Ballinlough Water Supply Scheme

Ballybane Springs

Groundwater Source Protection Zones

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Prepared by:
Monica Lee and Coran Kelly
Geological Survey of Ireland

In collaboration with:
Roscommon County Council

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1 Introduction

The Ballybane Springs provides the main supply for the Ballinlough area. They comprise five springs that feed into one sump, built over the main spring.

To augment the supply, production wells were installed in June 1993 next to the springs (KT Cullen & Co., 1993). Currently, there are two pumping wells in operation and the springs themselves are no longer used. There is only overflow in times of wet weather. The boreholes allow a greater abstraction than the springs, particularly during the summer. However during dry summers the water levels drop and the water becomes cloudy.

Due to continued water shortages, two trial boreholes were drilled (KT Cullen & Co., 1999) to investigate the possibility of further augmenting the supply. To date, these have not been utilised.

The objectives of the report are as follows:

- To delineate source protection zones for the Ballybane Springs and production boreholes using the national methodology (DELG/EPA/GSI, 1999).
- To outline the principle hydrogeological characteristics of the Ballybane area.
- To assist Roscommon County Council in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

Ballybane Springs are located approximately 3 km south of Ballinlough village. They supply both the Ballinlough urban area and the surrounding rural area.

The site comprises a pump-house with the main spring sump located adjacent the pump-house. The sump is situated over the main spring, with the remaining four smaller springs feeding into the sump. The springs are essentially in a line extending south-eastwards from the sump. There are also two pumping wells and a trial well in the site area.

Any overflow discharges from the sump via a shallow channel, which has a rectangular weir fitted. The overflow moves in a south-easterly direction to join a tributary of the Island River.

Well head protection has been compromised by the recent investigation work that was carried out.

The site area is separated from the surrounding field by a fence and a closed gate.

3 Summary of Well / Spring Details

GSI no.	:	1427SEW017
Grid ref. (1:25,000)	:	15738 27428
Townland	:	Ballybane
Well type	:	Springs and Boreholes
Drilled	:	June 1993
Depth	:	PW1 12.5 m; PW2 61.0 m
Owner	:	Roscommon County Council
Elevation	:	approximately 88 m OD
Depth to Rock	:	6 m
Static water level	:	approximately at ground level.
Present Abstraction	:	3600 – 4500 m^3/d
Estimated Average Discharge	:	4600 m^3/d

4 Methodology

4.1 Desk Study

Details regarding the borehole such as elevation, and abstraction figures were obtained from GSI records and County Council personnel. Geological and hydrogeological information was provided by KT Cullen & Co. (1993, 1999).

4.2 Site visits and fieldwork

This included depth to rock drilling, subsoil sampling and flow gauging of the spring overflow. 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

Ballybane Springs are located at the bottom of an esker ridge in a relatively low-lying area, which becomes saturated and marshy to the east of the springs. Approximately 1 km west of the springs the land begins to rise to a maximum of 160 m OD in the townland of Moanvane.

The low-lying area around and immediately east of the springs forms part of the Island River valley. This river flows south past the springs and then east towards Ballymoe where it joins the River Suck. There is a noted absence of surface drainage on the higher area to the west of the springs. Also a large number of karst features (dolines, swallow holes, springs and turloughs) have been recorded both to the west and south-west of the springs by the GSI and KT Cullen & Co. (1993).

Agricultural activity dominates the area with most of the land used for grazing. A number of houses and farmyards are present near the springs. There is also a small village (Garranlahan) situated on the high area west of the springs.

6 Geology

An understanding of the geological material underlying the Ballybane area provides a framework for the assessment of groundwater flow and for source protection zones, as discussed in Sections 7 and 8.

6.1 Bedrock Geology

Bedrock information (Figure 2) was taken from a desk-based survey of available data. These comprised:

- unpublished work undertaken by the Bedrock Section (GSI),
- KT Cullen & Co. (1993) Hydrogeological Investigation at Ballybane, Ballinlough.
- KT Cullen & Co. (1999) Report on the Drilling and Testing of Two Trial Wells at Ballinlough.

The springs are located in Oakport Limestone, which extends south west of the springs. The Oakport Limestone comprises three units. The upper unit is a medium to fine-grained, even bedded and well-jointed limestone. The middle (Rockingham) unit is described as a pale and dark grey fine-grained sedimentary rock with high silt content. The lower unit is similar to the upper, being recorded as a clean, thickly bedded and well-jointed coarse-grained limestone.

Boreholes located adjacent the springs record 25 m of ‘black limestone’ at approximately 6 m below ground level (b.g.l.). This is underlain by grey fissured limestone, which extends to greater than 61 m b.g.l (K.T. Cullen & Co., 1993). A borehole at the northern boundary of the pump-house site also records black limestone, but to a depth of greater than 61 m b.g.l. (K.T. Cullen & Co., 1993).

A fracture network is likely to run through the site because the springs occur along a line and the production borehole logs indicate a fracture zones at a depth of 8-12 m beneath the springs (K.T. Cullen & Co., 1993). A fracture zone was also detected at this depth in the boreholes at the northern boundary of the site (K.T. Cullen & Co., 1999).

6.1.1 Karst Features

Karst mapping was undertaken in the Ballinlough area during the summer 2001. As shown in Figure 1, the mapping identified an unusually large number of features. These included enclosed depressions (dolines), swallow holes, springs and turloughs. The mapping highlights the density of dolines and swallow holes.

6.2 Subsoils

Subsoils mapping was undertaken by Dr. R. Meehan (Teagasc) to produce the Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map (Figure 2). This information forms the basis of subsequent subsoil permeability assessments for the county (Lee and Daly, 2002). Further data was gathered from GSI drilling programmes (1999 and 2001). Additional information specific to the area of interest includes:

- KT Cullen & Co. (1993) Hydrogeological Investigation at Ballybane, Ballinlough
- KT Cullen & Co. (1999) Report on the Drilling and Testing of Two Trial Wells at Ballinlough.
- Doak, M., (1995) The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. M Sc. Thesis, Sligo RTC.
- Friel, G., (1991) A Groundwater Vulnerability Assessment of the Ballinlough Spring Catchment. B Sc. Thesis.

