Boyle-Ardcarn Water Supply Scheme

Rockingham Spring

Groundwater Source Protection Zones

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1 Introduction

Rockingham Spring supplies water for the Boyle-Ardcarn Water Supply Scheme. Several reports have previously been written on a number of aspects of the spring. This report is based largely on information provided by these reports, which are referenced to in the relevant sections.

In the late 1980s, the spring came under pressure to meet increasing water requirements. On a number of occasions during the summer months, it failed to meet the demand. In 1990 production boreholes were drilled to increase the output, especially during the summer months (KT Cullen & Co, 1990).

In 1993, an EIS was drawn up to investigate the possibility of further abstraction at Rockingham Spring. This was later implemented (KT Cullen & Co, 1993), although there were still problems with meeting demand in dry summers. Subsequently, another borehole was drilled in 1999, some 300 m away from the production wells (KT Cullen & Co, 1999). This augmentation borehole was used during the summer of 2000, but there has not been a need to use it since then.

The objectives of the report are as follows:

- To delineate source protection zones for the Rockingham Spring and boreholes using the national methodology (DELG/EPA/GSI, 1999). The area delineated represents the area required to supply the current and projected demands of the scheme, including the most recent borehole abstraction.
- To outline the principle hydrogeological characteristics of the Rockingham area.
- To assist Roscommon County Council in protecting the water supply from contamination.

2 Location, Site Description and Well Head Protection

Rockingham Spring and boreholes are located 5 km east of Boyle, within the Rockingham Demesne townland.

The site comprises a disused spring sump and three production boreholes (PW-1, PW-2, PW-3). The spring overflows via two channels to meet the Ballykeevican stream, which then flows to Lough Key.

The site is fenced off, and the boreholes are surrounded by concrete chambers. The spring is now completely covered over.

The augmentation borehole (approximately 300 m north east of the spring) is located in the adjacent field. The borehole appears to be adequately sealed and is fenced off from the main field area.

3 Summary of Spring and Production Well Details

GSI no.	:	1729NWW145
Grid ref. (1:25,000)	:	18494 30286
Townland	:	Rockingham Demesne
Well type	:	4 production wells (PW-1, PW-2 , PW-3 and PW-4)
Drilled	:	3 in 1990; 1 in 1999
Depth	:	19.2 m, 19.2 m, 32 m, 61 m
Diameter	:	300 mm, 300 mm, 300 mm, 250 mm
Owner	:	Roscommon County Council
Elevation (ground level)	:	approximately 45 m
Depth to rock	:	approximately 2 m
Static water level	:	approximately 2 m below ground level
Present Abstraction	:	approximately 6000 m^3/d
Estimated Average Discharge	:	16,000 m^3/d (average daily output, i.e. spring plus boreholes).

4 Methodology

4.1 Desk Study

Hydrogeological information and details about the spring and boreholes, such as elevation and abstraction, were primarily obtained from several reports outlined below:

1. Doak, M., 1995. The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. MSc. Thesis, Sligo RTC.

2. KT Cullen & Co., 1990. Report on the Drilling and Testing of Trial and Production Wells at Rockingham.

3. KT Cullen & Co., 1991. Draft Protection Plan for Rockingham Catchment.

4. KT Cullen & Co., 1991. Report on the Hydrogeological Investigation of Rockingham Springs, Phase 11.

5. KT Cullen & Co., 1991. Report on a Pumping Test carried out at Rockingham Springs.

6. KT Cullen & Co., 1993. Environmental Impact Statement for a Groundwater Abstraction at Rockingham, Co. Roscommon.

7. KT Cullen & Co., 1999. Report on the Drilling and Testing of a Production Well at Rockingham, Co. Roscommon.

8. Longworth, K. T., 1987. An appraisal of the geology and groundwater resources of the Boyle River Catchment in the Rockingham – East Boyle area. BSc. Thesis, Portsmouth Polytechnic.

9. Price, H., 1998. Strategies for Source Protection in Karstic Aquifers. Unpublished MSc. Thesis. Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

10. Robinson, A, 1990. Rockingham Spring Catchment, Co. Roscommon. Groundwater Vulnerability Assessment Report. Unpublished BSc thesis.

Geological information and archival records were also provided by GSI and County Council personnel.

4.2 Site visits and fieldwork

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

Rockingham Spring emerges in a relatively low-lying area, bordered by the Plains of Boyle to the south (rising to 120 m OD) and relatively low hills to the north. There are drumlins in the area, which generally increase in number and size in the east of the area around Lough Keel (Longworth, 1987).

Lough Key lies 400 m to the north of the spring, as shown in Figure **1**. The Boyle River is located to the west of the spring and flows into Lough Key near Boyle. Ballykeevican stream rises 600 m due west of Rockingham Spring and flows in an east to north-east direction into Lough Keel, which then flows into Lough Key. Apart from these, there is a noted absence of streams or rivers in the remaining area.

Lough Key Forest Park covers a large proportion of the area to the north of the main Boyle to Carrick-on-Shannon road. The main road runs east to west and lies about 600 m to the south of Rockingham

Spring. Agricultural activity dominates the area to the south of the main road with most of the land used for grassland. A number of houses and farmyards are located in the general area, some of which are within 500 m of the spring.

6 Geology

This section briefly describes the relevant characteristics of the geological materials that underlie the Rockingham Spring source and the adjacent area. It provides a framework for the assessment of groundwater flow and source protection zones that follow in Sections 7 and 8.

6.1 Bedrock Geology

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

- Bedrock Geology 1:100,000 scale GSI map series, Sheets 7 (Harney et al, 1996).
- Caldwell, W. G. E., (1957) The Lower Carboniferous rocks of the Carrick Syncline. Unpublished thesis. Glasgow University.
- Longworth, K. T., (1987) An Appraisal of the Geology and Groundwater Resources of the Boyle River Catchment in the Rockingham – East Boyle area.

The bedrock is shown in Figure 2 and a brief description of the individual rock units is given in Table 1. The units are presented in order of increasing age.

Table 1. The Bedrock Geology of the Rockingham Area.

Rock Type	Rock Material
Ballymore Limestone[1]. (formerly Keeloges Limestone)	*Upper Unit*: Dark fossiliferous limestone. *Middle Unit*: Thinly bedded, fine-grained dark limestone, alternating with shales and mudstones. *Lower Unit*: medium-bedded, fossiliferous, coarse-grained limestone (similar to the Oakport Limestone), with very thin shale partings.
Oakport Limestone. (formerly Ballyshannon Limestone)	*Upper Unit*: medium to fine-grained, even bedded and well-jointed limestone. *Middle (Rockingham) Unit*: pale grey fine-grained sedimentary rock with high silt content. *Lower Unit*: clean, thickly bedded and well-jointed coarse-grained limestone.
Kilbryan Limestone.	Limestone interbedded with calcareous, often fossiliferous shales, and strongly muddy limestone.
Boyle Sandstone.	*Upper Unit:* pale grey calcareous sandstone. *Middle Unit:* laminated black mudstones interbedded with sandstone. *Lower Unit:* poorly-bedded, coarse sandstone conglomerates, capped by intervals of mudrock.

