Durrow (Convent) Water Supply Scheme

Groundwater Source Protection Zones

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1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Durrow Water Supply Scheme(WSS).
- To outline the principal hydrogeological characteristics of the Durrow area.
- To assist Laois County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the well. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in ‘Groundwater Protection Schemes’ (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection scheme for the county. The maps produced for the scheme are based largely on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole county covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

2. Location and Site Description

The well at Durrow Convent is one of the two public drinking water sources for Durrow Town. The second source for Durrow is in Fermoyle (see separate source protection report, Cronin et al., 2000).

The location of the Durrow Convent source is shown in Figure 1b. The well is located within a small well-house, floored with concrete to a level approximately 0.1 m above the surrounding field. The well head lies within a small chamber whose base lies 0.86 m below the floor of the well-house. The top of the well casing within this chamber lies 0.5 m above the base of the chamber (i.e. 0.36 m below the well-house floor).

Though the well head lies below ground, under normal conditions it is protected from surface drainage to some degree by the well-house. However, the Erkina River routinely floods to within 10 m of the well-house (Figure 1b). The well-house floor is approximately 0.25-0.75 m above this flood level. Thus the well head is considered to be at considerable risk of flooding during an extreme flood event.

3. Summary of Well Details

GSI no.	:	2317SWW058
Grid ref. (1:25,000)	:	24023 17753
Townland	:	Durrow Demesne
Well type	:	Borehole
Drilled	:	August 1976
Owner	:	Laois County Council
Elevation (ground level)	:	79.75 m OD
Depth	:	Originally 29.3 m, now ~10 m*
Depth of casing	:	3 m of 200 mm diameter and a further 3 m of 178 mm diameter
Diameter	:	200 mm (8") and 178 mm (7”)
Depth to rock	:	1.2 m
Static water level	:	77.79 m O.D. (1.96 m b.g.l.) on 12/8/76
Pumping water level	:	Approximately 77 m O.D. (2.4 m b.g.l.) on 16/4/99*
Drawdown	:	0.1 to 2 m
Normal consumption	:	200 m^3/d - 300 m^3/d
Pumping test summary:		(i) abstraction rate : 927 m^3/d*
		(ii) specific capacity : 3800-4879 m^3/d/m*
		(iii) transmissivity : 2000 to 3000 m^2/d*

* *The well was tested at various rates in the winter of 1976/77, the longest test abstracting 927 m^3/d and lasting 15 days. The caretaker reported that in the early 1990s the well collapsed to a depth of ~10 m. The original submersible pump was lost as a result, and replaced by a suction pump. Even though the present pump has a restricted lift capacity of 5 to 7 m, there have been no reported problems with the required yield. The pumping water level measured on 16/4/99 is very approximate, using moisture observations on a simple tape measure, the aperture being too narrow for an electric dipper. While the well appears to be sufficient for the current yield, the degree to which the collapse has affected the potential yield of the well since the initial yield testing cannot be ascertained.*

4. Methodology

Desk Study

Bedrock geology information was compiled from the original 6" field sheets and from the GSI bedrock report for the area (Archer *et al*, 1996). Details of the current abstraction rate were obtained from Laois County Council. Drilling, pumping test and borehole geophysical data for the supply well were obtained from a report compiled by the GSI (Daly, 1978), while data on private groundwater wells in the area was taken from GSI archives.

Site Visits and Field Work

Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (1 day) and Quaternary (2 days) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and the current pollutant loading.

Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

5. Topography and Surface Hydrology

The Durrow Convent source is located 29 m south of the Erkina River, and some 530 m west of Durrow town square. The Erkina River forms a sub-catchment of the Nore basin. This sub-catchment extends eastwards to a point 1.2 km from the Durrow Convent source, where the river joins the Nore.

The Erkina occupies a 3 km wide, east-west trending valley at an elevation of 70 to 80 m OD. This valley is constrained by ridges to the north and south, both of which act as watersheds delineating the extent of the Erkina sub-catchment. The northern watershed ridge rises to an altitude of 96 m OD, and runs east to west, through Swan and Knockanoran townlands, at a distance of 0.9 km from the source. The southern watershed ridge (the 'Caponellan ridge') is much steeper, rising to a peak of 253 m OD. This peak lies 2.3 km south of the source and the ridge itself trends northeast to southwest.

Slopes on the valley bottom are generally about 0.025 (1 in 40), but locally slopes can be much steeper as a result of a series of small east-west ridges which rise up to 10-15 m above the surrounding land. Slopes on the Caponellan ridge are of the order of 0.2 (1 in 5).

There is a streamflow gauge on the Erkina River at Durrow. Low flows[1] at this station are of the order of 0.4 m^3/sec (An Foras Forbatha, 1976).

The sandy soils of the valley floor are well-drained, and hence the density of natural streams is very low. Aside from the Erkina itself, only one stream is found in the vicinity of the well. This stream rises as a small spring in Capponellan Townland, some 1.3 km south of the Durrow Convent source, and flows northwards into the Erkina at a point approximately 0.5 km upstream of the source.

[1]Q95 index of the flow duration curve for the drought year of 1976.

6. Geology

6.1 Introduction

This section briefly describes the relevant characteristics of the materials underlying the Erkina sub-catchment in the vicinity of the Durrow source. This provides a framework for the assessment of groundwater flow and source protection zones that follow.

Bedrock information was taken from a study of available data, which comprised:

- GSI publication on the bedrock geology of the region (Archer et al, 1996).
- Unpublished mineral exploration bedrock drilling information from an area lying approximately 2 km west of Durrow (Blaney & Slowey, 1994 and Blaney, 1996).
- Information from nineteenth century outcrop mapping on record at the GSI.

Subsoils information was taken from the 2-day field mapping exercise which was undertaken as part of the Laois Groundwater Protection Scheme.

6.2 Bedrock Geology

6.2.1 Lithology

The bedrock geology of the Durrow area is summarised in Figures 2a (plan view) and 2b (cross-section). Limestones occupy the whole Erkina valley, stretching southwards as far as the lower slopes of the Capponellan Ridge, which is composed of slightly younger sandstones and siltstones.