The subsoils comprise a mixture of coarse and fine-grained materials. An extensive area of peat is located in the low-lying area around and to the east of the springs. However there is a layer of peat in the immediate vicinity of the springs (1.5 m to 2.0 m, KT Cullen & Co, 1993), which forms the edge of a more extensive area of peat to the west of the springs.

Sand and Gravels. Extensive fluvioglacial sand/gravel are present immediately west of the springs in a north – south alignment (Figure 2). A large proportion of the sand/gravel forms a characteristically random, hummocky topography however long, sinuous, braided ridges of sand/gravel (eskers) have also been deposited. These form an unusual landscape, unique to this part of the county.

The material is described as generally poorly sorted coarse SAND and GRAVEL (BS5930), with occasional lenses of sorted material. The gravel, cobbles and boulders have a predominantly limestone composition.

K.T.Cullen & Co. (1999) also recorded 12.5 m of ‘clean gravel’ in a borehole approximately 100 m north of the springs, adjacent to the access road to the pump-house site area.

Tills. The tills in the area are located on the higher ground, to the west of the sand/gravel (Figure 2). There is one representative sample taken in the townland of Garranlahan. The matrix of this sample is described as a gravely SILT (BS 5930) and has a particle size distribution with 35% fines (silt + clay) and 11% clay (BS 5930).

6.2.1 Depth to Bedrock

Broad variations in depth to bedrock have been interpreted across the area by using information from the GSI databases, field mapping and air photo interpretation.

The available data indicate that the depth to rock varies from 0 m (outcrop) to greater than 10 m. The low-lying area around the spring has a relatively thick subsoil cover of between 3 m to 10 m (6.1 m at the springs). The higher ground west of the springs generally has thinner subsoil (0-3m), with outcrop recorded around Garranlahan Village. Some of the upstanding esker ridges in this area have a depth to bedrock of greater than 10 m.

6.3 Groundwater Vulnerability

The concept of vulnerability is discussed in the Roscommon Groundwater Protection Scheme Main Report (Lee and Daly, 2002). The vulnerability classifications for this region are shown in Figure 3 [1].

Sand/gravel covers a large proportion of the area of interest. Although frequently unsorted, these materials are considered to have relatively low fines and are therefore classified as having a 'high' permeability.

The till in this region is described as SILT (BS 5930) with an available particle size distribution to support this description. These materials are categorised as having a 'moderate' permeability.

Where subsoil thickness is greater than 3 m, the vulnerability classification ranges from 'moderate' to 'high', depending on the specific combination of permeability and subsoil thickness.

At subsoil thickness of less than 3 m, 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 areas of shallower subsoil.

Several types of karst feature (e.g. dolines, swallow holes) provide locations of point recharge i.e. surface water can infiltrate directly to the bedrock, by-passing any attenuation capacity of the subsoil. These locations are classified as 'extremely' vulnerable and they include an arbitrary buffer of 30 m radius.

7 Hydrogeology

This section presents our current understanding of groundwater flow around the Ballinlough Scheme. The interpretations and conceptualisations of flow are used to delineate source protection zones around the springs and production boreholes.

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

- GSI databases.
- GSI dye tracer testing.
- Roscommon County Council hydrochemistry data.
- KT Cullen & Co. (1993) Hydrogeological Investigation at Ballybane, Ballinlough
- KT Cullen & Co. (1999) Report on the Drilling and Testing of Two Trial Wells at Ballinlough.
- Doak, M., (1995) The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. M Sc. Thesis, Sligo RTC.
- Friel, G., (1991) A Groundwater Vulnerability Assessment of the Ballinlough Spring Catchment. B Sc. Thesis.
- Field work (flow gauging, drilling, subsoil sampling, water quality sampling).

[1] The permeability estimations and depth to rock interpretations are based on regional-scale evaluations. The mapping is intended only 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.

7.1 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 losses prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is important in source protection delineation as it can be used to estimate the size of the zone of contribution (i.e. the outer source protection area). The calculations are summarised in Table 1 below.

Table 1. Estimate of Recharge.

Parameter	Amount (mm/yr)	Data Source
Annual rainfall	1200	KT Cullen & Co, 1993.
Annual evapotranspiration	394	Potential evapotranspiration (PE) is estimated as 415 mm/yr (KT Cullen & Co, 1993). Actual evapotranspiration (AE) is estimated as 95% of PE.
Potential recharge	806	Rainfall minus AE. Estimation of the excess soil moisture available for either flow to groundwater, or soil quickflow and overland flow to surface water.
Runoff losses	–	Negligible due to: • thinner, relatively permeable till over approximately a third of the area • thicker, very permeable sand/gravel over approximately two thirds of the area. High infiltration also reflected in the lack of surface drainage channels.
Estimated Recharge	806	

7.2 Groundwater Levels, Flow Directions and Gradients

At the springs the water level is approximately at ground level and the entire area around the springs is relatively flat, low-lying and marshy. This would indicate a shallow water table.

There are no water level data for the area west of the springs. In this instance, the water table is generally assumed to be a subdued reflection of topography. Therefore as the topography rises to the west, the water table is also likely to increase.

Given that the water table reflects the topography, the dominant driving head for the springs is likely to be the higher ridge area between Garranlahan Village and Moanvane townland.

Groundwater flow direction is generally perpendicular to the topographic contour lines. Therefore rainfall reaching the water table in the springs' catchment is likely to flow in an easterly to north-easterly direction.

The GSI undertook dye tracer testing in the Ballybane area in April 2002. Dye was injected into two swallow holes; one in the higher area around Garranlahan Beg and the other at a lower elevation further to the south-west, in the Altore townland (Figure 1). Twelve springs, including the Ballybane Springs, were monitored in the surrounding area.

The results of the tracer test show established connections between the Garranlahan Beg swallow holes and the three springs in the Meeltraun townland. The dye was detected at the springs four days after injection, indicting a minimum groundwater velocity of 31 m/h.

Dye was not detected in the remaining springs, including the Ballybane Springs. Although these 'negative' results are not conclusive, they do suggest that the swallow holes are not connected to these springs under the flow conditions at the time of testing.

A number of other injection points were identified in the Ballybane area. It was initially anticipated that these additional points would be included in the April multiple tracer test. However, wetter conditions were required in order to facilitate flow through the conduits and reduce the chance of the dyes being adsorbed onto the sides of any conduits which may be dry. Tracer testing from the additional injection points is planned for autumn 2002.

