Glanworth Water Supply Scheme

Ballykenly Spring (Tobermore)

Groundwater Source Protection Zones

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1 Introduction

Ballykenly Spring and Curraghoo Well are used to supply the Glanworth Water Supply Scheme. This report deals specifically with Ballykenly Spring that provides most of the water for the area.

The objectives of the report are as follows:

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

2 Location, Site Description and Well Head Protection

Ballykenly Spring, which was commissioned in 1947, is located 3.5 km north of Glanworth village. The pumphouse is located on the main road in the townland of Ballykenly. The spring source is 150 m north of the pumphouse in a concrete sump. The water is fed from the source, by gravity to the pumphouse, where pumps send water to the Johnstown and Dunmahon reservoirs. The reservoir in Dunmahon has a capacity of 200 $m^3 d^{-1}$ (44,000 gallons) and the Johnstown reservoir has a capacity of 1000 $m^3 d^{-1}$ (220,000 gallons). A 90^0 v-notch weir is constructed in the overflow outlet that flows to a small stream. The spring is protected by concrete flags and a concrete wall between the road and the spring.

3 Summary of Spring Details

Grid ref. (1:25,000)	:	R ^{1}765 ^{1}077
Townland	:	Ballykenly
Well type	:	Spring
Owner	:	Cork County Council (Northern Division)
Elevation (ground level)	:	~51.7 m OD.
Depth to rock	:	~1 m
Static water level	:	Ground level
Normal Abstraction	:	910 $m^3 d^{-1}$
Estimated Average Discharge	:	4000 $m^3 d^{-1}$

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, geophysics, water tracing and spring flow measurements. 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 spring source occurs in a low-lying valley close to the River Funshion. A small hill rises to the north of the source and the Kilworth Mountains lie to the east of the source.

The spring occurs close to a small tributary of the River Funshion that is the main surface water feature in the area. There is also a dry valley feature to the west of the spring. An intermittent stream flows from the 'Commons' to the dry valley where it sinks and rises again close to the River Funshion. To the northeast and east streams off the Kilworth Mountains are more frequent.

The land is primarily used for grassland farming. There are several farms located within 3 km of the spring source. There is one piggery located about 2 km to the north of the spring.

A public road passes next to the spring, linking the main Mallow-Mitchelstown road to the Glanworth area.

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.)
- 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 spring were 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 and is shown in Figure 1.

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).

The spring occurs close to the core of a major antiform, known as the Knockmealdown Antiform.

Two major fault sets are widespread across the region; east-west trending (strike faults) and north-south trending (cross faults). One north-south ('cross') fault cuts through the Glanworth area within 500 m of the spring. It is likely that there are more north-south faults in the area. It is possible that one such north-south fault cuts across the nose of the antiform comprising the Ballysteen Limestone.

Table 1 The Geology of the area around Ballykenly Spring (after Sleeman, A.G, 1995; Shearley, E.P., 1988).

Name of Rock Formation		***Rock Material***	***Occurrence***
Waulsortian Formation		Pale grey, massive LIMESTONE.	Underlies the spring and covers much of the area.
Ballysteen Formation	Upper Unit (Shanrahan Member)	Dark-grey to black, extremely argillaceous bedded LIMESTONE, 25-50% argillaceous material, and 120 m thick.	Occurs about 2 km to the north of the spring in the townland of Commons.
	Lower Unit	Medium to dark-grey, argillaceous bedded LIMESTONE, with up to 30% mud, and has a minimum thickness of 30 m.	Occurs about 2 km to the north of the spring in the townland of Commons.

6.3 Subsoil (Quaternary) Geology

An extensive geophysics and drilling programme was carried out by GSI personnel to investigate the permeabilities of the subsoil and the depth to rock across the domain. The geological logs of the auger holes drilled are given in Appendix 1 and the locations are given in Figure 2. The subsoils comprise a mixture of coarse and fine-grained materials, namely till, and are directly influenced by the underlying bedrock, which is made up of limestones.

Three geophysical methods were employed, namely: EM-31(electrical conductivity survey), Wenner Sounding (electrical resistivity survey) and 2-D Electrical Resistivity surveys. Further details of the geophysics are given in Motherway (1999).

6.3.1 River Alluvium

This material occupies the area along the stream that flows past the spring, and comprises fine-grained black silty clay.

6.3.2 Till (Boulder Clay)

This material dominates the area and comprises an unsorted mixture of coarse and fine materials laid down by ice. Angular to subrounded limestone fragments are abundant in the tills. The tills comprise sandy CLAY, sandy SILT with cobbles, SAND, and GRAVEL (BS 5930).

6.3.3 Depth to Bedrock

The geophysical methods employed near the spring indicated that the depth to bedrock is generally shallow, mostly <5 m, with several localities where the depth to bedrock is somewhat deeper (12-18 m). The depth to rock is known in certain localities from the drilling programme carried out by the GSI. The depth to bedrock is variable, ranging from 0-13 m.

7 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the area of the springs. The spring is shown in Figure 1.

