DUNGARVAN PUBLIC SUPPLY

GROUNDWATER SOURCE PROTECTION ZONES

Prepared by:

Colette Cronin, Donal Daly and Robert Meehan
Geological Survey of Ireland

Assisted by:

Paul Johnston, Trinity College Dublin, Jer Keohane, Geotechnical and Environmental Services and
Donal Mc Daid, formerly TCD & GSI.

June 1998

DUNGARVAN PUBLIC SUPPLY

1. Summary of Well Details

GSI no.	:	2009SE W069, W070, W071, W072.			
Grid ref. (1:25,000)	:	22365 09462			
Townland	:	Ballinamuck			
Owner	:	Dungarvan UDC			
Well type	:	Four bored wells			
Borehole No.	**:**	**Well 1**	**Well 2**	**Well 3**	**Well 4**
Elevation (m O.D.)	:	5.978	5.99	5.903	6.532
Depth (m)	:	12.7	12.7	27.5	24.2
Diameter (m)	:	n/a	n/a	0.52	0.52
	:	n/a	n/a	(0 - 16 m)	(0.44)
	:	n/a	n/a	0.44	(0 - 24.2m)
	:	n/a	n/a	(0 - 27.4 m)	n/a
Depth-to-rock (m)	:	12.1	12.1	11.8	n/a
Static water level (m bgl)	:	1.14	0.52	n/a	4.57
Drawdown (m bgl)	:	2.9	2.9	2.9	2.9
Abstraction Rate	:	(Combination of two pumps can yield up to 9800 m^3/d)			
Normal consumption	:	5450 m^3/d			
Pumping test summary:		(i) abstraction rate : 7194 m^3/d (seven day constant rate test)			
		(ii) transmissivity : 900 - 13,000 m^2/d			

2. Methodology

There were three stages involved in assessing the area: a detailed desk study, site visits and fieldwork, and analysis of the data. The desk study was conducted in the Geological Survey where bedrock geology information were compiled from the GSI report and map of Sheet 22 (Sleeman & McConnell, 1995). Well details, such as borehole geometry, elevation and abstraction rate, were obtained from Waterford County Council.

The second stage comprised site visits and fieldwork in the Dungarvan area. This included a walkover survey in order to further investigate the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and the current pollutant loading. Robert Meehan mapped the subsoil types and assessed depth to bedrock throughout the area. Advice on numerical modelling was provided by Paul Johnston.

Stage three, the assessment stage, utilised analytical equations, hydrogeological mapping and numerical modelling to delineate protection zones around the public supply well.

3. Topography, Surface Hydrology and Land use

Dungarvan is located in a broad east-west trending and steep sided valley. Land to the north rises to an elevation of 600 m and to the south to an elevation of 300 m. The Ballinamuck Source is situated in the northern part of the valley which is relatively flat although it is hummocky in places where thicker till deposits occur.

The Dungarvan area is bounded to the east by the River Blackwater and to the west by the sea. The Colligan River which runs directly north of the public supply well, drains the steep slopes of the Monavullagh Mountains to the north of Dungarvan. The River Brickey runs along the southern margin of the valley and is largely fed by tributaries draining off the slopes of the Drum Hills. Both the Colligan and Brickey Rivers flow into Dungarvan Harbour. In general drainage density is higher on the sandstone ridges and lower in the limestone valley. The soils and subsoils are relatively free draining. The land is grassland dominated and is largely used for grazing. There is little tillage in the area.

4. Background Information

The Ballinamuck Source is the main public water supply for the Dungarvan area. The source is located northwest of Dungarvan town on the site of the old Ballinamuck Woollen Mills, alongside the Colligan River.

The Ballinamuck source consists of four bored wells - Well 1 was an existing artesian borehole obtained from the Glue Factory by the UDC. Well 2 was drilled shortly after the UDC acquired the site. Wells 3 and 4 were drilled on the site in the mid 1980's.

The normal consumption is maintained by a combination of four wells. Due to problems with silt in well 4, this well is usually pumped in combination with any one of the others. The pumping system is connected via a rising main to a water tower reservoir (which is used for distribution only). A public supply well located at Springmount supplements the Ballinamuck source.

5. Well Head Protection

Wells 1 and 2 are protected by a steel cover while wells 3 and 4 are covered over by small chambers. The site is enclosed by a high fence and is well maintained. There are no major roads in the vicinity of the source.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the Dungarvan area is dependent on the deposition of different sediments during Carboniferous and Devonian times (over 300 million years ago) and on the subsequent folding of these sediments. The rock units in the area, which are shown in Figure 1, are as follows:

Age	**Formation**	**Thickness**
Carboniferous	Waulsortian Limestone	400 - 750 m
	Ballysteen Limestone	300 m
	Lower Limestone shale	73 m
Devonian	Ballyquinn rock unit	390 m
	Kiltorcan Sandstone unit	405 m
	Knockmealdown rock unit	n/a
	Ballytrasna rock unit	n/a

6.1.1 Devonian/Old Red Sandstone

The Ballytrasna rock unit is found within the anticlinal ridge to the south and contains the oldest rocks in the Dungarvan area. This unit comprises red to purple mudstones with subordinate pale red sandstones. These rocks are overlain by the Ballyquinn rock unit (part of the Gyleen rock unit). The Ballyquinn rock unit contains alternating thick grey and red medium grained sandstones with thick red mudstones.

The geology to the north of Dungarvan, on the flanks of the Monavullagh Mountains, comprises the Knockmealdown rock unit and Kiltorcan sandstone unit, which both contain thickly bedded sandstones, siltstones and conglomerates.

6.1.2 Lower Limestone Shale

This sequence is composed predominately of thick massive and cross laminated grey sandstones with minor mudstones.

6.1.3 Lower Carboniferous Limestones

This rock succession is subdivided into two formations, the Ballysteen Limestones and the Waulsortian Limestones. The Ballysteen Limestones consist of dark grey, fossiliferous limestones with grey partings. The Waulsortian Limestones are present in the core of the valley and are comprised of fine grained calcareous beds and coarser grained limestones. They are pale in colour, poorly bedded and often contain calcite filled cavities.

6.1.4 Structure

The rock units in Dungarvan have been deformed by folding during the Hercynian mountain building event. These rocks were compressed from north and south to produce an east-west trend to the current rock distribution and ultimately to the topography of the Dungarvan area. The softer, more soluble limestones are present in the fold trough (syncline), which corresponds to the valley. The harder, more resistant sandstones are present in the fold crest (anticline), which corresponds to the ridges north and south of the Dungarvan valley. Commonly associated with folding is jointing and faulting – there are several faults to the north of Dungarvan which have a north-south trend.

6.2 Quaternary (subsoils) Geology

The subsoils in the Dungarvan area are shown in Figure 2, and have been subdivided into sandy till, sands and gravels, alluvium and slope deposits (Meehan, 1997):

6.2.1 Sandy Till

These are the most extensive deposits in the Dungarvan area. They are best observed in ditches and field cuttings. They contain small limestone and sandstone clasts. The matrix is predominately sandy although it does contain some silt and clay.

