Roscommon Central Regional Water Supply Scheme

Ballinagard Spring and Proposed Production Boreholes

Groundwater Source Protection Zones

(April 2003)

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

In collaboration with:
Roscommon County Council

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1 Introduction

To date Ballinagard Spring has been the primary source of water for the Central Regional Water Supply Scheme. This scheme supplies Roscommon Town and the surrounding area.

It has been proposed that the scheme abstraction be increased in order to supply 1) future demands of the existing area, 2) approximately 20 additional private group schemes around Roscommon Town, 3) any shortfall at the Castlerea and Knockcrogery Regional Water Supply Schemes and 4) the western portion of Athleague West. It is proposed that the additional groundwater be obtained by increasing the Ballinagard Spring abstraction and installing production boreholes around the spring. The proposal would be achieved in two stages:

1. Increase the existing abstraction (2728 m^3/d) to 4787 m^3/d. Additional groundwater would be supplied predominantly by the spring although may be supplemented by the proposed production boreholes during the drier summer months.
2. Increase the abstraction to 7758 m^3/d by 2020. The total abstraction is likely to be supplied by the spring throughout the majority of the year. It is anticipated that the total abstraction would be supplied by the production boreholes for longer periods during the summer (up to three months) in order to maintain a minimum design flow in the River Hind [1].

An Environmental Impact Statement (EIS) to assess the viability and impacts of these proposals was undertaken by Jennings O'Donovan and Partners (1996). K. T. Cullen & Co. Ltd (KTC) were sub-contracted to undertake the hydrogeological investigation presented in the EIS.

The work presented in this report is primarily based on that carried out by KTC. The objectives of the report are as follows:

- To delineate source protection zones for a) the Ballinagard Spring and b) the proposed production boreholes, using the national methodology (DELG/EPA/GSI, 1999). The zones delineated represent the areas that are required to supply the present and projected demands of the scheme respectively.
- To outline the principle hydrogeological characteristics of the Ballinagard area.
- To assist Roscommon County Council in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

The Ballinagard Spring and well field are located approximately 2 km south of Roscommon Town. The site area around the spring is a relatively flat, low-lying, marshy field, which is fenced off from the surrounding fields which are grazed.

The spring rises in a large deepened sump that is banked by limestone chippings. It overflows to the River Hind (approximately 75 m south of the spring) via a weir. The River Hind flows eastwards, discharging into Lough Ree.

Ten boreholes were drilled in close proximity to the spring. Five of these borehole locations have been identified as appropriate for the production boreholes.

[1] One of the requirements of the scheme is to maintain a minimum flow in the River Hind 10,368 m^3/d for dilution purposes.

3 Summary of Details

GSI Number of Spring	:	1725NEW108
Grid reference (1:50,000)	:	18742 26187
Townland	:	Ballinagard
Well type	:	Spring and Proposed Boreholes
Owner	:	Roscommon County Council
Elevation (ground level)	:	c. 44 m OD
Depth to rock	:	approximately 6 m
Static water level	:	ground level
Present Abstraction (Spring)	:	2728 m^3/d
Projected Abstraction	:	7758 m^3/d
Estimated Total Discharge (Spring)	:	7352 – 11763 m^3/d

4 Methodology

4.1 Desk Study

Hydrogeological information and details about the spring and boreholes such as elevation and abstraction figures were primarily obtained from two main reports:

1. Jennings O'Donovan & Partners. 1996. Environmental Impact Statement. Roscommon Central Regional Water Supply Scheme. Prepared for Roscommon County Council.
2. Doak, M., 1995. The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. M Sc. Thesis, Sligo RTC, 52 pp.

Other geological information was provided by the GSI and by County Council personnel.

4.2 Site visits and fieldwork

This included carrying out depth to rock drilling, subsoil sampling, and flow gauging of the spring overflows. 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 spring and proposed production boreholes.

5 Topography, Surface Hydrology and Land Use

Ballinagard Spring emerges at around 44 m OD in a relatively flat, low-lying, marshy area 75 m north of the River Hind. Five proposed production boreholes are located in a well field surrounding the spring. Their elevations are between 44 m and 50 m OD. The ground level gradually rises to the west of the spring (to 90 m OD) and more sharply to the north (to 123 m OD) and to the south of the River Hind (maximum elevation of 165 m OD).

The River Hind is the main surface water feature in the area. It rises to the south of the spring and has major tributaries rising in the immediate vicinity of Roscommon Town. The Hind drains a considerable area around the spring and flows east towards Lough Ree. Apart from the main river system, there is minimum surface drainage in the general area and especially to the west of the spring.

Roscommon Town is located approximately 2 km north of the springs. Outside of this urban area, agricultural activity is the main land use, which is dominated by grazing. A number of houses and farms are present in the area. Some of these are within 500 m of the spring. There are also a number of roads running through the area, which includes the main Roscommon to Galway road.

6 Geology

An understanding of the geological material underlying the Ballinagard 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-study of available data, which comprised:

- Bedrock Geology 1:100,000 scale GSI map series, Sheets 12 (Geraghty et al, 1996).
- Jennings O'Donovan & Partners. 1996. Environmental Impact Statement. Roscommon Central Regional Water Supply Scheme. Prepared for Roscommon County Council.

The general area is underlain by Undifferentiated Visean Limestone. In the southern part of the county, this limestone is equivalent to Burren Limestone, which is generally described as pale grey, clean, medium to coarse-grained, bedded limestone.

The drilling programme undertaken as part of the EIS shows that the limestone around and to the north-east of the spring has been dolomitised. This is a weathering process where calcium ions are replaced by magnesium ions in the crystal lattice of dolomite, thereby increasing the permeability of the rock. Dolomitisation has mainly occurred in the upper 30 m of the bedrock unit.

The borehole logs show that grey, white and occasionally thin layers of black limestone generally underlie the dolomitised rock. Of the ten boreholes drilled for the EIS, four recorded fissures in the grey limestone. Two boreholes adjacent the spring have fissures between 55 m and 60 m below ground level (b.g.l.). 'Fissured limestone' was recorded below 44 m b.g.l. at the pump-house, approximately 300 m north of the spring. The fourth borehole, located approximately 750 m north-east of the spring, describes grey limestone interbedded with large fissures between 6 m and 18 m b.g.l .