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

- A Study of Nitrate and Vulnerability in the Waulsortian Limestone Aquifer of North Cork, Ireland. Motherway, K., 1999. MSc Thesis, University College London.
- GSI files and archival Cork County Council data.
- Cork County Council annual drinking water returns.
- Cork County Council Nitrate monitoring programme.
- Flow measurements at the spring to determine the total discharge.
- Geoex Limited 1984. Report on Production Well at Glanworth, Co. Cork, Cork County Council (Northern Division).
- Geoex Limited 1984. North Cork Aquifer Protection Survey, Phase 2, report on Glanworth Water Supply Scheme Source at Ballykenly and Curraghoo Townlands, Cork County Council (Northern Division).
- Geoex Limited 1982. North Cork Aquifer Protection Survey, Phase I, report on Glanworth WSS, Mitchelstown WSS and Millstreet WSS, Cork County Council (Northern Division).

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 is assumed to consist of 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 for the Glanworth area are estimated as follows:

- Annual rainfall: 1034 mm. (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 based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for vertical downward flow to groundwater or for runoff.
- Annual runoff losses: 30 mm. This estimation assumes that 5% of the potential recharge may be lost to overland flow and shallow soil quickflow without 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

7.3 Groundwater levels, Flow Directions and Gradients

Groundwater level data are poor - there are only eight wells across the area, and their distribution is uneven. Groundwater levels were measured in the eight wells as a part of the investigation of the hydrogeology (Motherway, 1999).

The water table in the area is assumed to be a subdued reflection of topography. There is a water divide in the northern part of the area, about 3 km from the spring. The groundwater levels suggest that the groundwater moves from the divide toward the spring, however the actual path of groundwater flow may be variable due to the lithology and karstification. The average topographic gradient is 0.014 and the average groundwater gradient is 0.008.

7.4 Aquifer Characteristics

Aquifer characteristics of the two limestone formations that occupy the area depends on the lithology and to a large extent on the processes that they have undergone since deposition. The two main processes that influence the aquifer characteristics are deformation (Section 6.2.1 Structure) and karstification. Data from other parts of the county or neighbouring counties are used in conjunction with the data gathered at Glanworth to characterise the aquifers around the source as shown 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).

The Waulsortian Limestone is generally very productive in Munster, recording very high well yields and specific capacities. The resistivity surveys also indicate that the Waulsortian Limestone is highly karstified (Motherway, 1999). Several infilled cavities that have no surface expression have been interpreted from the geophysics. Local farmers indicated a line of collapse features (dolines) in the northern part of the area, north of the area named the 'Commons'. Test pumping of the Waulsortian Limestone at Downing Bridge and Moorepark suggested transmissivities ranging 15-3400 $m^2 d^{-1}$ (Motherway, 1999). This test pumping illustrates the variability of aquifer properties in the Waulsortian. The permeability and resulting groundwater velocities of the Waulsortian are likely to be very high, particularly as water approaches the spring.

The Ballysteen Limestone is not as good an aquifer as the Waulsortian Limestone due to the higher mud content and shalier nature of the beds which produce lower permeabilities than the Waulsortian Limestone. The two units in the Ballysteen probably differ hydrogeologically. The lower unit is 'cleaner' suggesting relatively higher permeabilities than the upper, muddier unit. The measurements of water levels in the wells over the area show that the gradient is steeper in the Ballysteen Limestone than the Waulsortian Limestone, again suggesting lower permeabilities. Surface drainage is locally poor over this area; the area known as the 'Commons' is susceptible to flooding. Apart from this small area the land is free draining with very few surface streams, i.e., the drainage density is very low, suggesting higher permeabilities than are normally reported for the Ballysteen Limestone. There are several wells in the area underlain by the Ballysteen, all for farm use, including a piggery, that suggests that the well yields are reasonable and the Ballysteen may be quite permeable.

As the data do not provide enough information on the aquifer properties around the source, particularly within the Ballysteen Formation, it is not known whether the permeability within the Ballysteen Limestone is high enough to allow groundwater to flow from the Waulsortian Limestone directly down-gradient in a southeasterly direction to the source. The relative hydraulic gradients indicate that this is true. Some groundwater may flow southwestwards *around* the Ballysteen Limestone, toward the River Funshion and spring that occurs at the southern end of the dry valley to the west of Ballykenly Spring. However, there are likely to be fracture zones cross-cutting the Ballysteen Formation that allow groundwater through, albeit at a lower rate.

Ballykenly Spring is a large spring, indicating that the bedrock has a high permeability. Flow is likely to be concentrated in high permeability zones, most likely along pre-existing bedding planes and joints.

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 that are controlled by structural deformation as seen in the 2-D-Resistivity Survey.
- A more dispersed slow groundwater flow component in smaller fractures and joints outside the main conduit systems.

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

Parameter	***Source of data***	***Ballysteen***	***Waulsortian***
Transmissivity (m^2 d^{-1})	Regional*	10-100	200-3500
Permeability (m d^{-1})	Regional	0.1-2.0	10-200
Porosity	Regional	0.005-0.015	0.025
Velocity (m d^{-1})		0.16-1	0.8-15
Hydraulic Gradient	Local**	0.008	0.002

* Regional data: based on information for Munster area.
** Local data: based on information for Glanworth.