The individual rock units in the Erkina sub-catchment are as follows:

Formation	Rock Material	Thickness	Occurrence
Moyadd Coal Formation	SHALES, SILTSTONES and SANDSTONES with thin coals.	<50m	Just south of Erkina watershed, near top of Caponellan ridge.
Bregaun Flagstone	SANDSTONES and SHALES.	50-100m	Forms the crest of Caponellan ridge.
Killeshin Siltstone	'Flaggy' SANDSTONE.	50-100m	Upper slopes of Caponellan ridge.
Clogrenan Limestone	Thinly bedded 'clean' dark grey LIMESTONE. Often very cherty.	~100m	Lower slopes of Caponellan ridge.
Ballyadams Limestone	Thickly bedded, 'clean', pale grey, 'crystalline' LIMESTONE.	~200m	Erkina valley floor.
Durrow Formation	Shaly LIMESTONES, limey SHALES, oolites (sand grain-sized limestones).	~200m	Northern watershed ridge, and Erkina valley floor east of the source.

The units are presented in the above table in order of increasing age, though all are believed to have been deposited in Carboniferous times (i.e. 355 to 290 million years ago).

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. As such, some degree of karstification is expected in both the Ballyadams and Clogrenan formations. Evidence of karstification has, in fact, been found regionally in both these formations (Archer at al. 1996).

6.2.2 Geological Structure

The structure of the rock units in the southern half of Ireland is dominated by a pronounced east-west trend of ridges and valleys, generally considered to be due to a continental impact from the south during the late Carboniferous age.

This pattern is slightly more complex in the Durrow area. Here, east to west structures have been broken up into blocks by north-south faulting. The blocks have then been shuffled and stacked such that most of the landforms have a northeast to southwest orientation (A. Sleeman, GSI, pers. comm.).

The sub-catchment around the Durrow source lies on the northern side of a large 'syncline' (downward fold in the rock mass). Rocks dip at 10° to 35° southwards in the valley, with the axis of the syncline running along the Caponellan watershed.

Rocks in such close proximity to a fold axis are typically extensively fractured and faulted. Evidence of a large thrust fault was identified by mineral exploration drilling in an area some 2 km west of the Durrow source. The trend of this fault suggests that it might also occur in the vicinity of the Durrow Convent source. There is, in fact, strong evidence of fracturing and fissuring from the drilling records of the Durrow source (Appendix 1). Daly (1978) reported large fissures at 8 m and 17 m below ground in this borehole.

6.3 Quaternary (subsoils) Geology

The main subsoil categories in the vicinity of the source are sand & gravel, alluvium, peat and till ('boulder clay').

The characteristics of each category are described briefly below:

6.3.1 Sand & Gravel

This is the dominant subsoil lithology in the area. It extends across the Erkina sub-catchment, from the Swan ridge in the north to the base of the Caponellan ridge in the south. It is considered to reach up to 10m in thickness in the centre of the valley. In this area, the material is associated with distinct east-west ridges, which rise up to ~10m above the valley floor. Some disused gravel pits are associated with these ridges. The ground surface becomes more even to the south of the main Cork road, and no disused gravel pits could be found in this area. Hence, it is considered that the sand & gravel is fairly free of fine material (i.e 'clean') in the area between the Erkina and the Cork road, but the proportion of fines is thought to increase to the south of this road.

6.3.2 River Alluvium

This material occupies the flood plain along the Erkina river and includes the subsoil at the Durrow source itself. Drilling records (Daly, 1978) from the Durrow Convent source indicate that the material is dominantly fine grained. Drilling and anecdotal information from the Council suggest that the alluvium lies directly on bedrock, and is unlikely to be more than 1-3 m thick in the immediate vicinity of the well. Further, anecdotal data from Council staff suggests that the river itself flows over less than 1 m of alluvium, or even over bare rock, near the well.

6.3.3 Peat

This material occurs in the base of the valley approximately 1.5 km west of the Durrow source. It is likely to overlie gravels or bedrock and is probably less than 10m thick.

6.3.4 Tills

Till is an unsorted mixture of coarse and fine materials laid down by ice. Some tills are mapped as occupying the ground to the south of the southern Erkina sub-catchment watershed, and to the northeast of the Nore River.

6.4 Depth-to-rock

The interpreted variation in depth to rock across the sub-catchment is presented in Figure 4. The interpretation is based on rock outcrop and geomorphological data, along with drilling records from the Durrow Convent source (E.P. Daly 1978).

In summary, the subsoils in the immediate vicinity of the well are thought to be less than 3 m thick. Moving 10-20 m south from the source, however, there is a break in the land slope[2] which suggests a sudden increase in depth to rock to approximately 10 m. Moving southwards again, the depth is thought to decrease steadily to less than 3 m at the foothills of the Capponellan ridge, and less than 1m on the ridge itself.

7. Hydrogeology

7.1 Introduction

This section presents our current understanding of groundwater flow in the vicinity of the Durrow source. The interpretations and conceptualisations of flow are used to delineate source protection zones around the well.

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

- A study of the groundwater in County Laois (E.P. Daly, 1978).
- County Laois Groundwater Protection Scheme, (Wright *et al*, 2000).
- A local, one-day hydrogeological mapping survey, which involved examining potential groundwater flow directions and subsoil permeability[3].

7.2 Rainfall, Evaporation and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. Recharge is generally estimated on an annual basis, and is assumed to consist of an input (i.e. annual rainfall) less water losses (i.e. annual evapotranspiration and runoff). The estimation of recharge is critical in source protection delineation as it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff:

- Annual rainfall: 879 mm (Met Eireann average annual (1961-90) rainfall measured at Durrow Garda Station.
- Annual evapotranspiration losses: 425 mm. This figure ('actual evapotranspiration') was developed by Daly (1992) in the Nore catchment, based on measurements at the Met Eireann synoptic station at Kilkenny (1958-81). More local measurements of evapotranspiration are not available.
- Potential recharge: 450 mm/year, based on average annual rainfall less estimated evapo-transpiration. -
- Annual runoff losses: 45 mm. This estimation is based on the assumption that 10% of the potential recharge will be lost to overland flow and shallow soil quickflow. This assumption is an empirical standard used in GSI for permeable sand & gravel subsoils of the type which dominate the area up-gradient of the Durrow source (Section 6.2.1).

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[2] Durrow convent stands on this feature.

[3]Typically, water levels in local wells are measured as part of such an exercise. However, very few existing wells were identified in the vicinity of the Durrow source. This is thought to be mainly due to the fact that the area is fully supplied by mains water. Of the six wells that were identified, with the help of the Council, only two could be accessed for measurement.

