Castletownroche
Water Supply Scheme

Groundwater Source Protection Zones

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1 Introduction

Two groundwater sources supply the Castletownroche Water Supply Scheme. These are springs that are situated on either side of the Awbeg River valley just north of Castletownroche, named Redstone Well and Ballinvoher Well.

The objectives of the report are as follows:

- To delineate source protection zones for the springs.
- To outline the principal hydrogeological characteristics of the Castletownroche area.
- To assist Cork County Council (Northern Division) in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

The sources are located on either side of the Awbeg River opposite to each other about 1.5 km north of Castletownroche. The supply was set up in 1954 and serves approximately 1,600 people (1998). Two reservoirs are located on either side of the valley, each with storage of about 90 m^3 (20,000 gallons).

Redstone Well is on the east side of the Awbeg River and comprises a large circular sump (5 m by 3 m), collecting water from three springs that emerge along a spring line at the valley bottom. The main sump is protected by a galvanise roof but the other two springs are fully exposed. The pumphouse is about 50 m to the south of the main spring.

Ballinvoher Well is on the west side of the Awbeg River and comprises a large rectangular sump (10 by 3 m), collecting water that emerges from bedrock at the bottom of the sump. The sump has a concrete cap. The pumphouse is situated next to the sump. The rest of the site is grassed over. The site area is closed off with a fence.

Chlorination is carried out at both spring sources.

3 Summary of Spring Details

		Redstone Well	Ballinvoher Well
Grid ref. (1:25,000)	:	R683 035	R685 036
Townland	:	Naglesborough	Ballinvoher
Well type	:	Spring	Spring
Owner	:	Cork County Council	Cork County Council
Elevation (ground level)	:	~ 43 m	~ 43 m
Depth & Diameter of sumps	:	5 m by 3 m	10 m by 3 m
Depth to rock	:	unknown	4.7 m (between river and spring)
Static water level	:	Ground level	Ground level
Normal Abstraction	:	650-850 $m^3 d^{-1}$	490-720 $m^3 d^{-1}$
Estimated Average Discharge*	:	8861 $m^3 d^{-1}$	5888 $m^3 d^{-1}$

*based on mean annual flow from entire spring line.

4 Methodology

4.1 Desk Study

Details about the springs such as elevation, and abstraction figures were obtained from GSI records and County Council personnel; geological and hydrogeological information was provided by the GSI.

4.2 Site visits and fieldwork

This included carrying out depth to rock drilling, subsoil sampling and spring flow measurements, including measurements of springs that are not being used for the public supply. Field walkovers were also carried out to investigate the subsoil geology, the hydrogeology and vulnerability to contamination.

4.3 Assessment

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

5 Topography, Surface Hydrology and Land Use

The springs are located in the Awbeg River valley, that in the Castletownroche area is gorge-like, a narrow, almost straight, steep sided valley, about 400 m wide and north-south trending. The valley floor is relatively flat and lies at about 43 m OD. On either side of the valley, the land is gently undulating and lies between 50 and 90m OD.

The most noticeable aspect of the surface hydrology is the general absence of streams apart from the Awbeg River itself. A few intermittent streams to the west of the valley tend to flow during particularly wet weather. On the eastern side of the valley, there are no surface streams between the Awbeg and Funshion rivers. There are some small ponds in the area, such as Lough Quin, Poulboy, and Inchanamanan, located in the townlands of Ballyhimock and Loughquin that are present all year round. These ponds tend to lie in small, localised low-lying areas where the drainage is poor. During wet weather, they tend to overflow and drain toward the Awbeg. Flooding is frequent in some areas of the land on either side of the river valley, but is usually very short lived. In the area of Ballyhimock up to 12 acres flood during the wettest parts of the winter but support crops during the summer months.

Local farmers report that 'sluggeras' are very frequent. There are two sinkholes between the townlands of Ballyhimock and Naglesborough. Another occurs in the townland of Ballyhadeen/Lough Quin into which an intermittent stream flows. Several minor caves are noted around the village of Castletownroche and single caves have been located in the townlands of Killuragh (Grid reference 1639 1011 and Ballinaltig Beg (Grid reference 1717 1043).

Agriculture is the principal activity in the area and the land is primarily used for tillage and grassland farming. There are a number of houses, farms, and stud farms on either side of the river, all within 1 or 2 km of the springs. One farm is located within 200 m of Redstone Well. A piggery is located in Loughquin townland, 3 km northwest of the springs. Annesgrove Gardens are famous public gardens and estate that are located about 1 km north of the springs on the west of the Awbeg River. Castletownroche village is located 1.5 km downstream of the springs.

Dry broad-leaved woodlands dominate the valley sides whilst wet grassland and marshes dominate the valley bottom.

The Awbeg River is designated a National Heritage Area from Ballydoyle to Kilcummer (a 5 km stretch that incorporates Anngesgrove Gardens, the springs and Castletownroche village and is given a Grade 4 by Cork County Council).

Until recently, an unauthorised site was used for industrial sludge composting, about 1 km due east of Ballinvoher Well.

6 Geology

6.1 Introduction

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

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

- Bedrock Geology 1:100,000 Map Series, Sheet 22, East Cork-Waterford. Geological Survey of Ireland. (Sleeman, A.G., *et al*, 1995).
- The Carboniferous Geology of the Fermoy and Mitchelstown Synclines, Southern Ireland. Shearley, E.P., 1988, Unpublished PhD thesis, University of Dublin.
- The Geology of the area around Mallow, County Cork. Campbell, K.J., 1988, Unpublished MSc thesis, University of Dublin.
- Information from geological mapping in the nineteenth century (on record at the GSI).

Subsoils information was gathered from a drilling programme that was undertaken by GSI personnel to investigate the subsoils of the area.

6.2 Bedrock Geology

The rocks around the springs are the result of sediments deposited during Carboniferous and Namurian times (over 300 million years ago); the rocks have subsequently been folded and faulted. Table 1 summarises the bedrock geology in the area. The geology is illustrated in Figure 1.