7.3 Aquifer Characteristics

The geology around the Ballybane area is recorded as Oakport Limestone. Essentially this is a clean, grey, bedded and well-jointed limestone with a fine-grained silty middle member. It is generally regarded as a productive aquifer. The rocks around the springs are described as 'black limestone' (Section 6.1). It is unclear whether this 'black limestone' is the middle Rockingham unit of the Oakport Limestone or if it represents a muddy limestone. Muddy limestones are also frequently darker in colour although are associated with limited aquifer potential.

Although located in a 'black limestone', the Ballybane Springs have a good, consistent yield. The springs occur along a discrete line and borehole records indicate a fracture network 8 – 12 m beneath the springs. The fracture zone is likely to cause the water to concentrate in this area and the production borehole appear to be intersecting this fracture zone.

The spring water in the sump became very cloudy during the drilling of the production boreholes (KT Cullen & Co., 1993). This would indicate that the springs are connected to the fracture zone. Although the production boreholes were initially noted as having artesian flow, this had dissipated to 'a mere trickle' six weeks after drilling. Therefore it is possible that the drilling initially released a build up of pressure, which may be due to groundwater having to force its way up through 6 m of overlying subsoil to emerge as the springs.

A borehole at the northern boundary of the site (approximately 20 m north of the sump) also shows a fracture zone at the same depth (Section 6.1). Drawdown in the production boreholes was observed during the pump test at the site boundary borehole (KT Cullen & Co: 1993, 1999). This indicates that that the boreholes are hydraulically connected, probably by the same fracture zone.

The borehole logs indicate that the limestone immediately around the springs is overlain by approximately 6 m of gravely clay. The extent of the gravely clay layer is not known however, the borehole at the site boundary records approximately 6 m of sand/gravel with clay. The access road borehole further to the north has 12.5 m of clean gravel. The borehole logs suggest that the gravel in the subsoil becomes increasingly cleaner (i.e. the percentage of fines is reduced) moving northwards.

The gravel in the access road borehole was saturated (9 m over the limestone) and during the investigation (1999) it was noted that water appeared to be flowing into the borehole from the gravel rather than from the limestone aquifer.

The available data indicate that the springs, production boreholes and borehole at the northern site boundary are supplied by a fractures between 8 m and 12 m b.g.l. In the access road borehole, it is the gravel that appears to be storing and transmitting the groundwater.

Pumping tests were undertaken at the production boreholes (1993), the site boundary borehole (1999) and the access road borehole (1999). The combined yield of the production boreholes was over 4000 m^3/d (K.T. Cullen & Co., 1993) and approximately 550 m^3/d was pumped from the site boundary borehole. The estimated transmissivity of the non-fractured part of the aquifer ranges from 80 m^2/d to 90 m^2/d although the transmissivity of the fracture zone is estimated as 400 m^2/d (K.T. Cullen & Co., 1999). It is noted that the pumping test at the site boundary borehole was stopped after 43 hours, as it appeared to make the water cloudy in the spring sump.

The saturated gravel in the access road borehole yielded 500 m^3/d with an estimated transmissivity of 100 m^2/d (KT Cullen & Co, 1999). The storage capacity of the gravel is not known.

Karstification is an important process in Irish hydrogeology. 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 'cleaner' limestones. Evidence of significant karstification in the Ballybane area includes the large number of karst features mapped (Figure 1; Section 6.1.1) and the results of the tracer test (Section 7.2), which recorded minimum groundwater velocities of 31 m/hr.

The karst features were predominantly found in the higher area to the west and south-west of the springs. The higher area to the west of the springs also has an absence of surface drainage. These features would indicate that the underlying limestone is clean, as would be expected with Oakport Limestone.

7.4 Aquifer Category

The Oakport Limestone underlies the entire area of interest and is classified as a Regionally Important Karstic Aquifer, which is characterised by conduit flow (**Rk**^{c}).

The derivation of this classification is presented in the County Roscommon Groundwater Protection Scheme Main Report (Lee and Daly, 2002).

7.5 Hydrochemistry and Water Quality

The available water quality data for the Ballybane Springs are from Roscommon County Council drinking water returns for 1999 to 2001. These samples were collected as part of the Rural Water Quality Monitoring Programme. The EPA biannual data (1997 – 2001) was also included in this assessment as were two sampling rounds undertaken by the GSI (February and September 2001).

The groundwater has a calcium bicarbonate hydrochemical signature, with hardness values generally greater than 350 mg/l (from 344 – 388 mg/l, averaging 363 mg/l). Conductivity values range from 558 µS/cm to 1040 µS/cm, averaging 675 µS/cm. The coefficient of variation of conductivity is calculated as 7.9% which does not specifically suggest point recharge (Doak, 1995).

Faecal coliforms are consistently present in the raw water samples and exceed the EU Drinking Water Directive maximum admissible concentrations (MAC). Of the 16 raw water samples, 11 have greater than 10 faecal coliforms per 100 ml. This level is considered to be gross contamination (Keegan *et al.*, 2002). Such levels of faecal coliforms are frequently associated with point recharge. These may therefore be reflecting the influence of recharge to, and flow from, the shallow karstic rock around Garranlahan Village and Moanvane.

Chloride levels range from 15 mg/l to 31 mg/l, averaging 18 mg/l. Concentrations higher than 30 mg/l usually indicate significant contamination. This level was only exceeded once in September 1993.

The level of iron ranges from 0.06 – 0.20 mg/l and manganese from 0.04 – 0.18 mg/l. The results show that iron exceeds the MAC (0.20 mg/l) once in August 1999 and manganese exceeds the MAC (0.05 mg/l) four times between August and December 1999. Elevated levels of iron and manganese can indicate effluent from organic wastes.

The sodium potassium ratios (Na:K) range from 0.28 – 0.60 (averaging 0.39) in 7 samples. Four samples exceed the GSI threshold (0.35). Elevated Na:K ratios suggest that farmyard waste, rather than septic tanks, are likely the source of organic wastes.

Nitrate levels range from 12 mg/l to 20 mg/l. These values are beneath the MAC and GSI threshold and there appears to be a very slightly declining trend in 16 samples taken between April 1999 and September 2001.