These calculations are summarised below:

Average annual rainfall (R)	879 mm
Estimated A.E.	425 mm
Potential Recharge (R – A.E.)	450 mm
Runoff losses factor (RO)	10%
Estimated Actual Recharge[4] (R-A.E.)*(1-R.O)	410 mm

7.3 Groundwater levels

Measurement of water levels was possible in only 3 wells in the vicinity. The water level in the public supply could not be measured accurately, due to the limited space between borehole casing and rising main, but was estimated at 2.4 m below ground (~77 m OD, 16/4/99). A similar groundwater level (2.2 m below ground) was also measured in a well (not currently pumping) some 300 m east of the Durrow source and 15 m south of the Erkina River. Both these readings corresponded approximately with the water level in the Erkina River. A third measurement was taken in a 3.1 m deep dug well, about 400m north of Capponellan House, at the southern limit of the valley floor. The water level in this area was shallower (0.4 m below ground) and is thought to reflect the presence of a small spring in the vicinity. This spring gives rise to the only stream flowing on the south side of the Erkina in the vicinity of the well (Figure 1).

The results of approximate measurements made suggest that the groundwater level in the pumping well is at, or slightly below, the level of water in the Erkina River. More detailed measurements taken during the well testing programme undertaken in 1976 tell a similar story. Results were as follows:

	Date	Level in River (m OD)	Level in Pumping Well (m OD)	Difference in Levels (m)
Before pumping	22nd Oct. 76	77.94	79.97	-0.03
During pumping	27 Oct. 76	Assume 77.94	77.49	+0.45

Thus, it appears that the head difference between the river and the aquifer forces groundwater into the river before pumping, but drags some water from the river towards the well during pumping.

7.4 Groundwater Flow Directions and Gradients

The water table in the area is assumed to reflect topography, with groundwater flowing from the sub-catchment watersheds and discharging into the Erkina River. Evidence of a good hydraulic connection between the river and groundwater is presented in Section 7.3. This is supported by evidence (Section 6.3.3) that very little low permeability material separates the river from the groundwater flow system.

It is clear that the dominant driving head in the sub-catchment comes from the Caponellan ridge, which forms the southern watershed. Thus, it is possible that some deep groundwater flow may be driven north underneath the northern watershed and into another sub-catchment. However, this effect is thought to be very minor as the rocks of the Durrow formation will form a lower permeability impedance, effectively forcing flow from the south up into the Erkina.

Groundwater gradients are difficult to calculate because of the limited well water level data available. However, assuming that the groundwater supplying the spring in Clonageera is hydraulically part of the same groundwater system feeding the well, a gradient of 0.013 (1 in 80) has been estimated using the current pumping water level in the Durrow source and the estimated altitude of the spring. This figure compares with a topographic gradient of 0.026 (1 in 40) between the spring and the well.

Groundwater levels along the steep-sided southern ridge are expected to be very shallow. Thus, the groundwater gradient is probably similar to the topographic gradient of approximately 0.2.

[4]All estimations used in this report are rounded off to two significant figures.

7.5 Hydrochemistry and Water Quality

Results of laboratory analyses of water samples taken in December 1997, July 1999, and September 1976 are presented in Table 1. Results from 1976 are taken from E.P. Daly (1978).

The following key points have been identified from the data:

- The groundwater samples indicate a 'hard' (329-351 mg/l $CaCO_3$) calcium-bicarbonate hydrochemical signature. This indicates that most of the groundwaters feeding the well have passed through limestone rock, that the waters are relatively 'young' and travel times from recharge area to the well are short.
- Of the parameters examined in the groundwater samples taken, only total coliforms were in excess of the European maximum admissible concentration (2 counts per 100 ml in November 1997). However, nitrate (36 mg/l as NO_3 in November 1997) occurred at elevated concentrations that may be indicative of significant contamination occurring within the groundwater system feeding the source. Reported nitrate levels have increased between 1976 (8.4 mg/l as NO_3) and 1997/99 (36-38 mg/l as NO_3).
- The major ion chemistry of surface water and groundwater samples taken during pumping tests in the late summer of 1976 was very similar. This suggests that groundwater is a significant contribution to the surface water low flows in the Erkina. Temperature, conductivity and bacteria counts in surface and groundwater samples, however, remained very different throughout the testing. This difference, coupled with the inferred close connection between the river and the groundwater system (Section 7.5), implies that river recharge is a very small proportion of the total flow to the well during pumping.

Table 1: Laboratory Analyses of Groundwater and Surface Water

Parameter	**Results of Laboratory Analyses**			
	Well Sample	Well Sample	Well Sample	Erkina River Sample *(taken during well pumping).*
	22/6/99	7/11/97	30/9/76	30/9/76
Conductivity (μS/cm)	652	629	650	675
Temperature (°C)	-	-	5.5	10.5
pH	-	-	7.4	7.8
Total Hardness	358	351	329	339
Total Alkalinity (mg/l)	314	300	312	300
Calcium	116.9	131	257	263
Magnesium	16	14.6	93	76
Chloride	20.1	19.3	26	28
Sulphate	14.6	15.4	20	19
Sodium	8.2	9.3	9.5	10
Potassium	2	2.4	1.7	4
Nitrate (as NO_3)	37.5	36.5	8.4	6.9
Iron	0.008	n.d	n.d	n.d
E. coli count per 100 ml.	n.d	n.d	n.d	130
Total Coliforms per 100ml	n.d	2	5	130

7.6 Aquifer Parameters

The data used in this section are based on pumping tests undertaken by GSI in September 1976 and January 1977 (Daly, 1978).

A constant discharge test in September 1976 at 1636 m^3/day for 72 hours gave a final drawdown of 0.43 m, and a very high specific capacity of 3800 m^3/day/m. Analysis of the data from this test provided a transmissivity estimate of 2900 m^2/d. Results from other tests in September 1976 and January 1977 gave a range of transmissivities of between 1800 m^2/d and 3000 m^2/d.

These figures cannot be taken as definitive values, due to the variable, karstic nature of flow in the aquifer, but they indicate that the transmissivity and permeability of the aquifer in the immediate vicinity of the Durrow source must both be ‘high’.

Storativity (specific yield) values estimated from early 1977 pumping test data ranged from 0.0025 to 0.0062. The effective porosity estimated for the limestone is expected to correspond with the upper end of this range; say 0.01. However, values of specific yield and effective porosity of a productive Irish limestone would typically be expected to be several times higher than these estimates.

7.7 Aquifer Category

As discussed in Section 6.1, the Ballyadams and Clogrenan limestone formations occupy the bulk of the valley floor area around the Durrow Convent source. Further, it is believed that most groundwater that flows to the well originates from this area (Sections 7.3 and 7.4). In the Laois Groundwater Protection Scheme (Wright et al, 2000), these rock formations are considered to be Regionally Important karstic aquifers (Rk).

The Durrow Formation limestone and the Killeshin Siltstone, Bregaun Flagstone, and Moyadd Coal are all considered, in the Laois Groundwater Protection Scheme (Wright et al, 2000) to be poor aquifers that are unproductive except in local zones (Pl).