6.2.2 Sands & Gravels

There is a flat terrace of sands and gravels stretching north-westward from Ballinamuck. The gravels are well sorted, horizontally bedded and contain some sand and silt beds in the lower few metres. These deposits are generally overlain by 1-2m of sandy till or alluvium. The true extent of these sands and gravels is not illustrated in the subsoils map, which only gives the uppermost Quaternary deposits.

6.2.3 Slope Deposits

These are present on the uplands north of Dungarvan (generally <1 m thick) and are clast dominated with a sandy matrix

6.2.4 River Alluvium

Alluvium consists of silts and clays deposited by streams. They are best seen on the banks of the River Colligan. Such areas are poorly drained and are vegetated by rushes and marshy plants. The

Ballinamuck Source lies on the southern edge of an alluvial flat, where the alluvial deposits are up to 6m thick (McDaid, 1994) and are underlain by sands and gravels. In the Ballylemon area, alluvial deposits are <2 m thick.

6.3 Depth-to-rock

Accurate information on depth to bedrock is based on outcrop information, well records and subsoil sections. Rock outcrops are visible along the valley floor particularly in the Ballyduff area where there is a large disused limestone quarry. Quaternary mapping in the general area suggests that the sandy till covering the upland areas is generally less than 3 m thick but is often greater than 10m in the valley floor. There is an extensive sand and gravel pit to the north-west of the Ballinamuck Source with exposed faces of up to 10m.

Depth to bedrock contours are shown in Figure 3. Subsoil thicknesses have been contoured at 3 m and 10 m intervals. The depth-to-rock is based on relatively few data points, however it can be refined as further depth-to-rock data become available.

7. Hydrogeology

7.1 Data availability

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

- A modelling study of the Dungarvan Limestone aquifer carried out by Donal McDaid, as part requirement for an M.Sc at Trinity College Dublin. Mr. McDaid was employed by the GSI and was assisted by Ms. Margaret Keegan, GSI and Mr. Pat Corbett, Waterford County Council. Much of the hydrogeological information used in this report was compiled as part of that study. Such information includes water level measurements and pumping test data.
- County Waterford Groundwater Protection Scheme, (Hudson *et al*, 1997).
- A project carried out by Sara Duffy on the Protection of Groundwater Resources in Co. Waterford.

7.2 Meteorology and Recharge

Rainfall data for the area are taken from a contoured rainfall map of Co. Waterford, based on data from Met Éireann. For 1951 - 1980, the mean annual rainfall (R) for the area was 1112 mm. Evaporation data for the area are taken from the national contoured map produced by Met Éireann. Potential evaporation is estimated as 500 mm/yr. Actual evapotranspiration (A.E) is then calculated by taking 93% of the potential figure, to allow for soil moisture deficits, so A.E. is estimated as 465 mm/yr. Using these figures, the potential recharge (R - A.E.) is taken to be approximately 647 mm. Runoff is taken to be 10% of available recharge in the valley floor and is estimated to be 65 mm. These calculations are summarised below:

Average annual rainfall	1112 mm
Estimated P.E.	500 mm
Estimated A.E. (93% P.E.)	465 mm
Available recharge	647 mm
Surface Runoff	65 mm
Recharge	582 mm

7.3 Groundwater levels

Groundwater levels in the area are variable, depending largely on elevation and rock type. A well survey carried out in June 1994 indicates that water levels in the Waulsortian limestone range from approximately 9.6 m OD in the Ballylemon Upper area to 3 m OD at Lisfennel, on the outskirts of

Dungarvan town. The water level at Ballinamuck was 2.93 m OD, however the well may not have fully recovered after pumping and so static water level is likely to be somewhat higher. Although there are no water levels available for the sandstone rock units it is expected that the water table is a subdued reflection of topography. Water levels for the Dungarvan area are given in Figure 4.

Water levels in the River Colligan are higher than groundwater levels in the Ballinamuck area. The alluvium deposits are approximately 6m thick in the vicinity of the river. As they are clayey and silty it is considered that the river is not hydrologically connected to the aquifer but is perched on the alluvium.

7.4 Groundwater Flow Directions and Gradients

The water table in Dungarvan is assumed to reflect topography but is also influenced by the permeability of the different rock types. The water table in the lower permeability sandstones and shales has a steep gradient and groundwater flow is toward the limestone in the valley (south on the northern side and north on the southern side). In contrast the groundwater gradient is flatter in the more permeable limestones (0.0015) and flow direction in the vicinity of Ballinamuck is eastward toward the sea. A groundwater divide is present to the west of the public supply well in the Whitechurch area. Water to the west of the divide flows toward the River Blackwater and water to the east flows toward Dungarvan Harbour.

7.5 Hydrochemistry and Water Quality

Hydrochemical analyses from 1994 to 1996 indicate that water at Ballinamuck tends to be moderately hard (212 - 244 mg/l $CaCO_3$). Chloride levels are slightly elevated, this is probably due to the proximity of the well to the sea. Nitrate levels tend to approach the E.U guidelevel of 25mg/l and on one occasion approached the E.U MAC. Nitrate levels are often elevated in winter and early spring. All other major cations and anions analysed are within EU limits. The pH measured on the 30/6/93 was 7.1; conductivities are in the range of 471 - 512 μS/cm.

There were faecal coliforms detected in the water on several occasions in the past especially following periods of heavy rainfall. This has been attributed by the water scheme caretaker to the leakage of shallow contaminated groundwater down the well. This however has since been rectified.

7.6 Aquifer Parameters

Analysis of constant rate pumping test data provided an aquifer transmissivity estimate in the range of 900 to 13000 m²/d. To the west of Dungarvan, at Lefanta, a transmissivity value of 3585 m^2/d was obtained by analysing tidal effects on groundwater. It is apparent from these values and from studies in karstified limestone aquifers elsewhere e.g. Cloyne, that transmissivity and therefore permeability can vary considerably across a region. The permeabilities derived from modelling range from 25 to 190 m/d in the Waulsortian limestones. There is no evidence of karstification in the Ballysteen Limestone and so a much lower permeability of 0.7 m/d was used during modelling. The effective porosity for the Waulsortian limestone is estimated to be 2.5% and about 1% for the Ballysteen Limestone.

7.7 Aquifer Category

The Waulsortian Limestone is classed as a **Regionally Important karstified** aquifer **(Rk).** The Kiltorcan Sandstone is classed as a **Regionally Important** fissured aquifer (**Rf**). The Ballytrasna, Knockmealdown, Ballyquinn and Ballysteen rock units are all classed as **Locally Important** aquifers which are **moderately productive only in local zones** (**Ll**). (For more information refer to the Co. Waterford Groundwater Protection Scheme, (Hudson *et al,* 1997).)

7.8 Conceptual Model

- The groundwater divides and the water table in the Dungarvan area are assumed to broadly coincide with the topographic divides and the topography. In the valley itself, the groundwater divide occurs at Whitechurch. Dungarvan harbour acts as a discharge area for groundwater in the east of the valley, whereas groundwater in the west of the valley discharges into the River Blackwater. This is supported by the available groundwater level data and by numerical modelling.