Elevated phosphate levels are a cause of eutrophication in surface water. All seven of the samples exhibited concentrations in excess of the EPA guide level (0.02 mg/l). This trend does not appear to be declining.

Turbidity has only exceeded the MAC in the Ballybane samples in December 1999. However ‘muddy’ water was observed during the borehole investigations (KT Cullen & Co, 1993; 1999). ‘Cloudy’ water is also frequently observed during low flow periods.

There is no significant difference between the spring water and the water that is currently being abstracted from the boreholes in the samples analysed (1992 to 2001).

7.6 Discharge

Total discharge from the site is currently the abstraction from the borehole plus any overflow. These values have been estimated on a number of occasions and are presented in Table 2.

Table 2. Estimates of Discharge.

Date	Data Source	Estimated Values (m^3/d)		
		Abstraction	Overflow	Total Discharge
January 2000	GSI and Roscommon Co. Co.	4600	1100	5700
July 1999	GSI and Roscommon Co. Co.	3600	0	3600
November 1999	KT Cullen & Co.	4600	–	–
1995	Doak, M.	–	–	3000
1992	Roscommon Co. Co.	2400	–	–
1972	Roscommon Co. Co.	–	–	3200

7.7 Conceptual Model

Ballybane springs have a high natural discharge, in excess of 3000 m^3/d. Borehole augmentation has increased the abstraction to a maximum of 4600 m^3/d, although this is reduced to approximately 3600 m^3/d in the summer months.

The geology of the general Ballybane area is recorded as Oakport Limestone. Borehole records indicate that black limestone underlies the springs, which probably corresponds with the middle unit of the Oakport. The black colour of the limestone indicates a high mud content, which is likely to result in a lowering of its aquifer potential.

Borehole investigation and pump tests (K.T. Cullen & Co., 1993; 1999) indicate that the springs, production boreholes and site boundary borehole are hydraulically connected. A large fracture zone identified between 8 – 12 m b.g.l. is most likely transmitting groundwater to the springs (via the overlying subsoil) and boreholes.

Fracture zones were not detected in the access road borehole, located approximately 100 m north of the springs. Furthermore, this borehole did not appear to be hydraulically connected to any of the springs or other boreholes. It would appear that the saturated gravel overlying the limestone at this location is supplying groundwater to the borehole. The storage capacity of the gravel is not known.

The higher area to the west and south-west of the springs is also underlain by Oakport Limestone and has a noted absence of surface streams. The lack of surface drainage suggests that potential recharge readily infiltrates into the groundwater system.

The clean Oakport Limestone to the west and south-west of the springs has undergone significant karstification as shown by the large number of dolines, swallow holes, springs and turloughs. Given the degree of karstification in the limestone, groundwater is likely to flow along interconnected, solutionally enlarged fractures and pronounced joints that exist in these rocks.

Tracer test results also infer that the karst is well developed, with the high groundwater velocities (minimum of 31 m/hr) possibly reflecting some of the larger conduits.

The precise pathways of groundwater flow are not known. However, the tracer test undertaken to date identified one general flow direction: south-westwards from the swallow hole on the western side of the higher area. These results suggest that the groundwater divide in the higher area is topographically controlled.

With regard to the Ballybane Springs and boreholes, the groundwater appears to move from the higher portion of the catchment (Moanvane townland and Garranlahan Village) through the karstified Oakport Limestone, to the lowest point in the catchment. At this location, some of the groundwater appear to concentrate in the fracture zone and emerges through the subsoils as the springs.

Although the springs and boreholes are likely to be supplied by the underlying fracture zone, the degree of karstification in the immediate vicinity of the springs is not known.

Both diffuse and point recharge occurs in this area. The high permeability sand/gravel and the area of relatively thin subsoil (<3 m) are likely to allow a high proportion of recharge to occur through them and into the bedrock. The variation of electrical conductivity (Section 7.5) is relatively low compared to other springs in Roscommon. This indicates that some recharge is likely to occur diffusely through the subsoil.

Karst mapping has identified a large number of dolines and swallow holes (i.e. potential locations of point recharge) up-gradient from the springs. Potential connections between these and the springs have not yet been established. However, consistently high faecal coliforms are frequently associated with point recharge in karst aquifers as rapid infiltration and flow through solutionally enlarged conduits result in minimal attenuation capacity of microbial contaminants.

8 Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the area that is believed to be contributing groundwater to the springs and current production boreholes and that therefore requires protection. The delineated area is based on the conceptualisation of the groundwater flow pattern, as described in Section 7.7 and is presented in Figure 1.

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 supply.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to both the springs and current production boreholes, i.e. the zone of contribution (ZOC). This 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 ZOC does not include the catchment area for the access road borehole. It is understood that groundwater to this borehole is stored and transmitted predominantly through the saturated gravel rather than the underlying limestone. Therefore specific further investigation would be required to determine the catchment for this borehole.

The ZOC for Ballybane Springs and production boreholes was delineated by the use of hydrogeological mapping, including dye tracer tests. The catchment boundaries and the uncertainties associated with them are discussed below:

1. The **Northern Boundary** is not clear due to the hummocky topography. However a low topographic ridge runs through the townland of Coosaun. Moving westwards, a topographic divide becomes more apparent as the gravel subsoil gives way to shallow till and outcrop around Garranlahan Village. This boundary also represents the southern catchment boundary of the stream to the north.

2. The **Western Boundary** is also defined by a topographic ridge, which is a continuation of the northern boundary. This bedrock-cored ridge runs through the townlands Garranlahan Beg and Moanvane The reservoir at Moanvane represents the highest point in the general area.

   The results of the dye tracer test have established a connection between the Garranlahan Beg swallow hole and springs in the Meeltraun townland, giving a generally south-western flow direction. The results infer that the topographic divide also represents a groundwater divide. Thus this section of the ZOC boundary is also the eastern catchment boundary for the swallow hole.

3. The **North-Eastern Boundary** is constrained by analytical modelling. The downstream limit of the cone of depression under pumping conditions ('null point') was based on the pumping test data (KT Cullen & Co, 1993 and 1999). This can be estimated by:

$$X_L = Q/(2\pi K.b.i.) \qquad \text{where}$$

Q = pumping rate, K = permeability, b = aquifer thickness and i = hydraulic gradient.