7.8 Conceptual Model

- Groundwater flow to the well is expected to come from the south side of the Erkina River, in the area between the Caponellan ridge and the river itself.
- The river is considered to be in hydraulic continuity with groundwater in the limestone aquifer. Groundwater is believed to discharge into the river along most of its course. However, in the immediate vicinity of the well, there is evidence that some river water is pulled back into the well. Hydrochemical data suggests, however, that the proportion of river water is relatively minor.
- The Durrow source is thought to be fed primarily from the regionally important aquifer that underlies the valley to the south of the source, comprising the Ballyadams and Cloghrenan limestone formations.
- The regionally important aquifer units are overlain by up to 10 m of sand & gravel. There is evidence that this material is very free-draining and moderately to highly permeable.
- Groundwater recharge to the aquifer is expected to occur primarily through the sands & gravels that occupy the valley floor. Some recharge is also thought to occur in the area on the southern watershed where excess rainwater is expected to migrate towards the valley-floor aquifer through the shallow weathered rock zone (upper 5-15 m of rock). There is very little surface drainage across the south side of the river, even on the steep-sided Caponellan Ridge. Thus, it is thought that groundwater recharge is distributed fairly evenly across the area. Recharge rates are thought to be of the order of 410 mm/year.
- Groundwater levels in the Durrow source lie some 1-2 m below the top of rock. Therefore, most groundwater is expected to be unconfined.

- The limestones have been subject to fracturing and subsequent karstification. Extensive fracturing to a depth of at least 17 m below ground was noted in the Durrow Convent borehole log, and Council staff report the presence of a small karstic feature (swallow hole) in Clonageera Townland. In addition, thrust faulting has been inferred close to the well. Intense fracturing and evidence of karstification usually indicate enhanced permeability. Pumping test data provide strong evidence of enhanced permeability around the Durrow source. Thus groundwater flow is likely to be both rapid and unpredictable in the limestone aquifer.
- The Durrow Formation limestones, and the sandstones, siltstones and shales that occur along the southern watershed are believed to have a much lower permeability than the Ballyadams and Cloghrenan limestones. This is largely because they are not as prone to solutional enlargement of fissures. Flow in these rocks is likely to occur in the upper weathered fissured zones and along fractured fault zones.
- In a similar manner to topographic gradients, the horizontal groundwater gradient is likely to be flatter within the Ballyadams and Clogrenan formations and relatively steep in the less permeable sandstone, siltstones and shales that occur along the southern watershed. Estimates of gradients for the limestone are approximately 0.013. Gradients for the lower permeability units are estimated to be as high as 0.2.

8. Delineation of Source Protection Areas

8.1 Introduction

This section delineates the areas around the well that are believed to contribute groundwater to the well, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 7.8.

Two source protection areas are delineated:

- ♦ Inner Protection Area (SI), designed to give protection from microbial pollution;
- ♦ Outer Protection Area (SO), encompassing the remainder of the zone of contribution (ZOC) of the well.

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), and is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the pumping rate, (b) the groundwater flow direction and gradient, (c) the rock permeability and (d) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation. Given the limited amount of calibration data available, a full groundwater numerical model was not undertaken.

The average abstraction rate for the Durrow Convent source was calculated using weekly pumping records from October 1997, June 1998, and January 1999. The rates were relatively constant, ranging from 193 m^3/day to 302 m^3/day. However, for analytical modelling, an abstraction rate of 900 m^3/day was used, for two main reasons:

– Yield testing in early 1977 suggested that the well is capable of producing at least 900 m^3/day in the long term. Thus, this rate is a useful figure to allow for future increases in abstraction.

– A safety factor is routinely incorporated by GSI in abstraction rate estimations in order to compensate for variations in recharge over the year and for intrinsic unpredictability in most groundwater flow systems.

The boundaries of the analytical model were taken from hydrogeological mapping and the conceptualisation outlined in Section 7, and were as follows:

– **Northern boundary:** Erkina river.

– **Southern boundary:** Erkina sub-catchment watershed at Caponellan ridge.

– **Western boundary:** spring and small streamflowing into the Erkina some 0.5 km west of the Durrow Convent source (Figure 1).

– **Eastern boundary:** the low ridge that trends north-south and lies in Durrow Townparks townland ~1 km south east of the source (Figure 1).

These boundaries delineate the physical limits within which the ZOC is likely to occur.

The water balance and analytical modelling were then used to determine whether some of the final interpretation of the ZOC could be reasonably reduced within this envelope. The calculation procedure and range of results are presented in Appendix 2. In summary, the results suggested that the boundaries as defined by the hydrogeological mapping and the conceptualisation processes were slightly conservative. Small reductions can be achieved in the vicinity of the western boundary (i.e close to the small spring). However, the initial boundaries of the ZOC are largely retained, for two main reasons:

- there is little available evidence to indicate where further reductions can be made.
- groundwater flow in the aquifer is considered to be karstic, and therefore rapid and extremely unpredictable. Thus, large safety factors need to be incorporated into planning decisions.

In addition, the results tended to support the inference drawn in Section 7.5 that only a small proportion of the abstracted water is drawn from the river into the well during pumping. Thus, the ZOC need not extend along the Erkina River itself for any significant distance.

8.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) to the source from a point below the water table and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the well. Calculations are reported and discussed in Appendix 2. Essentially, it is considered that, as a result of karst-enhanced permeability within the aquifer, travel times are very fast, and the 100-day time of travel zone is considered to occupy the entire ZOC.

9. Groundwater Vulnerability

The distribution of interpreted groundwater vulnerability in the ZOC is presented in Figure 2. The sands and gravels are considered to be moderately to highly permeable, depending on the fines content. They are generally 3 to 10 m thick in the ZOC as defined in Section 8. Therefore most of the land in the ZOC is classified 'highly' vulnerable to contamination. However, immediately around the well, and along the ridge at the downgradient limit of the ZOC, bedrock is expected to be less than 3 m below ground, and groundwater in these areas is considered 'extremely' vulnerable to contamination.

10. 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 the matrix in the table below). In practice, this is done by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code, e.g. **SI/H**, which represents an Inner 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. Just two groundwater protection zones are present around the Durrow Convent source (Figure 3), as shown in the matrix below.

Matrix of Source Protection Zones

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

The appropriate responses imposing restrictions on development are presented in the document 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

11. Land Use and Potential Pollution Sources

Agriculture in the area comprises pasture and tillage. There are a number of landspreading land banks in the area, and a pig farm lies some 900m south of the Durrow source. Durrow itself is a small town of XXX people, with a number of small commercial enterprises, including two petrol service stations.

