CLOYNE-AGHADA WATER SUPPLY SCHEME

GROUNDWATER SOURCE PROTECTION ZONES

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1. Introduction

The objectives of this report are:

1. To delineate source protection zones for the Cloyne-Aghada Water Supply Scheme (WSS).
2. To outline the principal hydrogeological characteristics of the Cloyne area.
3. To assist Cork County Council (Southern Division) in protecting the water supply from contamination.
4. Location and site description

The Cloyne-Aghada Water Supply comprises five production boreholes, of which four are currently in use. The boreholes are spread across the townlands of Town Parks (just southeast of the town of Cloyne), Castlemary and Lissanly (southeast of the town), Commons East (south of the town) and Farrannamanagh (southeast of the town).

Each of the bores is well protected from potentially polluting activities, by concrete chambers which enclose the wellheads. The pump controls are sited beside each of the bores; there are no pumphouses. However the concrete chambers make access to the wellheads (for dipping water levels etc.) difficult.

The water is pumped to a service reservoir in Carriglusky townland, at an elevation of about 80 metres O.D. on the ridge dividing the Cloyne valley from the Carrigacrump valley. Beside the service reservoir is a treatment plant and control room, from which all boreholes are monitored and controlled.

The scheme currently supplies a population of about 4,000 in addition to the Aghada power station. Daily abstraction is about 2,400 cubic metres. The water is chlorinated and fluoridated.

2. History of Development and Summary of Well Details

The Cloyne-Aghada sources have a complicated history. The boreholes were constructed in three phases:

Phase I was in 1973, when four boreholes were drilled for the proposed C.A.P. factory (later abandoned). These were at Commons East, Town Parks, Farrannamanagh and Whitewell Cross. The first three were very successful, while the last (Whitewell Cross) was abandoned as a failure. A shallow observation well was also drilled at Town Parks.

Phase II took place in 1976-78, when the Council were seeking a new water supply to serve the proposed Aghada power station. The three earlier boreholes were tested to confirm their reported yields, and new production wells and observation wells were drilled at additional sites at Lissanly and Castlemary, while another exploratory well was drilled at Carrigacrump and an observation well at Farrannamanagh. The Carrigacrump well was never brought into production because of fears of contamination from the quarry and cave system nearby.

Finally, in Phase III, a new production well and observation well were drilled at Commons East in 1980.

The Castlemary borehole was used for a time but use was discontinued in 1985 because of excessive sediment.

Summary details of the production wells and observation wells are presented in Table 1.

Table 1. Summary of Well Details

BH No.	1	2	3	4	5	6
Townland	Commons East	Town Parks	Castlemary	Lissanly	Carriga-crump	Farranna-managh
GSI Well No.	1705NEW356	1705NEW001	1705NEW336	1705NEW354	1705NEW057	1705NEW055
Depth, m	45.7	52	39.6	61	30.5	61
Diameter, mm	305	203	203	203	152	203
Casing, m	19.8 plain; 25.9 screen	2.7	21.6	2.4	1.5	18.3
Date drilled	April 1980	Nov 1973	Jan 1978	Jan 1978	Nov 1976	Nov 1973
Pumped?	Yes	Yes	No	Yes	No	Yes
Obs. well?	Yes	Yes	Yes	Yes	No	Yes
GSI Well No.	1705NEW337	1705NEW338	1705NEW335	1705NEW355	-	1705NEW357
Depth, m	?	21.3	46.4	31	-	30.5
Diameter, mm	152	152	152	152	-	152
Date drilled	March 1980	Nov 1973	Jan 1978	Jan 1978	-	Jan 1978
Previous well	Yes	No	No	No	No	No
GSI Well No.	1705NEW002	-	-	-	-	-
Depth, m	14	-	-	-	-	-
Diameter	200	-	-	-	-	-
Casing, m	14	-	-	-	-	-
Date drilled	Nov 1973	-	-	-	-	-
					-	

3. Methodology

4.1 Desk Study

Bedrock geology information was compiled from the published GSI 1:100,000 Bedrock Series (Sheet 25), (Sleeman & Pracht, 1994). Subsoil data were compiled from limited subsoil information available for the area from the GSI's Quaternary Section unpublished maps. Borehole details such as depth, elevation, abstraction and yield test data were obtained from GSI records and Council personnel.

4.2 Site Visits and Field Work

This included well surveys. Water samples for chemical and bacteriological analysis were taken in April and September 1999. A numerical model (using MODFLOW) was constructed by Mark Conroy (MSc Hydrogeology Course, University of Birmingham, UK) to aid in the conceptualisation of the hydrogeology. Vulnerability assessment, including the drilling of continuous-flight auger holes, was undertaken in 2001 during Phase 2 of the Groundwater Protection Project.

4.3 Assessment

Field studies, the numerical modelling, and a knowledge of the flow regime in the area were utilised to delineate protection zones around the public supply well.

5. Topography& surface hydrology

The topography of the area is controlled by the geology. The high ground to the north of Cloyne reaches a maximum elevation of 110 m O.D., the hills to the south of Cloyne reach 90 m O.D., while the ridge south of Carrigacrump reaches about 72 m O.D. These ridges represent the remnants of an old erosion surface (possibly of Cretaceous age) gradually falling towards a former coastline.