If *Q* [2] is estimated to be 6250 m^3/d, *K.b* is equivalent to estimated *T* [3], which is 400 m/d, and *i* [4] is estimated to be 0.01, $\mathbf{X_L}$ is approximately **250 m**.

This boundary extends just beyond the river. The river runs through a more extensive area of peat, which is likely to be thicker than the peat at the springs. Due to this layer of low permeability peat underlying the river, there is likely to be negligible hydraulic connection between the river and the aquifer. Thus the river is unlikely to contribute water to the boreholes.

4. As with the northern boundary, the **Eastern Boundary** is complicated by the hummocky gravel topography. The eskers are local high points but they are not saturated and are unlikely to influence the groundwater flow, which is assumed to be in the limestones beneath the eskers. Therefore the eastern boundary is also based on a low non-esker ridge, which is considered to be the catchment boundary for the stream to the east (Island River tributary). The eastern boundary also includes karst features south of Milltown. Although connections from these to the Ballybane Springs have not yet been established, they appear to be within the springs' general catchment area. The eastern boundary includes an arbitrary buffer of 30 m down-gradient of the springs.

5. The **Southeastern Boundary** crosses gravel, which also includes eskers. The boundary is based on the more general topographic ridges, which coincide with the general surface drainage patterns, including apparent dry valleys.

6. The **Southern Boundary** is relatively easily defined by the bedrock-cored topographic ridge, which continues on from the western boundary. This boundary passes through the Stonepark South townland.

These boundaries delineate the physical limits within which the ZOC is likely to occur and give an approximate area of 2.5 km^2.

The available discharge data (Section 7.6) are not comprehensive enough to undertake a water balance and thus accurately estimate the catchment area for the total discharge from the springs and boreholes. However, an approximation of the averaged discharge data and recharge data (Section 7.1) indicate that the delineated catchment area is large enough to support the springs' discharge, i.e. 4600 m^3/d would require 2.1 km^2.

Although the area delineated by hydrogeological mapping approximates to that required by the discharge, the underlying aquifer is karstified. Groundwater flow through karst areas 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.

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[2] The discharge used in this estimate was based on the combined discharge from both boreholes in 1993 as well as the site boundary borehole in 1999 (approximately 5000m^3/d). 25% was then added to the discharge value in order to account for a potentially larger ZOC in dry weather conditions.

[3] The transmissivity is that estimated for the fracture zone.

[4] In the absence of further data, the hydraulic gradient is assumed to be less that the topographic gradient i.e. somewhere in the region of 0.01.

8.3 Inner Protection Area

According to the National Groundwater Protection Scheme (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 to the supply.

The tracer tests carried out by the GSI recorded rapid groundwater velocities in the Oakport Limestone (minimum 31 m/hr) in the Ballybane area. Given this minimum velocity, it is possible that the groundwater could reach the spring from any point in the ZOC within 3 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.

9 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see Table 3). In practice, this is achieved by superimposing the vulnerability map (Figure 3) on the source protection area map. Each zone is represented by a code, e.g. **SI/H**, which represents an Inner Source 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. Three protection zones are present around the Ballybane Springs and production boreholes (Figure 4), as shown in the matrix below.

Table 3. Matrix of Source Protection Zones.

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

10 Potential Pollution Sources

There are a number of houses and farmyards within the ZOC, some of which are located within 500 m of the springs. A large proportion of Garranlahan Village is also in the ZOC, at the western boundary.

The hydrochemical data highlight consistently elevated levels of faecal coliforms. Analysis of the other indicator parameters suggests that at least one of the sources of this contamination is likely to be organic waste originating from farmyard wastes.

The main hazards associated within the ZOC are therefore considered to be agricultural (farmyard waste leakage, landspreading) and domestic, such as on site treatment systems (septic tanks). The location of the these activities in any part of the ZOC categorised as ‘extremely’ vulnerable presents a potential risk, given the rapid travel times through the underlying bedrock to the springs and production boreholes. It should be noted that detailed assessments of hazards were not carried out as part of this study.

11 Conclusions and Recommendations

- The area surrounding and to the west and south-west of the Ballybane Springs is described as Oakport Limestone. More specifically, the groundwater immediately around the springs and boreholes is transmitted through a fracture zone in a 'black limestone'.
- The springs have a 'high' discharge, although the supply has been improved by the installation of two production boreholes, which intersect the same fracture zone supplying the springs.
- Only a small number of sporadic overflow measurements have been taken since 1972. A comprehensive range of overflow measurements would enable more accurate water balance estimates, and thus catchment area estimates, to be made.
- It is unlikely that significantly larger quantities of water can be abstracted from the springs and current production boreholes. However, investigations undertaken along the pump-house site access road (approximately 100 m to the north of the springs) indicate that a saturated gravel overlies the limestone bedrock, which is another possible source of groundwater.
- Dye tracer testing (April 2002) aided in the determination of the ZOC presented in this report. However, there are a number of other injection points around the Ballybane Springs. Tracer testing from these was not undertaken in April 2002 because wetter conditions were required to increase the success rate of this test i.e. to facilitate flow through the conduits and reduce the risk of the dye adsorbing onto dry conduit walls.
- The source protection zones delineated for the springs and current production boreholes do not include zones for the access road borehole due to inadequate data availability.
- Vulnerability to potential contamination in the ZOC ranges from 'extreme' (the western portion of the catchment area where subsoil is less than 3 m thick and around certain karst features), to 'moderate' (thicker subsoil).
- The pump-house site is adequately fenced off from the surrounding fields and is well maintained.
- The protection zones delineated in this report are based on our current understanding of groundwater flow conditions in this area. Additional data obtained in the future may indicate than amendments to the boundaries are necessary.
- It is recommended that:
    - further tracer tests are undertaken to enhance the delineated ZOC and to gain a greater understanding of the groundwater flow regime in the Ballybane area. This is of particular interest as little is known about the groundwater movement between the clean Oakport Limestone and 'black' limestone around the springs/boreholes.
    - more comprehensive overflow measurements are taken to aid estimates of catchment area.
    - if augmentation from the saturated gravel layer is considered, the source and long-term recharge of this groundwater is further investigated and understood.
    - if required, the pump-house site area is adequately sealed off from possible surface contamination.
    - the present chemical and bacteriological analyses of raw water should be continued. The chemical analyses should include all major ions – calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate.
    - particular care should be taken when assessing the location of any activities or developments in the ZOC which might cause contamination at the springs.
    - the potential hazards in the ZOC should be adequately located and assessed.