6.1.1 Karst Features

A brief karst mapping programme was undertaken in the Rockingham 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.

[1] The subdivision of the Lower, Middle and Upper Ballymore Limestone is limited to this specific area based on data provided by Longworth (1987). These data are not available for the rest of the county and hence these subdivisions are not used in the county scale Groundwater Protection Scheme maps (Lee and Daly, 2002).

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 a GSI drilling programme (2001). Additional information specific to the area of interest includes:

- Paul, T. and King. M., (1996). Proposed Pumping Station at Rockingham Springs, Ardcarn, Boyle, Co. Roscommon. Ground Investigation Preliminary Geotechnical Report. Barnett, J., & Associates Ltd. (CSA Group).
- Doak, M., 1995. The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. MSc. Thesis, Sligo RTC.
- Longworth, K. T., (1987) An Appraisal of the Geology and Groundwater Resources of the Boyle River Catchment in the Rockingham – East Boyle area.
- Robinson, A, 1990. Rockingham Spring Catchment, Co. Roscommon. Groundwater Vulnerability Assessment Report. Unpublished BSc thesis.

The subsoil comprises a mixture of coarse and fine-grained materials. Peat and alluvium are located in the low-lying area around the shores of Lough Key.

'Till' is the dominant subsoil type in the area and is generally described as an unsorted mixture of coarse and fine materials laid down by ice. There are three till samples taken from road cutting in the vicinity of the spring. All three are described as CLAY (BS 5930).

A number of drumlins occur in this general area and are described as being oval in plan, up to 15 m in height and up to several hundreds metres in length. The drumlins trend north-east to south-west (Longworth, 1987).

6.2.1 Depth to Bedrock

Much of the area surrounding Rockingham Spring has a high proportion of rock outcrop or subcrop. It is therefore assumed that much of the subsoil in the intervening areas is relatively shallow, being less than 3 m in depth. This is particularly evident on the Plains of Boyle, to the south-west of the spring. The drumlins represent areas of thicker till.

6.2.2 Groundwater Vulnerability

The concept of vulnerability is discussed in the Roscommon Groundwater Protection Scheme Main Report (Lee and Daly, 2002).

The till in this region is generally described as CLAY (BS 5930), which is categorised as 'low' permeability. The drumlins represent areas of thicker low permeability till. The vulnerability categories range from 'high' to 'low', as the till thickness increases.

Where there is a high proportion of outcrop, subcrop, and subsoil thickness of less than 3 m, 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. In these areas, a vulnerability classification of 'extreme' has been assigned [2].

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, these features are classified as 'extremely' vulnerable and they include an arbitrary buffer of 30 m radius. The vulnerability for this area is shown in Figure 4.

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[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 Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow around Rockingham Spring. The interpretations and conceptualisations of flow are used to delineate source protection zones around the spring and the production boreholes. Hydrogeological data was gathered from the following sources:

- GSI: databases and fieldwork (subsoil sampling, karst mapping, dye tracer test).
- Doak, M., 1995. The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland. MSc. Thesis, Sligo RTC.
- KT Cullen & Co., 1990. Report on the Drilling and Testing of Trial and Production Wells at Rockingham.
- KT Cullen & Co., 1991. Draft Protection Plan for Rockingham Catchment.
- KT Cullen & Co., 1991. Report on the Hydrogeological Investigation of Rockingham Springs, Phase II.
- KT Cullen & Co., 1991. Report on a Pumping Test carried out at Rockingham Springs.
- KT Cullen & Co., 1993. Environmental Impact Statement for a Groundwater Abstraction at Rockingham, Co. Roscommon.
- KT Cullen & Co., 1999. Report on the Drilling and Testing of a Production Well at Rockingham, Co. Roscommon.
- Longworth, K. T., (1987) An Appraisal of the Geology and Groundwater Resources of the Boyle River Catchment in the Rockingham – East Boyle area. BSc. Thesis, Portsmouth Polytechnic.
- Price, H., 1998. Strategies for Source Protection in Karstic Aquifers. Unpublished MSc. Thesis. Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.
- Robinson, A, 1990. Rockingham Spring Catchment, Co. Roscommon. Groundwater Vulnerability Assessment Report. Unpublished BSc thesis.

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 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 is used to estimate the size of the zone of contribution (i.e. the outer source protection area). The calculations are summarised in Table 2 below.

Table 2. Estimate of Recharge.

Parameter	Amount (mm/yr)	Data Source and Comments
Annual rainfall	1037	KT Cullen & Co. (1993).
Annual evapotranspiration	405	Potential evapotranspiration (PE) is estimated as 426 mm/yr (KT Cullen & Co., 1993). Actual evapotranspiration (AE) estimated as 95% of PE.
Potential recharge	632	Rainfall minus AE. Estimation of the excess soil moisture available for either downward flow to groundwater, or lateral soil quickflow and overland flow direct to surface water.
Runoff losses	–	Negligible as the high proportion of outcrop/subcrop and thin subsoil results in a high infiltration capacity. Also reflected in the lack of surface drainage channels.
Estimated Recharge	632	

7.3 Groundwater Levels, Flow Directions and Gradients

Groundwater levels were surveyed in 1986 using 14 wells near the spring (Longworth, 1987). The interpreted map indicates general features of the water table, such as level, flow direction and gradient. The data are unevenly spread, with a higher concentration of wells located in the Kilbryan Limestone.

The contours are tightly spaced in the Kilbryan Limestone and are widely spaced in the Oakport and Ballymore Limestones. The spacing of the contours would tend to suggest that permeability is higher in the Oakport Limestone than in the Kilbryan Limestone. The regional groundwater flow direction is from south-west to north-east. The groundwater flow pattern indicates that the flow direction is parallel to the main direction of jointing in the area (Longworth, 1987).

From these data groundwater gradients were estimated for the different bedrock units below:

- Oakport Limestone: 0.01.
- Kilbryan Limestone: 0.02.
- Ballymore Limestone: 0.015.

The GSI undertook a multiple tracer testing in the Rockingham area (November 2000). Dye was injected into five swallow holes located to the south and south-west of Rockingham Spring. Nine springs, (including the Rockingham Spring overflow), and five rivers (including the Boyle River) were sampled (Figure 1).

Dyes from two swallow holes were detected in the Rockingham Spring (Figure 1). These swallow holes were located 6.0 km and 6.2 km west to south-west of the source. Dye was detected at the spring just over a day later for both swallow holes, indicating minimum groundwater velocities of 218 m/hr and 279 m/hr respectively.