Table 1 The Geology of the Castletownroche area (after Sleeman, A.G, 1995; Campbell, K.J., 1988).

Name of Rock Formation	***Rock Material***	***Occurrence***
Annabella Formation	Interbedded SILTSTONES and SANDSTONES.	Occurs 5 km to the north-west of the springs.
Caherduggan Formation	Thin well-bedded grey fossiliferous (crinoids) medium to coarse grained LIMESTONE.	Occurs 4 km to the north-west of the springs.
Hazelwood Formation	Pale grey, medium-coarse grained massive reef LIMESTONE.	Occurs mainly on the west side of the Castletownroche gorge.
Copstown Formation	Dark grey, fine-medium bedded muddy LIMESTONE, with nodules of chert.	The springs emerge from this rock unit. It crosses the gorge as a narrow band striking southwest to northeast.

Waulsortian Formation		Pale grey, massive LIMESTONE. Similar to the Hazelwood Formation in Castletownroche area.	Occurs over much of the eastern side of the Castletownroche gorge.
Ballysteen Formation	Ballinaltig Member	Well bedded (0.1-0.3 m) fine-grained muddy LIMESTONE	Occurs about 3 km to the east of the springs.
	Carrigoon Member	Well-bedded (0.4-1.0 m) medium to coarse grained fossiliferous LIMESTONE.	Occurs about 3 km to the east of the springs.

6.2.1 Structure

The succession outlined in Table 1 has been deformed during a 'mountain building event', known as the Variscan Orogeny. The rocks were compressed from north and south to produce an east-west trend to the current rock distribution (Sleeman, A.G. *et al,* 1995; Campbell, K.J, 1988; Shearley, E.P., 1988). Associated with the deformation are folds and faults that can be seen in and around the cliffs and caves of the Castletownroche area.

Two major fault sets are widespread across the region; east-west trending (strike faults) and north-south trending (cross faults). There is possible evidence for cross faults in the Castletownroche area in the form of scarps that make up the sides of the gorge north of the village. The caves also indicate the presence of faults and fractures and most of these indicate a north-south or an east-west trend.

6.3 Subsoil (Quaternary) Geology

The subsoils comprise a mixture of coarse and fine-grained materials, namely: alluvium, till, sand & gravel. They are directly influenced by the underlying bedrock, which is made up of limestones. The locations of the auger holes are given in Figure 2 and the logs are given in Appendix 1.

The characteristics of each category are described briefly below:

6.3.1 River Alluvium

This material occupies the flood plain along the Awbeg River and the material is dominantly fine grained. Drilling suggests that the alluvium lies directly on bedrock, and is about 4 m thick and covers the entire valley floor within the gorge.

6.3.2 Till

'Till' is an unsorted mixture of coarse and fine materials laid down by ice. Angular to subrounded sandstone and limestone fragments are abundant in the tills. Till is the dominant subsoil type. The matrix of the till is SILT, with occasional or frequent gravel size fragments of limestone and occasional sandstone.

6.3.3 Sand & Gravel

Sand & Gravel occurs in two localities on either side of the Awbeg River. They sit on the edges of the valley above the springs opposite to each other. They comprise mostly sandy GRAVELS and GRAVELS with frequent boulders and cobbles (BS 5930). Finer-grained layers also occur, comprising SAND or sandy CLAY with silt (BS 5930). The boulders and cobbles are mostly limestone in composition, often cherty. Occasional sandstone fragments occur also. Most of the fragments are sub-rounded to rounded, but angular fragments also occur. Most of the sand & gravel has been extracted for construction purposes.

6.3.4 Lake Clay

This material occupies a low-lying area in the townland of Ballyhimock. It is a predominately fine-grained layer (BS 5930: CLAY). This area floods in the wettest times of the winter months. It is about 1 m thick and overlies till. It is likely to occur in other low-lying areas that have small permanent ponds in them, for example Lough Quin.

6.3.5 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 depth to bedrock is variable but is generally less than 10 m. In one location it is greater than 10 m and it is likely that there may be more sites where it is greater than 10 m.

7 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the area of the springs. The springs that are used for the public supply are individual springs that belong to a spring line system, i.e., a series of springs emerging along a discrete line on either side of the valley. The springs are shown in Figures 1, 2 and 3. The interpretations and conceptualisations of flow are used to delineate source protection zones around all the springs within the spring lines. This is because it is very difficult to differentiate the flow to one spring from another.

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

- Hydrogeological mapping survey carried out by GSI.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability.
- GSI files and archival Cork County Council data.
- Cork County Council annual drinking water returns.
- Flow measurements at the springs, including overflow from the springs that are used for public supply and flows from other springs that occur nearby.

7.2 Rainfall, Evaporation 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 to the source.

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: 1034 mm (data from Met Éireann).
- Annual evapotranspiration losses: 434 mm. Potential evapotranspiration (P.E.) is estimated to be 457 mm $yr.^{-1}$ (based on data from Met Éireann). Actual evapotranspiration (A.E.) is then estimated as 95 % of P.E.

- Potential recharge: 600 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.
- Annual runoff losses: 30 mm. This estimation is based on the assumption that 5% of the potential recharge will be lost to overland flow and shallow soil quickflow prior to reaching the main groundwater system.

These calculations are summarised as follows:

Average annual rainfall (R)	1034 mm
Estimated A.E.	434 mm
Potential Recharge (R – A.E.)	600 mm
Runoff losses	30 mm
Estimated Actual Recharge	570 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

The water table in the area is assumed to be a subdued reflection of topography, with groundwater flowing from the watersheds and discharging via the springs to the Awbeg River. It is assumed that the Awbeg River represents the water table and the true groundwater elevation along the river. There are no boreholes in the area, so the only groundwater levels known are those at the springs, the Awbeg River and the streams to the west of the area.

Flow directions will tend to follow topography and the general direction of the Awbeg river, i.e., flow will tend toward the river with a strong southerly component. Therefore, groundwater will tend to flow east-west and northeast-southwest on the east side of the valley and on the western side of the valley groundwater will tend to flow west-east and northwest-southeast.