A major fault (Strokestown Fault) trends north-east to south-west to the north Roscommon Town.

6.1.1 Karst Features

Specific karst mapping has not been undertaken in the Ballinagard area. However a small number of karst features have been identified comprising a swallow hole and three turloughs.

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 3). This information forms the basis of subsequent subsoil permeability assessments for the county (Lee and Daly, 2002). Further data was gathered from the EIS and from GSI drilling programmes (1999 and 2001).

Peat is located in the low-lying, marshy area around the spring, as well as along the River Hind to the south and east of the spring. The peat is generally considered to be less than 2 m in thickness however, in a small area immediate surrounding the springs this increases to a maximum of 6.5 m (Jennings O'Donovan & Partners, 1996).

The EIS boreholes record a thin layer of clay underneath the peat (1 – 3 m), which is underlain by gravel (1 – 5 m) in the three boreholes adjacent to the River Hind.

Till is an unsorted mixture of coarse and fine materials laid down by ice and is the dominant subsoil type in the Ballinagard area (Figure 3). Six representative till samples were taken within a 5 km radius of the spring. These are all described as a sandy SILT (BS 5930), with gravel-sized fragments composed of angular to sub-rounded limestone. One particle size distribution is also available, which has 38% fines (silt + clay).

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. Generally the subsoil is thicker in the lower-lying areas, including around the spring. The subsoil becomes thinner as the ground level rises and gives way to areas of outcrop on the higher ground. The outcrop is particularly extensive on the higher ridges to the south of the River Hind and north of Roscommon town.

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 inFigure 4 [2].

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. Accordingly the swallow hole in the townland of Fuerty and the stream flowing into this swallow hole are classified as 'extremely' vulnerable. This classification includes an arbitrary buffer of 30 m radius around the swallow hole and along the length of the in-flowing stream.

7 Hydrogeology

This section presents our current understanding of groundwater flow in the Ballinagard area. The interpretations and conceptualisations of flow are used to delineate source protection zones around a) the Ballinagard Spring and b) the proposed production boreholes.

Hydrogeological and hydrochemical information for the study was obtained from:

- GSI databases.
- Roscommon County Council hydrochemistry data.
- Jennings O'Donovan & Partners. 1996. Environmental Impact Statement. Roscommon Central Regional Water Supply Scheme. Prepared for Roscommon County Council.
- 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.
- Field work (flow gauging, drilling, subsoil sampling, water quality sampling).

[2] 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	1022	Average annual rainfall 1961 – 1990 (Met Éireann, 1996).
Annual evapotranspiration	405	Potential evapotranspiration (PE) is estimated as 427 mm/yr Met Éireann). Actual evapotranspiration (AE) is estimated as 95% of PE.
Potential recharge	617	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	123	Assumed as approximately 20% of potential recharge. Based on a qualitative assessment of infiltration through relatively permeable till.
Estimated Recharge	494	

7.2 Groundwater Levels, Flow Directions and Gradients

The water level at Ballinagard Spring is at ground level and the surrounding area is relatively flat, low-lying and marshy. This would indicate a shallow water table.

Groundwater level surveys indicate the general features of the water table, such as the level, direction, and gradient. Such surveys were undertaken by Roscommon County Council in October 1987 and by KTC in May and August 1995 as part of the EIS.

The direction of groundwater flow is influenced by the topography. To the west of the springs the flow is essentially north-west to south-east. South of the River Hind, the flow is from south to the north. Groundwater not contributing to the spring or the Hind is likely to continue to flow eastwards towards Lough Ree.

The groundwater contours are relatively widely spaced which indicates that the bedrock has a high permeability. Groundwater gradients (Table 2) were calculated from the KTC information, as the data for May and August 1995 are comparable.

Table 2. Groundwater Gradients.

	West of Spring (upper slopes)	West of Spring (lower slopes)	South of Spring
May 1995	0.007	0.003	0.005
August 1995	0.004	0.002	0.004

Hydrographs show that the boreholes near the River Hind have smaller water level fluctuations throughout the year than those located further away on the higher ground.

Roscommon County Council undertook a tracer test in July 1991. Dye was injected into a swallow hole in the townland of Fuerty (Figure 1). The dye was detected at the Ballinagard Spring approximately 7 days later, indicating a minimum groundwater velocity of 25 m/hr.

7.3 Aquifer Characteristics

The geology in the Ballinagard area is recorded as Undifferentiated Visean Limestone. In south Roscommon this is generally described as a clean, pale grey, medium to coarse-grained, bedded limestone. The uppermost unit of the rock (approximately 30 m) around and to the north-east of the spring have been dolomitised (Section 6.1).

The dolomitised rock is generally underlain or surrounded by grey limestone, with occasional, thin, black limestone layers. Fissures and fissure zones were recorded around and to the north-east of the spring. The fissures were located at both shallower (10 – 30 m b.g.l.) and deeper (55 – 60 m b.g.l.) depths.

Dolomitisation is considered to increase the permeability of the rock and large inflows were recorded from these layers and any overlying gravel. Possible inflow from the fissures was generally obscured by the larger inflow from the overlying dolomitised rock. However the borehole at the pump-house did not identify any dolomitised rock and had inflows associated with the fissure zones (i.e. below 44 m b.g.l.). This would indicate that the groundwater is mainly circulating through the higher permeability dolomitised and fissured zones.

As part of the EIS individual pumping tests were undertaken on five boreholes between June and September 1994. The boreholes were located adjacent to the spring (two), 200 m north of the spring, 750 m north-east of the spring and 750 m east of the spring. Yields were generally high (1400 m^3/d, 2062 m^3/d, 2042 m^3/d, 2066 m^3/d respectively) although the eastern spring had a lower yield of 700 m^3/d and water was still cloudy at the end of the 54 hr pumping test.

The estimated transmissivity from the individual pumping tests ranged from 60 m^2/d in the lower permeability rock to 180 m^2/d in the high permeability zones (Jennings O'Donovan & Partners, 1996).