The dyes injected into the remaining three swallow holes were not detected at any of the springs or rivers monitored. Although these ‘negative’ results are not conclusive, they do suggest that the swallow holes are not connected to the springs and rivers under the flow conditions at the time of testing.

7.4 Aquifer Characteristics

Pump tests have been carried out on several of the rock units in the area. These details are shown in Table 3 below.

Table 3. Pump Tests Results for Differing Rock Types

Rock Type	**Transmissivity (m^2/d)**	**Data Source**	
		Report	***Borehole***
Ballymore Limestone	15 – 30	Longworth, 1987	1729NEW035 (6/58)
	50	Ibbotson, 2000	1427NEW062 (14/91)
Oakport Limestone	100	Longworth, 1987	1729NWW103 (6/60)
Boyle Sandstone	15 – 20	Longworth, 1987	1729NEW016 (6/55)

The results from pump tests indicate that the Oakport and Ballymore Limestones have better aquifer properties than the Boyle Sandstone. These Limestones provide the groundwater to Rockingham spring and boreholes.

The Ballymore Limestone are described as dark fine-grained limestones with a distinct lack of pronounced vertical jointing (Longworth, 1987). However, the Lower Ballymore is generally a clean limestone, comparable to the Oakport Limestone.

The Oakport Limestone comprises well bedded, well-jointed pale clean coarse grained rock, with thin shales. The boreholes drilled around the springs indicate fracture zones in the first 20 m. These fractures are likely to act as the major conduits for groundwater flow.

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. The Oakport and Lower Ballymore Limestones have evidence of significant karstification. Epikarst (clints and grikes) has been observed in the uppermost metres of quarry sections. Furthermore, there is a high density of karst features (dolines, swallow holes, springs and turloughs) located in the Oakport and Lower Ballymore Limestones.

The widely spaced groundwater contours in the Oakport Limestone suggest high permeability. The tracer tests indicate minimum groundwater velocities of 218 m/hr and 279 m/hr for both the Oakport and Lower Ballymore Limestones. These flow rates depend on several factors including topography, rainfall and groundwater levels. However, these very high velocities are characteristic of flow in well developed karst aquifers.

Well hydrographs and spring discharge show rapid response to rainfall events, indicating rapid recharge and groundwater flow through the aquifer. Response to rainfall at the springs is about one day (Longworth, 1987; Price, 1998). This corresponds to the results of the tracer test.

The Oakport and the Lower Ballymore Limestones are likely to be characterised by:

- groundwater flow in solutionally enlarged bedding plane partings, joints, faults and conduits;
- high groundwater velocities, several orders of magnitude greater than in sand/gravel aquifers;
- concentration of groundwater flow into zones of high permeability;
- minimal attenuation of contaminants, except by dilution;
- high turbidity, suspended solids and colour after heavy rain, particularly in the autumn;
- short response times when pollution incidents occur.

It is possible that the muddier nature of the Middle and Upper Ballymore Limestone limits the extent of karst development, although specific karst mapping has not been undertaken in these areas. However, the lack of surface drainage over these rocks in this region does infer that recharge can readily infiltrate to the groundwater.

The lithology of the Kilbryan Limestone (high clay contents and shale layers) and Boyle Sandstone (muddier middle unit) are likely to restrict groundwater circulation in these rocks. This is reflected in the transmissivity estimates for the Boyle Sandstone shown in Table 3.

7.5 Aquifer Classification

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

Due the lack of outcrop and exposure data throughout County Roscommon, the three main Ballymore beds have not been differentiated. The Ballymore Limestone aquifer category is therefore based on the available hydrogeological data, which may be biased towards the cleaner units.

The Ballymore Limestone is also classified as a Regionally Important Karstic Aquifer, which is characterised by conduit flow (**Rk**^{c}). The Oakport and Ballymore Limestones are thought to be in hydraulic continuity due to their clean limestone lithologies, and the groundwater pathway suggested by the tracer test.

Development potential of the Kilbryan Limestone is considered to be limited by its clay content and shale layers. Similarly, groundwater circulation through the Boyle Sandstone is thought to be inhibited by its muddier middle bed. These rocks are therefore categorised as Locally Important Aquifers, which are moderately productive in local zones (**Ll**).

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

7.6 Hydrochemistry and Water Quality

The available water quality data for the Rockingham 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).

- The hydrochemical analyses show that Rockingham Spring has very hard calcium bicarbonate water with high hardness values (96 – 408 mg/l; 70 samples); high alkalinity (96 – 400 mg/l; 54 samples) and high conductivity (365 – 796 µS/cm; 25 samples). The coefficient of variation of the conductivity is high at 18% (Doak, 1995). This signifies that recharge is rapid.
- Chlorides range from 12 – 32 mg/l, with an average of 23 mg/l (29 samples). Chloride reached 32 mg/l on three occasions (Jan 1984, Feb 1993, May 1993). In the 1984 sample, the water was also 'noticeably yellow'. Chloride is a constituent of organic wastes and levels higher than 25 mg/l may indicate contamination. Concentrations higher than the 30 mg/l usually indicates significant contamination. Only coliform levels were significant on the dates that chloride reached 32 mg/l.
- Nitrates are low, ranging from 2 – 12 mg/l, with an average of 6 mg/l (26 samples).
- Sodium Potassium ratios (Na:K) range from 0.19 – 0.4 in 7 samples (averaging 0.26). One sample exceeded the GSI threshold (0.35). Elevated Na:K ratios suggest that farmyard waste, rather than septic tanks, are the likely source of organic wastes.
- Total and faecal coliforms are constantly present in the raw water samples and exceed the EU Drinking Water Directive maximum admissible concentrations (MAC). All of the 21 raw water samples had greater than 10 faecal coliforms per 100 ml. This level is considered to be gross contamination (Keegan *et al*., 2002)
- Turbidity also exceeded the EU MAC (4 NTU) in March 1999, February 2000 and May 2001.
- The dataset shows that the spring water is hard, and is regularly contaminated with bacteria.

7.7 Discharge

Monitoring of daily abstraction and overflow was undertaken from July 1993 to April 1994 by Price (1998). As mentioned in Section 2, the spring overflows via two channels that meet the Ballykeevican stream. The first channel flows over the weir, via the front of the pond area. The second is a smaller stream flowing from the rear of the pond area. It is likely that the second channel also takes discharge from a fracture zone, which is adjacent, or part of, that feeding the Rockingham Spring. These data indicate an annual discharge of approximately 5.9M m^3/yr, which suggests a daily discharge of approximately 16,000 m^3/d.