Groundwater gradients are difficult to calculate because of the limited well water level data available. However, as the Awbeg river is assumed to represent the water table, the gradient of the river in the area of the springs probably gives a good approximation of the general groundwater gradient in the area. This is calculated to be between 0.001 and 0.002, between Shanballymore and the springs. As the limestones are quite permeable the gradients would be expected to be low. As a comparison gradients in the Waulsortian Limestone at Downing Bridge and Glanworth near Fermoy have been estimated at between 0.001 and 0.005 (Motherway, 1999).

7.4 Aquifer Characteristics

Several Carboniferous limestone formations occupy the area and are generally pale grey and massive or dark grey and well bedded. Aquifer characteristics of these rocks depends on the lithology and to a large extent the processes that they have undergone since deposition. The two main processes that give the present aquifer characteristics are deformation (Section 6.2.1 Structure) and karstification. Data from other parts of Munster are used in conjunction with hydrogeological mapping to characterise the aquifers in the Castletownroche area. The aquifer characteristics for the major formations are given in Table 2.

Karstification is the process whereby limestones are slowly dissolved away by acidic waters moving through them. This most often occurs in the upper bedrock layers and along some of the pre-existing fissures and fractures in the rocks, which become slowly enlarged. One of the consequences of karstification is the development of an uneven distribution of permeability which results from the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones (Deakin *et al*, 1998).

There is evidence that the Hazelwood, Waulsortian and the "purer" Carrigoon member of the Ballysteen Formation have undergone karstification. Dry valleys, collapse features/dolines (sluggeras), disappearing streams, swallow holes, caves, and solution features on outcrop can be seen in the area. Several infilled cavities within the Waulsortian Limestone that have no surface expression have been interpreted from the geophysical surveys carried out in Glanworth and Kilworth. (Motherway, 1999).

The Ballysteen Limestone is generally not as good an aquifer as the Waulsortian Limestone due to the higher mud content and shalier nature of the beds and has lower permeabilities than the Waulsortian Limestone. The two units in the Ballysteen probably differ hydrogeologically. The lower unit is "purer" (sometimes described as ‘cleaner’) suggesting relatively higher permeabilities than the upper muddier unit.

The Waulsortian Limestone is generally very productive in Munster, recording very high yields and specific capacities. Test pumping of the Waulsortian Limestone at Downing Bridge and Moorepark suggested transmissivities ranging 15-3400 $m^2 d^{-1}$ (Motherway, 1999). This illustrates the variability of aquifer properties in the Waulsortian Limestone. In general, the permeability and resulting groundwater velocities of the Waulsortian are likely to be high.

The Copstown Limestone being relatively ‘muddier’, finer-grained and distinctly bedded would normally be expected to have poor aquifer characteristics. However, almost all the springs on either side of the Awbeg River issue from the Copstown Formation along the bedding planes that act as conduits for groundwater flow. It is probable that the solution has taken place along the bedding planes and fractures serving to increasing its permeability. Considering the quantity of water that discharges from the springs the permeability must be high, particularly near the springs. It is also likely that the permeability is heterogeneous, i.e., it is likely that the horizontal permeability is very far greater than the vertical permeability.

The Hazelwood Limestone is also very productive in North Cork, with high yields and specific capacities, however, there are no specific data for the Hazelwood Limestone in Castletownroche.

The area is free draining and there are few surface streams, hereby indicating the high permeabilities of the limestones. In contrast, there is a much higher density of streams over the Annabella Formation (Namurian) indicating the relatively poor permeability of bedrock.

Table 2 Estimated Aquifer parameters for the rock units in Castletownroche.

Parameter	***Source of data***	***Ballysteen***	***Waulsortian***	***Copstown***	***Hazelwood***
Transmissivity ($m^2 d^{-1}$)	Regional*	10-100	200-3500	-	200-3500
Permeability ($m d^{-1}$)	Regional*	0.1-2.0	10-200	30-150	10-200
Porosity	Regional*	0.005-0.015	0.025	0.005-0.015	0.025
Velocity ($m d^{-1}$)		0.16-1.1	0.8-16	2-150	0.8-16
Hydraulic Gradient	Local**	0.001-0.008	0.001-0.005	0.001-0.005	0.001-0.005

* Regional data: based on information for Munster area.

** Local data: based on information for Glanworth.

The Hazelwood Limestone is assumed to have very similar characteristics to the Waulsortian.

Groundwater flow is likely to occur in three main hydrogeological regimes within the limestone aquifers:

- An upper, shallow highly karstified weathered zone, known as the epikarst, in which groundwater moves quickly, through solutionally enlarged conduits, in rapid response to recharge;
- A deeper zone, where groundwater flows through interconnected, solutionally enlarged conduits and cave systems which are controlled by structural deformation.
- A more dispersed slow groundwater flow component in smaller fractures and joints outside the main conduit systems.

7.5 Hydrochemistry and Water Quality

The hydrochemical analyses of both springs show that the water is hard to very hard, with total hardness values of 316-331 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 590-843 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 and indicate that the groundwater emerging from the springs is very similar. The analyses are given in Appendix 2.

Nitrate concentrations consistently range 34-45 mg l^{-1} (13 samples; 1995-2000) which probably represents the background level associated with tillage and grassland farming in the area and in North Cork in general. Other groundwater sources in North Cork indicate comparable nitrate concentrations levels (Kelly, 1999; Motherway, 1999). Nitrate concentrations differ slightly between the two springs. At Redstone Well (CTR1) concentrations range 34-42 mg l^{-1}, with an average of 38 mg l^{-1}. At Ballinvoher Well (CTR2) concentrations are generally slightly higher, ranging 37-45 mg l^{-1}, with an average of 40 mg l^{-1}. There is no trend in either dataset and neither has exceeded the EU Drinking Water Directive maximum admissible concentration (MAC).