- The Dungarvan source is fed mainly from the Waulsortian Limestone and to a lesser degree from the Ballysteen, Kiltorcan and Knockmealdown rock units further north.

- These rock units are overlain by moderately to highly permeable tills and sands/gravels. Therefore the groundwater can be considered as unconfined. However at Ballinamuck, the static water level lies within an upper alluvial unit, which confines the groundwater at the well site.

- At Cappagh quarry, approximately 5 km west of the site, the Waulsortian limestone shows evidence of dolomitisation and vertical jointing. While drilling wells 3 and 4, a conduit was encountered at 27.2 m depth which indicates the presence of some karstification at the site itself (McDaid, 1994). Other evidence of karstification in the Dungarvan area includes caves in the Whitechurch region (see Figure 4), and a number of springs e.g Springmount. Therefore the permeability in this aquifer depends on the development of such karst features as well as fissuring.

- The Ballysteen Limestone, the Kiltorcan Sandstone and the Knockmealdown rock unit have a much lower permeability than the overlying Waulsortian limestones. This is largely because they are not prone to solution and they are less fissured than the limestones. Flow in these rocks is likely to occur in the upper weathered fissured zones and along fractured fault zones.

- The groundwater gradient is flatter within the more permeable Waulsortian Limestones and relatively steep in the less permeable Ballysteen, Kiltorcan and Knockmealdown rock units. Measured groundwater levels suggests that gradients for the Waulsortian limestone are approximately 0.0015 and gradients for the Ballysteen Limestone are approximately 0.013. Gradients in the Knockmealdown and Kiltorcan rock units, though not measured, are believed to be much higher.

- The River Colligan is considered to be perched on the clay deposits which are approximately 6 m thick in the Ballinamuck area. Temperature and conductivity readings taken at regular intervals during the pumping test at Ballinamuck indicate that the boreholes are not drawing any water from the river (McDaid, 1994).

- The aquifer was modelled using FLOWPATH - a 2D finite difference model which was calibrated using measured water levels. Two models were set up, in the first (Model 1) the Waulsortian and Ballysteen Limestones were modelled. Hydraulic controls for the model consisted of the sea to the east, the River Blackwater to the west and the boundary between the limestone and the sandstone to the north and south. In the second model (Model 2) the sandstone rock units were also modelled to help understand groundwater flow in these rock units. The northern hydraulic control was extended to the topographic divide.

8. Delineation Of Source Protection Areas

8.1 Introduction

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 well.

Outer Protection Area-*

The Outer Protection Area (SO) includes the complete catchment area to the source, i.e. the zone of contribution (ZOC), and it is delineated 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 as follows:

i) An estimate of the area size is obtained by using the average recharge and the abstraction rate.
ii) The shape of the area is then derived by both numerical modelling (using FLOWPATH) and hydrogeological mapping techniques.
iii) To allow for errors in the estimation of groundwater flow direction and to allow for an increase in the ZOC in dry weather, a safety margin is incorporated by assuming a higher abstraction rate than the current rate.

At present the Dungarvan area is supplied by two sources - the Ballinamuck Source and the Springmount Source. The average annual abstraction rate for the two sources is approximately 6800 m^3/d. However in summer the two sources combined, supply a maximum abstraction rate of 9000 m^3/d (information from the Water Scheme Caretaker). It is estimated that the Ballinamuck source has a maximum yield of 9800 m^3/d.

For the purposes of modelling the Dungarvan source, the combined maximum yield (9800 m^3/d) is used for the following reasons:

- If the Springmount source is not in operation in the future, then the Ballinamuck supply would have to accommodate total water demands in the area.
- Assuming the Springmount supply continues in use, the higher yield allows for increased water demand due to expansion in Dungarvan.
- Numerical modelling assumes average conditions all year round, i.e. recharge is averaged out over winter and summer, therefore the model does not allow for an increase in the ZOC during dry weather. This is overcome by assuming a higher abstraction rate in the calculations.

Taking the recharge to be 582 mm as indicated in Section 7.2, the area required to supply a pumping rate of 9800 m^3/d, is calculated to be 6.13 km^2 (613 ha). However this area will increase in dry weather.

The most accurate ZOC at Dungarvan is derived from numerical modelling of the groundwater system together with hydrogeological mapping techniques.

The defining conditions for the numerical model are discharge, aquifer thickness, effective porosity and recharge:

Discharge	Public Supply Well	9800 m^3/d
Thickness	Limestone	20 - 50 m
Effective porosity	Limestone	1 - 2.5%
Recharge		582 mm/yr

The model-derived parameter for Model 1 is hydraulic conductivity:

Hydraulic conductivity	Waulsortian Limestone	25 - 190 m/d
	Ballysteen Limestone	0.7 m/d

Using the above parameters, the groundwater conditions in Dungarvan were successfully modelled using FLOWPATH. A graph of calculated versus observed heads indicates that a good calibration with measured water levels was achieved (Appendix 1). In order to test the robustness of the model a sensitivity analysis (Appendix 2) was carried out by varying recharge and permeability – the parameters that are normally poorly specified in terms of data. The results of the sensitivity analysis are incorporated into the ZOC, which is shown in Figure 5. The ZOC is controlled primarily by the groundwater flow direction and by the recharge mound to the north and north east. The boundaries of the ZOC are based on:

- the output of Model 1.
- the knowledge gained from Model 2.

Consequently the boundaries of the ZOC were extended into the sandstone as far as the topographic divide. These boundaries are based on our current understanding of groundwater conditions in the area and on the available data. The area of the ZOC is substantially greater than the area calculated (6.13 km^2) using the recharge estimate, however it is advisable to take a conservative approach in view of the uncertainties with groundwater flow in karstified and fissured bedrock, and the expansion of the ZOC in dry weather.

8.2 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) from a point below the water table to the source 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.

Due to the highly permeable, karstic nature of the limestone aquifer at Dungarvan, it is probable that all groundwater in the portion of the ZOC underlain by the Waulsortian limestone could reach the well in less than 100 days. (While this conclusion is arguable, it is advisable to take the precautionary approach in view of the uncertainties concerning flow in karstic limestones.) The 100 day TOT is extended 100m into the Ballysteen Limestone. This distance was calculated using the model-derived estimates of permeability, porosity and hydraulic gradient for the Ballysteen limestone.

9. Vulnerability

The sandy tills are considered moderately permeable and range from 0 - >10 m thickness in the valley floor. Therefore groundwater over the region ranges from moderate to extremely vulnerable to contamination. Sands and gravels are taken to be highly permeable and tend to be relatively thick. The unsaturated zone in the sands and gravels are assumed to be at least 3m in thickness and so groundwater in these areas is considered to be highly vulnerable.

To the northwest of Ballinamuck, the sands and gravels are overlain by sandy till. The sandy till is probably <3m thick whereas the sands and gravels are likely to be up to 10 m thick. Consequently groundwater in these areas is also believed to be 'highly vulnerable' to contamination.