7.8 Conceptual Model

- There are minimal surface streams in the catchment, except for the stream that rises in Ballykeevican, close to Rockingham Spring. The lack of surface drainage suggests that potential recharge readily infiltrates into the groundwater system.
- The Oakport Limestone and the Lower Ballymore Limestones mainly provide the groundwater to the springs and boreholes, as suggested by the tracer tests. These two units are characterised by higher transmissivity values than the Boyle Sandstone (100 m^2/d and 50 m^2/d respectively) and high groundwater velocities (minimum of 218 m/hr and 279 m/hr in two tracer tests).
- The Oakport Limestone is bounded by the significantly less permeable Kilbryan Limestone to the north. Similarly, the Middle and Upper Ballymore Limestones to the south are likely to be less permeable than the Lower Ballymore Limestone.

- The Kilbryan Limestone is considered to act as a barrier to groundwater flow that is flowing from the south. This is likely to be forcing the groundwater to move in a south-west to north-east direction, rather than from south to north as suggested by the topography. The flow direction is therefore parallel to the strike of the beds, and the geological contact between the Kilbryan and the Oakport Limestone.
- The groundwater moves from the higher portion of the catchment (Plains of Boyle), through the Oakport and Lower Ballymore Limestones, to the lowest point of the catchment. At this location, some of the groundwater emerges at the surface as the Rockingham Spring, other associated springs and the Ballykeevican stream.
- The boreholes drilled at Rockingham Spring indicate several fracture zones up to 20 m below ground level. These fractures, which are likely to be karstified, act as the major groundwater conduits.
- Groundwater flowing through these fractures is intersected by the production wells. Groundwater bypassing the stream, springs and wells probably continues in this same direction, to meet the Lough Keel Fault. The fault is likely to channel the groundwater to Lough Key.
- Karstification is evident in the Oakport Limestone and Lower Ballymore Limestones. Thus groundwater is likely to flow along solutionally enlarged fractures and pronounced joints that exist in these rocks.
- Recharge is rapid, as the springs react within a day to rainfall events. The variation of electrical conductivity (18%) also indicates the rapid response of the springs to recharge.

8 Delineation Of Source Protection Areas

8.1 Introduction

This section delineates the area that is believed to contribute groundwater to the spring and production wells (including PW-4), and therefore requires protection. The delineated area is based on the conceptualisation of the groundwater flow pattern, as described in the conceptual model 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 spring and production wells.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source (spring and production wells), i.e. the zone of contribution (ZOC), and 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 this 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.

Three methods were used to delineate the ZOC for Rockingham Spring and production wells:

- ♦ hydrogeological mapping

- test pumping results (KT Cullen & Co., 1999)
- water balance estimations.

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

1. The main constraint to the **Northern Boundary** of the ZOC is the Kilbryan Limestone, which effectively acts as a barrier to groundwater and contains it within the Oakport Limestone. It therefore prevents groundwater flowing directly to Lough Key. The topographic boundary is mainly located to the south of this geological contact. If precipitation falls between the topographic boundary and geological contact, it is most likely to infiltrate rapidly into the underlying karstified Oakport Limestone, as inferred by the lack of surface drainage. If precipitation falls to the north of the contact, it is likely to flow as surface water or soil quickflow over the less permeable Kilbryan Limestone, towards Lough Key. Therefore the northern boundary of the ZOC comprises the geological contact with an arbitrary buffer of 100 m, or the topographic catchment boundary, where this is to the north of the geological contact.
2. Given the available data, the **North-Eastern Boundary** is constrained by analytical modelling. Theim's steady state equation was applied to the pump test data (KT Cullen & Co, 1999) to estimate the maximum radius of the cone of depression for PW-4. The maximum radius was used as the down-gradient extent of the catchment. The radius was calculated as 120 m from the borehole (Appendix 1).
3. The **Eastern Boundary** is difficult to define accurately. A ridge located in the townland of Glebe probably acts as a topographic divide. This is likely to separate the water which may be flowing north to the spring, from that flowing east toward the Lough Keel Fault.
4. The **Southern Boundary** is marked by a distinct topographic ridge that runs from east to west through the Plains of Boyle. The topographic boundary acts as the regional surface water, and probably groundwater divide, between water flowing to the north and the south. The 'negative' tracer test results in this area also support the delineation of this boundary.
5. The **Western Boundary** is more complicated as there is no distinct control. The tracer tests show that there is a link to Rockingham Spring from two swallow holes to the south west of Boyle Town. The western boundary is therefore delineated to include the catchment areas for these two swallow holes, based on a topography ridge. The area to the north and west of the boundary appears to be part of either the Boyle River or Lough Gara catchments.
   It is noted that the western boundary comprises a ridge of till, which has been deposited on the bedrock. Groundwater could possibly flow from the west of the boundary, through the bedrock, underneath the till ridge. However given the data available, precise groundwater flow directions in this area cannot be determined and a more accurate western boundary cannot be delineated.

   These boundaries delineate the physical limits within which the ZOC is likely to occur. The area constrained by the hydrogeological mapping is approximately 16 km^2.

8.2.1 Water Balance Estimates

Price (1998) analysed discharge and recharge data from July 1993 to April 1994. Data from four months within this period were used to determine the catchment area required to provide the discharge (abstraction plus overflow measurements). The months chosen were at the beginning, middle and end of winter and therefore represent the highest and lowest rainfall and flow periods (Table 4).

Table 4. Water Balance Estimates (after Price 1998).

Period	Discharge (m^3)	Change in Storage (m^3)	Net Recharge (mm)	Estimated Area Required (km^2)
05 Sept 1993 – 01 Nov 1993	586,281	+ 17,619	52.2	11.6
02 Nov 1993 – 27 Nov 1993	333,170	+ 83,686	46.0	9.1
24 Jan 1994 – 16 Feb 1994	545,441	- 17,967	89.5	5.9
12 Mar 1994 – 18 Apr 1994	824,203	- 19,430	100.3	8.0

Evidently, the ZOC constrained by hydrogeological mapping is greater than the area required by the water balance. However, the ZOC determined using the mapping is the smallest area that could be delineated with the available data.

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.

From Section 7.4, the tracer test recorded rapid groundwater velocities in the Oakport and Lower Ballymore Limestones (minimum of 218 m/hr and 279 m/hr). Given these flow rates, it is possible that water could reach the spring from the furthest catchment boundary (approximately 7 km away) in just over one day.

The Middle and Upper Ballymore Limestones cover a strip of the ZOC along the southern boundary, which is a maximum of 900 m wide. There are limited specific data for these limestones units however, there are permeability estimates for similar rock types in other counties (Daly, 1994). Assuming these rocks are dominated by fracture flow, the estimated permeability ranges from 0.1 to 20 m/d. It is therefore possible that groundwater could reach the source from the furthest point on the southern boundary in 45 days. The presence of some karst features in these rocks illustrates some degree of karstification and thus flow rates are likely to be faster.