A five-week multiple borehole pumping test was also undertaken as part of the EIS at the end of September 1994. The two boreholes adjacent the spring and the borehole 200 m north of the spring were pumped simultaneously. The test also included continuous abstraction from the spring, which gave a combined discharge of 12,000 – 14,000 m^3/d over the entire period. Groundwater levels were monitored in approximately 40 boreholes and domestic wells around the Ballinagard area.

The cone of depression from the multiple borehole pumping test extended approximately 700 m from the well field. Interestingly, drawdown was observed in the aquifer to the south of the River Hind. This shows that within the period of the pumping test (five weeks), the River Hind did not act as boundary and groundwater was drawn from the south underneath the river.

The multiple borehole pumping test was used to calibrate a model for the proposed production boreholes, which comprised the four highest yielding boreholes in the individual pumping tests. The modelling exercise concluded that over a longer period of pumping (i.e. three months), the proposed well field is hydraulically connected with the River Hind (and its tributaries). Thus, even though groundwater will initially be drawn from the rock to the south of the Hind, once steady state conditions are achieved (i.e. after three months) a proportion of the pumped groundwater will be derived by induced recharge from the Hind.

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. Although karst mapping was not undertaken specifically in the Ballinagard area, the regional information suggests that the karst is reasonably well developed in this area. The high minimum groundwater velocity (25 m/hr) determined by the tracer test (Section 7.2) also supports the regional information.

To summarise, the bedrock in the Ballinagard area is likely to be characterised by:

- concentration of groundwater flow in zones of high permeability, such as dolomitised rock;
- groundwater flow in solutionally-enlarged bedding plane partings, joints, faults and conduits;
- high groundwater velocities, several orders of magnitude greater than in sand/gravel aquifers;
- a combination of diffuse and point means of recharge (e.g. through swallow holes);
- often extreme vulnerability to contamination;

- minimal attenuation of contaminants, except by dilution;
- short response times when pollution incidents occur.

7.4 Aquifer Category

The Undifferentiated Visean Limestone underlies the entire area 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 Ballinagard Spring 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). Water quality from the spring, trial boreholes and surrounding domestic wells were also assessed in the EIS.

The groundwater has a calcium bicarbonate hydrochemical signature, with hardness values generally greater than 350 mg/l (from 328 – 376 mg/l, averaging 352 mg/l). Conductivity values range from 385 µS/cm to 747 µS/cm, averaging 650 µS/cm. The coefficient of variation of conductivity for the spring is 9.2% which suggests that diffuse and point recharge exist (Doak, 1995).

Faecal coliforms are consistently present in the raw water samples from the spring and boreholes, which exceeds the EU Drinking Water Directive maximum admissible concentrations (MAC). Approximately 75% of the 16 raw water samples have greater than 10 faecal coliforms per 100 ml. This level is considered to be gross contamination (Keegan *et al*., 2002).

Chloride levels in the spring range from 16 mg/l to 23 mg/l, averaging 20 mg/l. Elevated concentrations exceeding 30 mg/l usually indicate significant contamination. The EIS compares the chloride levels in the boreholes (17 – 18 mg/l) and in the spring (21 – 22 mg/l). The slightly higher values in the spring may indicate that this groundwater is slightly more susceptible to contamination.

The sodium potassium ratios (Na:K) from the spring range from 0.30 – 0.47 (averaging 0.36) in 6 samples. Two 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 in the spring range from 11 mg/l to 23 mg/l although the values only exceeded 20 mg/l once in April 1999. These levels are beneath the MAC and GSI threshold. There does not appear to be any seasonal or long term variation in the dataset. The boreholes also exhibited low nitrate levels (4 – 10 mg/l).

Magnesium levels in the boreholes ranged from 15 – 27 mg/l, averaging 22 mg/l. The spring exhibited levels of 6 – 10 mg/l. This may indicate that the residence time of the spring water in the dolomitised limestone is not long enough to acquire the higher magnesium levels recorded in the borehole samples.

The EIS notes that there are elevated levels of chlorides, nitrates, ammonia, and sodium:potassium ratios in the domestic wells. This is likely to indicate contamination by organic wastes.

7.6 Discharge Estimates

Total discharge from the ***spring*** is currently the abstraction plus any overflow. These values have been estimated on a number of occasions and are presented below in Table 3.

Table 3. Discharge Estimates for Ballinagard Spring

Date	Data Source	Estimated Values (m^3/d)		
		Abstraction	Overflow	Total Discharge
January 2000	GSI	2728	9035	11763
July 1999	GSI	2827	4525	7352
August 1994	KTC	–	–	8628

Flows on the ***River Hind*** are gauged at the Ballymurray Station, which is downstream of the Ballinagard Spring. The catchment area for this gauging station is approximately 69 km^2. Historic flow data (1958 to 1992) have been analysed by KTC as part of the EIS.

The flows in this period range from 10,000 m^3/d (August 1984) to 466,560 m^3/d (December 1959), with an average of 118,800 m^3/d. Records show that 90% of the flows have exceeded 17,280 m^3/d for any summer month.

The ***proposed abstraction rate*** for Stage 2 is 7785 m^3/d. In order for the spring to meet the stage two abstraction rate, it would be supplying an additional 5412 m^3/d, which would therefore not be discharged to the River Hind, thus reducing the flow in the Hind. In contrast, the modelling indicates that by abstracting totally from the boreholes during the summer months, the spring can continue to contribute to the River Hind flow. By using the boreholes, the estimated reduction of baseflow to the River Hind would be 3376 m^3/d. Thus by switching to the boreholes for the summer period, the impact on the Hind is lessened and the design low flow[3] is more likely to be maintained (Jennings O'Donovan & Partners, 1996).