Geophysical and borehole logging at the Ballinamuck site indicate that there are 6m of clay overlying 8m of sand and gravel overlying limestone. As a result the groundwater beneath the site is considered to be moderately vulnerable to contamination.

Much of the upland areas have rock at less than 1 m and so groundwater is extremely vulnerable. The vulnerability of groundwater in the Dungarvan area is shown in Figure 6.

10. Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories) – a possible total of 8 source protection zones (see the matrix in the table below). In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SO/H**, which represents an Outer 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 each local authority source. There are 6 groundwater protection zones present around the Ballinamuck source (see Figure 7), 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)		

It is not within the scope of this report to delineate the protection zones in the surrounding area and this is dealt with at the regional resource protection scale.

The accompanying response measures imposing restrictions on developments will follow when discussions have been carried out between the Council, the EPA and the GSI as to the degree of restriction necessary in each protection zone.

11. Potential Pollution Sources

The land to the north and northwest of the source is largely grassland-dominated and is primarily used for grazing. The main hazards within the ZOC are farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides, and possible spillages along the roads. No detailed assessment of hazards was carried out as part of this study; however, the general impression gained was that there are no obvious major hazards in the ZOC.

12. Conclusions and Recommendations

- The source at Dungarvan is an excellent yielding well, which is located in a regionally important karstic limestone aquifer.

- The area around the supply is 'moderately' to 'extremely' vulnerable to contamination.

- 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:
    - chemical and bacteriological analyses of raw water rather than treated water should be carried out on a regular basis (every 2-3 months initially);
    - full analyses (see Waterford GWPS, Hudson *et al*, 1997) should be carried out on a proportion of the samples.
    - the nitrate data should be reviewed regularly;
    - in the short term, until the groundwater quality situation can be properly assessed, 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;
    - an interim code of practice for dealing with spillages along the roads in the area should be drawn up.

13. References

Duffy, S. 1994. The protection of Groundwater Resources in County Waterford. Unpublished M.Eng. Sc. thesis, UCG.

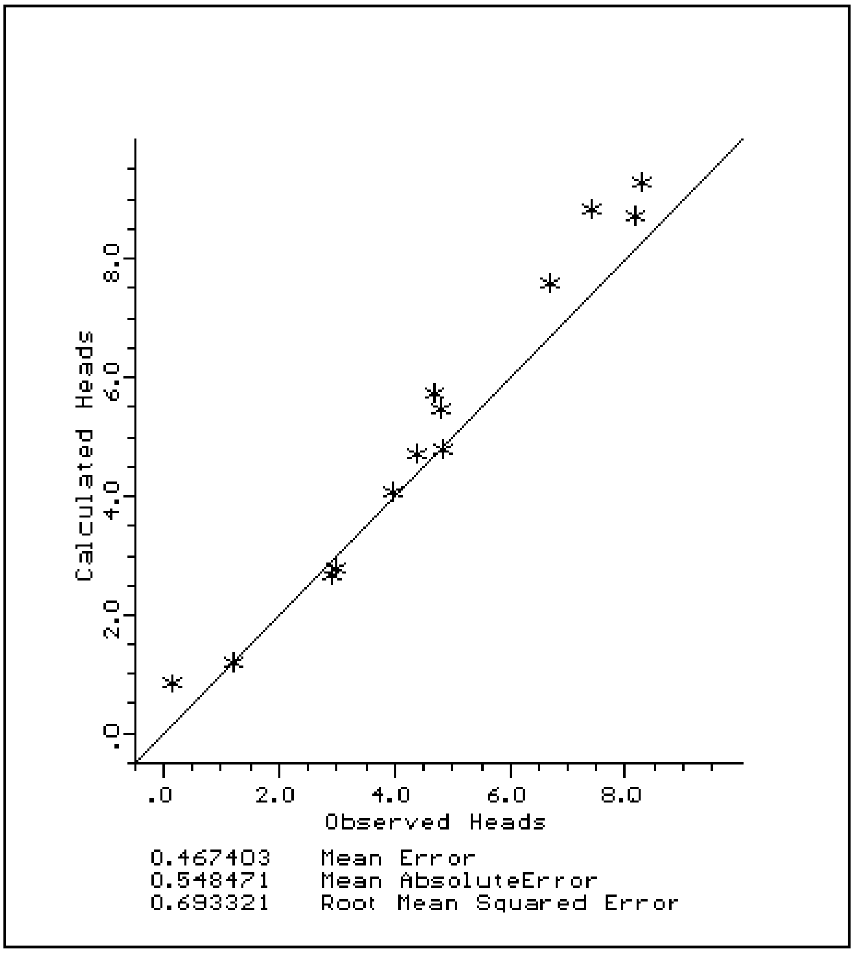
Hudson M., Daly D., Duffy S., & Johnston P., 1997. County Waterford Groundwater Protection Scheme.

Keating, M & Packman M.J. 1995.Guide to Groundwater Protection Zones in England and Wales. National Rivers Authority

McDaid, D. 1994. Groundwater modelling for resource management (of the Dungarvan limestone aquifer). Unpublished M.E. thesis, TCD.

Sleeman A.G., & McConnell, B., 1995. Geology of East Cork - Waterford, Map and Report for Sheet 22, Geological Survey of Ireland.

APPENDIX 1



Graph of Calculated versus Observed heads (m O.D.) obtained by numerical modelling

APPENDIX 2

2. Delineation of the Zone of Contribution

To examine the robustness of the numerical model, a sensitivity analysis was carried out using methods employed by the U.K's Environment Agency (Keating & Packman, 1995). Optimum 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 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's were overlain upon each other. The following areas are delineated on the overlay map which is available on request at the GSI.

Best Estimate: The model which was produced using best estimate values of permeability and recharge.
Area of Certainty: This represents the area of overlap of all nine models
Area of Uncertainty: This represents the outer envelope of all nine models.

In view of the variability of karst limestone aquifers and the resulting uncertainties, it was decided to include not only the best estimate but also the area of uncertainty within the delineated ZOC in Figure 5.

