not present
<i>High (H)</i>	SI/H	Not present
<i>Moderate (M)</i>	SI/M	Not present
<i>Low (L)</i>	SI/L	Not present

Table 3: Matrix of Source Protection Zones at Gortgarrow

11 Potential Pollution Sources

There are a large number of houses and farmyards within the ZOC. Land use in the vicinity of the springs is described in Section 5; within the ZOC, agriculture is the main land use. A disused sand/gravel pit is located approximately 2.3 km to the east of the springs, and a petrol station is present in Lerhin townland, 1.25 km to the southeast.

The hydrochemical data mainly highlight consistently elevated levels of total and faecal coliforms in raw water samples; the other pollution indicators suggest that at least one of the sources of waste is likely to be organic wastes. This is likely to be from farmyard wastes.

The main hazards associated with the ZOC are therefore considered to be agricultural (farmyards leakage, landspreading of organic and inorganic fertilisers) and oil/petrol spills. Though domestic septic tanks and treatment systems are not a major problem as is, the installation of these systems should be monitored closely. The location of these activities in any part of the ZOC categorised as ‘extremely’ vulnerable presents a potential risk, given rapid travel time through the underlying bedrock and lack of attenuation by subsoils. These are delineated as red zones on Figures 7 and 8.

Detailed assessments of hazards have not been carried out as part of this study.

12 Conclusions

- The five springs at Gortgarrow, including the water supply source, are located in, and supplied by, the Visian limestones of the Knockma and Corranellstrum Formations.
- In the Gortgarrow-Kilkerrin area the Visian limestone aquifer is highly karstified, as illustrated by the high number of karst features, the tracer test results and the geophysical investigations.
- The ZOC has been delineated for the five springs together. This approach is necessary due to the complicated nature of groundwater flow in the area of karstified rock, as shown by the available data.
- Due to the rapid groundwater velocities, it is considered that groundwater in any part of the ZOC could potentially reach the spring within 100 days. Therefore the entire ZOC should be classified as the Inner Protection Area.
- The ZOC as delineated covers 23.7 km², which equates well to the expected recharge area of 20.3 km² when using water balance calculations.
- Available data suggests that there is contamination at the source from organic sources, probably a combination of farmyard runoff, septic tank effluent and fertilisers.
- The groundwater in the Source Protection Area ranges in vulnerability from Extreme to Low.
- The Protection Zones delineated in this report are based on the current understanding of groundwater conditions and on the available data. Additional data obtained in the future might indicate that amendments to the boundaries are necessary.

13 Recommendations

It is recommended that:

1. Dye tracing should be carried out on the swallow holes at Gortnagier East, at the base of Kiltullagh Lough, and just east of Kilkerrin Village. This will help refine the boundaries of the ZOC and would help our understanding of groundwater flows in the area.
2. The potential hazards in the ZOC should be located and assessed, especially given the high number of farmyards and houses up-gradient of the springs in the ZOC.
3. A full chemical and bacteriological analysis of the **raw** water should be carried out on a regular basis by the Local Authority.
4. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the springs.