7.5 Hydrochemistry and Water Quality

The hydrochemical analyses (18 samples) of Ballykenly Spring show that the water is a hard to very hard water with total hardness values of 265-390 mg l^{-1} (equivalent $CaCO_3$) and electrical conductivity values of 423-731 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. The variation in electrical conductivity suggests rapid response to recharge. The analyses are given in Appendix 2.

Nitrate concentrations range 52-88 mg l^{-1} (50 samples), consistently exceeding the EU Drinking Water Directive maximum admissible concentration (MAC) of 50 mg l^{-1}. The average concentration is 68 mg l^{-1}.

Chloride concentrations range 24-54 mg l^{-1} (3 samples; 1992-1999). Chloride is a constituent of organic wastes and levels higher than 25 mg l^{-1} in the North Cork area may indicate significant contamination.

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. However, there is only one analysis for Ballykenly Spring that reports the K:Na ratio and it is 0.3. Future samples should be analysed for these parameters.

From 17 'treated' water analyses between 1992 and 1999, faecal coliforms have been recorded in 3 of the samples and total coliforms have been recorded in 3 of the samples. From one 'untreated' analysis (July 1999) total coliforms were reported and no faecal coliforms were reported. For this project, the spring was sampled for cryptosporidium and giardia, using customised equipment provided by Inniscarra Laboratory. Subsequent analysis by the City Analyst found the samples to be negative for both cryptosporidium and giardia.

Other wells in the area were sampled to compare with the analyses from Ballykenly Spring. All the wells analysed show similar hydrochemistry and water quality characteristics to Ballykenly Spring. The analyses show that faecal and total coliforms are present in almost all the wells analysed. K:Na ratios are high, with an average of 0.66.

High ammonia levels and low nitrate levels are recorded at two wells that are very close to the piggery, conversely low ammonia levels and high nitrates are recorded at Ballykenly Spring. This illustrates the process of ammonium converting to nitrate due to oxidation. High levels of nitrate and low levels of ammonium suggest that the spring is located at a point where almost all the ammonium has been converted to nitrate, i.e., the spring is at a distance from the source of nitrogen pollution. The high ammonia levels and low nitrate levels at the wells in the piggery indicate the wells are very close to a source of nitrogen pollution and that the process of conversion of ammonium to nitrate is only beginning (Motherway, 1999). Slurry is likely to be the source of this ammonium as it is a rich source of ammonium and ultimately a major contributor to nitrate levels.

Manganese levels are above the EU MAC of 0.05 mg l^{-1} in the 3 of the wells in the area underlain by the Ballysteen Limestone. These could to be due to organic waste or alternatively due to being located in a muddy limestone lithology. Iron levels are elevated in these wells but do not exceed the EU MAC.

In summary, the water at the springs is hard with levels of nitrates and chlorides that are significantly higher than would be expected from groundwater. Faecal and total coliforms and manganese have exceeded the EU MAC and probably indicate contamination from farmyard wastes or perhaps in some instances septic tank systems. The K:Na ratio is very high indicating contamination from organic pollution possibly farmyard wastes. It is likely that pig slurry is a major contributor to the high nitrate levels at Ballykenly spring.

7.6 Spring Discharge

The total discharge at the springs is difficult to measure accurately. There have been several estimates of the total yield and these are summarised in Table 3. Only one of the estimates was carried out during winter months, hence the majority of estimates are likely to represent low flow periods. An average of these figures would underestimate the average annual mean flow. Motherway (1999) estimated the mean annual average flow to be about 4000 m^3 d^{-1}, based on a direct comparison with another high yielding spring within the Waulsortian named the Dower Spring, near Castlemartyr. However, this may not be directly comparable because the flow regime may be different between the two springs. The mean annual flow may still be an underestimate as there are no true winter flow records. It is recommended that more frequent or continuous monitoring is carried out.

Table 3 Estimates of discharge for Ballykenly Spring

Date	*Source*	*Estimate (m^3 d^{-1})*	*Total Discharge*
28/2/1972	Cork Co. Co.	Overflow 1523 Abstraction 1637	3160
1979	Cork Co. Co.	Overflow 1364 Abstraction 841	2205
25/9/1979	Cork Co. Co.	Overflow 145 Abstraction 1137	1282
27/9/1978	Cork Co. Co.	Overflow 156 Abstraction 1137	1293
4/9/1981*	Cork Co. Co.	Overflow 3032 Abstraction 1637	4669
10/9/1981	Cork Co. Co.	Overflow 1219 Abstraction 709	1928
18/9/1981	Cork Co. Co.	Overflow 990 Abstraction 1636	2626
30/9/1981	Cork Co. Co.	Overflow 1219 Abstraction 622	1841
12/8/1983	Cork Co. Co.	Overflow 1191 Abstraction 1637	2828
11/9/1984	Cork Co. Co.	Overflow 0 Abstraction 1637	1637
1/7/1999	GSI	Overflow 571 Abstraction 2236	2807

*This figure is anomalous, as rainfall data, general water levels and discharge from other springs around County Cork indicate that the general condition of the water table was relatively low at that date.