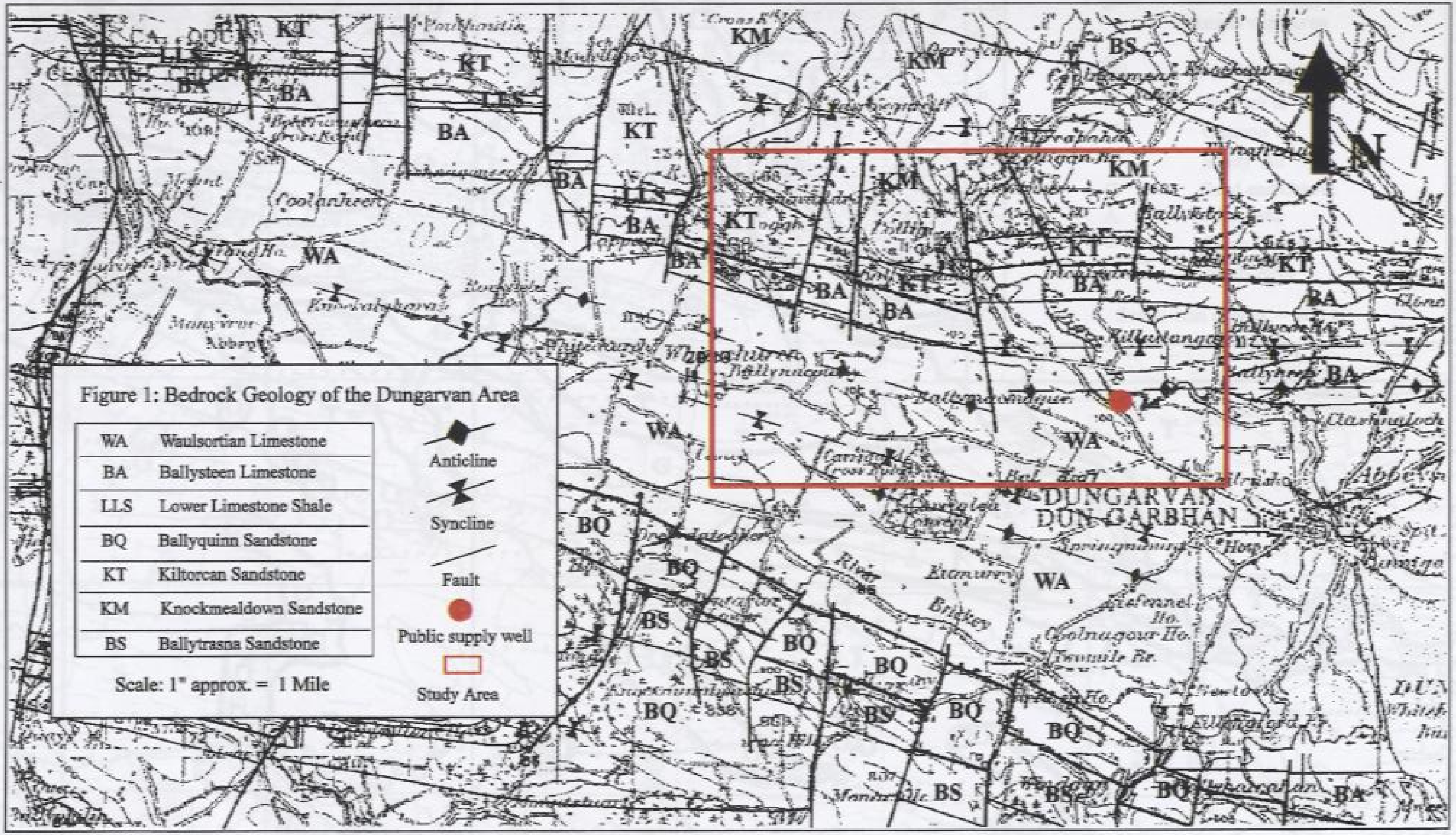


Figure 1: Bedrock Geology of the Dungarvan Area

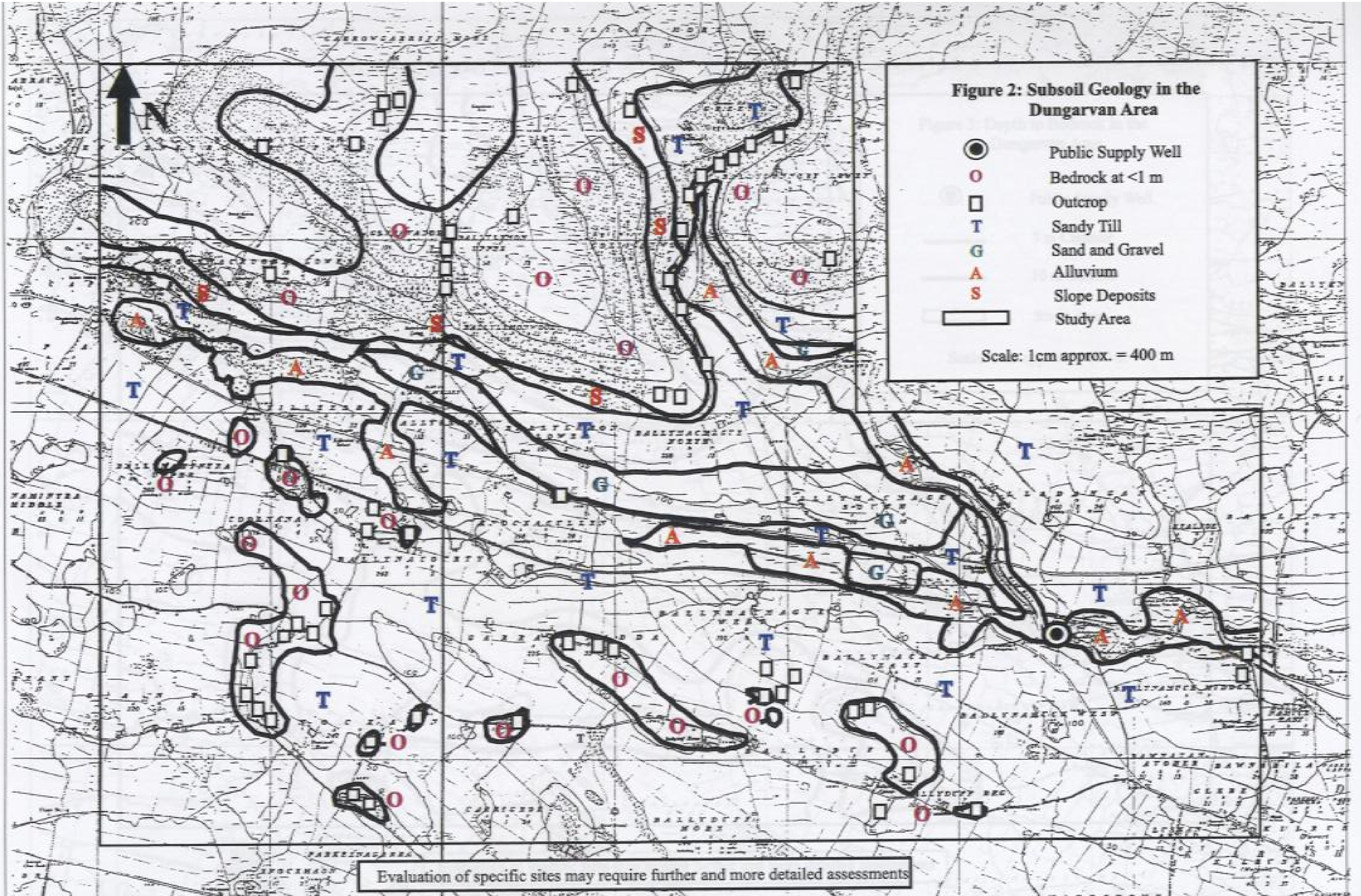


Figure 2: Subsoil Geology in the Dungarvan Area
Public Supply Well
Bedrock at <1 m
Outcrop
Sandy Till
Sand and Gravel
Alluvium
Slope Deposits
Study Area
Scale: 1cm approx. = 400 m
Evaluation of specific sites may require further and more detailed assessments