From the available data, it likely that all groundwater within the delineated catchment could reach the source in less than 100 days. This could occur entirely as groundwater flow, or intermittently via any surface channels. Thus, 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 5). 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 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. Four groundwater protection zone is present around the Rockingham Spring (Figure 5), as shown in the matrix below.

Table 5. 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)	SI/L	na

10 Potential Pollution Sources

Within the ZOC, there are a number of houses and farmyards. Some of these are located within 500 m of the Rockingham Spring. There are also a number of roads crossing the ZOC including the main Boyle to Carrick-on-Shannon road. Agriculture in the main land use in the area, which is dominated by pasture. There is also a limestone quarry within close proximity to the spring.

The hydrochemical data mainly highlights consistently elevated levels of total and faecal coliforms. Given the levels of other indicator parameters, the source of this contamination is likely to be organic farmyard wastes as well as other organic 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). Road runoff is also a potential contaminant. The location of these activities in any part of the ZOC categorised as 'extremely' vulnerable presents a potential risk, given rapid travel time through the underlying bedrock. It should be noted that detailed assessments of hazards were not carried out as part of this study.

11 Conclusions and Recommendations

- The source at Rockingham is predominantly supplied by the Oakport Limestone.
- It is unlikely that the Rockingham Spring can provide additional long-term water supplies during drier periods. However, flow from the rear of the pond area was recorded after the Rockingham Spring overflow (flow over the weir from the front of the pond) had ceased.
- Due to the rapid groundwater velocities through the karstified bedrock, it is considered that waters within any part of the ZOC could potentially reach the spring within 100 days. The entire ZOC is therefore classified as the Inner Protection Area.
- Groundwater in a large proportion of the Protection Area is 'extremely' vulnerable to contamination, due to the high proportion of outcrop, subcrop and thinner subsoils (estimated to be less than 3 m in thickness). Areas of thicker till, which are generally drumlins, give rise to 'high', 'moderate' and 'low vulnerability classifications.
- Farmyard waste leakage, landspreading, septic tank leakage and runoff from roads present potential threats to the water quality in the spring.
- The enclosed boreholes and relatively tidy appearance of the pump house area suggest that there will be limited susceptibility to surface water inundation specifically at the source.
- 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:
  - flow monitoring is continued, both at the weir and from the rear of the pond area.
  - the potential source of the latter discharge is investigated further because if appropriate, these flows may have development potential for augmentation purposes.
  - further work be undertaken at the western boundary to confirm flow directions.
  - 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.
  - the potential hazards in the ZOC should be located and assessed.
  - the sump and pump house area should continue to be adequately maintained to minimise the risk of inundation by surface water at the source.
  - particular care should be taken when assessing the location of any activities or developments which might cause contamination at the spring.

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Appendix 1

Rockingham Springs and Production Boreholes: North-Eastern Boundary.

Determined by finding down-gradient extent of pumping PW4 – based on Thiem Equation:

$$Q = \frac{2\pi T (h_2 - h_1)}{2.30 \text{ Log } r_2/r_1}$$

Where Q = discharge (m^3/d) T = transmissivity of the aquifer (m^2/d)

h_1 and h_2 = respective steady-state elevations of the water levels in the piezometers (m)

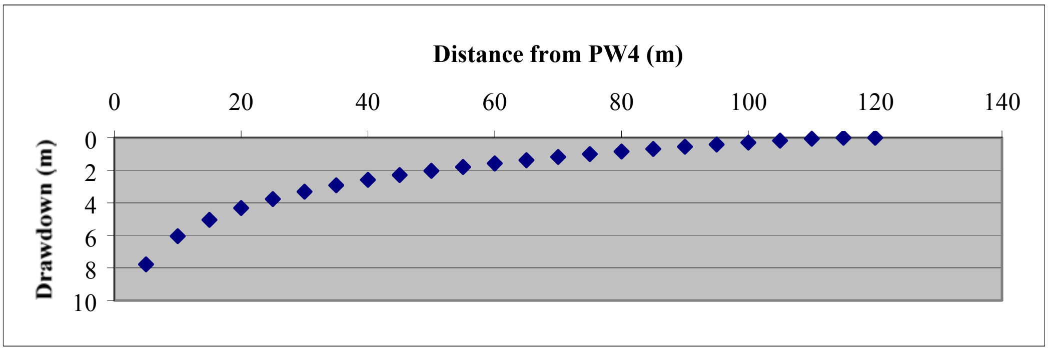
r_1 and r_2 = respective distances of the piezometers from the well (m)

And assuming the aquifer is confined by any overlying low permeability subsoil (till).

Calculated drawdown curve based on pumping test data (KT Cullen & Co, 1999):