7.7 Conceptual Model

- Ballykenly Spring is a large spring with a mean annual flow of around 4000 m^3 d^{-1}. The source of the groundwater is the Waulsortian and Ballysteen Limestones. The groundwater regime in the area is complex and the available hydrogeological information does not allow a definitive understanding of the hydrogeology.
- The geophysics indicates that rock is very close to the surface where the spring emerges. It is a low-lying area where the water table intersects the valley bottom. It is possible that a fracture system in association with a small area of very thin permeable till is causing the groundwater to focus in this location.
- Groundwater flow is likely to occur through shallow, interconnected, solutionally enlarged fracture zones and along fractures and joints outside the main fracture systems. The main fracture system has a north-south trend. Caves in the north Cork area have two main trends; NNW-SSE and E-W.
- The Waulsortian has high permeabilities as indicated by the hydraulic gradients, the high discharge at the spring and the karstified nature of the bedrock. The Ballysteen Limestone has somewhat lower permeabilities as indicated by the steeper gradient in the area that is underlain by the Ballysteen Limestone. In particular the upper unit of the Ballysteen is far more impermeable. Thus, it is likely that as groundwater flows from the northern boundary of the ZOC to the spring, particularly in winter, some of it could be directed southwestwards around the Ballysteen Limestone toward the spring that occurs in the dry valley to the west of Ballykenly Spring. However, most of the groundwater will move through the Ballysteen, although at a lower rate. This is facilitated by north-south fracture zones that are prevalent in the area.

- The hydrochemistry shows that the groundwater is hosted in limestone but the variation in the electrical conductivity shows some groundwater has reached the spring faster, possibly via a shorter pathway, and so does not reside in the limestones for long enough time to acquire the same chemical signature as the main bulk of the groundwater emerging at the springs.
- The quality of the groundwater emerging at the spring and in the majority of wells in the area is poor with respect to certain parameters; coliforms are often present in treated and untreated water and nitrate levels are consistently above the EU MAC.

8 Delineation of Source Protection Areas

8.1 Introduction

This section delineates the area around the spring that is believed to contribute groundwater to the spring, and that therefore requires protection. The area is delineated based on the conceptualisation of the groundwater flow pattern, and is 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 remainder of 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 Figures 2 and 3. The ZOC catchment boundaries are discussed as follows:

The **Northern boundary** is constrained by topography; a watershed is located along a topographic ridge that is located in the townland of Glennahulla. To the north of this divide the River Funshion flows west parallel to the main Mallow-Mitchelstown road. Water flows toward the River Funshion on the north side of this divide. South of this divide water flows toward Ballykenly Spring.

The **Eastern boundary** is constrained by topography, the measured water levels and the water table map. A topographic ridge runs northwest-southeast into the townland of Castleterry and then swings southwest and then through the townlands of Kilnadrow and Ballindangan, acting as a watershed, separating water draining toward an unnamed stream that flows northeast-southwest past Ballykenly Spring, and water that flows toward Ballykenly Spring.

The **Western boundary** is defined using topography and assumes that the majority of groundwater flows through the Ballysteen toward the spring. A dry valley feature into which an intermittent stream flows from the ‘Commons’ in Ballindangan adds to the complexity of this boundary. It is assumed that groundwater that flows around the Ballysteen Formation will flow toward the spring that rises in the dry valley to the west of Ballykenly Spring. The boundary cuts though the path of the intermittent stream as this stream takes excess surface water from the 'Commons' during periods of very heavy rainfall.

The **Southern boundary** is constrained by the location of the spring itself in relation to the unnamed tributary that flows past the spring toward the River Funshion. The spring is at a higher elevation than the stream, thus groundwater to the south of the spring and east of the stream cannot flow to the spring which is downgradient. An arbitrary buffer of 30 m is placed on the downgradient side of the spring.

The area delineated using the boundaries described above is about 3 km^2; however by using the extended boundary for the western boundary, the area delineated is doubled. The water balance shows that to provide the discharge at the source an area of about 2.6 km^2 is required. However, the water balance uses a mean annual flow that may underestimate the true mean flow. To get an accurate mean annual flow, continuous monitoring of the spring discharge over the winter and summer months is recommended.

8.3 Inner Protection Area

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 to the supply. Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling using the aquifer parameters in Table 2 assists in estimating the 100-day ToT boundary.

It is estimated that groundwater velocities range up to approximately 15 m d^{-1} in the Waulsortian Limestone, although velocities would be greater where the flow to the spring is via a solutionally formed (karst) conduit. Groundwater velocities in the Ballysteen Limestone, and particularly in the Upper Unit, would be significantly less; perhaps 0.5-2.0 m d^{-1}. It is not feasible to draw a definitive 100-day ToT boundary, as specific data on permeabilities and porosities are not available for the area. Therefore, the boundaries drawn are estimates, based on information on the Waulsortian and Ballysteen Limestones in the Munster area, experience and judgement. More definitive boundaries would require a detailed site investigation in the area, including drilling and tracing.