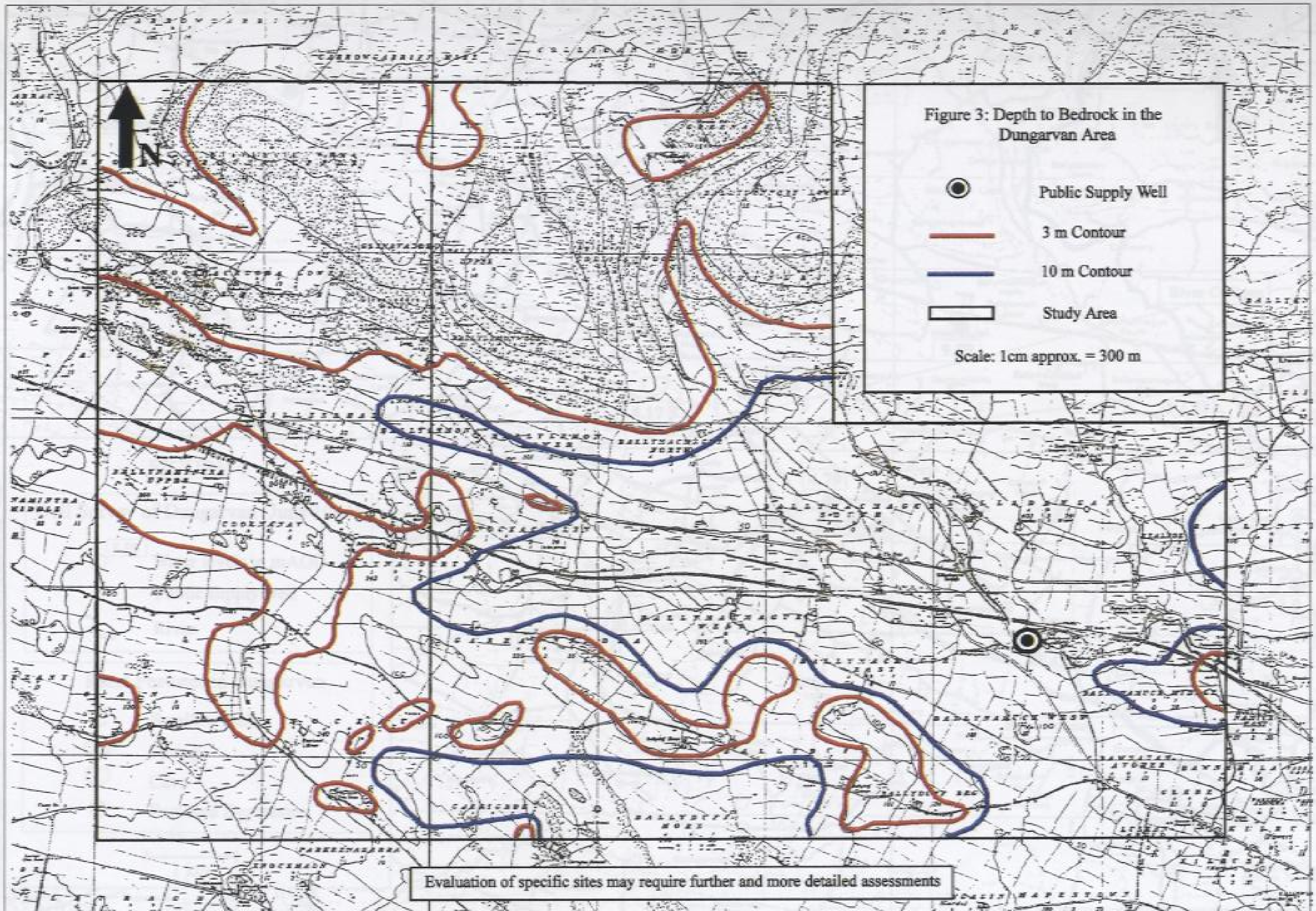


Figure 3: Depth to Bedrock in the Dungarvan Area
Public Supply Well
3 m Contour
10 m Contour
Study Area
Scale: 1cm approx. = 300 m
N
Evaluation of specific sites may require further and more detailed assessments