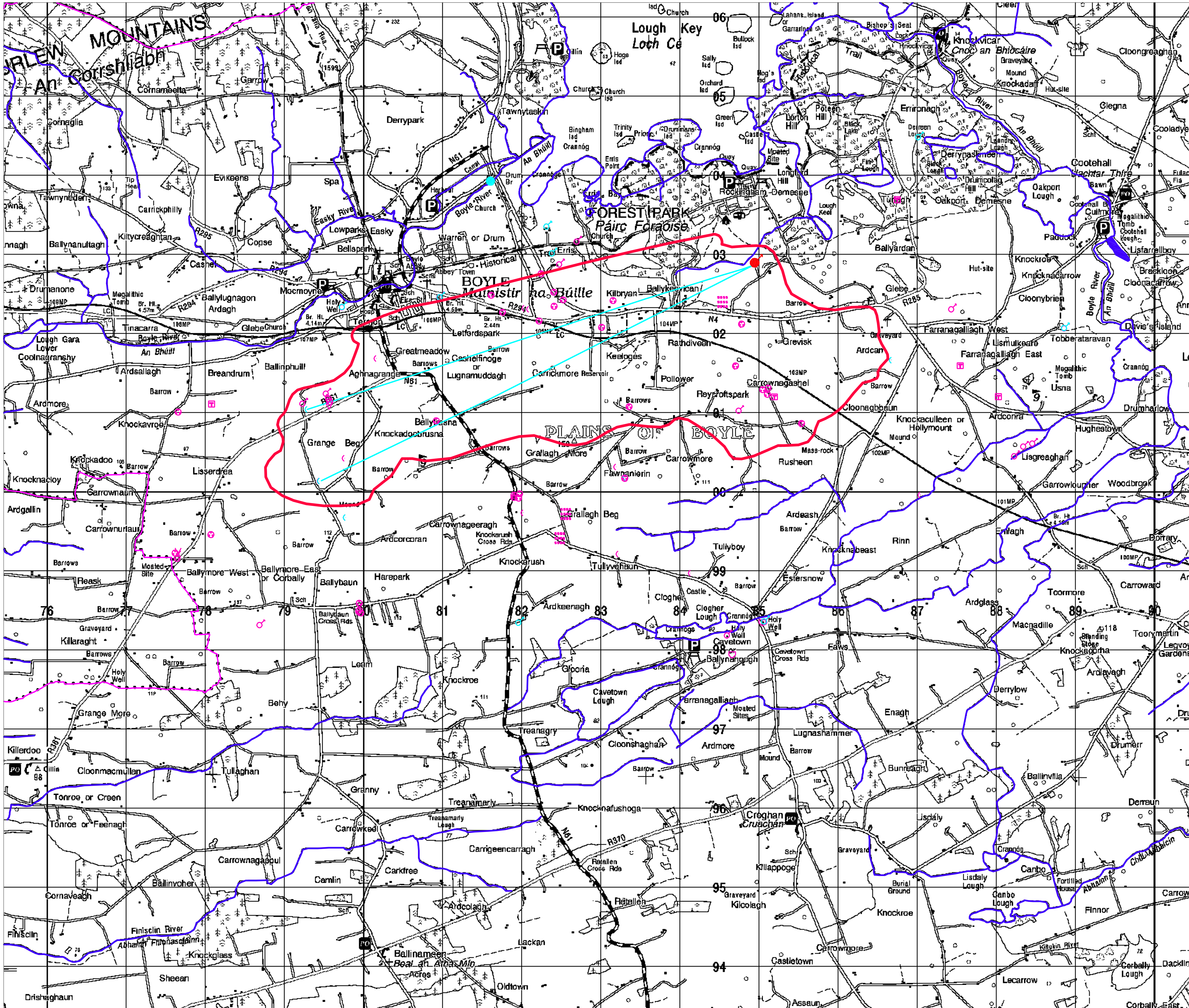
Q = 1100 m^3/d T = 70 m^2/d

$(h_2 - h_1)$ = 17 m r_1 = 0.125 m



It is estimated that the drawdown in PW4 will have an influence of upto 110 m down-gradient of the well. Thus a north-eastern boundary set at 120 m down-gradient of the well will allow for a margin of error.

BOYLE/ARDCARN WATER SUPPLY SCHEME
Figure 1. Site Location and Feature Map



Karst Features
- Turlough
- Enclosed Depression
- Swallow Hole
- Cave
- Spring
- Injection Point
- Monitoring Spring

Other Features
- Streams
- Zone of contribution (ZOC)
- Public Supply Spring
- River monitoring points for tracer testing
- Established Connections (tracer test lines)

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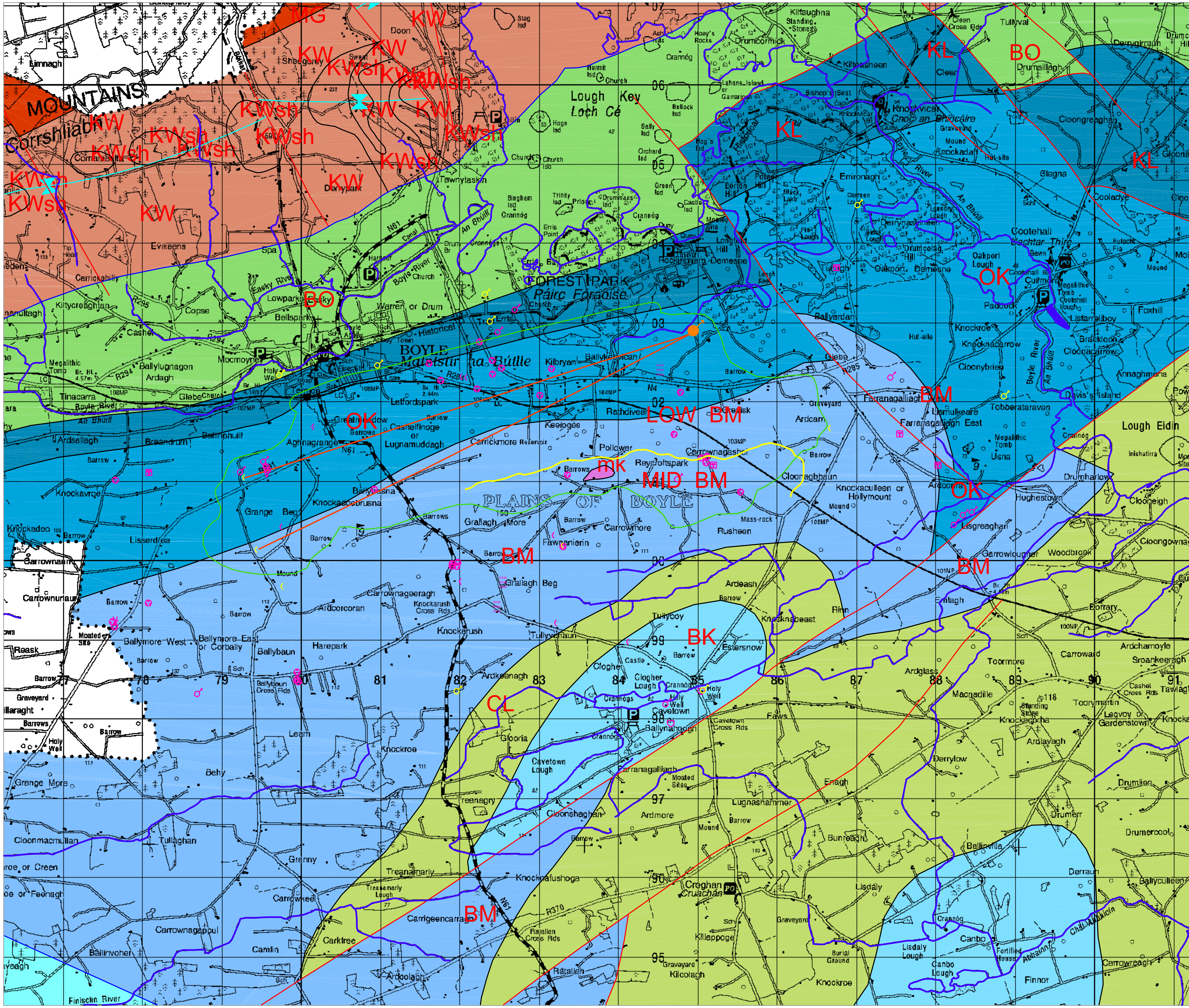
0 1km 2km