7.7 Conceptual Model

Ballinagard Spring

- The Ballinagard area is underlain by Undifferentiated Visean Limestone. This is a clean, medium to coarse-grained, bedded limestone, which has been dolomitised in the uppermost unit of the rock.
- It is likely that a large proportion of the groundwater is reaching the spring through highly permeable zones comprising 1) the dolomitised limestone beneath and around the spring and 2) fissured limestone beneath and/or around the dolomite.
- The clean Visean Limestone aquifer in this area has undergone some karstification, as indicated by presence of karst features and the tracer test results on regional and local scales. Given the degree of karstification, the 'fissure zones' are likely to be interconnected, solutionally enlarged fractures and pronounced joints that exist in these rocks.
- Groundwater levels indicate that the water moves primarily from the higher ground to the north-west (Rathbrenan) and west (Lissaneaville) to the spring. The spring emerges at the lowest point in the catchment. It is probable that groundwater concentrates in the dolomitised and fissured zones at this location.
- The tracer test indicates a general west to east flow direction to the spring, although the precise groundwater pathways are not known. The test highlights the rapid groundwater velocity through these rocks (minimum velocity of 25 m/hr).
- Apart from the River Hind, much of the general area has minimal surface drainage (natural or artificial), which would suggest that potential recharge can readily infiltrate into the groundwater system.

[3] One of the requirements of the scheme is to maintain a minimum flow in the River Hind 10,368 m^3/d for dilution purposes.

- Groundwater recharge to the aquifer is assumed to occur primarily diffusely over the area. However one swallow hole has been identified in Fuerty which is a location of point recharge.

Proposed Production Boreholes

- It is proposed that the boreholes will abstract a maximum of 7785 m^3/d, which is likely to be limited to the summer months.
- Water will be drawn from the area surrounding the calculated cone of depression. The radius of the cone of depression extends approximately 700 m from the well field. This area also includes abstraction from the rock to the south of the River Hind.
- The modelling indicates that once steady state conditions are reached (i.e. after three months), a proportion of the abstraction will be derived by induced recharge from the Hind. Thus the River Hind is considered to be in hydraulic connection with groundwater in the limestone aquifer.

8 Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the areas that are believed to be contributing groundwater to the source and that therefore require protection. The general basis for delineation is the conceptualisation of the groundwater flow pattern, as described in Section 7.7. The areas (Figure 1) have been delineated in two parts:

1. ***Spring*** area as this is the current and future source of groundwater.
2. ***Proposed production boreholes*** area as these are likely to supply future abstraction in the summer months. This boundary also includes the area delineated for the spring.

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 source.

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). 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.

Although relatively good hydrogeological data exists for the Ballinagard area, 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.

8.2.1 Spring ZOC

The ZOC for Ballinagard Spring is delineated by the use of hydrogeological mapping, including the flow direction inferred by the groundwater level survey and the dye tracer test results. The catchment boundaries and the uncertainties associated with them are discussed below:

1. The **North-Eastern Boundary** is defined by a low topographic ridge which passes through the Ballinagard and Stonepark townlands. This boundary takes into account the general drainage patterns in the area as it also represents the catchment boundary of the stream to the north.

2. The **North-Western and Western Boundaries** are based on the more clearly defined topographic catchment for the swallow hole at Fuerty, which has an established connection to the Ballinagard Spring. It also takes into account the inferred groundwater flow direction (i.e. from the north-west). The boundary runs through the townlands of Ardkeel, Brackloon, Lissacarrow and down to Gortmore. The western boundary is coincident with part of the catchment boundary between the Rivers Hind and Suck.

3. The **Southern Boundary** is more complicated due to the undulating nature of the topography, the number of turloughs in this area (i.e. at Stonepark, Carrowkeel and Ballygalda) and the general uncertainty due to the karstified nature of the area. The boundary is taken as a low topographic divide through the southern part of Stonepark townland. This boundary includes the Stonepark turlough in the ZOC. It is unknown whether any of the turloughs are connected to the spring via swallow holes although the Stonepark turlough is located directly between the Fuerty swallow hole and the spring.

4. The **Eastern Boundary** differentiates the groundwater moving towards the spring (mainly from the higher ridge immediately to the north) from that which is down-gradient of the spring and that which is flowing towards the River Hind and its tributary. This is based on the west to east groundwater flow direction indicated by the groundwater level survey in the immediately vicinity of the spring. This boundary includes a 30 m buffer around the spring.

These boundaries delineate an area of approximately 9 km^2 within which the ZOC for the spring is likely to exist.

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 spring discharge. 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 spring's discharge, i.e. an annual average recharge of 12200 m^3/d is estimated in the ZOC area.

8.2.2 Proposed Production Boreholes ZOC

The delineation of the ZOC for proposed production boreholes is essentially based on the hydrogeological work undertaken by KTC and presented in the EIS. This work includes the implications of the pumping test results and modelling exercise.

The catchment boundaries and the uncertainties associated with them are discussed below:

1. The **North-Eastern Boundary** is initially based on the extent of the cone of depression as defined by the pumping test and modelling exercise, which is presented in the EIS. This boundary defines the area within which drawdown occurs during steady state pumping of the well field i.e. after three months. The limit of the cone of depression is amended in two main ways. Firstly it is extended to the local groundwater divide, which is inferred from the topography. Secondly, the streams feeding into the ZOC may be contributing to borehole abstraction due to the inferred hydraulic connection between the River Hind and the limestone aquifer. These have therefore been included in the ZOC and have been given an arbitrary 30 m buffer.

2. The **Eastern Boundary** is down-gradient of the proposed well field and adjacent to the River Hind. This divide has also been based on the amended cone of depression (refer to Point 1). Although the water table is lowered within the cone of depression, its extent may not coincide exactly with the ZOC boundary but may be slightly closer to the boreholes i.e. all of the groundwater in the cone of depression may not be drawn back to the boreholes. However, a more accurate and somewhat smaller area cannot be delineated with the data presently available.

3. The pumping tests and modelling indicate that there is hydraulic continuity between the boreholes and a) the aquifer south of the River Hind and b) the River Hind. Thus groundwater and surface water within the southern and western areas of the Hind's catchment may be contributing water to the well field and are included in the ZOC. Accordingly the **South-Eastern, Southern, Western**

and North Western Boundaries are essentially the catchment boundaries of the main River Hind channel. These boundaries takes into account the inferred groundwater flow directions in this area.

The boundaries delineate the physical limits within which the ZOC for the proposed borehole abstraction is likely to occur. Figure 1 highlights that this ZOC includes the ZOC for the Ballinagard Spring. This is of particular use because the proposal is to abstract from the spring throughout most of the year and then switch to the boreholes during the summer months. Therefore the entire area requiring protection comprises the resultant ZOC of both spring and boreholes. The delineated area is approximately 35 km^2.