The 100-day ToT boundary in the Waulsortian Limestone is estimated to be 1500 m from the spring. This may be conservative if flow to the spring is in fractures, with only slight enlargement due to solution. However, if karst conduits are present, it is likely to be an underestimate. Some of the area of Ballysteen Limestone is within 1500 m of the spring. The 100-day ToT boundary in the Ballysteen Limestone is drawn, somewhat arbitrarily, along the contact between the Lower and Upper units. This is a conservative boundary if there are no high permeability zones taking water southwards through the upper unit. However, some high permeability zones are probable.

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 bedrock 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 in upland areas to produce a 3 m depth to bedrock contour, thus 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 area to the north of the spring has a relatively steep topography and is for the purposes of this exercise considered to be an 'upland area'. There are only 3 known points >10 m; to produce a 10 m contour the distance between the known depth to bedrock point and the nearest outcrop is measured and the approximate distance to 10 m is calculated.

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 glacial till and alluvium. The till overlying the area is considered to have a high, moderate or low permeability. This assessment is based on the behavioural characteristics assessed using the British Standard BS5930 in conjunction with the drainage and recharge characteristics. Therefore, depending on the depth to rock, the *vulnerability* of these deposits ranges from 'High' (3->10 m thick) to 'Moderate' (>10 m). Most of the area falls under the 'High' vulnerability classification. One area falls into the 'Moderate' vulnerability classification.

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 Inner Protection area where the groundwater is highly vulnerable to contamination. Six groundwater protection zones are present around the spring source as shown in Table 4. The final groundwater protection map is presented in Figure 3.

Table 4 Matrix of Source Protection Zones for Ballykenly Spring

VULNERABILITY RATING	**SOURCE PROTECTION**	
	Inner	***Outer***
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
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. 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 and pig slurry. The main potential pollutants are nitrogen, faecal bacteria and viruses.

12 Conclusions and Recommendations

- Ballykenly spring is a large spring that is 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.

- The hydrogeology of the area is complex and the available information is not adequate to allow the delineation of definitive groundwater protection zone boundaries. The protection zones delineated in the report are based on our current understanding of groundwater conditions, on the available data and our judgement. Additional data obtained in the future may indicate that amendments to the boundaries are necessary. A more definitive understanding of the hydrogeology would require an extensive site investigation that would include drilling, geophysics, spring flow measurements and tracing.

- It is recommended that:

1) A chemical and bacteriological raw water analysis should be carried out on a regular basis at the source.
2) particular care should be taken when assessing the location of any activities or developments that might cause contamination at the well.
3) the potential hazards in the ZOC should be located and assessed.
4) The discharge of the spring is monitored regularly.

13 References

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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.

Bore no.	Depth	BS5930 description	Permeability classification
GLAN1	1-7m	Sandy SILT with clay	Moderate
GLAN2	0-1.3	Sand	High
	1.3-2	Sandy SILT with clay	Moderate
	2	EOH*	
GLAN3	0-1.9	Sandy SILT with clay	Moderate
	1.9	EOH	
GLAN4	0-4.8	Sandy CLAY	Low
	4.8	EOH	
GLAN5	0-4.7	Sandy CLAY	Low
	4.7-12.75	Sand SILT with clay	Moderate
GLAN6	0-6.5	GRAVEL	Moderate
	6.5-7	Sandy SILT with clay	Moderate
	07-12.	CLAY	Low
	12	EOH	
GLAN7	0-2.8	Silty SAND	High
	2.8	EOH	
GLAN8	0-5.	Sandy SILT with clay	Moderate
	5	EOH	
GLAN9	0-5	Silt	Moderate
	5-7.9	CLAY	Low
	7.9	EOH	
GLAN10	0-2	Sandy SILT with clay	Moderate
	2-5.	CLAY	Low
	5-8.	Sandy Clay	Low
	8-11.5	SAND	Mod/High
	11.5-12.5	Sandy SILT with clay	Mod/Low
	13	EOH	
GLAN11	0-1.3	Sandy SILT with clay	Moderate
	1.3	EOH	

*EOH = End of Hole.

Appendix 2 Hydrochemical Analyses

Parameter	Analyses		
	13/5/1992 treated	14/12/1994 treated	1/7/1999 untreated
Conductivity (μS/cm)	697	667	912
Temperature (°C)	-	-	
pH	7.31	7.11	7.2
Total Hardness (mg l^{-1} $CaCO_3$)	328	244	307
Total Alkalinity (mg l^{-1} $CaCO_3$)	240	296	
Calcium	-	-	115.2
Magnesium	-	-	13.0
Chloride	38	54	
Sulphate	11	21	16.3
Sodium	-	-	11.3
Potassium	-	-	3.0
Nitrate (as NO_3)	58	66.0	70.2
Iron	0.04	<0.02	
Manganese	<0.02	<0.02	
Total Coliforms per 100 ml	0	0	19
E. coli count per 100 ml.	1	0	0

Current Monitoring (C2) from Inniscarra Water Laboratory.