In the Cloyne valley a maximum elevation of 30 metres O.D. is recorded near the town, and this gradually falls to sea level at the coast. Topographic lows, along the edges of the limestone, are due to preferential erosion of the softer shales and shaly limestones in that area. This has led to an unusual topography where elevations are higher in the middle of the valley than at the sides.

Cloyne town stands at the catchment divide separating drainage going east (into Cork Harbour) and west (into Ballycotton Bay). Owing to the karstic environment, there is little surface drainage in the middle of the valley, and the streams flow in the lower ground at the foot of the hills on either side of the valley. West of Cloyne, several springs rise, including White Well and Dick Neill's Well on the south side. A spring rising in Commons West townland flows eastward and eventually disappears into Cloyne Cave. East of Cloyne, two main streams drain the north and south sides of the valley.

The Carrigacrump valley has a simpler shape, and a valley bottom elevation which falls from about 30 m at its upper end (Ballyfin townland) to 5 m at its lower end (by Titeskin Church). A single stream, rising in Ballyfin, drains the valley, then turns northwest to join the Whitewell stream and reach the sea at Rostellan.

For a short period in 1976, a v-notch weir was maintained on this stream near Titeskin bridge. Flow on 28/8/76 (near the end of a very dry summer) was about 9.7 lps or 940 m^3/d.

6 Geology

6.1 Bedrock geology

6.1.1 Geological succession

Formation	Code	Description	Occurrence
Cork Red Marble Formation	CK	Red brecciated calcilutite limestone	In a narrow strip west of Cloyne
Waulsortian Limestone	WA	Massive unbedded fine-grained limestone	Throughout the Cloyne & Carrigacrump valleys
Kinsale Formation, Cuskinny Member	KNcu	Sandstone & mudstone	Most of ridge south of Cloyne valley; small areas north of Cloyne and south of Rostellan
Old Head Sandstone Formation	OH	Sandstone & minor mudstone	Margins of ridge south of Rostellan; south of Carrigacrump valley
Gyleen Formation	GY	Green sandstone, siltstone & mudstone	Southern slope of Great Island Ridge
Gyleen Formation, Ballyknock Member	GYbn	Green sandstone, siltstone & mudstone	Ridge south of Carrigacrump valley; Ridge south of Rostellan
Ballytrasna Formation	BS	Purple mudstone with some sandstone	Underlies centre of Great Island Ridge

The production boreholes all abstract water from the Waulsortian Limestone. The bedrock geology is presented in Map 1.

6.1.2 Geological Structure

The dominant influence of the geological structure was the Variscan Orogeny (mountain-building event). The rock formations are folded into anticlines and synclines, with approximately West-East axes. The rocks are also broken by a strong system of steeply-dipping cross faults running approximately NNW-SSE, or roughly at right angles to the fold axes. The faulting has generally resulted in moving the rocks on the east side of each fault a little way to the south (i.e. they are dextral wrench faults). There are also other faults roughly parallel to the fold axes.

The Carrigacrump area is mapped as a fault-bounded trough ("graben").

6.2 Subsoil geology

6.2.1 Subsoil types

Subsoil types identified in the area on the 1905 Drift Map of Cork are Till, Gravel and Alluvium. In addition, it is convenient to include with the subsoil descriptions some deposits of silica sand and colloidal ('Colbond') clay, although these are much older than the Quaternary deposits.

Till

⇒ Ballycroneen Till: This is described as a massive grey-brown diamicton, rich in clay and silt. It is restricted to low-lying areas, and is probably derived from ice moving down the Irish Sea.

⇒ Garryvoe Till: This is characterised by fragments of Devonian sandstone and shale, with some Carboniferous limestone, shale and chert, in a red-brown matrix. Derived from ice moving from the west. Overlies the Ballycroneen Till at Ballycotton Bay.

Gravel

The Cloyne Esker runs on a sinuous path westwards from Cloyne to the coast at Saleen. Other small patches of gravel lie just north and northeast of Rostellan. The first Commons East borehole encountered 13 metres of gravel, probably filling in a small hollow in the limestone. None of these gravel occurrences is considered large enough to constitute a local gravel aquifer.

Alluvium

Small tracts of alluvium occupy the lower ground near Rostellan and Saleen, near the coast.

?Tertiary Silica Sand and Jurassic ('Colbond') Clay

Small deposits of white clayey sand, and yellow, red & blackish colloidal lacustrine clay (given the proprietary name 'Colbond'), are found in small hollows in the karst limestone surface in the Cloyne & Rostellan areas.

The main 'Colbond' Clay Pits were in Lissanly and Spital townlands, within about 600 m north, south and southwest of the Lissanly borehole. The deposits have also been identified in places in Lurrig, Aughane, Crocane and Kilboy townlands. The deposits were worked in the 1930s, 1940s and early 1950s by the Cloyne Mineral Company, and some later trials took place between 1954 and 1960.

The Silica sands are more extensive and have been found in Rostellan, Ballydwyre, and Castlemary townlands as well as those mentioned above. The origin and age of the silica and clay deposits are still in doubt. Some silica deposits in the area exhibit features (relict bedding and veins) indicating that they resulted from deep in-situ weathering of silica-rich layers in the limestone, apparently near the base of the limestone succession. However, other deposits are clearly re-deposited in karstic hollows

in the limestone. The Jurassic-aged plant spores found in the Colbond clay indicate that this re-working of the material occurred in the Jurassic, rather than in the Tertiary Period as previously thought. This demonstrates that karstification of the limestone is very old.