Water balance calculations show that the delineated ZOC area for the boreholes considerably exceeds the area required to supply the proposed abstraction rate. However, whilst pumping from the boreholes is proposed for only three months in the summer, groundwater from *any* part of the ZOC could be abstracted from the boreholes during that period.

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 Roscommon County Council recorded rapid groundwater velocities in the Visean Limestone (minimum 25 m/hr) in the Ballinagard area. Given this minimum velocity and the regionally karstified nature of the bedrock, it is possible that the groundwater could reach the spring from any point in the ZOC within 10 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 4). In practice, this is achieved by superimposing the vulnerability map (Figure 4) on the source protection area map. Each zone is represented by a code, e.g. **SI/H**, which represents an <u>Inner Source Protection area</u> where the groundwater is <u>highly</u> 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 Ballinagard Spring and proposed production boreholes (Figure 5), as shown in the matrix below.

Table 4. 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 ***spring*** ZOC, some of which are located within 500 m of the spring. There are also a number of roads crossing the ZOC including the main Galway to Roscommon road.

Apart from houses, farmyards and roads located throughout the ***proposed production borehole*** ZOC, part of Roscommon Town is situated within the northern boundary. There are likely to be number of potential sources of contamination in the town area, such as garages. Furthermore, a wastewater treatment works and its associated outfall into the River Hind are also within the ZOC of the proposed boreholes.

For both the spring and boreholes, the hydrochemical data highlight consistently elevated levels of faecal coliforms in raw water samples. 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), domestic, such as on site treatment systems (septic tanks) and runoff from roads. 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 Ballinagard Spring provides a consistently high discharge (7352 m^3/d to 11763 m^3/d). The present abstraction is 2728 m^3/d which is likely to be increased to approximately 7758 m^3/d by 2020. It is also proposed that the borehole abstraction will replace the spring abstraction during the summer months.
- The Ballinagard spring and proposed boreholes are located in Undifferentiated Visean Limestone. In the Ballinagard area the Visean Limestone aquifer is karstified, as illustrated by the presence of karst features and the tracer test results, both regionally and locally.
- The ZOC delineated for the proposed production boreholes is influenced by the modelling undertaken by KTC, which is presented in the EIS.
- There are no long-term flow data for the spring overflow or the River Hind immediately upstream of the spring. These data would confirm whether the spring could supply further abstractions and they would help to identify the precise impact of the proposed scheme on the River Hind.
- Due to the rapid groundwater velocities through the karstified bedrock, it is considered that groundwater within any part of the ZOC could potentially reach the spring within 100 days. Therefore the entire ZOC is classified as the Inner Protection Area.
- The groundwater in the Protection Area is 'extremely' to 'moderately' vulnerable to contamination.
- The protection zones delineated in this chapter 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.
- It is recommended that:
  - frequent and consistent flow monitoring is undertaken at the spring overflow and on the River Hind, preferably immediately upstream of the spring's confluence.
  - the turloughs (and any other potential karst features) are assessed to determine whether these have a possible connection to the spring and therefore require inclusion in the ZOC.
  - given the inclusion of part of Roscommon Town and the wastewater treatment works in the ZOC of the proposed boreholes, all potential hazards in this area are located and risk assessments of each potential hazard undertaken.

- 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 which might cause contamination at the springs.

12 References

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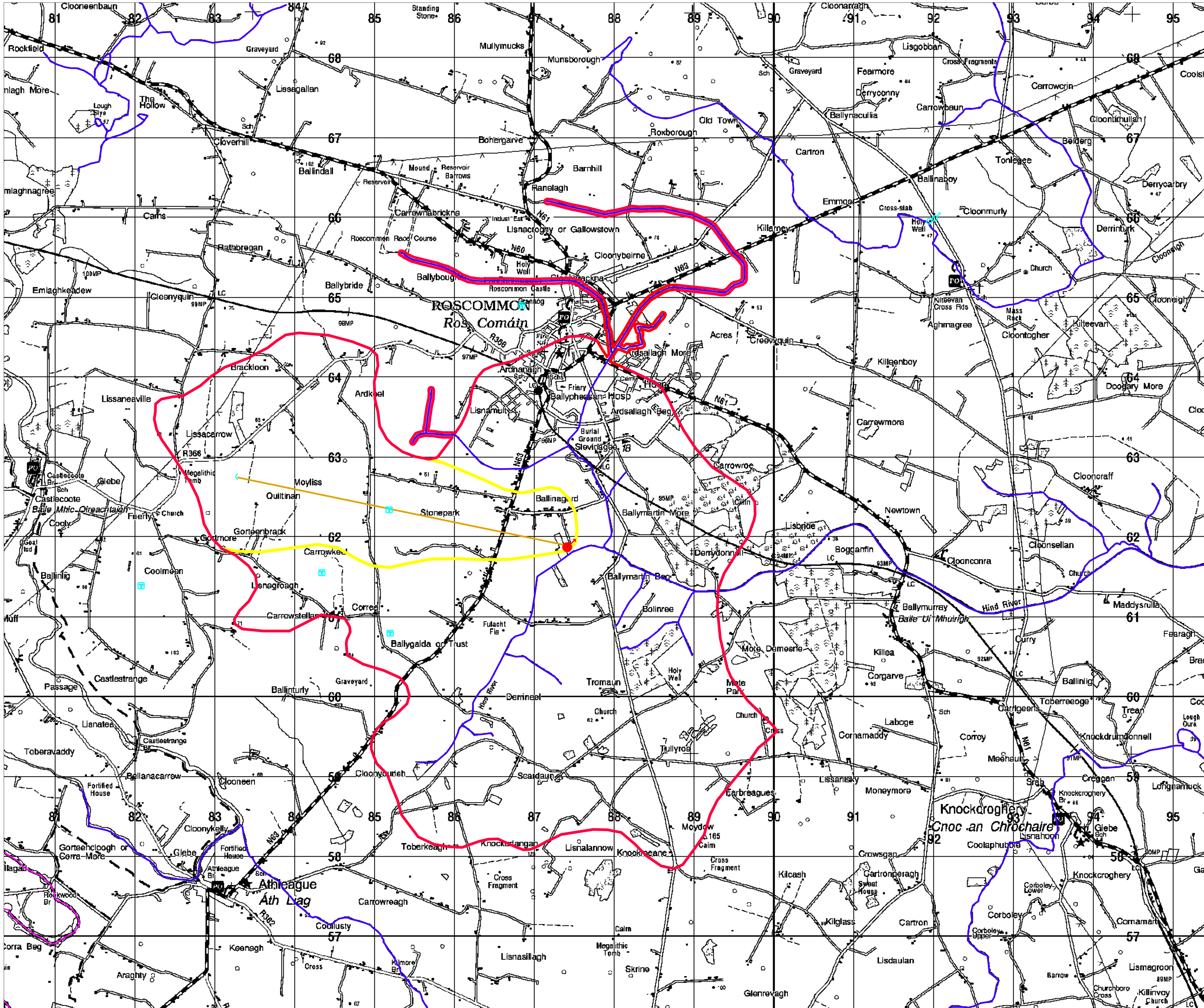
Figure 1. Site Location and Feature Map.
Figure 2. Geology Map.
Figure 3. Subsoils Map.
Figure 4. Vulnerability Map.
Figure 5. Source Protection Zones.