Chloride concentrations range 23-28 mg l^{-1} (5 samples; 1995-1999). Chloride is a constituent of organic wastes and levels higher than 25 mg l^{-1} may indicate significant contamination (in North Cork). Concentrations higher than the 30 mg l^{-1} usually indicates significant contamination (this would not be true for coastal areas). Chloride concentrations appear to have a steady high background level associated with the nitrate concentrations. There are several farmyards within 2km of the springs on either side of the valley.

The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated along with other parameters and may indicate contamination if the ratio is > 0.4. From 4 analyses the ratio for the springs is quite low, ranging 0.12-0.14.

The untreated water analyses (1 sample for each source, 1999) record the presence of total coliforms in both springs and faecal coliforms in only one of the springs (Redstone Well). The springs were also sampled for cryptosporidium and giardia, using customised equipment provided by Inniscarra Laboratory. Subsequent analysis by City Analysts found the samples to be negative for both cryptosporidium and giardia.

In summary, the water at the springs is hard, with levels of nitrates and chlorides that would be expected from groundwater in an intensively farmed land and compare with nitrate and chloride levels at other groundwater sources in North Cork.

Faecal and total coliforms are the only parameter to exceed the EU MAC and probably indicate contamination from farmyard wastes or septic tanks.

7.6 Spring Discharge

The total discharge at the springs is difficult to measure accurately, because of the number of springs involved, particularly on the western side of the river. The whole area on either side of the river is liable to flood during periods of heavy rain when the river water backs up to the spring discharge areas.

Four clusters of springs were counted emerging from the valley bottom on the western side of the river (Redstone Springs). Each cluster has a number of discrete springs associated with it. Each of the channels associated with the springs is overgrown and access is generally difficult. At least 3 discrete springs make up the spring line on the eastern side of the river (Ballinvoher Springs). However, several estimates have been made to quantify the amount of water emerging from the bigger springs and an allowance was made to take into account the other springs that were not measured.

In the 1970's several small weirs were installed on the overflows at Redstone Well. These were made out of wood and plastic sheeting. They have not been maintained, thus currently are not in working order. However, there are reasonable spot estimates for the springs at Redstone Well using the old records and recently acquired data using flow meters. Only recent spot estimates are available for Ballinvoher Well. There is an excellent record of the daily abstraction from both springs. The discharge data are presented in Table 3 and Table 4. An additional measurement of a large spring just downstream of Redstone Well was also made. Visual inspections were carried out of all the springs along the spring lines to get a relative estimate of the quantities discharging along the entire spring line.

Table 3 presents the estimates for the total yield from the spring line on the western side of the valley. The subtotal is the estimate for the total discharge at Redstone Well. The mean annual discharge is estimated at 8861 $m^3 d^{-1}$. Similarly Table 4 presents estimates for the total yield from the spring line on the eastern side of the valley. The subtotal is the total discharge from Ballinvoher Well and this is multiplied by three to account for all the springs along the spring line. The mean annual discharge is estimated at 5888 $m^3 d^{-1}$.

Table 3 Discharge figures for the western spring line. Units $m^3 d^{-1}$.

Date	Abstraction	Overflow	subtotal	Total
10/10/1978	Pumps off	1922	1922	7688
11/9/1981	Pumps off	2260	2260	9040
11/9/1984	1418	538	1956	7824
6/7/1999	1327	860	2194	8776
17/6/1999	1319	800	2119	8476
19/5/2000	1300	1540	2840	11360

Table 4 Discharge figures for the eastern spring line. Units $m^3 d^{-1}$.

Date	Abstraction	Overflow	subtotal	Total
28/6/1999	1382	771	2153	6459
17/8/1999	1150	745	1895	5685
19/5/2000	1240	600	1840	5520

7.7 Conceptual Model

- Groundwater discharges along spring lines that occur on either side of the Awbeg River, that flows through a narrow gorge in the Castletownroche area. The groundwater discharges at up to 11,000 $m^3 d^{-1}$ from the western spring line (Redstone) and up to 6500 $m^3 d^{-1}$ from the eastern spring line (Ballinvoher). Each spring line comprises several clusters of discrete springs. The spring lines occur at the intersection of the side walls of the gorge with the valley floor along bedding planes in the Copstown Limestone Formation. The formation of the gorge may be due to north-south trending faulting (cross faults) across the area.

- Several limestone formations contribute groundwater to the springs. These limestones are important karstified aquifers, with localised high permeability zones that give rise to rapid groundwater velocities. Groundwater flow is probably confined to and controlled by fractures, fissures, joints, bedding planes all of which have been solutionally enlarged due to karstification.

- Groundwater is assumed to flow toward the Awbeg river from either side of the valley, roughly following the topography. The Awbeg river represents the lowest point of the water table, with groundwater making up a large proportion of the river water. The Awbeg River is in full hydraulic connection with the groundwater on either side. Groundwater gradients are likely to be similar to the gradient of the Awbeg River.

- Groundwater on the western side of the river toward the Redstone springs flows from the karstified permeable Hazelwood Limestone into the apparently less permeable Copstown Limestone, facilitated by the strike of the Copstown allowing the water to flow easily and quickly toward the springs.

- On the eastern side of the river, it is less likely that the groundwater flows as easily into the Copstown Limestone as on the western side of the river, due to the strike and outcrop pattern of the Copstown Limestone. It is easier for groundwater in the Waulsortian and Ballysteen Limestones to flow in a southwesterly direction toward the Awbeg River. This may be reflected in the fewer spring occurrences on the eastern side of the river. Thus, groundwater discharging at the Ballinvoher springs is likely to come from a more north easterly direction. However considering the discharge at the springs the Copstown must be permeable enough to allow water through from the Waulsortian.

- In general there are very few surface streams occurring over the limestones, indicating the free draining nature of the subsoils and the high permeabilities of the bedrock. In contrast there are frequent springs and streams in the north west of the area, located on the Annabella formation of the Namurian. These surface water streams are short-lived, most flow a short distance north to the Awbeg River, a couple flow east where they become intermittent and disappear down swallow holes as they travel over the karstified limestones.