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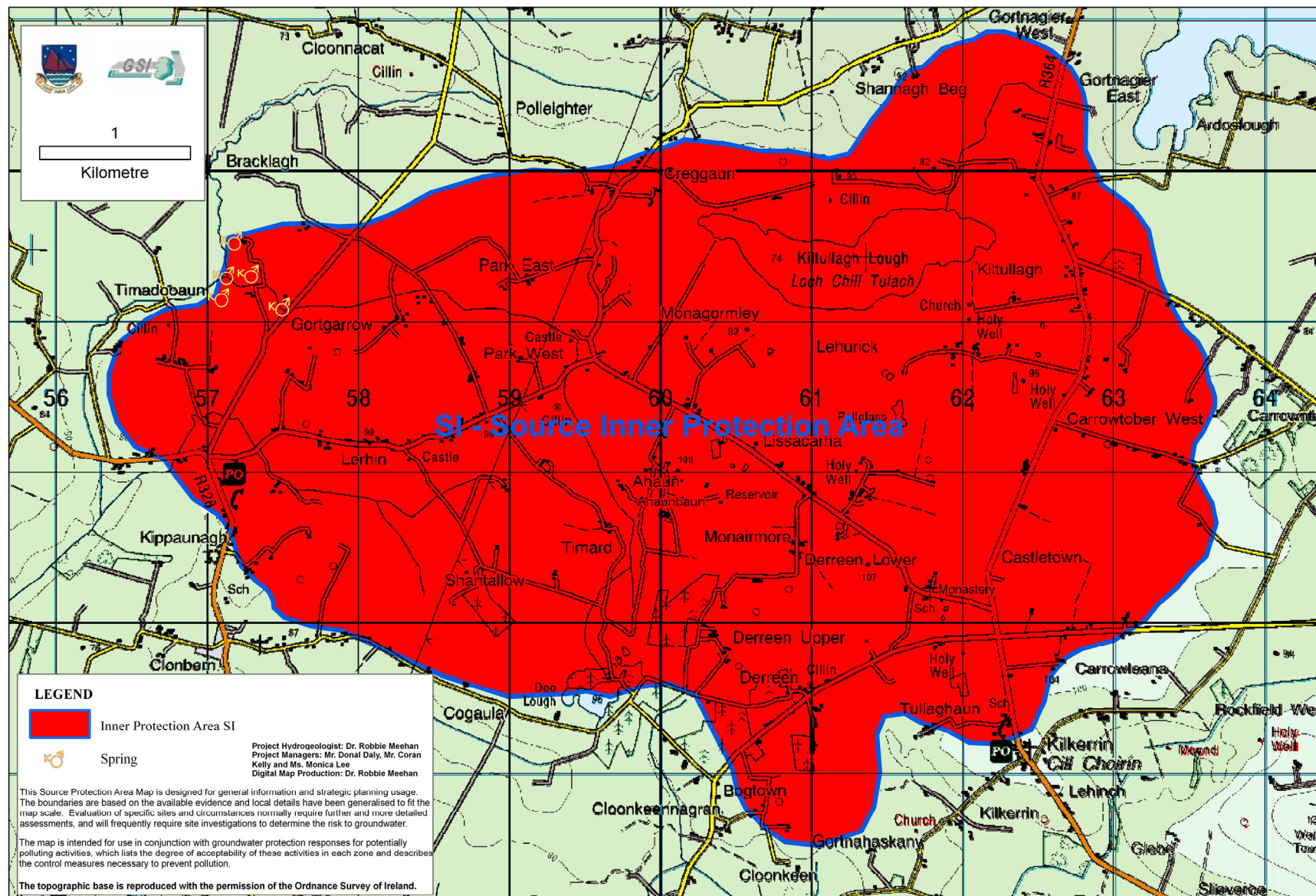


Figure 6: Source Protection Areas for Gortgarrow Springs.