Date	Conductivity	Nitrate	T. Coli	Faecal Coli.	pH
2/4/91	464	56.5	0	0	7.4
6/8/91	423	61.85	0	1	7.0
30/6/92	659	62.5	10	4	7.3
19/11/92	682	65	0	0	7.4
30/3/93	567	70.79	0	0	7.2
29/7/93	731	53.4	0	0	7.0
9/2/94	571	73.17	0	0	7.3
6/7/94	713	62.11	0	0	7.4
6/9/94	633	55.36	3	0	7.4
7/3/95	659	64.5	0	0	7.5
25/5/95	651	68.8	0	0	7.4
10/7/95	652	52.18	0	0	7.4
5/2/96	648	58.15	3	0	7.3
15/4/96	649	54.29	0	0	7.4
24/6/96	648	75.44	0	0	7.4

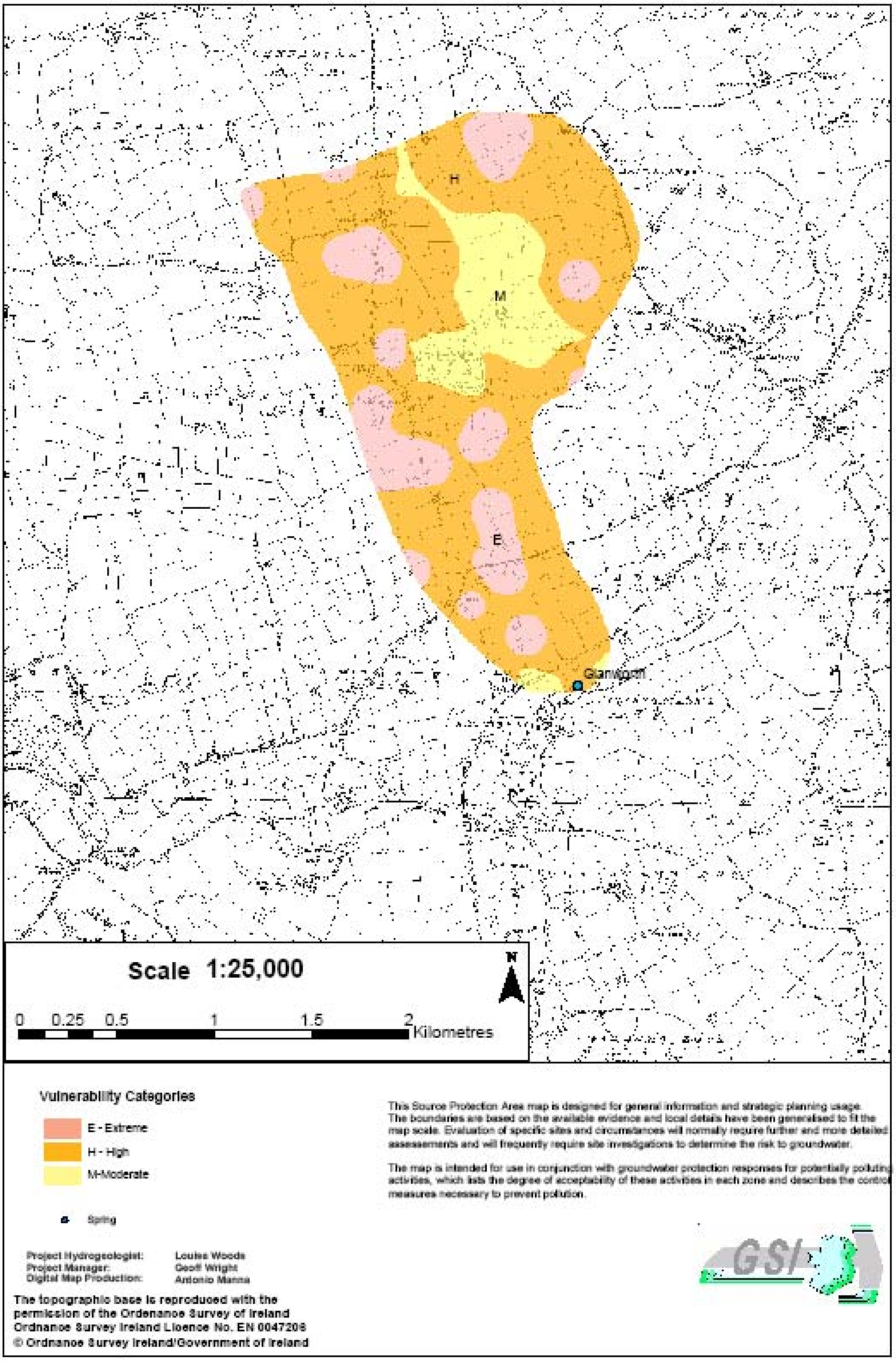

Figure 1 Groundwater Vulnerability around Clanworth

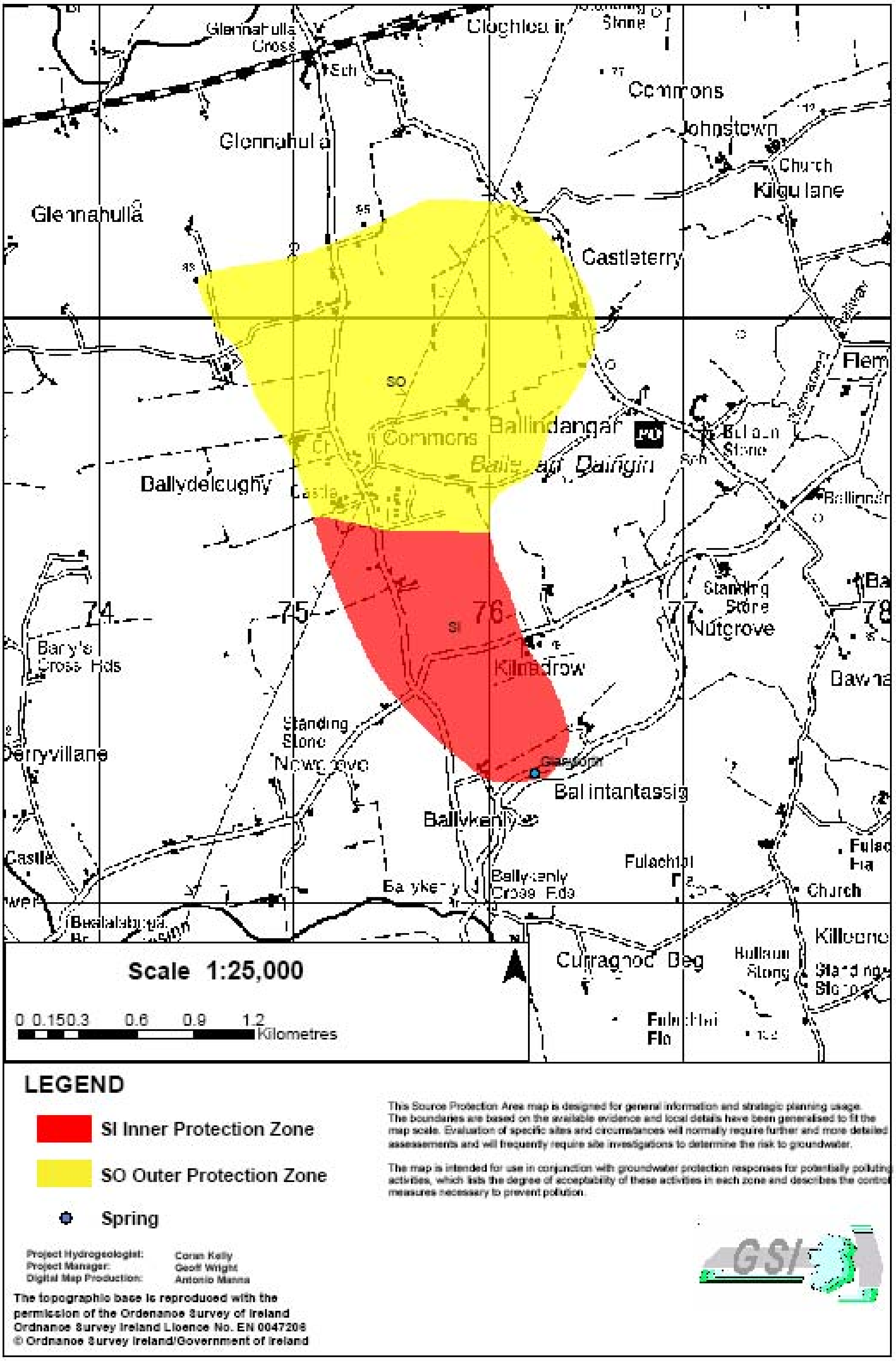