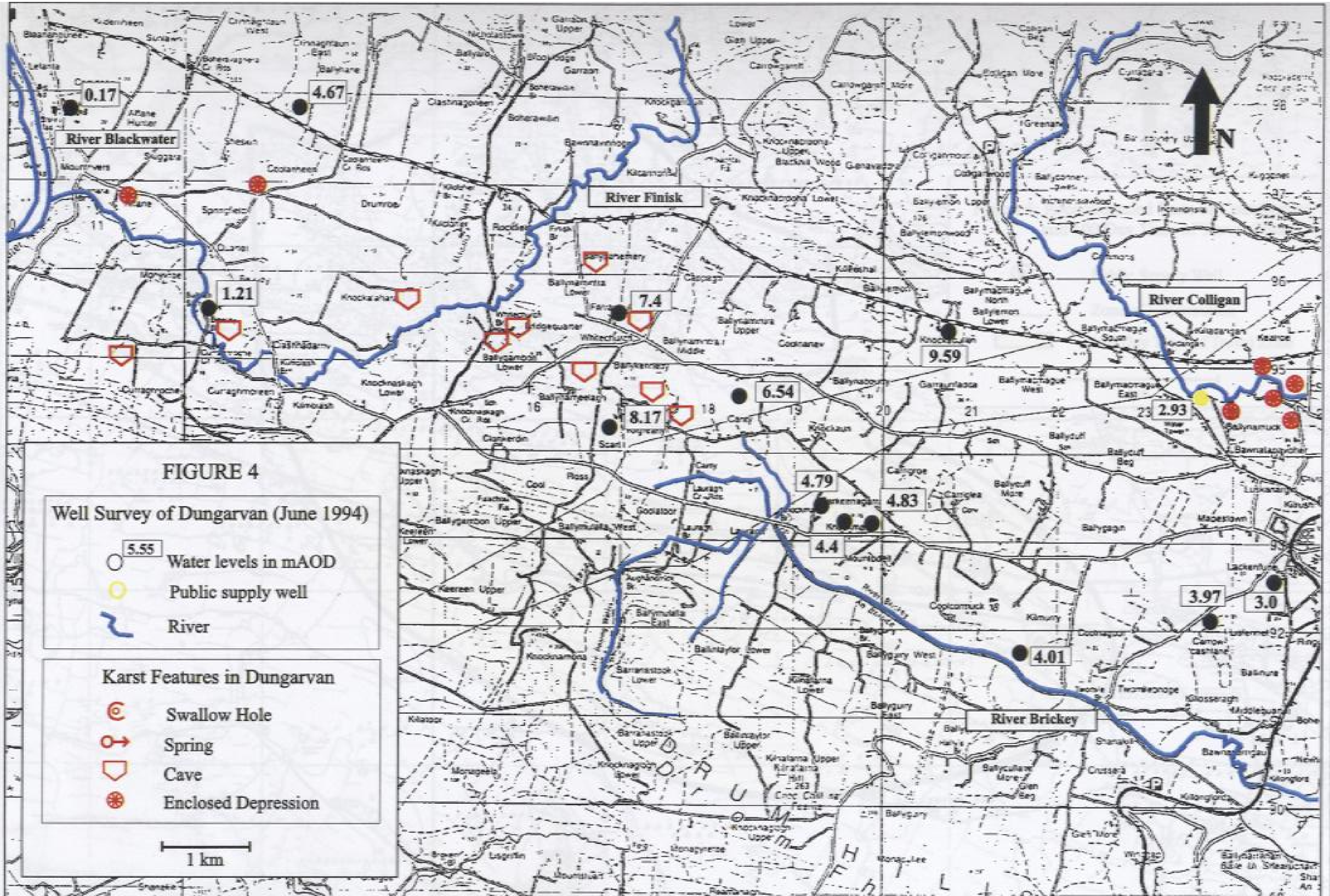


FIGURE 4

Well Survey of Dungarvan (June 1994)

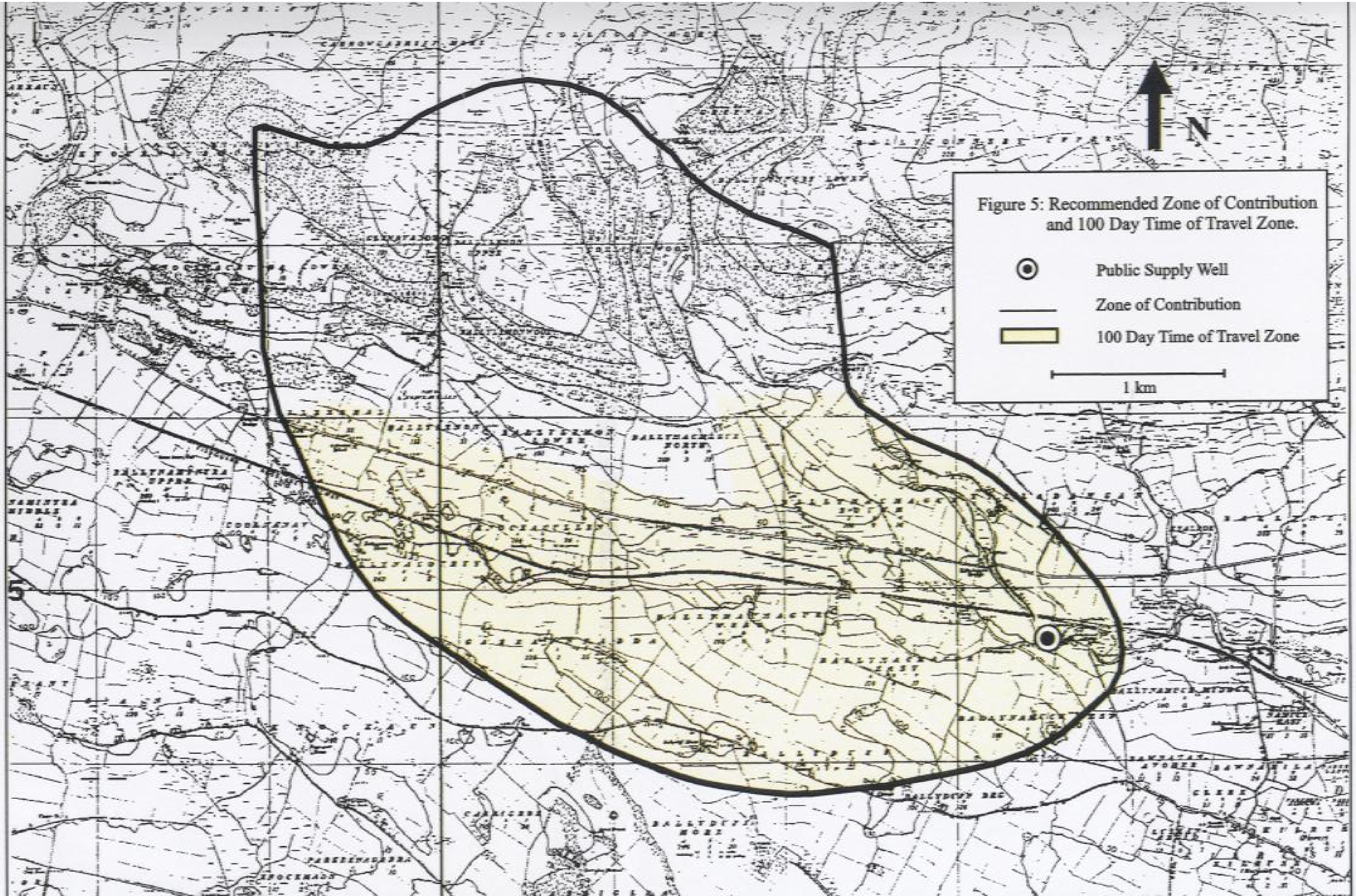
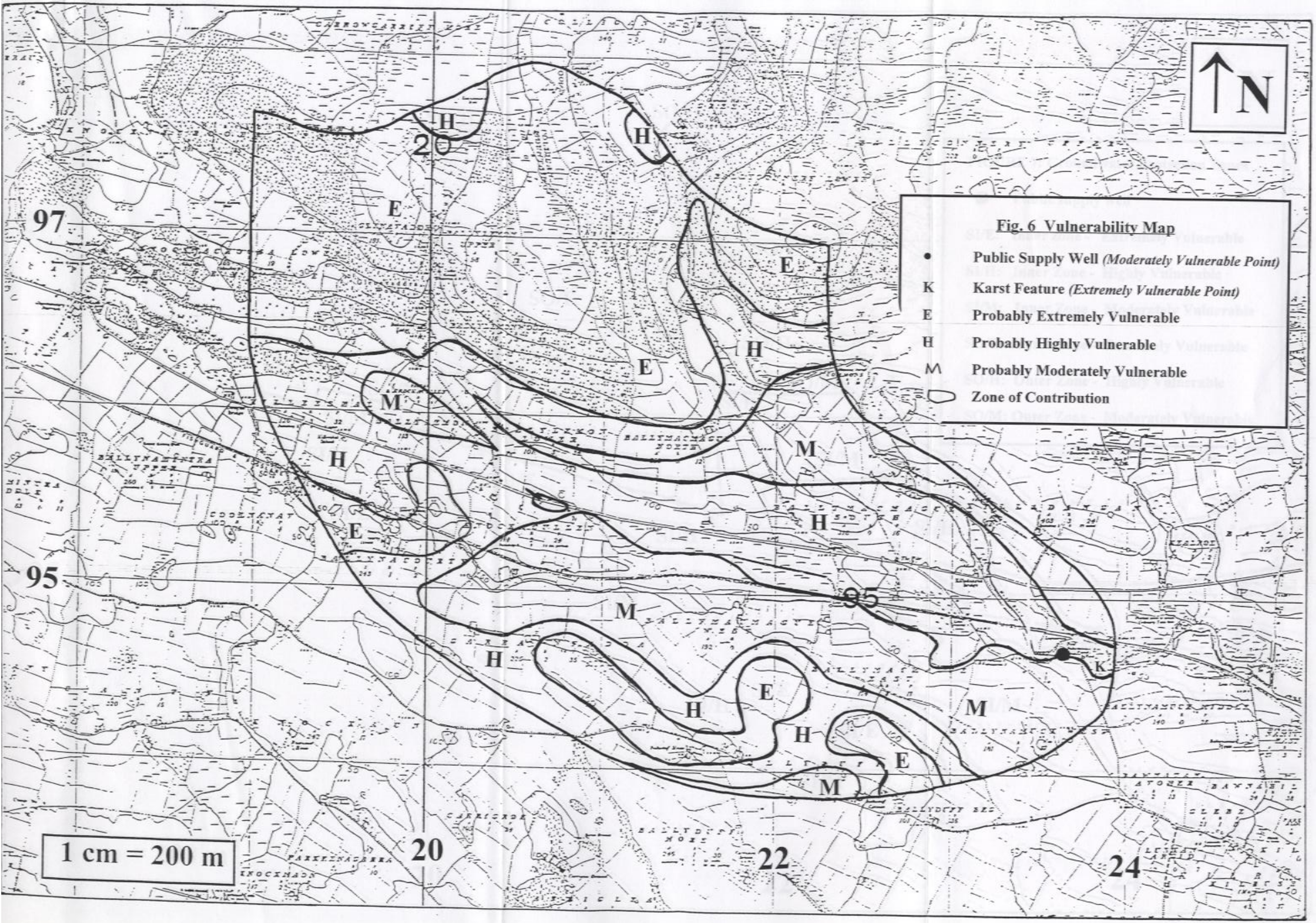