BALLINAGARD SOURCE
Figure 1. Site Location and Feature Map

Karst Features

- Turlough
- Swallow Hole
- Spring

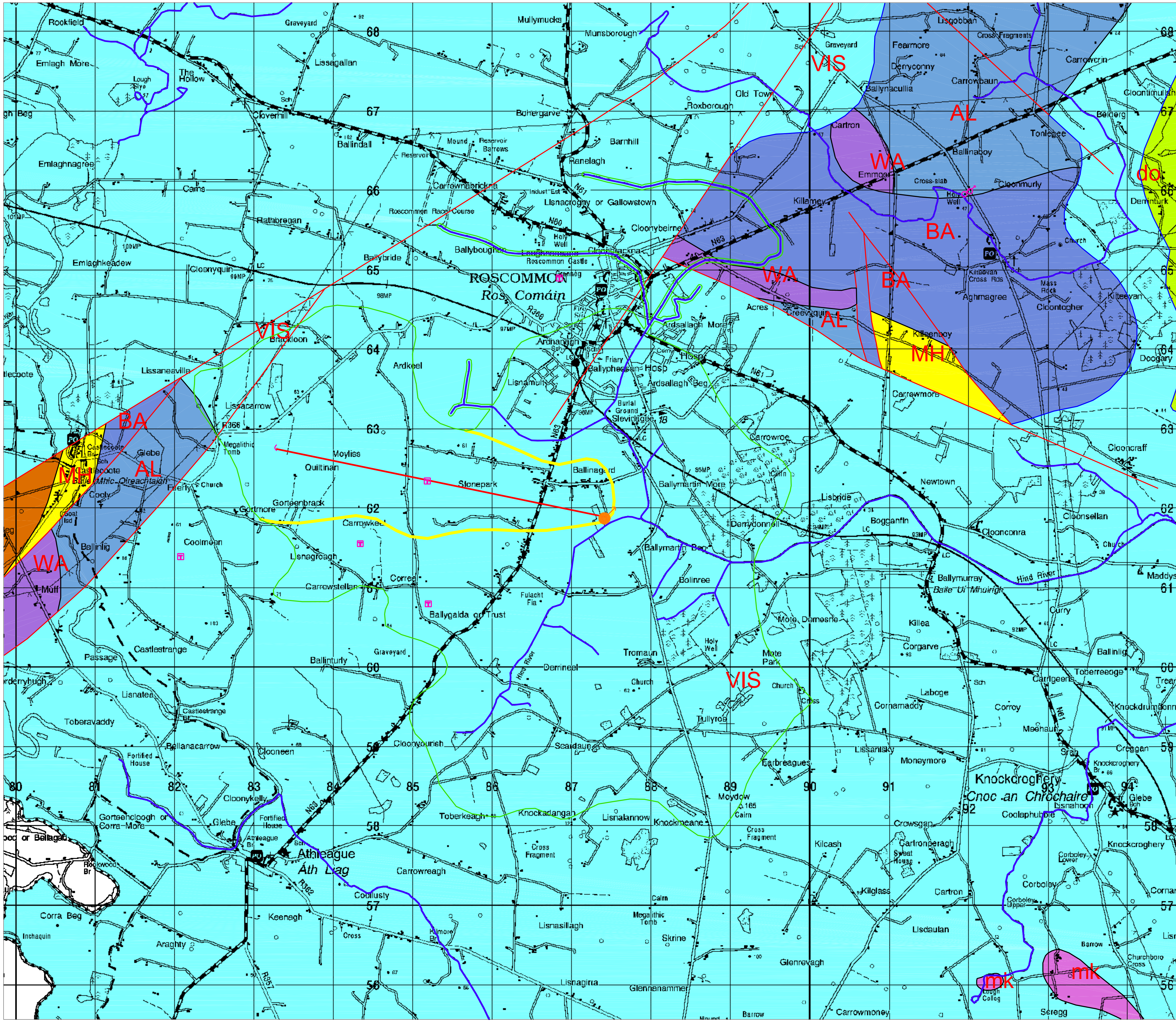
Other Features

- Streams
- Production Boreholes Zone of contribution (ZOC)
- Public Supply Spring
- Spring Zone of Contribution
- Tracer test lines

0 1km 2km

BALLINAGARD WATER SUPPLY SCHEME

Figure 2. Geology Map



VIS	Visean Limestone (undifferentiated)	Generally poorly exposed. Likely to comprise units of clean and muddy limestones north of Tulsk. Likely to comprise clean limestone south of Tulsk.
AL	Argillaceous Limestones	Dark, bedded limestones, shales, chert
WA	Waulsortian Limestones	Massive unbedded Lime-mudstone
BA	Ballysteen Formation	Dark grey muddy limestones
MH	Moathill Formation	Limestones, sandstones, shale
FT	Fernaght Formation	Congolomerates and red sandatones
do	Dolomitized limestone	

Streams

Established Connections
(tracer test lines)