The main hazards within the ZOC are considered to be landspreading and commercial activities in Durrow Town. One example of a potential commercial activity of interest would be petroleum storage and handling in retail petrol stations. Other hazards include farmyards, septic tanks, application of inorganic fertilisers and pesticides, and possible spillages along the main Cork road. No detailed assessment of hazards was carried out as part of this study. However, the general impression is that landspreading may become a significant issue. This is supported by elevated nitrates levels in recent sampling rounds (Section 7.5).

12. Conclusions and Recommendations

- The source at Durrow is an excellent yielding well, which is located in a karstic limestone aquifer. The test pumping indicates that the present normal abstraction rate of the well could be significantly increased if the well were re-bored and lined more effectively.
- The area around the supply is 'highly' to 'extremely' vulnerable to contamination. Further, the well-head is vulnerable to surface water inundation during extreme flooding of the Erkina River.
- The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.
- It is recommended that:
  - chemical and bacteriological analyses of raw water rather than treated water should be carried out regularly (every 3 months). This high frequency is required because of the highly variable nature of flow in the groundwater system feeding the well. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and especially nitrate. In addition, indicators of pesticide and petroleum contamination should be selected (e.g 'total petroleum hydrocarbons');
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - the potential hazards in the ZOC should be located and assessed;
  - guidelines should be drawn up for dealing with underground petroleum storage/transfer, and spillages along the roads in the area.

13. References

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APPENDIX 1

Durrow Convent Source: Geological Log.

APPENDIX 2

Analytical Modelling of the Zone of Contribution and 100-day Time of Travel Zone

Analytical modelling was used to delineate the extent of the ZOC within the constraints imposed by the hydrogeological mapping and groundwater flow system conceptualisation exercises. The techniques used were as follows:

- Estimating the ZOC area using a balance of annual recharge to the Durrow Convent source and annual abstraction from the source.
- Width of the ZOC area using Darcy's Law.
- Distance to the limit of the ZOC downgradient of the well, using the uniform flow equation.
- The width of the ZOC at the upgradient limit, using the geometrical equation for the sector of a disc of a set radius (i.e distance to downgradient watershed) and set area (i.e required recharge area). The equation assumes that the ZOC is the shape of a sector, or 'cake slice'. Such a shape is a useful guide, but would typically slightly over-estimate the ZOC at the upgradient limit, and under-estimate close to the source.

Analytical modelling was also used to delineate the extent of the 100-day TOT Zone within the ZOC. This involved estimating the velocity of groundwater to the well using Darcy's Law.

Input values to the various equations were taken from the measurements, estimations and inferences drawn in Section 7, and are summarised below:

• Discharge	Durrow Convent Source	900 m^3/d
• Recharge		410 mm/yr
• Transmissivity	Limestone	2500 m^2/day
• Effective thickness	Limestone	16 m
• Permeability[5]	Limestone	160 m/day
• Effective porosity	Limestone	0.01
• Hydraulic gradient	Limestone	0.013
• Upgradient limit (distance to watershed)		2.275 km

Output Derivations are summarised in a table at the end of this appendix. Key findings are discussed below:

- ZOC width ('w'): Estimations give a 'worst case' width of 22m. A length of over 30 km would be required to generate a zone comparable with even the smallest area generated using a simple recharge/abstraction balance. Thus, though mathematically valid, this estimation method is not considered conceptually valid in this case and is not considered further.
- ZOC area ('A'): Estimations give a 'worst case' of 1 km^2, compared to a maximum area of 1.9 km^2, as defined by the hydrogeological mapping and conceptualisation exercise.
- ZOC angle ('Θ'): Estimations give sectors which are comparable with the conceptualised width of the ZOC at the upgradient limit ('r'). Between this limit and the well, however, the sector is smaller (i.e narrower) than the conceptualised physical constraints of the ZOC.
- ZOC Null Point: Estimations give distances which fall slightly short of the distance from the Durrow Convent source to the river (refer to Figure 1b). This supports the inference drawn in Section 7 that very little water is drawn from the river to the well during pumping, and therefore the ZOC need not extend along the Erkina River for any significant distance.
- 100-day time of travel limit: Due to very high estimations of 'K' and very low estimations of 'n', all permutations produce an estimated extent which is much further from the well than the distance to the upgradient watershed ('r'), as defined by hydrogeological mapping and conceptualisation.

[5] Inferred from measured transmissivity and presumed effective thickness.

This data therefore cannot be considered hydrogeologically ‘realistic’. As such, the actual distance to the limit of the 100 day time of travel zone is assumed to be equal to ‘r’.

In summary, the analytical modelling data suggests that the initial mapped, conceptualised area is slightly conservative, and that the ZOC need not be extended to include the surface water protection of the Erkina itself.

The capture zone of the spring and stream along the western boundary of the conceptualised physical constraints of the ZOC can be removed, as most groundwater in this area is likely to discharge into the stream and flow away from the well. This reduces the initial area from 1.9 km^2 to 1.5 km^2. However, no data are available to further reduce this area with any confidence.

In addition, as a result of karst-enhanced permeability within the aquifer, travel times are fast, and the 100-day time of travel zone is considered to occupy the entire ZOC.

ZOC and 100-Day Time of Travel Dimensions:

Summary of Analytical Modelling and Sensitivity Analysis Results.

Input Values								Output				
Recharge (R)	**Assumed Future Abstraction Rate (Q)**	**Transmissivity (T)**	**Thickness of Water - Bearing Zone (b)**	**Permeability (k)**	**Porosity (n)**	**Horizontal Gradient (i)**	**Upgradient Distance to Watershed (r)**	**ZOC Area (A)[6]**	**ZOC Angle (Θ)[7]**	**ZOC Width ('w')[8]**	**ZOC Null Point[9].**	**100-day Limit[10]**
mm/yr	m^3/day	m^2/day	m	m/day			km	km^2	°	m	m	km
410	900	2500	16	156	0.01	0.013	2.275	0.8	18	28	4	20
492	900	1250	16	78	0.01	0.013	2.275	0.7	15	55	9	10
492	900	2500	16	156	0.01	0.013	2.275	0. 7	15	28	4	20
492	900	3750	16	234	0.01	0.013	2.275	0.7	15	18	3	30
410	900	1250	16	78	0.01	0.013	2.275	0.8	18	55	9	10
410	900	3750	16	234	0.01	0.013	2.275	0.8	18	18	3	30
328	900	1250	16	78	0.01	0.013	2.275	1.0	22	55	9	10
328	900	2500	16	156	0.01	0.013	2.275	1.0	22	28	4	20
328	900	3750	16	234	0.01	0.013	2.275	1.0	22	18	3	30

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[6]Area required to balance 'Q' with 'R'

[7]Angle of that portion of a circle, with its centre at the Durrow Convent source, and radius 'r', whose area matches 'A'.