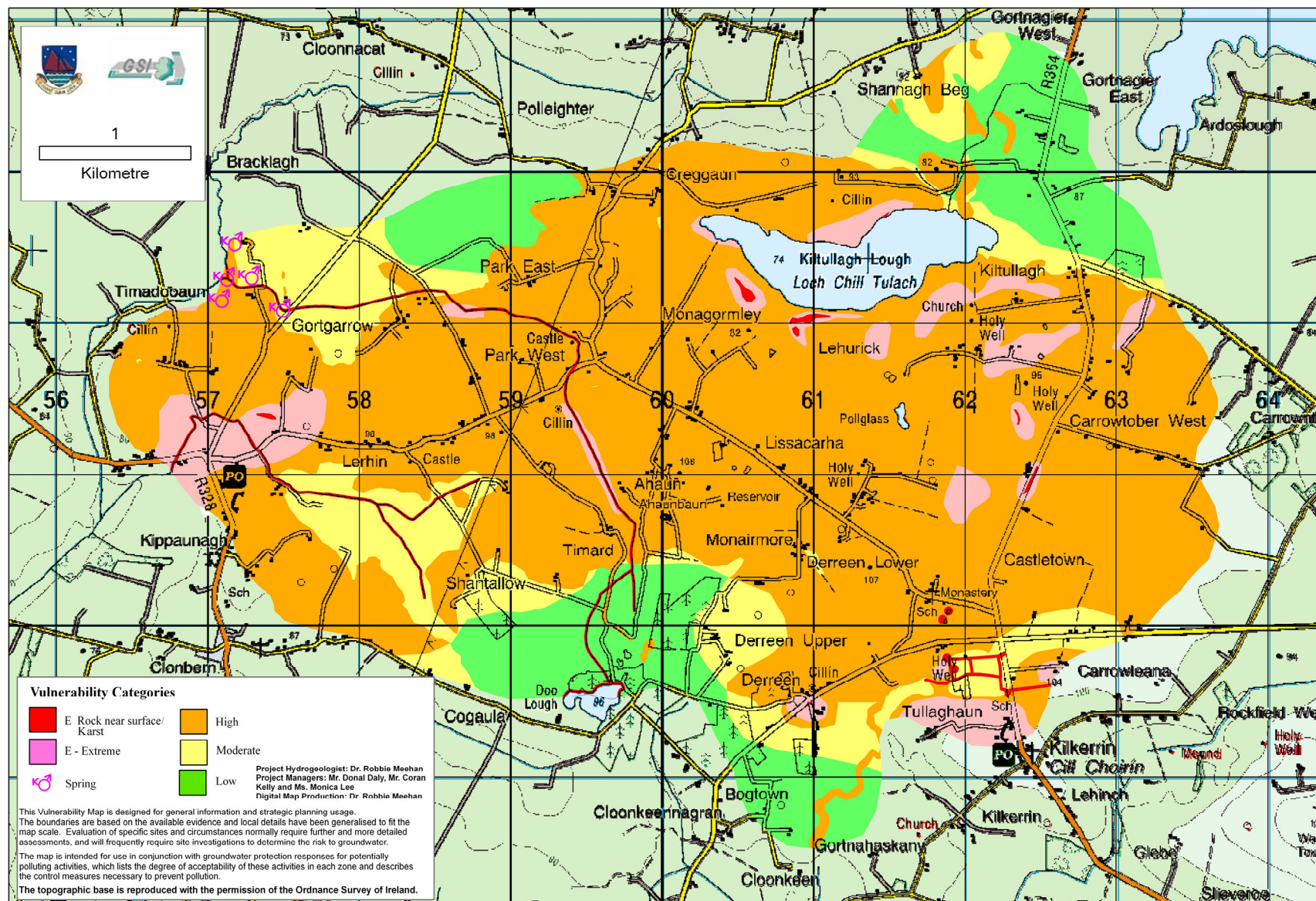


Figure 7: Groundwater Vulnerability within the Source Protection Areas for Gortgarrow Springs.