Figure 2 Groundwater Source Protection Areas for Clanworth

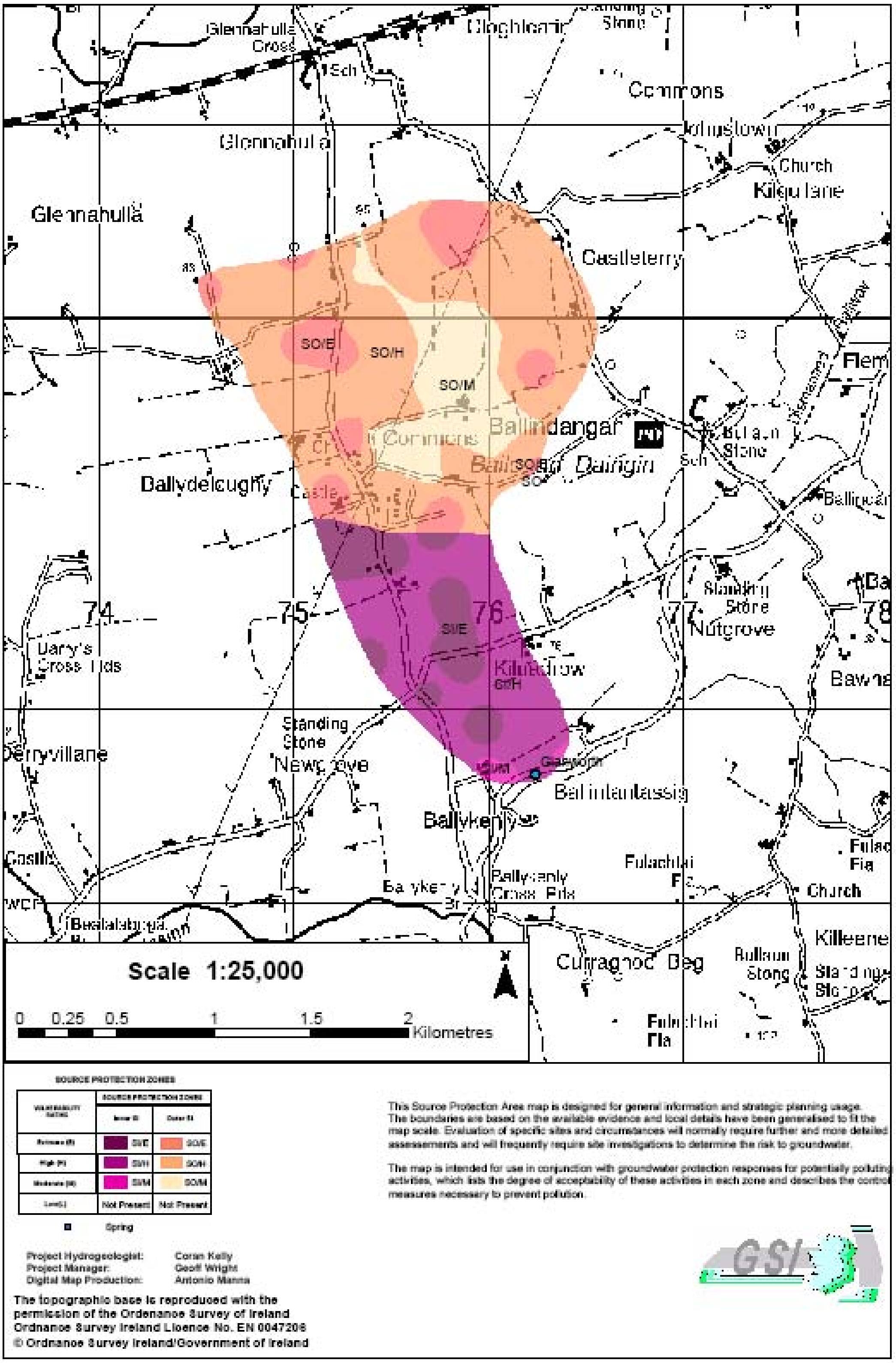

Figure 3 Groundwater Source Protection Zones for Clanworth

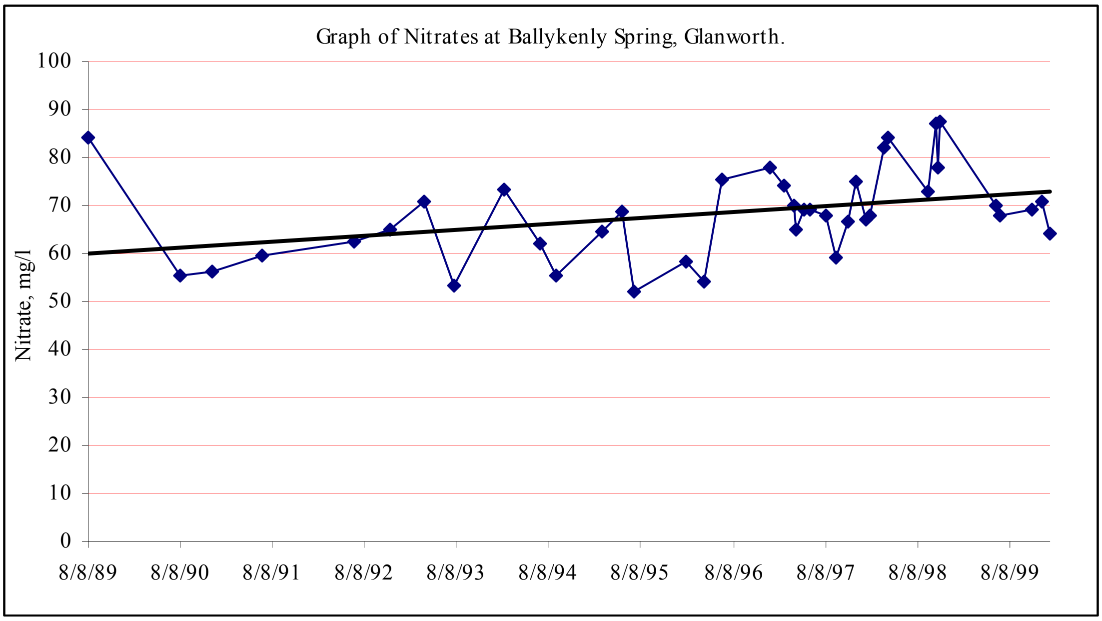

Figure 4 Graph of nitrate levels for Ballykenly Spring near Glanworth, County Cork.