6.2.2. Depth to bedrock

Subsoil cover over rock is quite thin over much of the area around Cloyne Town, but very variable on the karst limestone surface further away from the town. The original Commons East borehole penetrated at least 14 m of gravels, and later (unsuccessful) boreholes close by encountered up to 17 m of gravel. However, later boreholes in the same field found only a few metres of gravel above limestone.

The thickness of the silica sand and clay deposits is variable. Records of several hand-bored exploratory holes indicate silica sand thicknesses of at least 6 metres. The Colbond clay is said to be 1.8 to 4 metres thick (Higgs & Beese 1986), and covered by 3-5 m of gravelly till. Two old silica pits in Lissanly and Aughane were over 9 m deep, but this was probably in-situ silica. Hand-borings in Lurrig were a maximum of 6 m deep. At Rostellan, silica was found in pits up to 7.6 m deep, and was said to have been proven to a depth of 16.8 m, but again at this depth the material was probably in-situ weathered rock. The adjacent Lissanly and Spital pits were worked to a depth of at least 12 m and the deposit was overlain by 1.2 to 3 m of subsoil.

The Farrannamanagh observation borehole met 18 m of till above limestone.

7 Rainfall, Evapotranspiration and Recharge

7.1 Rainfall

Long term average annual rainfall (P) is estimated at 1100 mm (Met Eireann).

7.2 Evapotranspiration

Long term average annual actual evapotranspiration (AE) is estimated at 500 mm (EPA).

7.3 Recharge

Long term average annual potential recharge is (1100 – 500) 600 mm. From the absence of surface drainage in the central valley area it appears that most potential recharge actually infiltrates to the water table.

8 Water Quality

8.1. Data availability

A number of analyses were available for each of the original boreholes in the scheme, from the pumping tests carried out in the late 1970s. Each of the boreholes in current use was again sampled in the project sampling rounds of April and September 1999. Apart from these, most of the available data are for mixed samples, and therefore of limited value in the context of this report.

8.2 Nitrate

Nitrate levels in water from the Cloyne-Aghada sources have given some cause for concern although there have been no known breaches of the MAC of 50 mg/l. Average nitrate levels have been consistently above 25 mg/l in recent years.

Most analyses have represented mixed samples from more than one borehole. The sampling undertaken for this project revealed significant differences between the nitrate levels at different boreholes:

From these two sampling rounds it appears that Commons East has the lowest nitrate level and Lissanly the highest. The nitrate content of a mixed sample will depend to a considerable extent on which boreholes have been pumping prior to sampling.

Table 3: Nitrate concentrations, Cloyne boreholes

Date / Borehole	14 April 1999	14 September 1999
Commons East	19.1	20.9
Town Parks	26.2	28.3
Farrannamanagh	30.7	31.4
Lissanly	34.2	38.2
mean	27.55	29.70

The difference in nitrate level between the boreholes may be related to differences in local land use. In former times, there was a landfill not far from the Lissanly borehole, which may still be a source of slowly percolating nitrate. Town Parks is close to the town, whereas Commons East is a good distance outside the town. It may also be significant that the Commons East borehole had the highest specific capacity.

8.3 .... Nitrite and Ammonia

Nitrite and ammonia levels recorded in the April and September 1999 sampling rounds do not give cause for concern.

8.4 Bacteria

Bacterial counts for raw water samples from all four boreholes sampled in April 1999 were zero except for the Town Parks borehole, which recorded a total coliform count of 20 and E. *coli* count of 3. In the September 1999 samples only the Commons East borehole was clean; the other three showed substantial counts of total coliforms and E. *coli*, with Town Parks again being the most contaminated.

8.5 Potassium

Potassium levels and potassium:sodium ratios in water from the Town Parks borehole are substantially above normal and confirm a degree of contamination.

8.6 Other inorganic parameters

Electrical conductivity averages about 600 μS/cm. The water is hard (c. 240 – 270 mg/l as $CaCO_3$). Chloride concentrations are fairly normal for South Cork groundwater.

9 Hydrogeology

9.1 Aquifer

The limestone bedrock at Cloyne is of the Waulsortian Limestone Formation and is classified as a **Regionally Important karst Aquifer (Rk)**.

The sandstone/mudstone rocks which underlie the upland ridges between the limestone valleys are classified as Locally Important Aquifers, moderately productive only in local zones (**Ll**).

9.2 Karst features

Karst features are prominent in both the Cloyne and Carrigacrump synclines (see references). The main features are:

- Cloyne Cave, the most extensively developed cave in South Cork, comprises a complex series of tunnels (a 'maze'), aligned roughly north-south and east-west, underlying an area of 7-8 acres beneath Cloyne House. There have been some moves towards developing this cave as a 'Show Cave'. A small stream disappears into the entrance.
- Shanagarry sink and rising, where a small stream disappears into a low limestone cliff and reappears about 100 metres east, considerably augmented.
- Carrigacrump Quarry Caves, partly destroyed by quarrying (both in the past and more recently) for cut stone. There are several caves in this complex, of which the largest is the 'Lake Cave' which contains water to a plumbed depth of 15 metres.
- Ballyfin Cave, in a small limestone outcrop, east of Carrigacrump.