Figure 5: Recommended Zone of Contribution and 100 Day Time of Travel Zone.
Public Supply Well
Zone of Contribution
100 Day Time of Travel Zone
1 km
N



↑N
Fig. 6 Vulnerability Map
Public Supply Well (Moderately Vulnerable Point)
K Karst Feature (Extremely Vulnerable Point)
E Probably Extremely Vulnerable
H Probably Highly Vulnerable
M Probably Moderately Vulnerable
Zone of Contribution
1 cm = 200 m
97
95
20
22
24
E
H
M
K

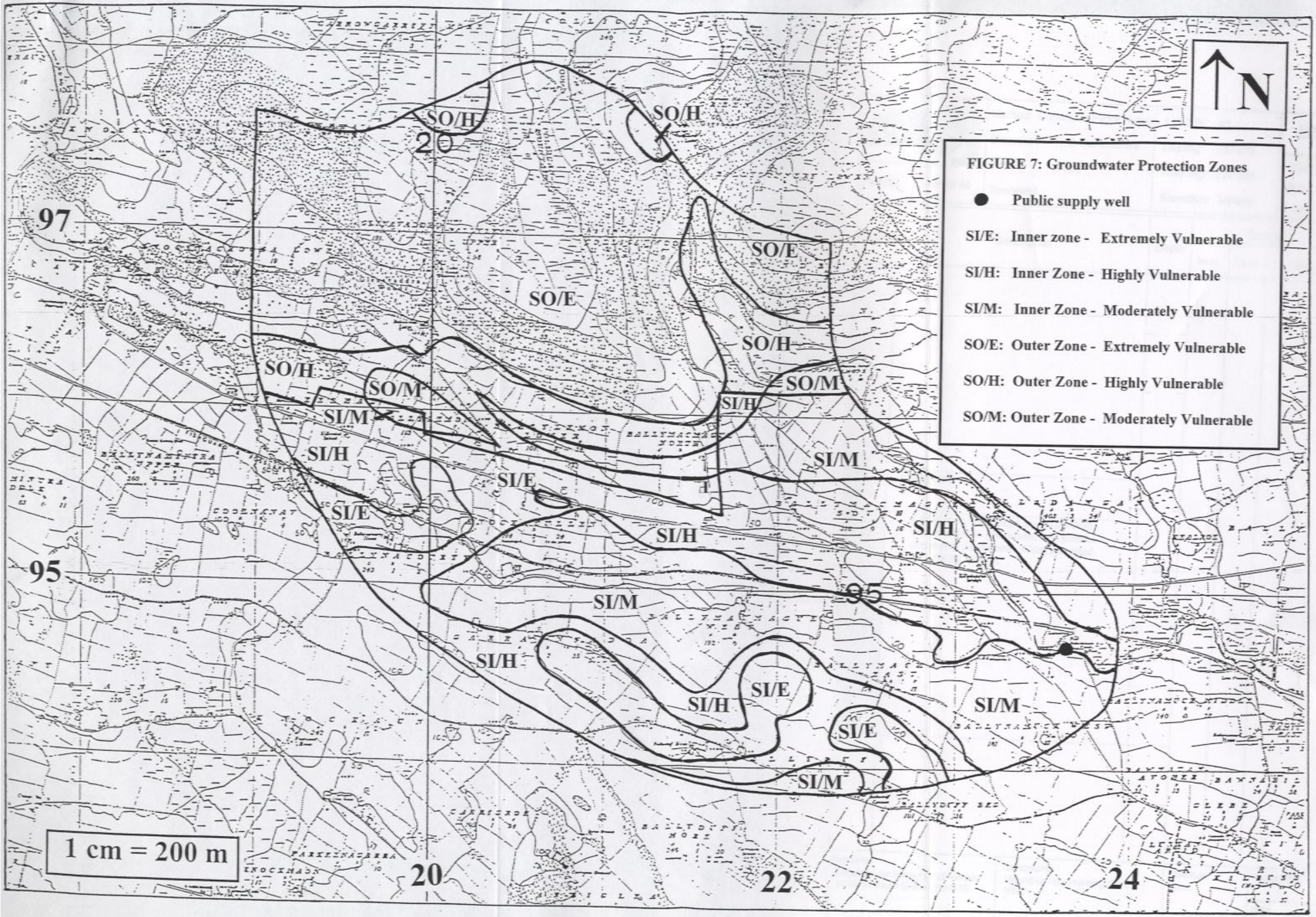


FIGURE 7: Groundwater Protection Zones
Public supply well
SI/E: Inner zone - Extremely Vulnerable
SI/H: Inner Zone - Highly Vulnerable
SI/M: Inner Zone - Moderately Vulnerable
SO/E: Outer Zone - Extremely Vulnerable
SO/H: Outer Zone - Highly Vulnerable
SO/M: Outer Zone - Moderately Vulnerable
N
1 cm = 200 m
97
95
20
22
24
SO/H
SO/H
SO/E
SO/E
SO/H
SO/H
SO/M
SO/M
SI/H
SI/M
SI/H
SI/M
SI/E
SI/E
SI/H
SI/H
SI/M
SI/H
SI/H
SI/E
SI/M
SI/E
SI/M