[8]Estimated from Darcy's law, using 'n', 'i', and 'K'.

[9]Represents the maximum distance downgradient of the well from which the well can still draw groundwater. Estimated from the 'Uniform Flow Equation', using 'n', 'i', and 'K'.

[10]Estimated extent of 100-day time of travel zone from the well.

APPENDIX 3

Sensitivity Analysis: Rationale and Procedure.

3a. Zone of Contribution

To examine the robustness of the analytical model, a sensitivity analysis was carried out using methods employed by the U.K's Environment Agency (Keating & Packman, 1995). Best estimate permeability (K) and recharge (R) values were initially chosen and the sensitivity analysis was based on varying these parameters. Recharge was varied over a range of 80 to 120% and permeability by 50 - 150%. This involved creating nine analytical models – each model has a different permeability and recharge value. The nine models are as follows:

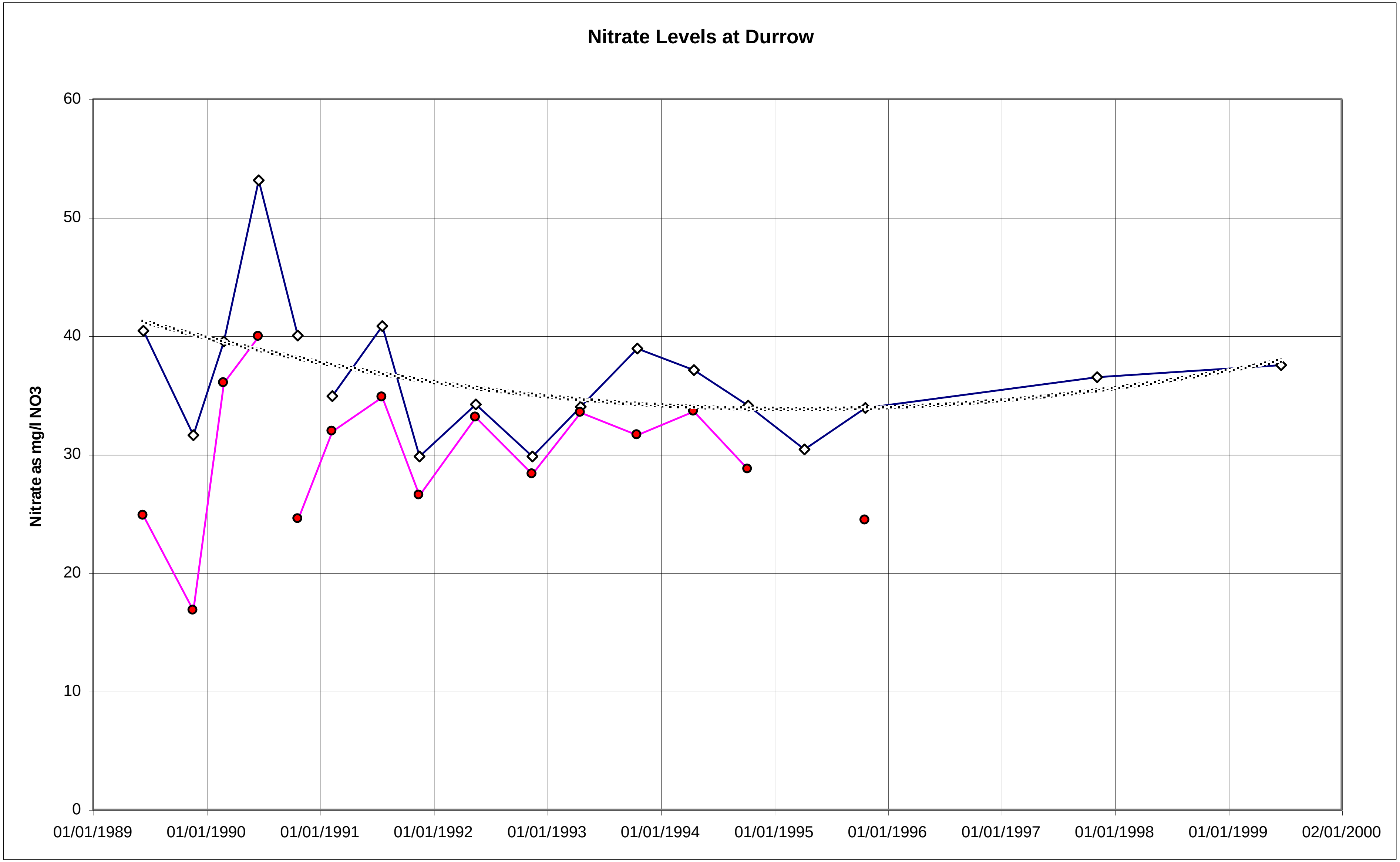
↑ Recharge (R)			
	1.2R, 0.5K	1.2R, K	1.2R, 1.5K
	R, 0.5K	R, K	R, 1.5K
	0.8R, 0.5K	0.8R, K	0.8R, 1.5K

Permeability (K) →

Each model was run and the resulting ZOC dimensions are presented in Appendix 2.

3b. Delineation of the 100 day Time of Travel Zone.

In the delineation of the 100 day TOT zone, the GSI also uses the cautious U.K Environment Agency approach. Consequently, the “best estimate” porosities of the aquifer units are typically reduced by 50% (velocity increases as porosity is reduced) in each of the nine models. However, in the case of Durrow, porosity is already considered to be unusually low, and no further changes were made in the sensitivity analysis.