9.3 Pumping tests

Numerous pumping tests have been carried out on the Cloyne boreholes at different times. The data are given in detail in Appendix 1. In addition, the detailed water level records from several of the observation wells during long periods of continuous pumping have been analysed to obtain confirmation of the aquifer properties.

Analysis and interpretation of the tests are complicated by a number of features:

- The original borehole at Commons East was fully cased, i.e. water could only enter the borehole at the bottom.
- The aquifer at Farrannamanagh and Carrigacrump is very narrow, leading to 'barrier boundary' effects as the cone of depression expands to meet the aquifer boundaries.

The aquifer is much more permeable within its upper few metres than further down. This is most pronounced at Lissanly, where the drawdown in the nearby (18 m) observation well is about 10 times as great in summer as in winter, in response to a change in water table of about two metres. Results from the Town Parks and Castlemary sites show lesser degrees of variation, while Farrannamanagh shows little change.

9.4 Aquifer properties

Pumping tests on the Cloyne-Aghada boreholes indicate quite a range of aquifer properties, with apparent transmissivities of about 200 to over 2000 m^2/day, and specific yields of a few (1-4) percent. The highest confirmed transmissivity is at Commons East, which may be due to the proximity of a strong north-south fault. The Farrannamanagh borehole also showed a very high transmissivity, although the pumping test analysis is complicated by the limited width of the aquifer, which constrains the cone of depression and increases the drawdown during pumping. The relatively lower transmissivities shown at the other boreholes may be attributable to the presence of fewer faults/fractures, or to lithological differences, or both.

9.5 Groundwater levels and gradients

9.5.1 Cloyne Syncline

The natural water table around Cloyne town, as evidenced in the observation boreholes, ranges from about 23 metres O.D. in winter to 19 metres O.D. in summer. Three other wells in the limestone (mainly dug wells formerly serving hand pumps) were monitored between 1976 and 1979, and another (Ballyduff) has been continuously monitored since 1976. Three lie to the east of Cloyne and one to the west. (Figure 3). The area around Cloyne town straddles the groundwater divide. From here,

groundwater moves both eastward (towards Ballycotton Bay) and westwards (towards Cork Harbour). The groundwater divide appears to lie about one kilometre to the east of the Commons East borehole.

To the east of the divide, the fall in water level from Ballybranagh (dug well) to Ballyduff (dug well) varies from approximately 3.5 to 3 m (winter to summer), giving a gradient (over a distance of 1500 metres) varying from 0.0023 to 0.002.

To the west of the divide, the fall in water level from Lissanly (borehole) to Lurrig (dug well) varies from approximately 6 to 12 metres (winter to summer), giving a gradient (over a distance of 1300 metres) varying from 0.0045 to 0.009.

The steeper gradient west of Cloyne is probably due to the existence of a group of springs (including 'White Well' and Dick Neill's Well') which provide a discharge zone at an elevation of about 7 m O.D. and hence draw down the water table down-gradient of Lurrig. To the east of Cloyne, the topographic gradient is gentler, and groundwater discharge from the limestone is probably impeded by a layer of glacial sediment.

Discharge measured from White Well (by a v-notch weir) in 1976 (26/8/76) was 7.7 lps (660 m^3/d)

An interesting feature revealed by the water level monitoring is that the Town Parks and Commons East boreholes exhibit tidal fluctuations of several centimetres.

9.5.2 Carrigacrump Syncline

Water level records are available for three wells in this valley: Farrannamanagh observation well (12.0 m. to 10.5 m. O.D.), a dug well at Ballyfin, about 1200 m up-gradient (30 m to 25 m O.D., 1976-79) and the Carrigacrump borehole, some 500 m down-gradient of Farrannamanagh (normally 0.25 to 0.5 metres below that at Farrannamanagh). These levels suggest that the groundwater gradient above Farrannamanagh (c. 0.012 – 0.015) is much steeper than below (0.0005 – 0.001), but the water table in the Ballyfin well may be perched. The aquifer transmissivity inferred from pumping tests at Farrannamanagh and Carrigacrump is certainly more consistent with a low gradient.

Water level monitoring of the Carrigacrump borehole from 1977 to 1999 indicates an overall decline in the water table of about 0.5 m, which may be attributable to the groundwater abstraction at Farrannamanagh. While not a cause for concern, this does indicate that this monitoring should be recommenced.

10 Conceptual Model

10.1 Cloyne Syncline

The groundwater beneath the town can come from three sources:

- direct recharge from rainfall
- infiltration of surface water runoff from the adjacent upland ridges, notably via the stream which sinks into the Cloyne Cave.
- subsurface flow into the limestone aquifer from neighbouring formations

Each of these has different implications for groundwater protection.

Given that the neighbouring formations have much lower permeabilities, and that the boundary between them and the limestone coincides with a topographic low, it is likely that subsurface inflow into the limestone from this source is small.

If annual average recharge is estimated at 500 mm, and designated abstraction rate is taken as 3600 m^3/d (allowing for a 50% increase in current abstraction), the catchment area required is approximately 2.6 km^2.

Most of the water abstracted is exported out of the catchment (to the Aghada power station), thereby reducing the return of water to the hydrologic system (e.g. via sewerage, irrigation returns, etc.).