- Diffuse recharge primarily occurs through the permeable tills on either side of the valley. Point recharge occurs through the swallow holes and sluggeras that occur across the area. Recharge is likely to be rapid due to the permeable nature of the subsoils and bedrock; the general shallow depth to bedrock; the 'point' recharge occurrences; presence of faecal bacteria; the change of conductivity of several hundred $\mu S\ cm^{-1}$ over a short time.

8 Delineation of Source Protection Areas

8.1 Introduction

This section delineates the areas around the springs that are believed to contribute groundwater to them, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, and are presented in Figures 2 and 3.

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 springs.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), 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 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 the conceptual model and are shown in Figure 1. The ZOC catchment boundaries are discussed for each spring line in turn and are as follows:

8.2.1 Redstone Well

1. The **Eastern boundary** is reasonably certain and is constrained by the Awbeg river. The elevation of the spring line is above that of the river and discharge from the springs flows to the river. It is assumed that the springs do not drag water from the area between the springs and the river, from the river itself or from the other side of the river.
2. The **Western boundary** is based on the surface watershed that occurs in the townlands of Skenakilla and Rathnacarton. There is a topographic high that occurs in this area. It is not a distinct ridge and it is difficult to locate the divide precisely. To the west of this watershed water flows southwards toward the Blackwater River.

3. The **Southern boundary** is less well defined and is based on topography. It is assumed that groundwater flows from west to east and northwest-southeast. Groundwater south of the springs would not be expected to get to the springs. The topographic highs that are used to define the boundary are located to the south of the springs. It cannot be ruled out that some groundwater may be able to flow along the strike of the Copstown Formation toward the springs. A conservative approach is used for this boundary.
4. The **Northern boundary** is constrained by topography. High ground with outcrop exposed or close to surface runs from Ballyhimock to Annesgrove. This boundary is uncertain as the flow directions north of this line are likely to bring groundwater to the river north of Annesgrove it is not impossible for groundwater from the Loughquin and Knockacappul localities to get to the springs. However a stream disappears into a swallow hole at Ballyhadeen where a dry valley slopes north toward the Awbeg. A stream rises close to the river within the dry valley, thus supporting that a divide exists in this locality.

The area defined by the boundaries described above is about 6 km^2. The water balance estimations (using total yield, estimated recharge figures) indicate that the area required to provide enough groundwater to the springs is about 5.5 km^2. Therefore the area constrained by hydrogeological mapping compares favourably with the area required to provide the discharge.

8.2.2 Ballinvoher Well

1. The **Western boundary** is reasonably certain and is constrained by the Awbeg river. The elevation of the spring line is above that of the river and discharge from the springs flows to the river. It is assumed that the springs do not drag water from the area between the springs and the river, from the river itself or from the other side of the river.
2. The **Eastern boundary** of the spring line catchment is based on topography. It is delineated with a great deal of uncertainty as the conceptualisation for the flow on this side of the river is difficult. To account for the area needed to provide the discharge at the spring and to allow for flow to enter the Copstown Formation from the Waulsortian the boundary is delineated using the topographic ridge that extends from Lackabrack toward Ballinvoher.
3. The **Northern boundary** is difficult to define. The geology is unmapped in detail to the north, specifically, the Copstown Limestone Formation ‘stops’ just north of Lackabrack. The boundary delineated is based on a topographic ridge in the area of Lackabrack. It probably acts as a watershed divide between water flowing northeast toward the Funshion River and southwest toward the Awbeg River.
4. The **Southern boundary** is defined simply by extending a line 30 m south of the spring toward the geological boundary between the Waulsortian and the Copstown Limestone Formations.

The area defined by the boundaries described above is a little over 4 km^2. The water balance estimations (using total yield, estimated recharge figures) indicate that the area required to provide enough groundwater to the springs is about 4 km^2.

8.3 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 and viral contamination and it is based on the 100-day time of travel (ToT) to the supply. Estimations of the extent of this area are made by hydrogeological mapping, analytical modelling and conceptualisation methods.

The estimated velocity for the Copstown Limestone given in section 7.4 (Aquifer Characteristics) is used to estimate the 100-day ToT. The velocity is calculated using the permeability, gradient and the porosity. Considering the quantity of water discharging the higher value for velocity is used. A velocity of 150 m d^{-1} is estimated that results in a 100-day ToT to be about 15 km. This means that recharge to anywhere in the catchment would reach the springs within 100 days. This is typical of sources located in karstified limestones. As a result the entire ZOC is within the 100-day ToT, all of the area supplying water to the springs lies within the inner protection area.

9 Groundwater Vulnerability

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities and depends on the thickness, type and permeability of the subsoils. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999).

Outcrop, areas of shallow rock, auger holes, topography and geophysics are used to contour depth to rock that are used along with the permeability classifications to develop the vulnerability zones. An average buffer of 100 m is used around areas of outcrop to produce a 3 m depth to bedrock contour, i.e., the limit of the 'Extremely' vulnerable zones. This buffer incorporates topography and known points of depth to bedrock and is based on calculations made by measuring the distance along the ground between outcrops and known points of depth to rock. An average figure of 100 m was calculated and represents the average distance from outcrop to a point where the depth to bedrock is about 3 m.

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 2. There is widespread outcrop and subsoil thickness are <3 m in several instances, giving rise to a vulnerability classification of 'Extreme' over a large proportion of the area.

The subsoils comprise sand & gravel, glacial till, alluvium and lake clay. The till overlying the area is largely considered to have either a moderate or high permeability. This assessment is based on the behavioural characteristics assessed using the British Standard BS5930 in conjunction with the drainage and recharge characteristics. Due to the depth to rock being <10 m, the vulnerability is 'High'. The sand & gravel deposits are considered to have a high permeability and due to the depth to rock, the vulnerability is 'Extreme' (0-3 m). The alluvium and lake clays are considered to have a low or moderate vulnerability, and depending on the depth to rock, the vulnerability ranges from 'Extreme' (0-3) or 'High' (3-10 m) or 'Moderate' (>10 m). There are a number of karst features in the area, such as swallow holes and collapses which are all designated as points of Extreme vulnerability, including a buffer of 30 m around the karst feature.