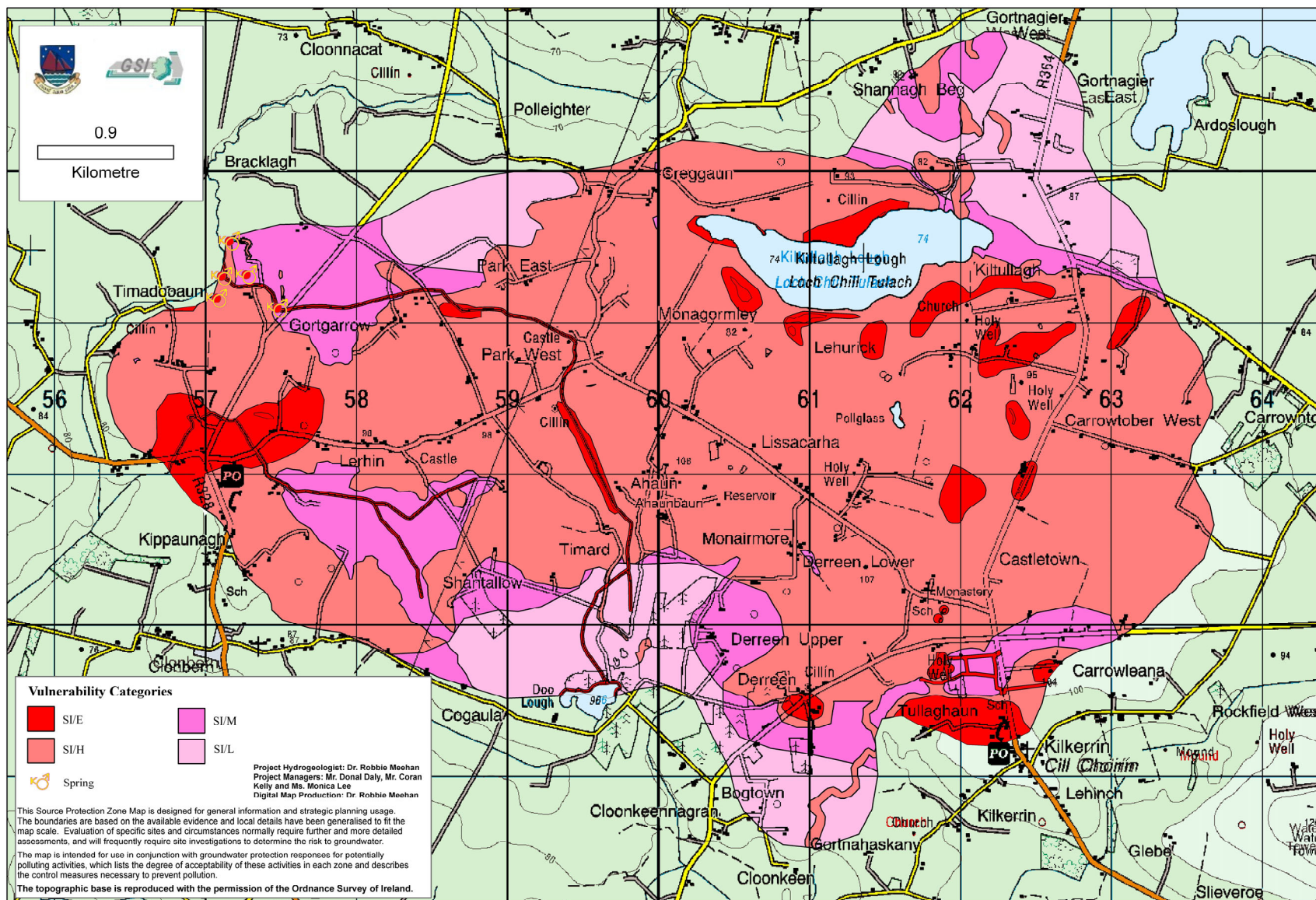


Figure 8: Source Protection Zones for Gortgarrow Springs.

Appendix

Swallow holes in the region around Gortgarrow that were investigated as potential contributors to the spring:

Number	Townland	Easting	Northing	Elevation (m O.D.)	Potential contributor?	Comments
1	Tullaghaun	161853	256805	95.8m	Yes (confirmed)	Traced
2	Tullaghaun	161863	256798	96.1m	Yes (confirmed)	Overflow for #2
3	Tullaghaun	161734	256658	94.9m	Yes (confirmed)	Overflow for #2 & #3
4	Gornagier East	162855	261293	84.4m	Yes	To be traced in future
5	Shannagh Beg	160419	259681	c. 78m	Yes	To be traced in future (base of Kiltullagh L)
6	Lehinch	163245	256102	85.5m	Yes	To be traced in future
7	Tonrevagh	151122	255092	67.6m	No	Too low in elevation
8	Carrowroe East	150952	257772	87.6m	No	Different regime? (west of the springs)
9	Polleagh South	158990	268582	86.8m	No	Too distant/far north
10	Knockanarra	162054	273016	73.9m	No	Too distant/far north
11	Ballyroe	162032	270137	82.4m	No	Too distant/far north
12	Corralough	162150	269857	78.5m	No	Too distant/far north
13	Corralough	162100	269269	88.8m	No	Too distant/far north
14	Pollshask	161862	286096	82.4m	No	Too distant/far north
15	Pollshask	162533	267934	83.7m	No	Too distant/far north
16	Ballinastack	164762	264898	80.2m	No	Too distant/far north
17	Ballinastack	164741	264922	80.2m	No	Too distant/far north
18	Moylough More	161488	249096	76.2m	No	Too distant/far south
19	Moylough More	161603	249098	76.2m	No	Too distant/far south
20	Moylough	161482	249189	75.3m	No	Too distant/far south