12 References

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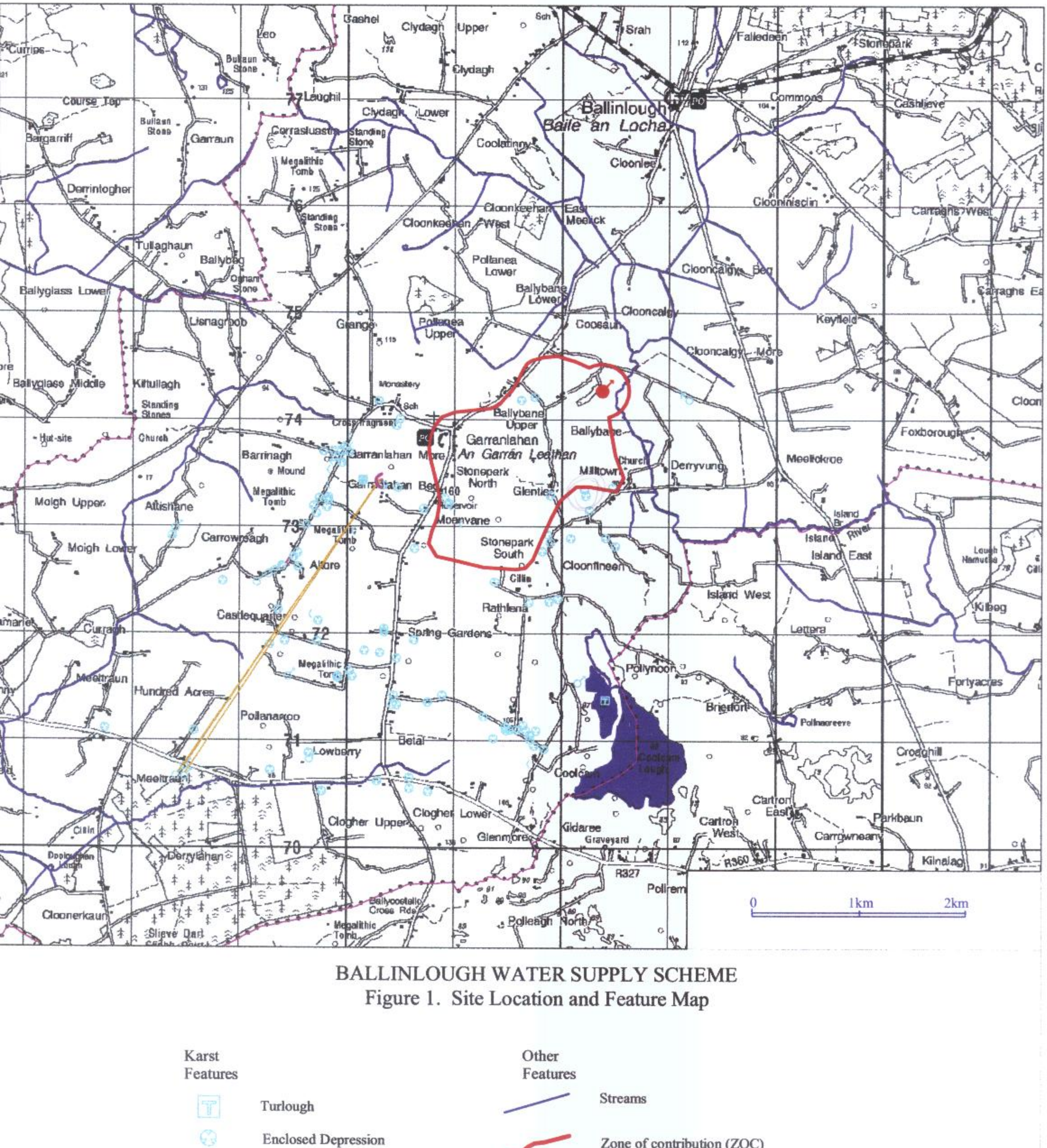

BALLINLOUGH WATER SUPPLY SCHEME

Figure 1. Site Location and Feature Map

Karst Features		Other Features	
	Turlough		Streams
	Enclosed Depression		Zone of contribution (ZOC)
	Swallow Hole		Public Supply Spring
	Cave		Tracer test lines
	Spring		Tracer test injection points
	Borehole		
	Superficial Solution Feature		