The numerical modelling confirms that the Cloyne boreholes lie near the groundwater divide across the Cloyne syncline. This means that the ZOC occupies the central part of the syncline and extends downstream as far as the estimated null point for the furthest boreholes down-gradient (i.e. Lissanly and Commons East).

10.2 Carrigacrump Syncline

The entire surface water catchment above the bridge near Titeskin church is approximately 4 km^2. All the effective rainfall from this catchment either recharges the aquifer of flow out via the stream. The normal abstraction rate is 1080 m^3/d, which would require a ZOC of approximately 0.8 km^2.

11 Groundwater Vulnerability

11.1 Subsoil thicknesses

The limited borehole data indicate that subsoil thicknesses are very variable, from almost zero to well over ten metres, and that lateral changes can be very sharp.

11.2 Subsoil permeabilities

There is no evidence of low permeability subsoil overlying the limestone aquifer, so the assumption is made that the tills are of moderate permeability and the sand & gravel deposits have a high permeability.

11.3 Water table depth

Extensive groundwater level monitoring undertaken by GSI and the Council since 1976 has shown that the water table in the Waulsortian limestone fluctuates seasonally from about 23 metres O.D. in winter to 19 metres O.D. in summer in the Cloyne area, and from about 11.5 m. O.D. to 9.5 m. O.D. in the Carrigacrump Syncline.

11.4 Vulnerability assessment

Three vulnerability classes have been delineated, i.e. ‘Extreme’ ‘High’ and ‘Moderate’.

In general, the till appears to have a moderate permeability, and there are no areas of ‘Low’ vulnerability.

12 Groundwater Protection Zones

12.1 Zone of Contribution (ZOC)

12.1.1 Cloyne Valley

As noted above, the required ZOC is estimated at 2.6 km^2 if the entire supply is pumped from this syncline. However, it is possible to delineate a topographic/hydrologic catchment of approximately 7 km^2 which could contribute to the sources.

To estimate the eastern downstream limit of the ZOC, the following parameters have been assumed:

Abstraction		3600 m^3/d
Permeability (K)		20 m/d (derived from modelling by Conroy (1997)
Saturated aquifer thickness		20 metres
Groundwater gradient		0.0015
Null point downstream	=	$Q/(2\pi.k.b.i)$
	=	$3600/(2\pi \times 20 \times 20 \times 0.002)$
	=	716 metres

To estimate the western downstream limit of the ZOC, the following parameters have been assumed:

Abstraction		3600 m^3/d
Permeability (K)		20 m/d (derived from modelling by Conroy (1997)
Saturated aquifer thickness		20 metres
Groundwater gradient		0.003
Null point downstream	=	$Q/(2\pi.k.b.i)$
	=	$3600/(2\pi \times 20 \times 20 \times 0.003)$
	=	480 metres

Thus the ZOC is estimated to extend approximately 500 metres down-gradient to the west from the boreholes at Lissanly and Castlemary and 700 metres down-gradient to the east from the Commons East borehole.

Up-gradient from the wells, the catchment extends up to the groundwater divide, and up the hillside on either side of the valley, as far as the summit ridges. To derive the final proposed Source Protection Areas, however, the maximum 'null point' has been extended across the valley in a straight line to the boundary of the limestone, and then the upland catchment to that part of the valley has been delineated. This gives an area on the limestone of about 3.5 km^2, and a total catchment area of about 3.5 x 2 km = 7 km^2.

12.1.2 Carrigacrump Valley

The total catchment area above the Carrigacrump observation well is approximately 2.7 km^2. The area of aquifer is about 0.75 km^2.

12.2 Inner Source Protection Area (SI)

The Inner Protection zone is normally defined by the 100-day time-of-travel zone to each groundwater source. However, in karst areas groundwater can move relatively quickly. Therefore, in the Cloyne and Carrigacrump areas it is deemed prudent to designate as the SI zone all the ZOC within the karst limestone. This gives an area of about 3.5 km^2 in the Cloyne Valley and 1 km^2 in the Carrigacrump Valley. In the Cloyne area it is also proposed to include in the SI area a 30-metre buffer zone along the stream which enters Cloyne Cave, as shown on Map 3.

12.3 Outer Source Protection Area (SO)

This encompasses the remaining areas of the two catchments, as shown in Map 3.

12.4 Source Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories), i.e. by superimposing the vulnerability map on the source protection area map. This gives a possible total of 8 source protection zones (see the matrix in the table below). Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. Only six groundwater protection zones have been delineated around the Cloyne boreholes (Map 3), as shown in the matrix below.

Matrix of Source Protection Zones

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

The response measures imposing restrictions on certain developments and activities within these zones are included in “Groundwater Protection Schemes”, published by DELG, EPA and GSI in 1999. These measures indicate the degree of restriction recommended in each protection zone.

13 Land Use and Potential Pollution Sources

The main land use in the area is farming of dairy and beef cattle, and the normal activities of a small urban area in Cloyne town. There are small areas of forestry in the west of the area and some marshy land near the coast which is covered in reeds.

There is an old landfill in one of the abandoned Colbond/silica sand pits in Lissanly townland, near the Lissanly borehole.

The principal hazard is probably the stream which disappears into the Cloyne Cave.