BOYLE/ARDCARN WATER SUPPLY SCHEME

Figure 2. Geology Map

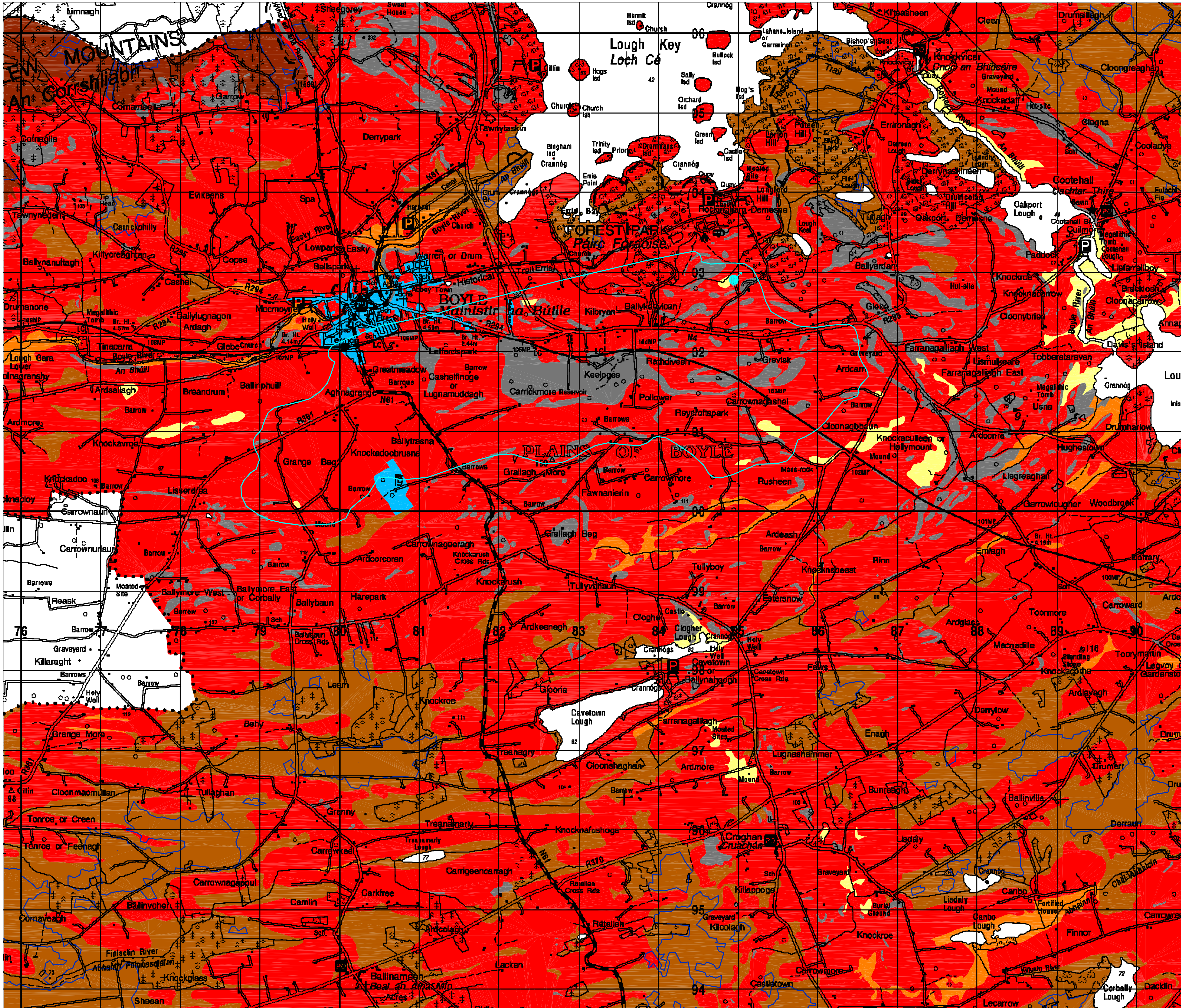
BK	Bricklieve Limestone Formation (BKU&BKL)	Thick bedded, clean, cherty limestone
CL	Croghan Limestone Formation	Medium bedded, fine-grained, muddy limestones
VIS	Visean Limestone (undifferentiated)	Generally poorly exposed. Likely to comprise units of clean and muddy limestones north of Tulsk. Likely to comprise clean limestone south of Tulsk.
BM	Ballymore Beds	Thin bedded dark limestones, mudstones, shales
mk	Mudbank Limestones	
OK	Oakport Limestone Formation	Bedded, medium/fine grained limestone, shelly horizons, palaeokarstic surface
KL	Kilbryan Limestone Formation	Dark nodular calcarenites and shales
BO	Boyle Sandstone Formation	Sandstone and red green conglomerates
KW	Keedew Formation	Sandstone and thin mudstone
KWsh/KWbk		Sheegorey and Bockagh Members. Andesitic pyroclastics and lavas
MG	Moygara Formation	Conglomerates pebbly sandstone mudstone

- Streams
- Karst Features
- Zone of Contribution
- Established Connections (tracer test lines)
- Additional Geological Boundary (after Longworth, 1987)
- Fault
- Fold Axis
- Geological Contact
- Unconformity
- Public Supply Spring

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.

0 1km 2km

BOYLE/ARDCARN WATER SUPPLY SCHEME
Figure 3. Subsoils Map



	Alluvium undifferentiated
	Peat
	Lake Sediments
	Lake
	Made or built ground
	Rock outcrop or subcrop
	Tills
	Cut peat boundaries used for Vulnerability map