10 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an <u>Inner Protection area</u> where the groundwater is <u>highly</u> vulnerable to contamination. As the inner protection zones covers the entire ZOC there is no specific outer protection zone, resulting in just 3 groundwater protection zones present around the springs source as shown in Table 5. The final groundwater protection map is presented in Figure 3.

Table 5 Matrix of Source Protection Zones at Castletownroche

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

11 Potential Pollution Sources

Land use in the area is described in Section 5. The land near the source is largely grassland-dominated and is primarily used for grazing. Agricultural activities and septic tanks are the principal hazards in the area. Based on the current conceptual model for groundwater flow in the area the piggery at Lough Quin is outside the zone of contribution to the springs at Redstone Well, however this may not be the case and if recommended work is carried out this may change. The main potential sources of pollution within the ZOC are farmyards, septic tank systems, runoff from the roads, leaky sewers and landspreading of organic fertilisers. The main potential pollutants are faecal bacteria and viruses.

12 Conclusions and Recommendations

♦ The springs at Castletownroche are an excellent yielding supply, located in a karstified limestone aquifer.

♦ The area around both supplies is generally extremely or highly vulnerable to contamination.

♦ Septic tanks, farmyards, landspreading and runoff from the roads pose a threat to the water quality at the springs.

♦ It is recommended that:

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

♦ The protection zones delineated in the report are 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, geophysics, spring flow measurements and tracing. Geophysics and drilling would also improve the accuracy of the vulnerability boundaries. Drilling would improve considerably the information on the water table, thus delineation of the boundaries could be improved.

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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.

Borehole No.	*Grid Ref.*	*Depth (m)*	*BS5930 Description*	*Permeability*	*Vulnerability*
CTR1	R687 038	0-1.4	Sandy SILT with clay and frequent angular limestone fragments (Till)	Moderate	EXTREME
CTR2	R684 036	0-1.5	CLAY black fine-grained (Alluvium)	Low/moderate	HIGH
		1.5-4.7	Struck water table, no returns (Alluvium)	Low/moderate	
CTR3	R685 035	0-0.75	GRAVEL, base of quarry. (Sand & Gravel)	High	EXTREME
CTR4	R686 035	0-1.5	Silty SAND with occasional sandstone angular fragments (Till)	High	HIGH
		1.5-6.5	Sandy SILT with clay and frequent limestone subrounded fragments (Till)	Moderate	
CTR5	R686 037	0-1.0	Clayey SAND with frequent limestone fragments (1-4cm) (Till)	High	EXTREME
		1.0-2.0	Sandy SILT with frequent limestone fragments (Till)	Moderate	
CTR6	R686 036	0-1.25	Sandy SILT with clay and limestone fragments (1-4cm) (Till)	Moderate	HIGH
		2.0-3.1	Sand & gravel, very little matrix sandy SILT (sand &gravel/till?)	Moderate	
		3.1-9.0	GRAVEL (sand & gravel)	High	
CTR7	R695 038	0-9.0	Brown dense stony sandy CLAY, wet at 4.5m (water table); drier after 7.5m, still a sandy CLAY with silt. (TILL)	Low	MODERATE
CTR8	R711 039	0-5.0	angular to subrounded sandstone and limestone frags in a fine-grained matrix. Sandy SILT with clay. (TILL)	Moderate	MODERATE
		5.0-10.0	Red dense sandy SILT with clay, at 10m water strike. (TILL)	Moderate	

		10.0->12.0	Sandy CLAY quite stony, some silt. Very wet, little returns. (TILL)	Low	
CTR9	R706 044	0-2.0	Sandy SILT with clay and frequent sandstone fragments. (TILL)	Moderate	EXTREME
Borehole No.	***Grid Ref.***	***Depth (m)***	***BS5930 Description***	***Permeability***	***Vulnerability***
CTR10	R673 033	0-1.5	Sandy SILT with clay (TILL)	Moderate	EXTREME
CTR11	R684 035	6.0	Sandy GRAVEL with limestone and sandstone frags. (Sand & Gravel)	High	HIGH
CTR12	R683 035	2.2	Sandy clayey GRAVEL (sand & gravel – margins ?	High	EXTREME
CTR13	R682 042	2.0	Silty SAND with frequent sandstone/limestone fragments (margin of sand & gravel)	High	EXTREME
CTR14	R673 048	2.0	Clayey SAND (TILL)	High	EXTREME
CTR15	R673 045	5.0	Sandy CLAY with frequent black angular-subrounded limestone fragments. (TILL/lake clay)	Low	MODERATE
CTR16	R661 047	4.8	Sandy CLAY (silt?) frequent small angular black limestone. Some sandstone. (Lake clays/TILL)	Low	HIGH
CTR17	R662 045	0-3.0	CLAY with a little silt/sand, some black angular to subrounded limestone frags. (Lake clays/Till). At nearly 3m broken weathered bedrock encountered	Low	EXTREME

Appendix 2 Hydrochemical Analyses

Parameter	Redstone Well (CTR1)			Ballinvoher Well (CTR2)	
	14/03/1995	18/11/1997	15/7/1999	18/11/1997	15/7/1999
Conductivity (µS/cm)	589	615	615	628	623
Temperature (°C)	8	11	-	11	-
pH	7.3	7.2	7.4	7.5	7.4
Total Hardness (mg l^{-1} $CaCO_3$)	316	288	331	241	329
Total Alkalinity (mg l^{-1} $CaCO_3$)	-	274	283	288	288
Calcium	-	103.1	120	82.5	120
Magnesium	-	7.5	8.8	8.5	9
Chloride	28	25	24	20	22.8
Sulphate	15	14.9	15.3	15.4	15.2
Sodium	-	10.3	9.7	10.1	9.6
Potassium	-	1.3	1.2	1.3	1.3
Nitrate (as NO_3)	36	35	41.2	38.6	41.9
Iron	0.1	0.05	<0.1	0.05	<0.1
Manganese	0.025	0.02	<0.05	0.02	<0.05
Total Coliforms per 100 ml	0	0	5	1	2
E. coli count per 100 ml.	0	0	1	0	0

All the samples are for treated water, except those taken in 1999.