The Cloyne sewage treatment (STP) works is located due west of Cloyne town, about 250 m northwest of the Town Parks borehole and 430 m northeast of the (unused) Castlemary borehole. The STP discharges to a small west-flowing stream.

As in all urban areas, it must be assumed that Cloyne town contains a number of potential or actual hazards, ranging from leaking sewers and soakaways to small workshops and garages with their attendant risks of spillages and leakages, particularly of hydrocarbon products.

14 Conclusions and Recommendations

- The Cloyne-Aghada Water Supply Scheme comprises five boreholes, of which four are in use.
- Three of the pumping boreholes are in the Cloyne area, while one (Farrannamanagh) is in the neighbouring valley about 3 kilometres south-southwest of Cloyne.
- The limestone aquifer is classified as a regionally important karst aquifer (Rk).
- Water quality from some of the boreholes can be significantly contaminated and requires treatment. The Commons East borehole appears to provide the best quality water, while the Lissanly and Town Parks boreholes are the least good.
- The inner and outer 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:
- raw water samples should be taken from each borehole individually in addition to sampling of mixed waters. This will enable problems to be seen at the earliest opportunity. Otherwise, mixed sampling will allow problems to be masked until they become more serious.
- chemical and bacteriological analyses of raw water should be carried out on a regular basis (every month). The chemical analyses should include all major ions – calcium, magnesium sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate.
- particular care should be taken with any activities or developments which might significantly increase nitrate levels or cause contamination at the source.
- the potential hazards in the Zone of Contribution should be located and assessed.
- interim guidelines should be drawn up for dealing with underground petroleum storage/transfer, and spillages along the roads in the area.
- Given the inevitable hazards which arise in an urban area such as Cloyne, the Council should consider seeking new borehole sites in areas less prone to such contamination, in order to replace the Town Parks and Lissanly boreholes.

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Appendix 1

Water Quality Data

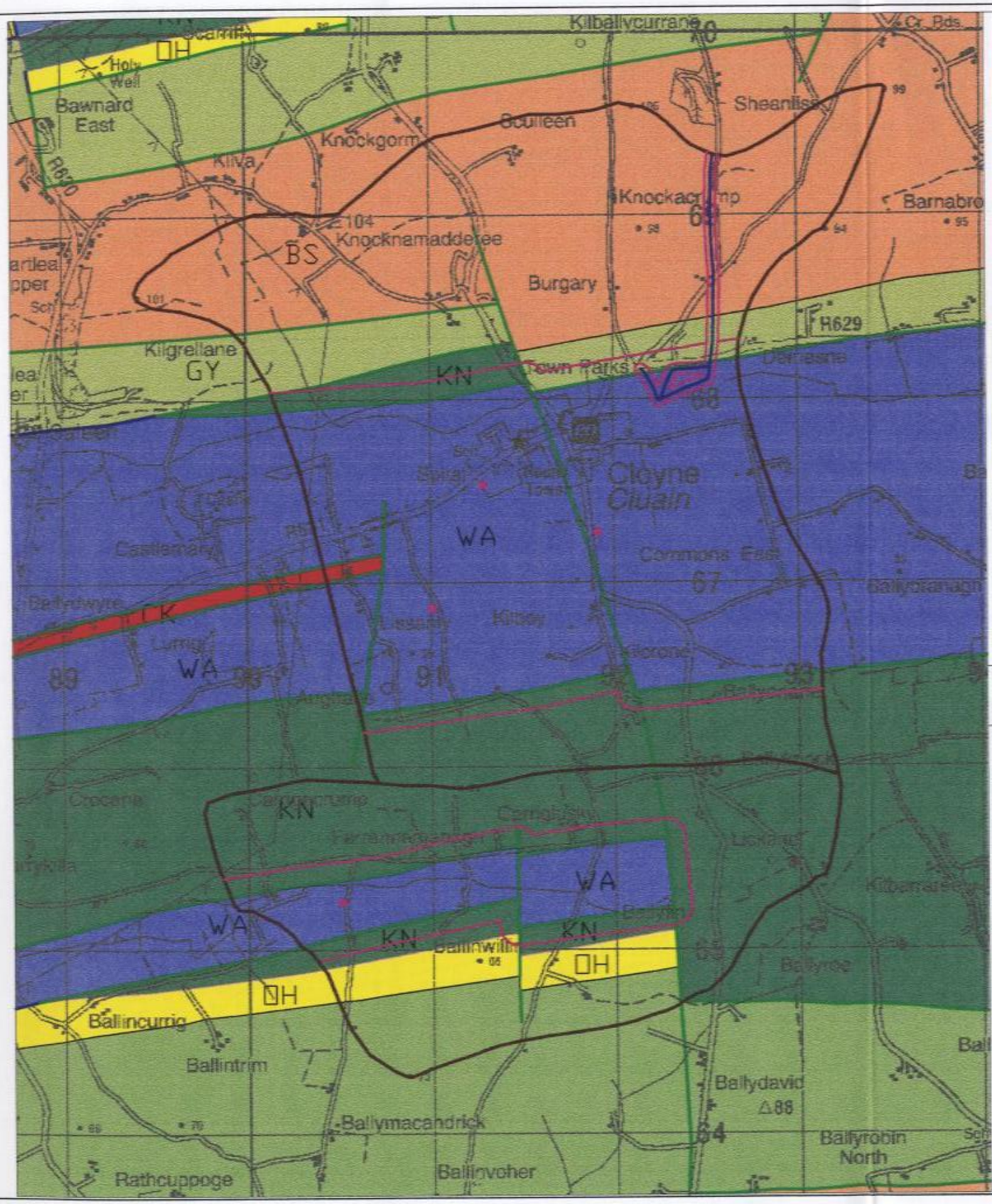
Water quality analyses, Cloyne boreholes