Zone of Contribution

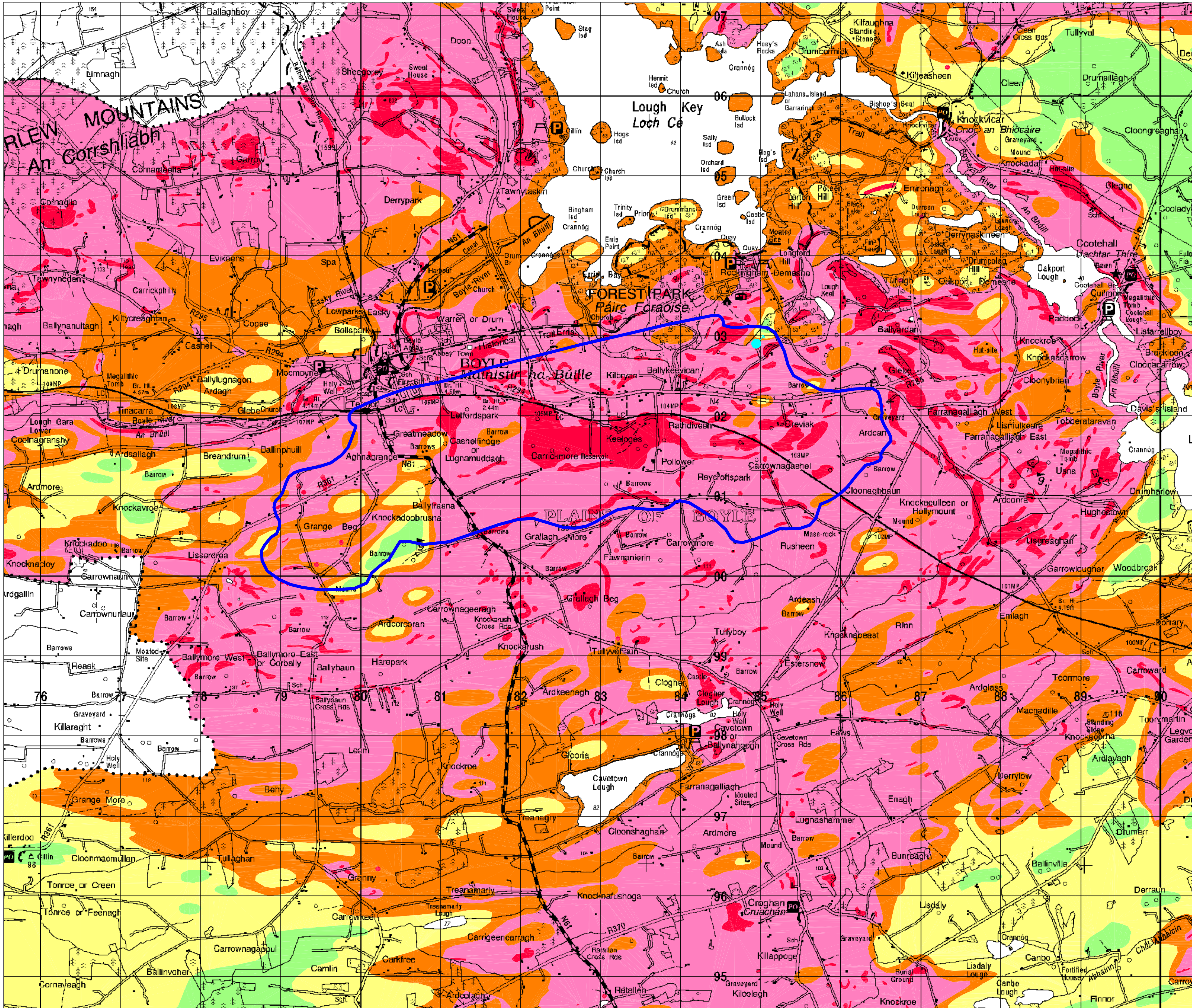
Public Supply Spring

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

0 1km 2km

BOYLE/ARDCARN WATER SUPPLY SCHEME

Figure 4. Vulnerability Map



Extreme (E)

Outcrop/Shallow rock (E)

High (H)

Moderate (M)

Low (L)

Zone of Contribution to Well

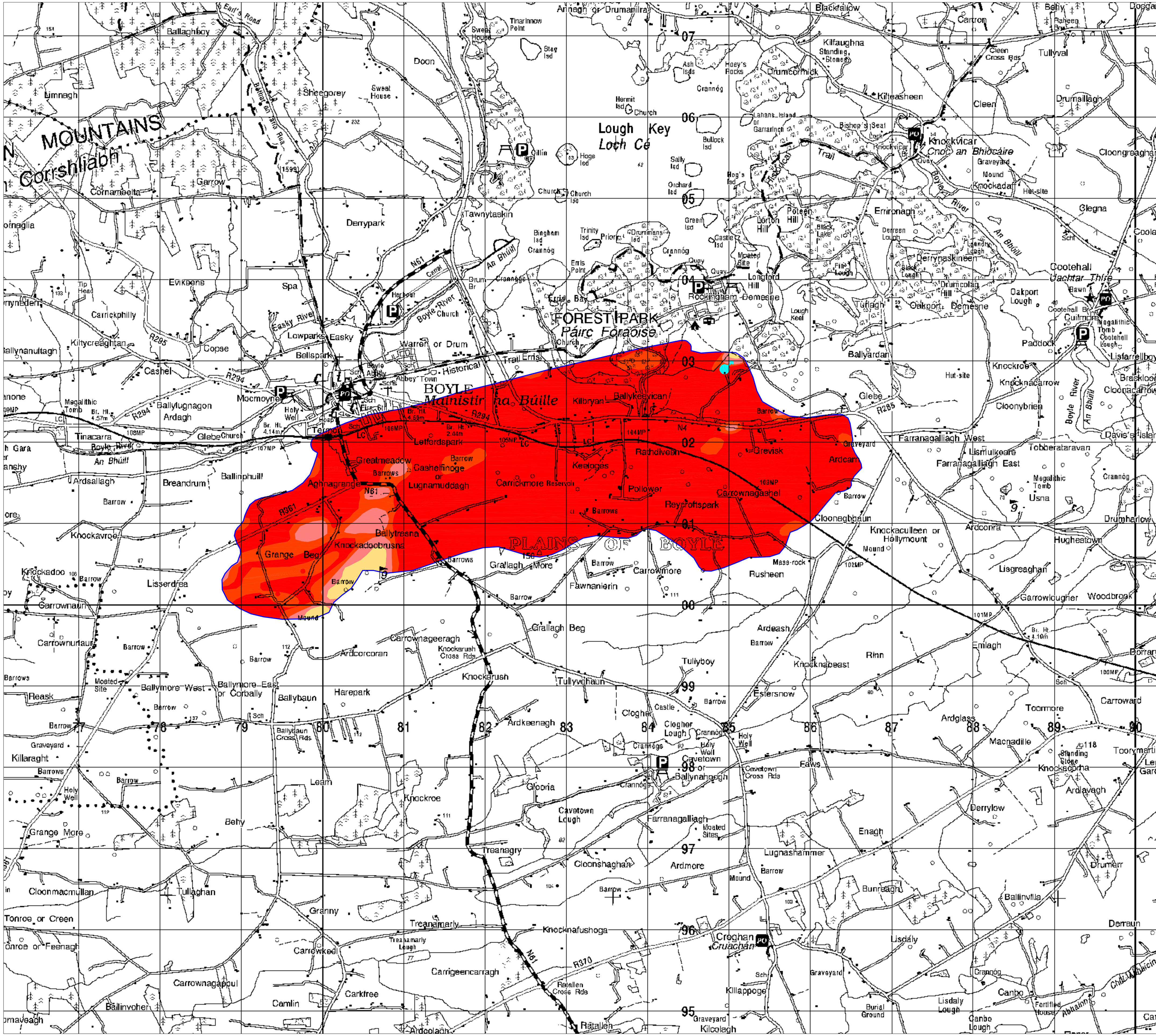
Public Supply Spring

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.

0 1km 2km



BOYLE/ARDCARN 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)	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 assessements 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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0 1km 2km