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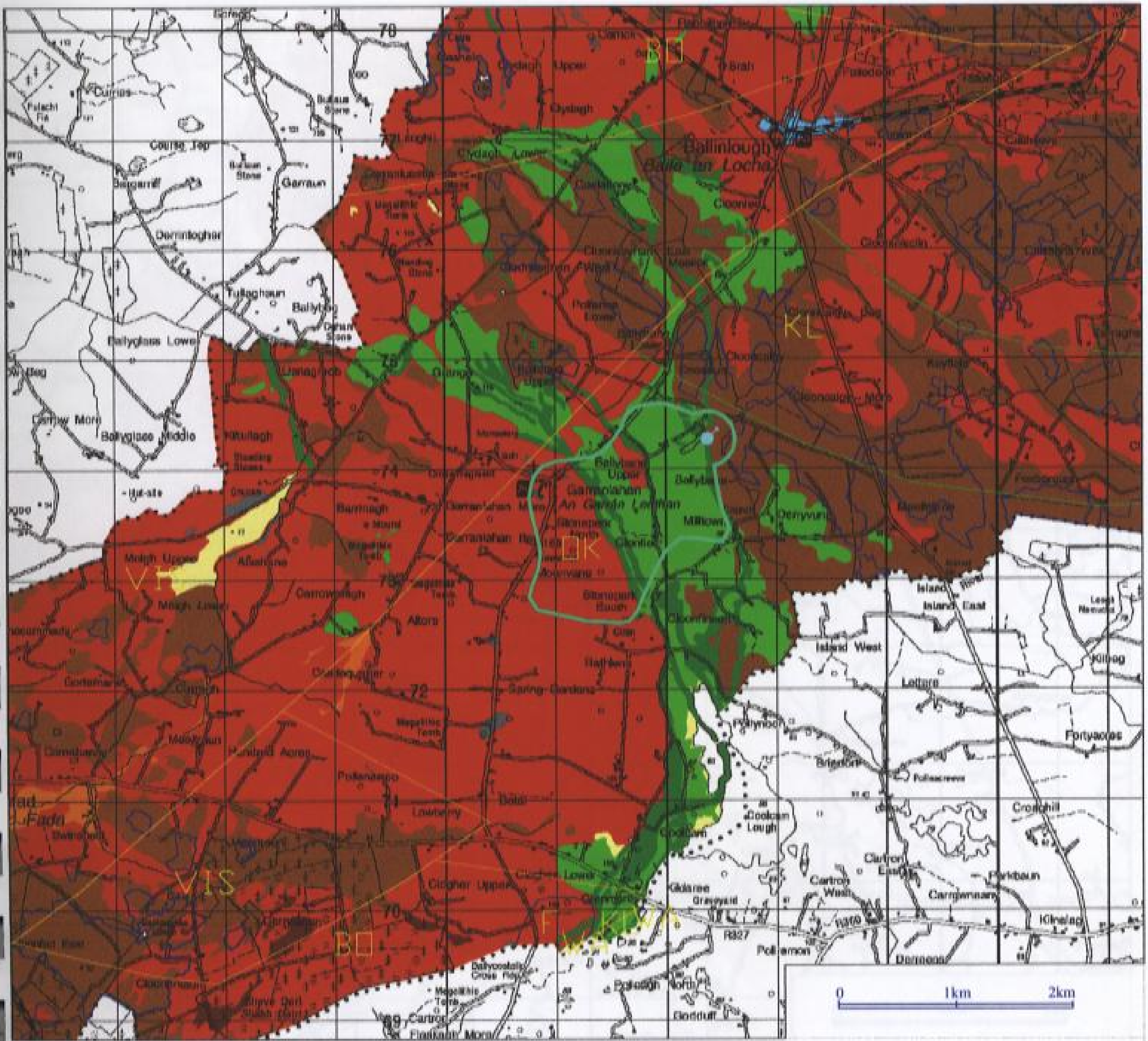


BALLINLOUGH WATER SUPPLY SCHEME

Figure 2. Geology and Subsoils Map

Alluvium undifferentiated	Lake Sediments	Tills
Cut Peat	Lake	
Esker Sands and Gravels	Made or built ground	
Sands and Gravels	Rock outcrop or subcrop	

- Cut peat boundaries used for Vulnerability map
- Geological Boundaries
- Geological Faults
- Zone of Contribution
- Public Supply Spring

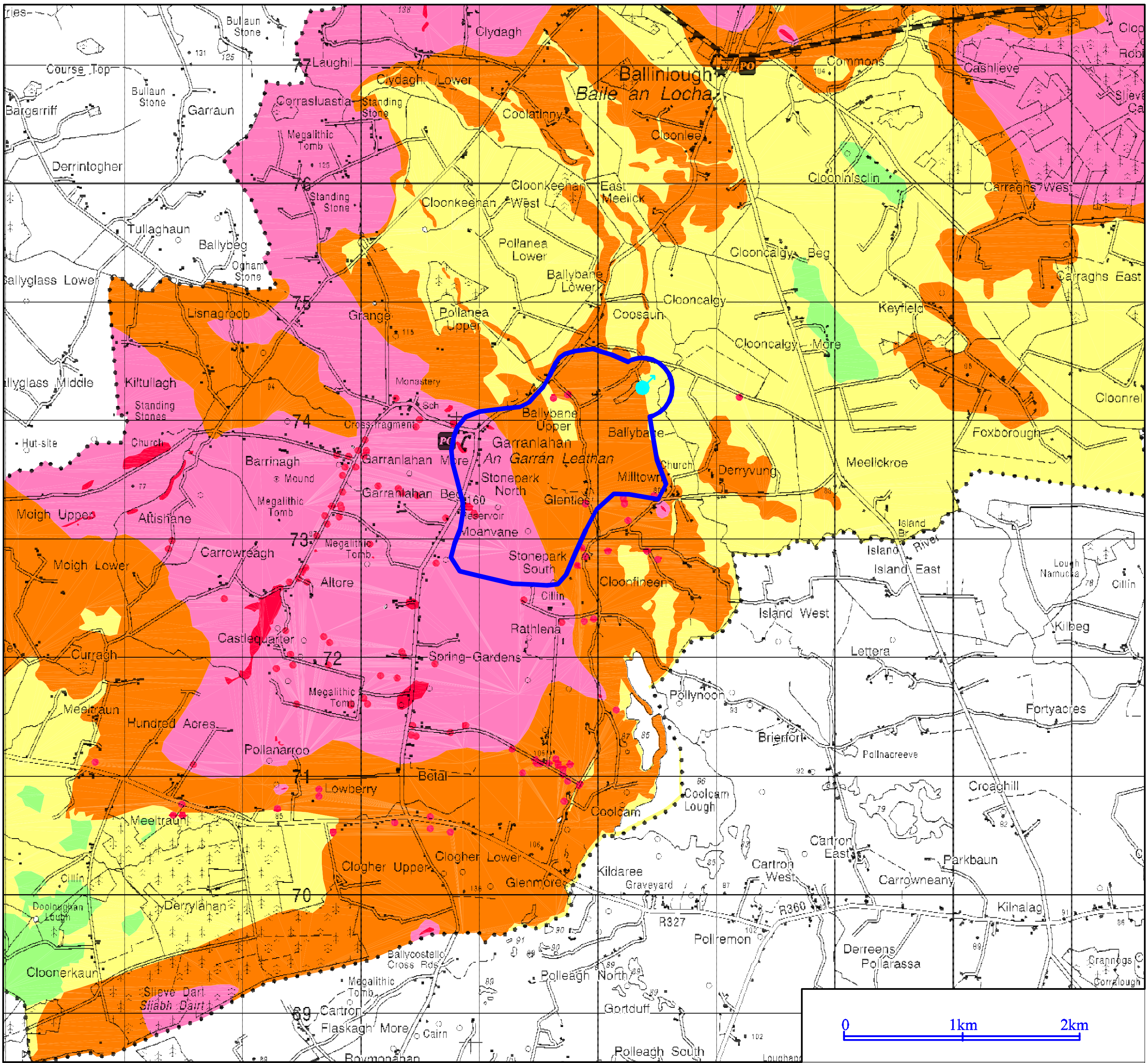
VIS	Visean Limestone	Clean and muddy limestones.
OK	Oakport Limestone Formation	Medium/fine grained limestone.
KL	Kilbryan Limestone Formation	Calcarenites and shales
WA	Waulsortian Limestones	Lime-mudstone
BO	Boyle Sandstone Formation	Sandstone and red green conglomerates
F	Felsic	Extremely fine grained volcanic rock.