Greater than Guide levels
Greater than MAC levels

Location	Lab	Well No.	Date	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l	TDS mg/l	E.C. Lab uS/cm	pH Lab	Ratios K:Na	Ratios Mg:Ca
				200	50	150	12		250	250		1500			
Commons East	IIRS	1705NE W356	28/7/1977	276	46	16.3	1.8		16.8	35		530	7	0.11	0.17
Commons East	Inniscarra		14/4/1999	107.3	7.6	18.2	1.6		16	35.7		806	7.4	0.088	0.0708
Commons East	Inniscarra		14/9/1999	114.04	8.22	19.27	1.65		18.8	33.4		644	7.4	0.086	0.0721
Town Parks	AFT	1705NE W355	25/7/1977	112	5.1	14.3	1.64		29.1	27		690	7.3	0.11	0.05
Town Parks	Inniscarra		14/4/1999	111.9	9.6	23.2	16.6		27.7	37.5		617	7.3	0.716	0.0858
Town Parks	Inniscarra		14/9/1999	117.4	10.96	25.49	13.01		31.4	35.3		696	7.5	0.510	0.0934
Lissanly	IIRS	1705NE W354	16/1/1978	248	46	32			23.2	42		466	7.5	0.00	0.19
Lissanly	Inniscarra		14/4/1999	118.3	8.1	18.4	1.6		16.1	40.4		633	7.3	0.087	0.0685
Lissanly	Inniscarra		14/9/1999	123.22	9.85	19.52	2.03		19	37.4		688	7.3	0.104	0.0799
Farrannamanagh	AFT	1705NE W357	9/6/1977	91	10.9	16.1	1.74		9.4	26.6			7.6	0.11	0.12
Farrannamanagh	Inniscarra		14/4/1999	102	12.7	19.5	2.2		17.9	42.3		644	7.3	0.113	0.1245
Farrannamanagh	Inniscarra		14/9/1999	106.32	13.89	20.58	2.37		20.7	39		644	7.4	0.115	0.1306
Cloyne (mixed)	Inniscarra	1705NE W354-357	13/3/1995			0	0		18	38		592	7.6		
Cloyne (mixed)	Inniscarra	1705NE W354-358	13/3/1995						18	38		589	8.0		
Cloyne (mixed)	Inniscarra	1705NE W354-357	28/4/1998									619	7.6		
Cloyne (mixed)	Inniscarra	1705NE W354-357	15/9/1998									623	7.6		

Water quality analyses, Cloyne boreholes

	Other Commonly Analysed Parameters								*Bacteria*		*Turb*				*metals*		
	Alk.	TH	Fe	Mn	Nitrite	Nitrate	NH4	Al	E.coli	TC	Lab	PO_4	F	Cu	Pb	Zn
	mg/l CaCo3		mg/l	mg/l	NO2	NO3	mg/l	mg/l	no/100ml		NTU	mg/l	mg/l	mg/l	mg/l	mg/l
			0.2	0.05	0.1	50	0.23	0.2	0	0	4		1	0.5	0.05	1
Commons East	269	322	<0.1			3.1								<0.02	<0.1	<0.01
Commons East		299	<0.05	<0.05	<0.013	19.1	<0.026		0	0		0.025		<0.04		<0.05
Commons East	248	317.7	0.16	<0.05	<0.013	20.9	<0.026		0	0		<0.01		<0.02		<0.05
Town Parks	265	304	0.14			7										
Town Parks		319	<0.05	0.05	<0.013	26.2	<0.026		3	20		0.027		<0.04		<0.05
Town Parks	270	337.4	<0.1	0.06	<0.013	28.3	<0.026		79	>120		<0.01		<0.02		<0.05
Lissanly	225	294	0.1			2.5								<0.02	<0.1	<0.05
Lissanly		329	<0.05	<0.05	<0.013	34.2	<0.026		0	0				<0.04		<0.05
Lissanly	268	347.3	<0.1	<0.05	<0.013	38.2	<0.026		8	22		<0.01		<0.02		<0.05
Farrannamanagh	262	282	0			17.4										
Farrannamanagh		307	<0.05	<0.05	<0.013	30.7	<0.026		0	0				<0.04		<0.05
Farrannamanagh	241	321.8	<0.1	<0.05	<0.013	31.4	<0.026		18	29		<0.01		<0.02		<0.05
Cloyne (mixed)	262	268	0.1	0.025	0.003	27.14	0.102	0.05	0	0	0	0.039	1.04	0.1	0.01	0.05
Cloyne (mixed)	263	298	0.1	0.025	0.003	26.94	0.085	0.04	0	0	0	0.01	1.03	0.1	0.01	0.05
Cloyne (mixed)					0.01	31.4	0.02		0	0	0.11		0.8			
Cloyne (mixed)					0.013	31.96	0.02		0	0	0.09		0.9			