Results of Nitrate monitoring

Redstone Well		Ballinvoher Well	
14/03/1995	35.72	01/03/1997	41
05/03/1997	37	02/04/1997	40
01/04/1997	41	15/04/1997	41
15/04/1997	38	01/05/1997	43
09/06/1997	37	09/06/1997	38
22/09/1997	36	12/09/1997	39
18/11/1997	35	18/11/1997	39
15/12/1997	37	15/12/1997	39
28/01/1998	34	28/01/1998	37
25/03/1998	42	25/03/1998	45
28/04/1998	38	28/04/1998	43
15/01/1999	38	15/01/1999	39
15/07/1999	41.2	15/07/1999	41.9
15/01/2000	36	15/01/2000	38
		15/02/2000	41
min	34	min	37
max	42	max	45
average	37.6	average	40.3

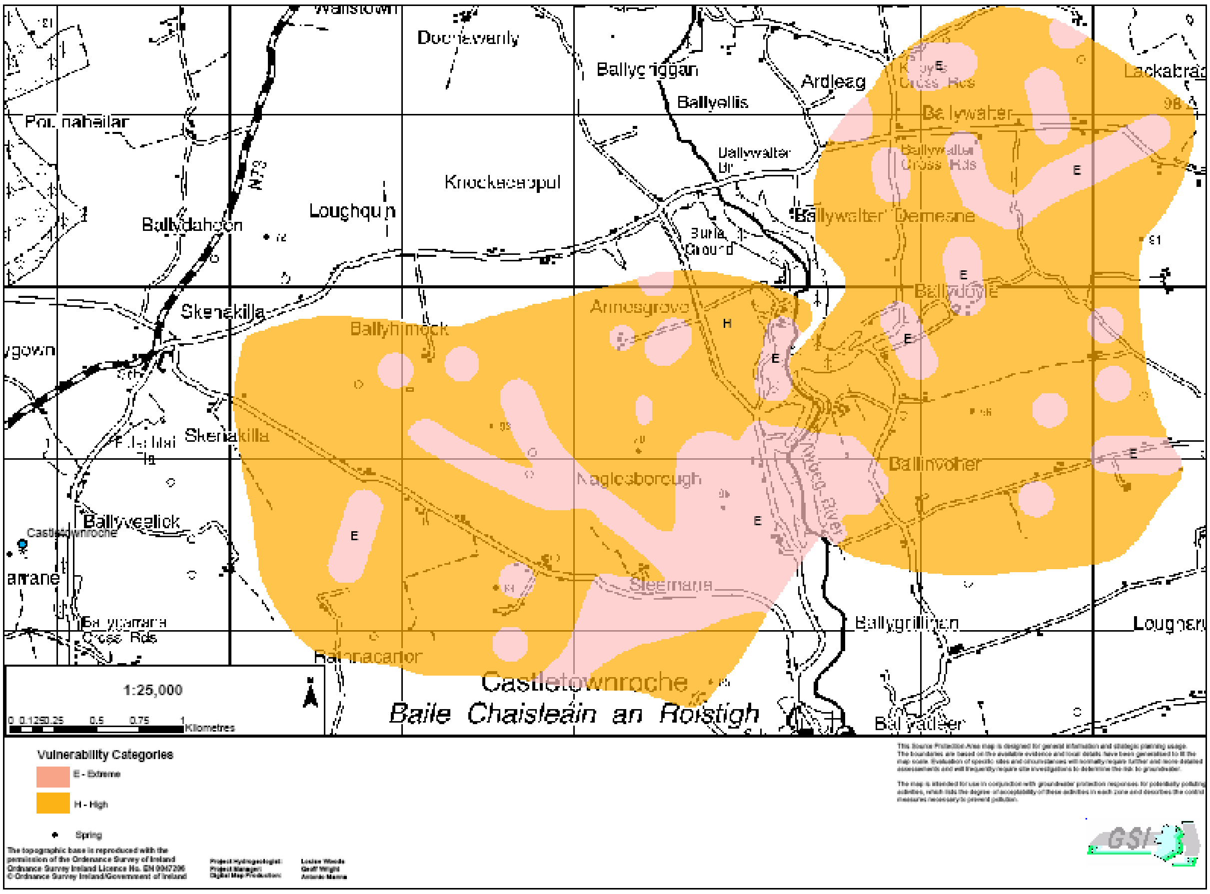

Figure 1 Groundwater Vulnerability around Castletownroche

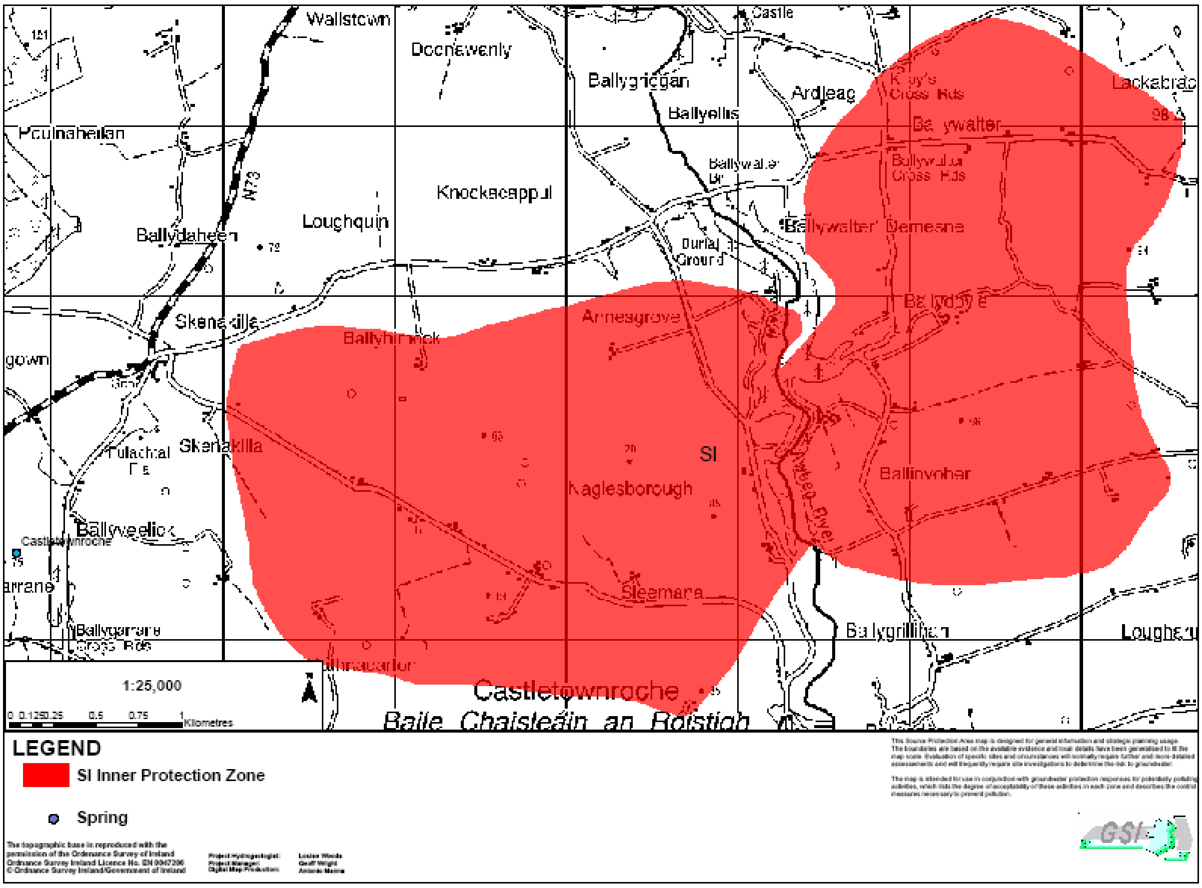

Figure 2 Groundwater Source Protection Areas for Gastletownroche

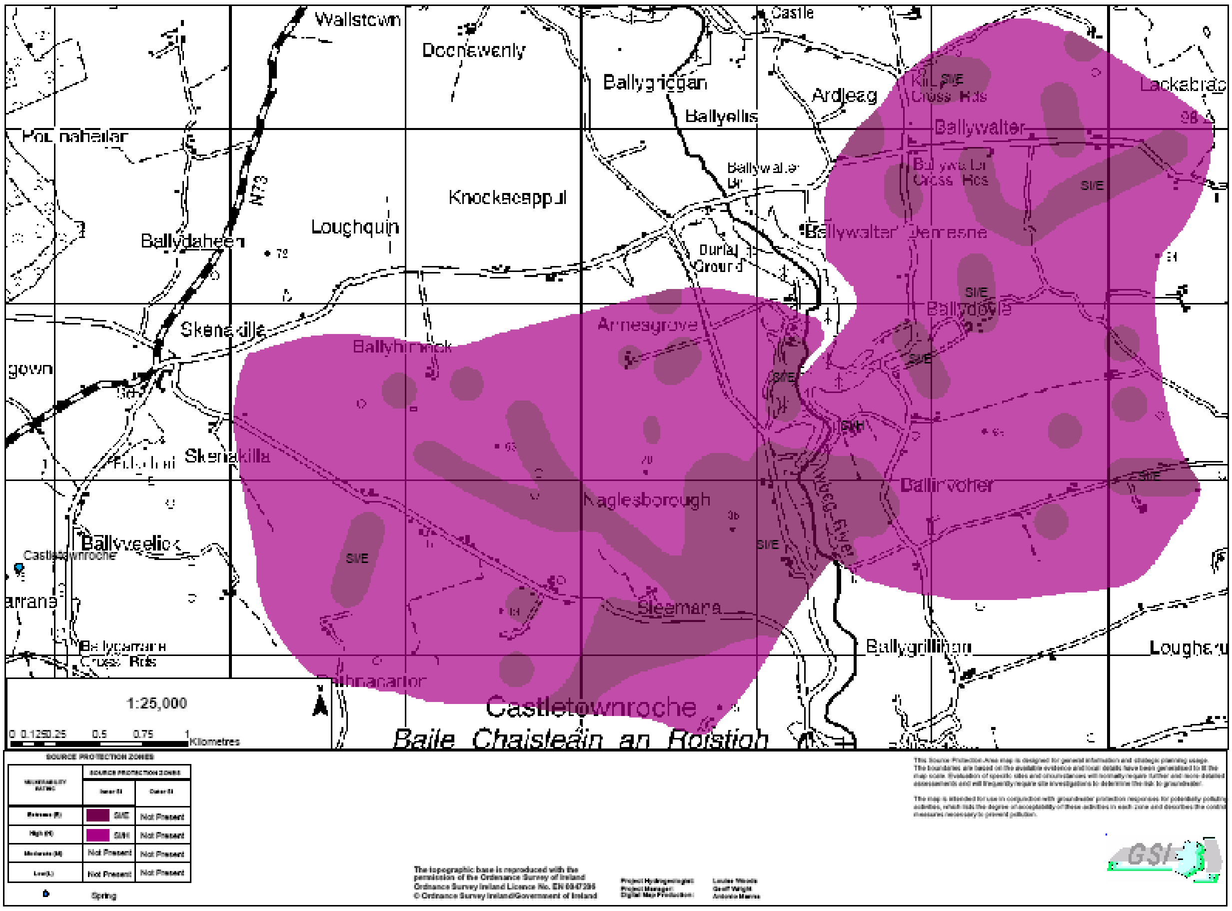

Figure 3 Groundwater Source Protection Zones for Castletownroche