Nitrate Levels at Durrow
Nitrate as mg/l NO3
60
50
40
30
20
10
0
01/01/1989
01/01/1990
01/01/1991
01/01/1992
01/01/1993
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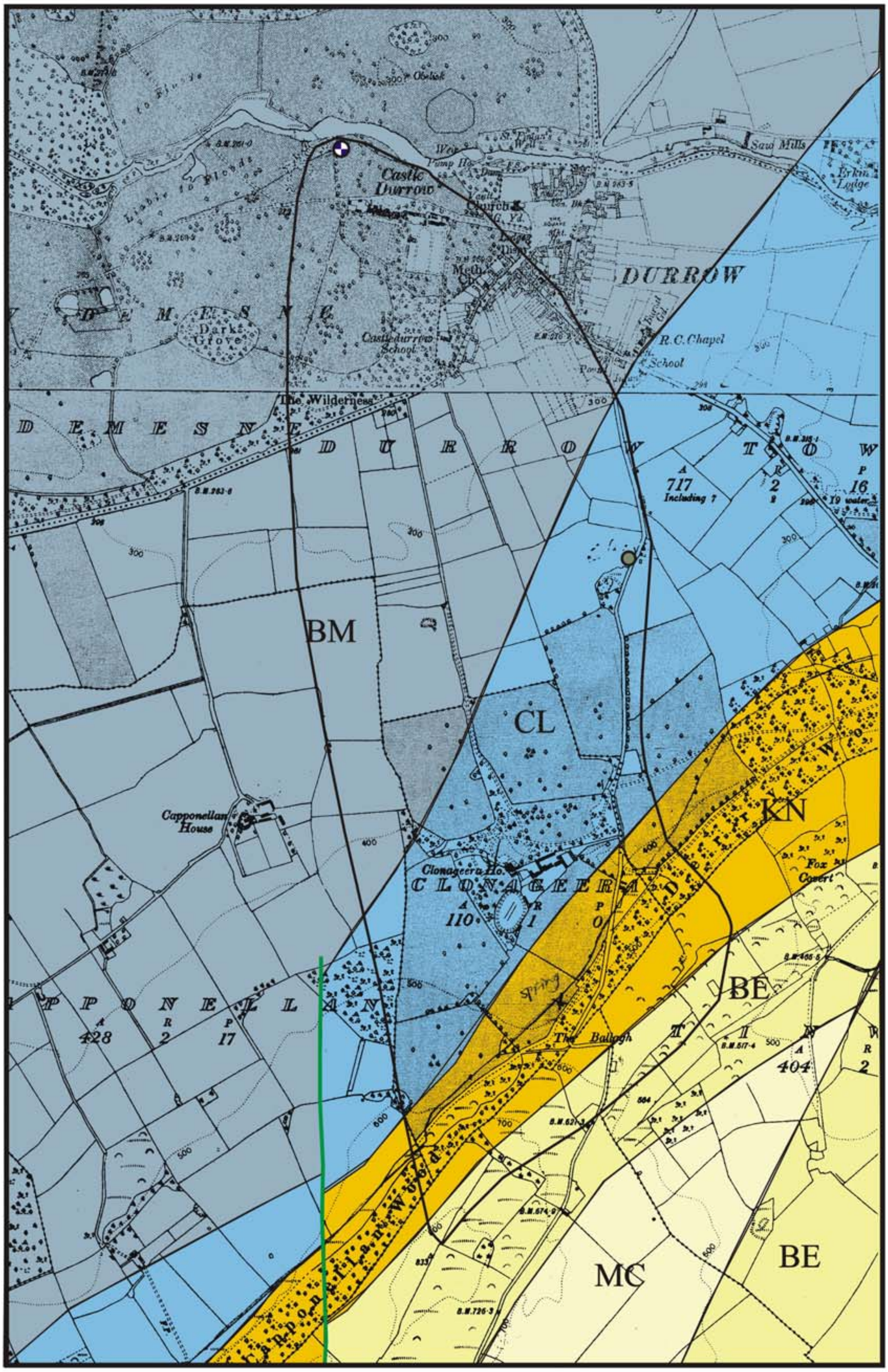
01/01/1999
02/01/2000



Map 1: Geology of the Durrow District

Legend

MC	Moyadd Coal Formation
BE	Bregaun Flagstone Formation
KN	Killeshin Siltstone Formation
CL	Clogrenan Formation
BM	Ballyadams Formation
	Fault
	Geological Boundary
	Zone of Contribution
	Borehole
	Public Supply Well

N

Scale (metres)