Karst Features

Production Boreholes Zone of Contribution

Spring Zone of Contribution

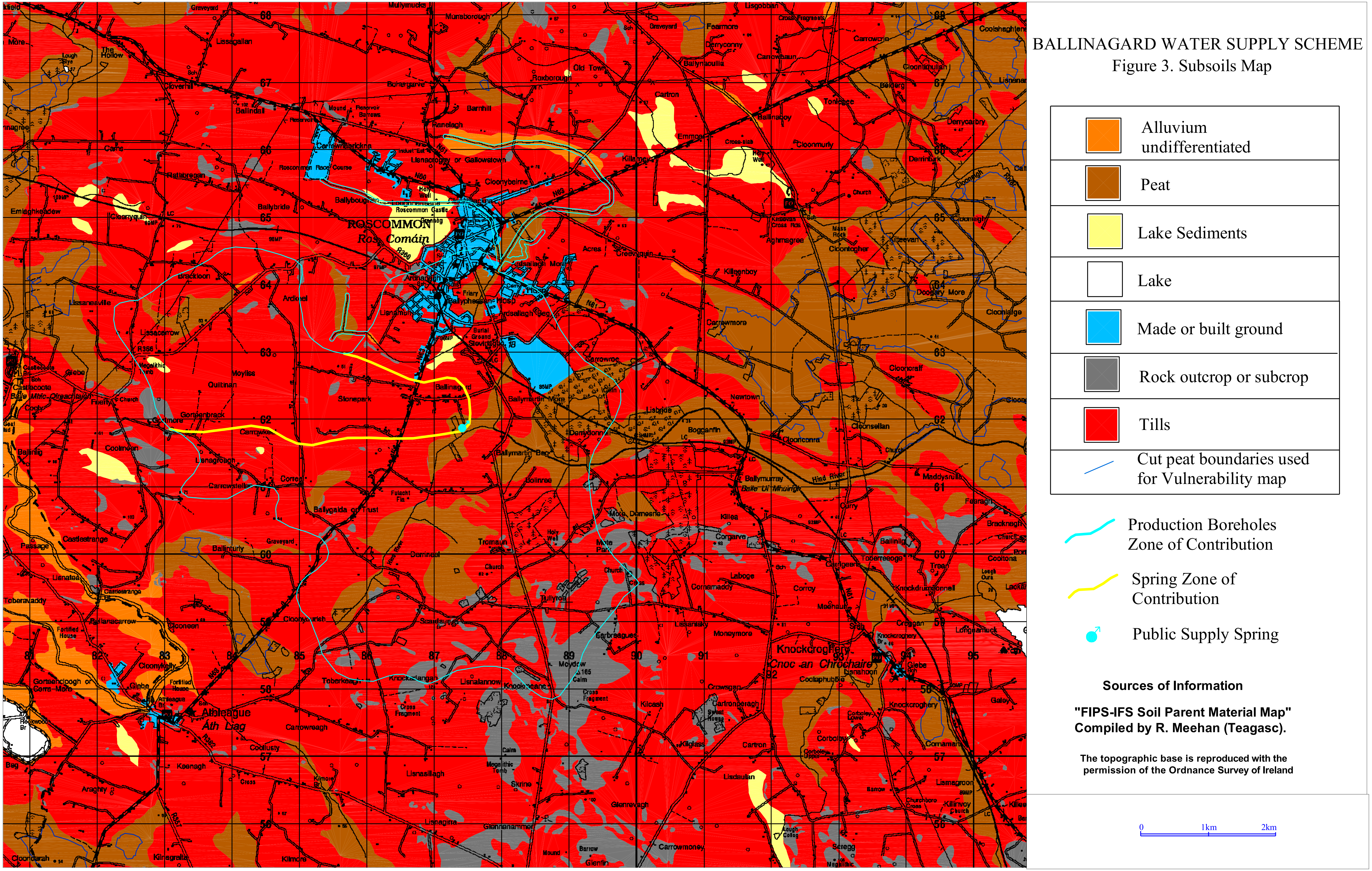
Public Supply Spring

Geological Contact

This **bedrock 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.

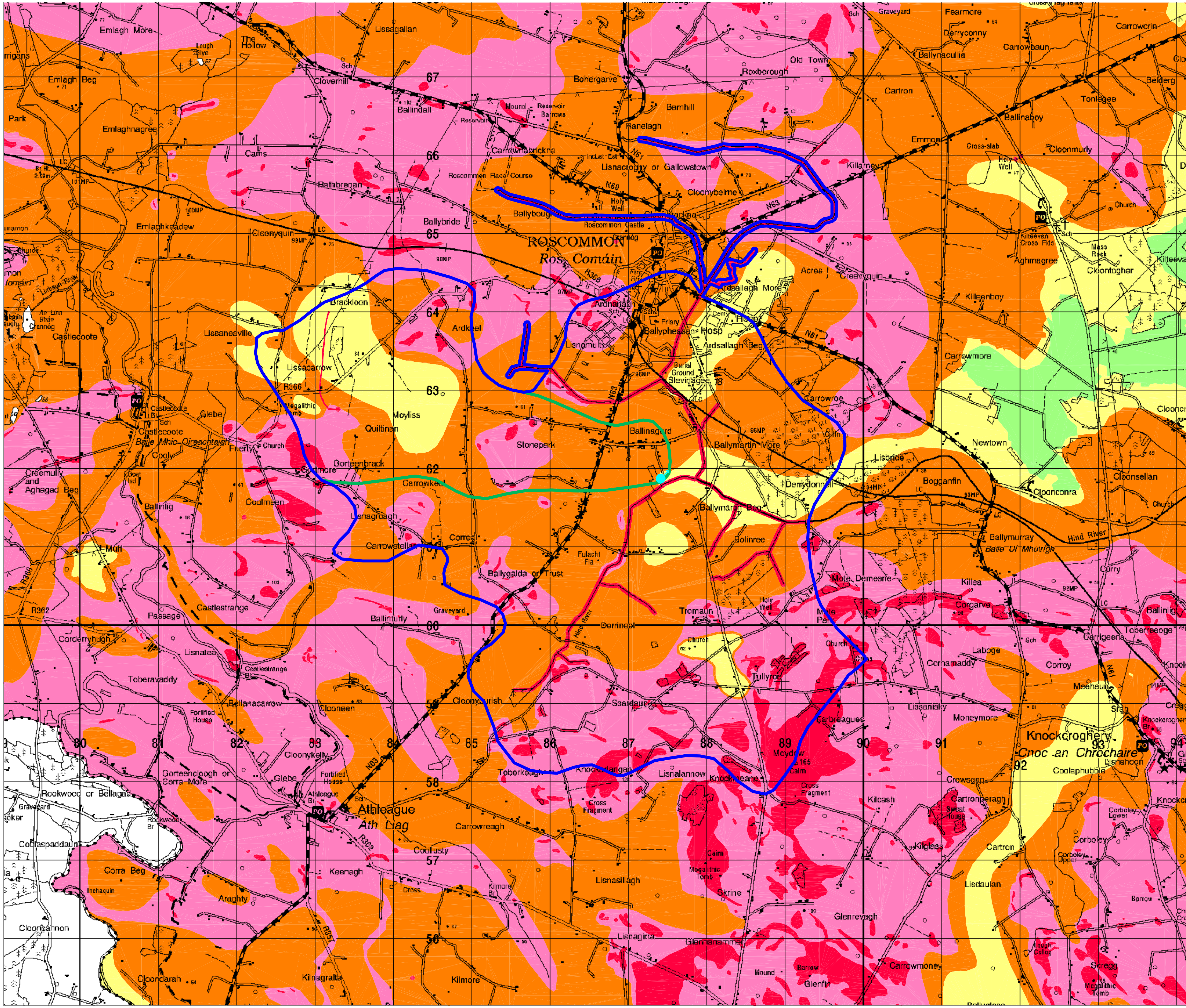
The topographic base is reproduced with the permission of the Ordnance Survey of Ireland