Cloyne-Aghada Water Supply Scheme

Map 1. Geology

- KN — Kinsale Formation
- OH — Old Head Sandstone Formation
- CK — Cork Red Marble Formation
- WA — Waulsortian Limestones
- GY — Gyleen Formation
- GYbn — Ballyknock Member
- BS — Ballytrasna Formation

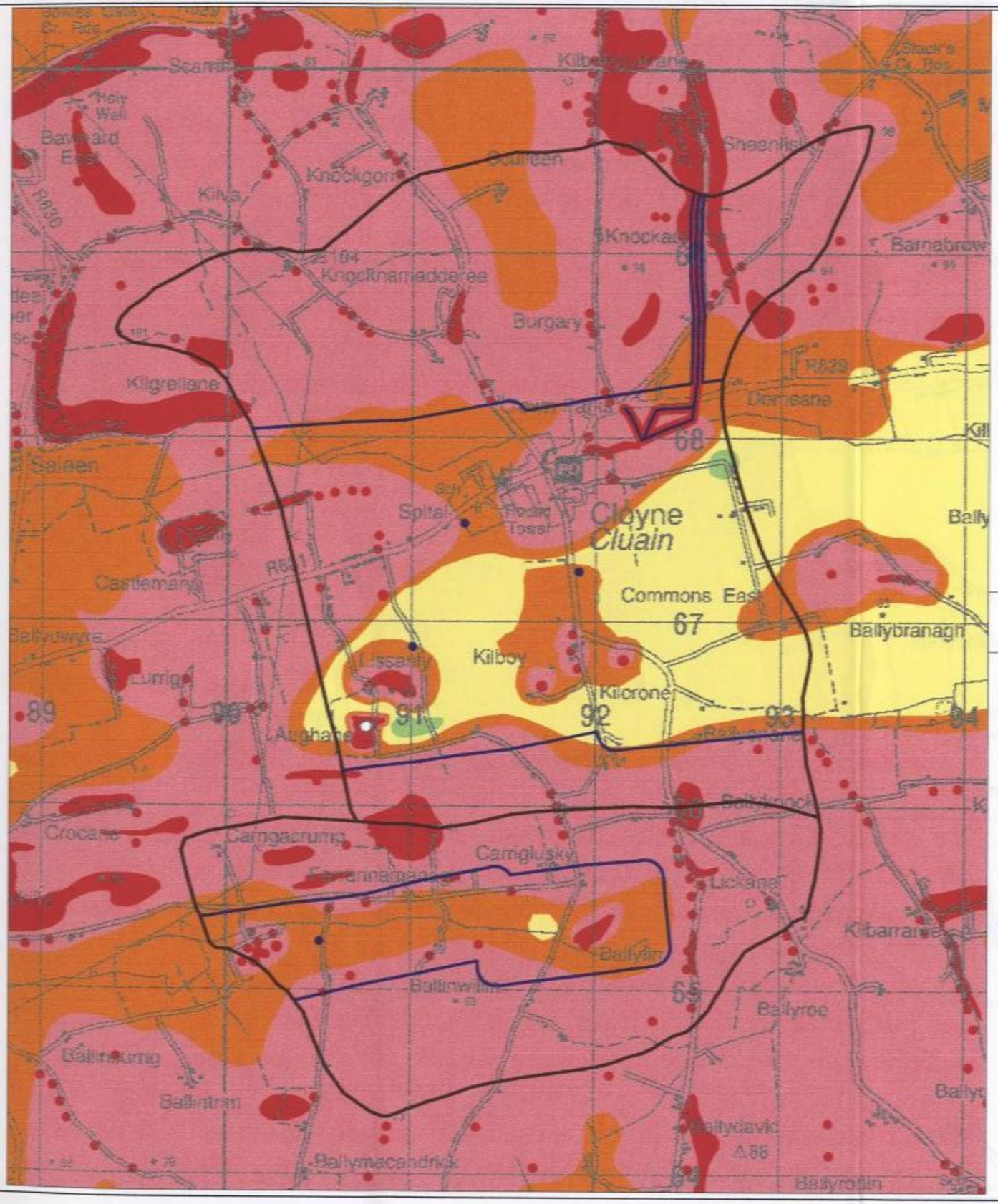
- Fault
- Public Supply Well
- Inner Protection Zone
- Zone of Contribution
- Stream

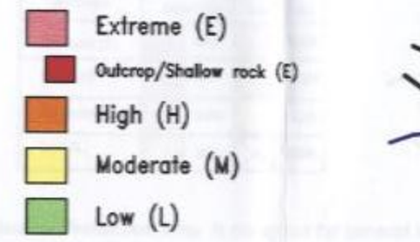
This Bedrock Map is designed for general information and stragegic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale.
Evaluation of specific sites and circumstances will normally require further and more detailed assessments,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

0 500m 1 km

Cloyne-Aghada Water Supply Scheme

Map 2. Groundwater Vulnerability

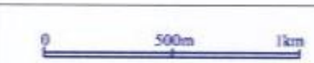




Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

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 assessements, and will frequently require site investigations to determine the risk to groundwater.



Cloyne-Aghada Water Supply Scheme

Map 3. Source Protection Zones

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

Public Supply Well

Inner Protection Zone

Zone of Contribution

This **Source Protection Map** is designed for general information and stragegic 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 500m 1km