0 500

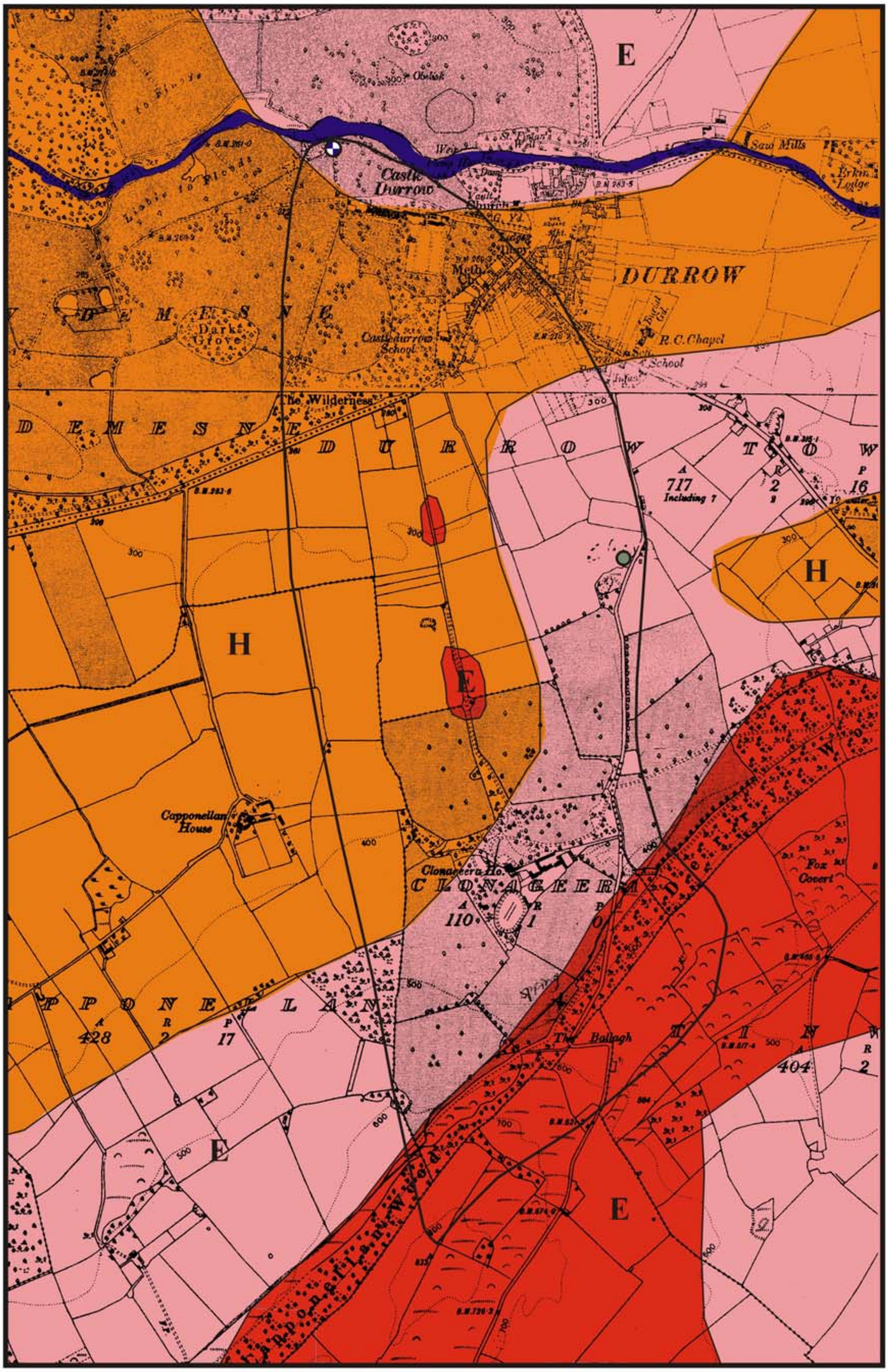
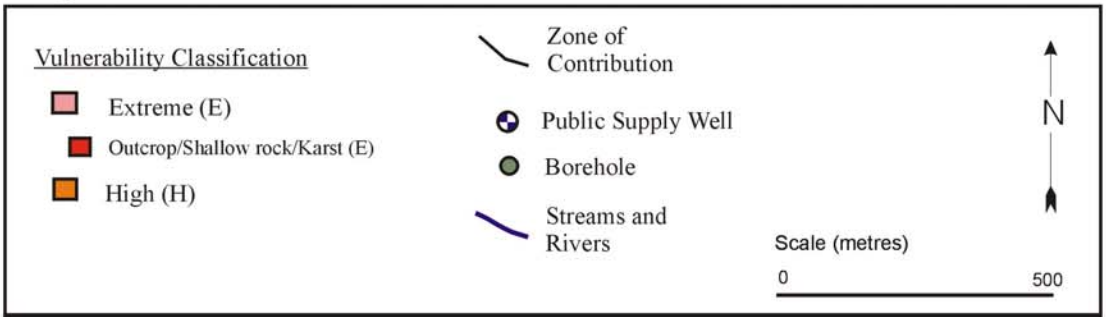
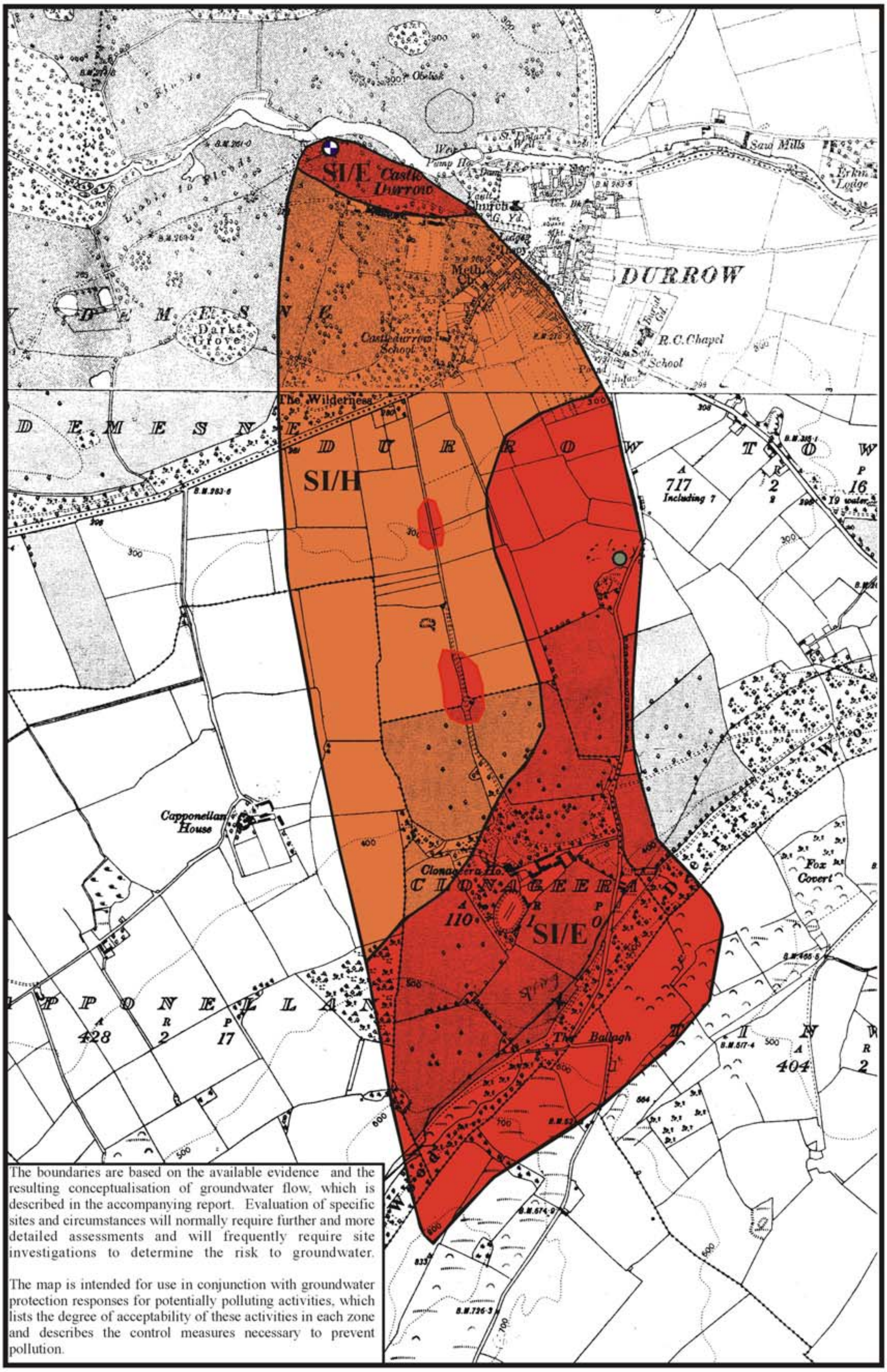


Fig. 2: Groundwater vulnerability zones for Durrow water supply scheme.

Legend





Map 3: Groundwater Protection Zones for the Durrow District

Legend

- SI/E — Inner Zone-Extreme
- SI/H — Inner Zone-High
- Public Supply Well
- Zone of Contribution
- Borehole
- N
- Scale (metres) 0 — 500