Sources of Information

G.S.I. 1:100,000 Bedrock Series Sheet 11 (unpublished) : compiled by C.MacDermot and M.Philcox.

"FIPS-IFS Soil Parent Material Map" Compiled by R. Meehan (Teagasc).

This **geology and subsoils map** is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments and will frequently require site investigations.



BALLINLOUGH WATER SUPPLY SCHEME

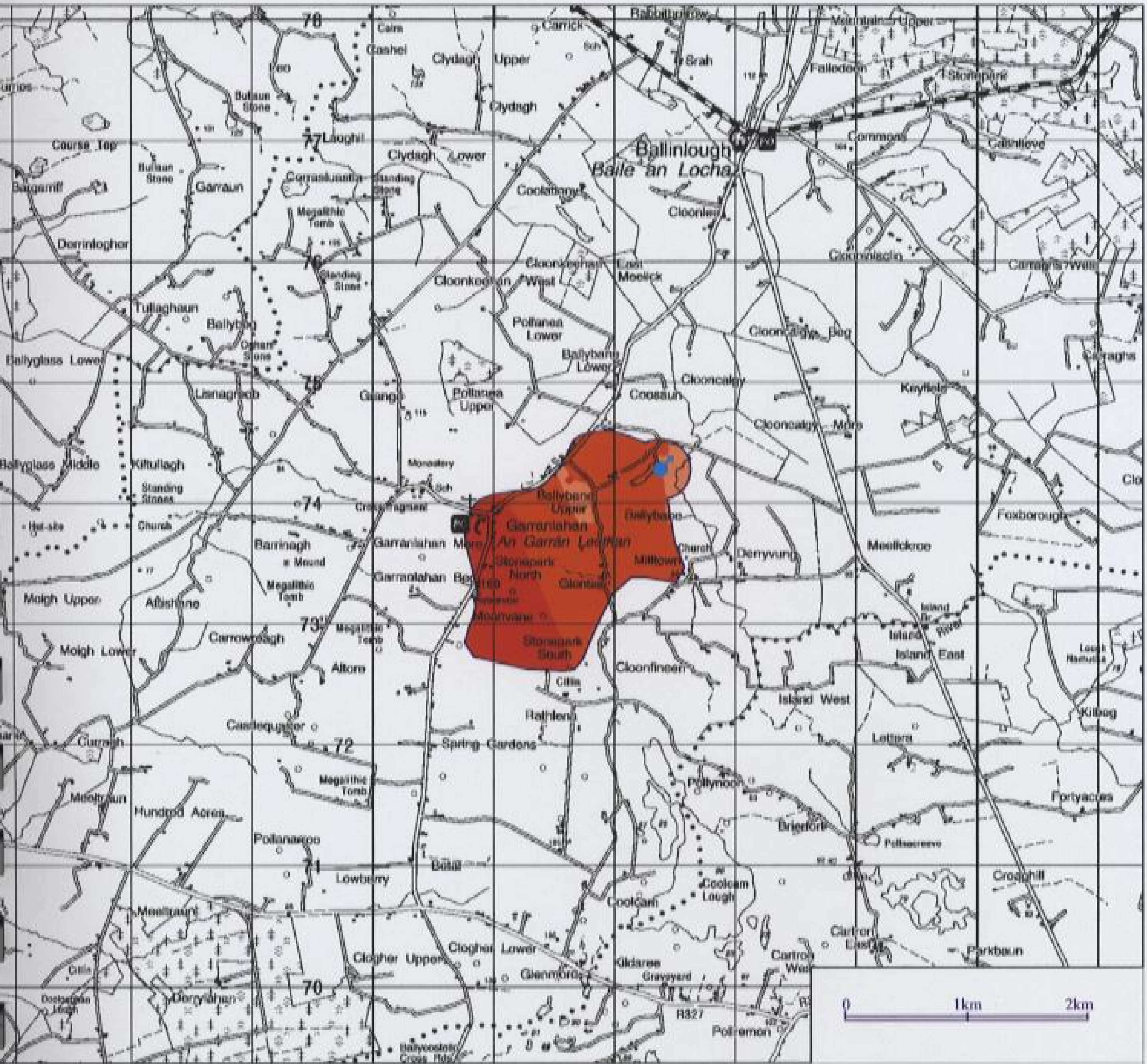
Figure 3. Vulnerability Map

- Extreme (E)
  - Outcrop/Shallow rock (E)
- High (H)
- Moderate (M)
- Low (L)
- Zone of Contribution to Well
- Public Supply Spring

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.

The map shows the **vulnerability** of the first groundwater encountered (in either sand/gravel aquifers or in bedrock) to contaminants released at depths of 1-2 m below the ground surface. Where contaminants are released at significantly different depths, there will be a need to determine groundwater vulnerability using site-specific data. The characteristics of individual contaminants have not been taken into account.

This **vulnerability** map is designed for general information and strategic planning usage.The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments,and will frequently require site investigations to determine the risk to groundwater.



BALLINLOUGH WATER SUPPLY SCHEME

Figure 4. Source Protection Zones

VULNERABILITY RATING	SOURCE PROTECTION ZONES	
	Inner (SI)	
Extreme (E)		SI/E
High (H)		SI/H
Moderate (M)		SI/M
Low (L)	not present	SI/L

Zone of Contribution to well (SI)

Public Supply Spring

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

The map is intended for use in conjunction with groundwater protection responses for potentially polluting activities, which lists the degree of acceptability of these activities in each zone and describes the control measures necessary to prevent pollution.

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