0 1km 2km



BALLINAGARD WATER SUPPLY SCHEME

Figure 3. Subsoils Map



BALLINAGARD WATER SUPPLY SCHEME

Figure 4. Vulnerability Map

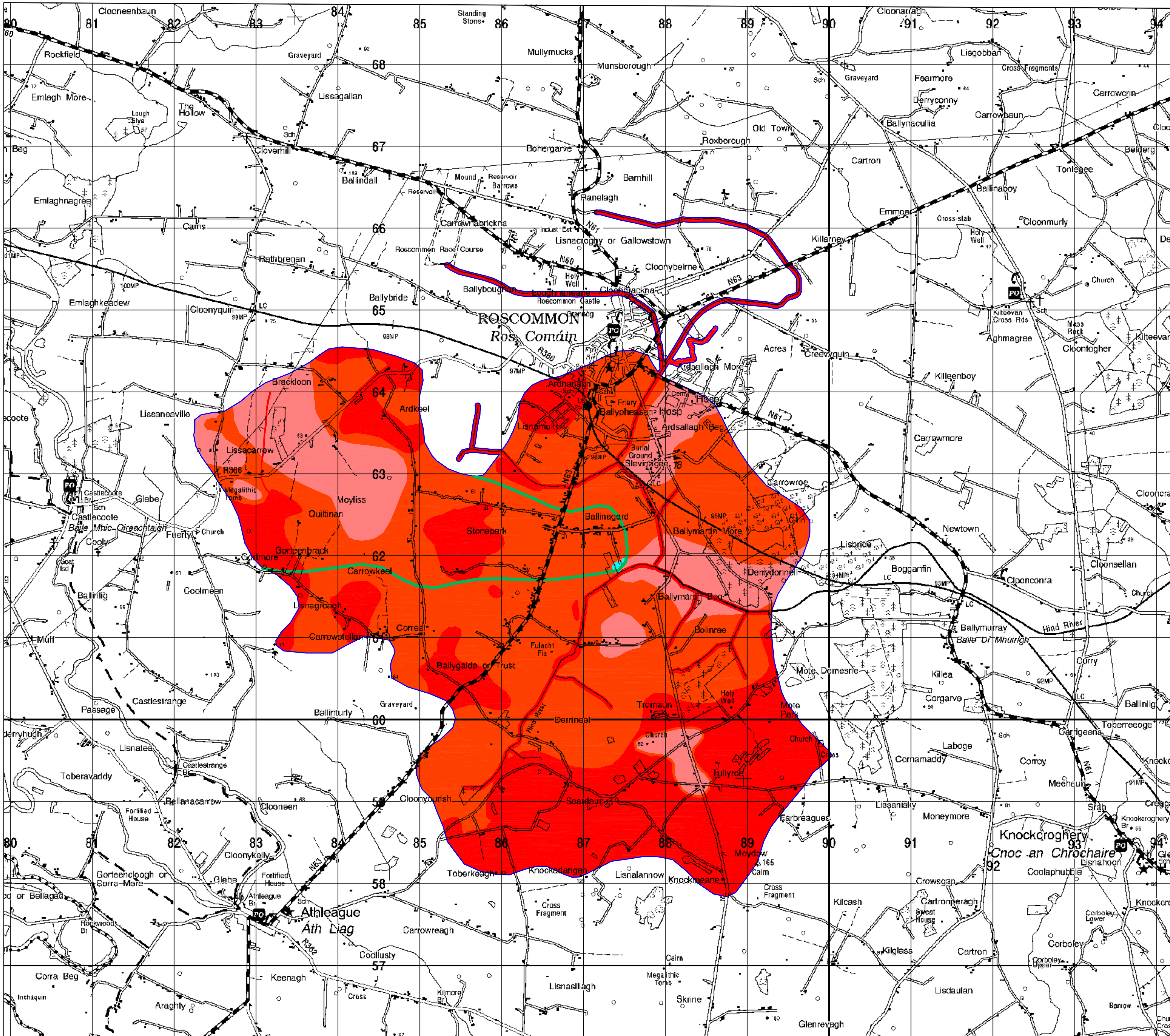
- Extreme (E)
- Outcrop/Shallow rock (E)
- High (H)
- Moderate (M)
- Low (L)
- Production Boreholes Zone of Contribution
- Spring Zone of Contribution
- Public Supply Spring

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.

0 1km 2km



BALLINAGARD WATER SUPPLY SCHEME
Figure 5. 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

Production Boreholes Zone of Contribution (SI)

Spring Zone of Contribution (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.

0 1km 2km