

USK Gormanstown Group Water Scheme

**Extracted from:
County Kildare Groundwater Protection Scheme,
Volume II: Source Protection Zones**

‘Note:

Since this report was published, the Source Protection Area and, possibly, other component maps have been updated based on improved geoscientific evidence and hydrogeological knowledge. The most up-to-date version of the Source Protection Areas (SPAs) and other maps can be found on the Geological Survey Ireland website

(<https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx>).’

County Kildare Groundwater Protection Scheme

Volume II: Source Protection Zones

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Table of Contents – Volume II

Sections 1 to 6 are contained within Volume I. They comprise an Executive Summary, an overall introduction, classifications of aquifers and vulnerability, and overall conclusions.

7	OVERVIEW OF GROUNDWATER QUALITY.....	1
7.1	INTRODUCTION.....	1
7.2	SCOPE.....	1
7.3	METHODOLOGY.....	3
7.4	GROUNDWATER OCCURRENCE AND EXPLOITATION IN COUNTY KILDARE.....	5
7.5	INDICATORS OF GROUNDWATER CONTAMINATION.....	5
7.6	GENERAL GROUNDWATER QUALITY ASSESSMENT OF SUPPLY SOURCES.....	13
7.7	APPRAISAL OF WATER QUALITY ISSUES AT SPECIFIC SUPPLY SOURCES.....	14
7.8	CONCLUSIONS.....	14
7.9	RECOMMENDATIONS.....	15
8	ATHY TC WATER SUPPLY.....	17
8.1	INTRODUCTION.....	17
8.2	SUMMARY OF SUPPLY DETAILS.....	17
8.3	METHODOLOGY.....	17
8.4	LOCATION & SITE DESCRIPTION.....	18
8.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE.....	19
8.6	GEOLOGY.....	19
8.7	GROUNDWATER VULNERABILITY.....	20
8.8	HYDROGEOLOGY.....	20
8.9	HYDROCHEMISTRY AND WATER QUALITY.....	23
8.10	AQUIFER CHARACTERISTICS.....	23
8.11	CONCEPTUAL MODEL.....	24
8.12	DELINEATION OF SOURCE PROTECTION AREAS.....	24
8.13	GROUNDWATER PROTECTION ZONES.....	26
8.14	POTENTIAL POLLUTION SOURCES.....	26
8.15	CONCLUSIONS AND RECOMMENDATIONS.....	26
9	CASTLEMITCHELL (CHURCHTOWN) PWS.....	28
9.1	INTRODUCTION.....	28
9.2	SUMMARY OF BOREHOLE DETAILS.....	28
9.3	METHODOLOGY.....	29
9.4	BOREHOLE LOCATION & SITE DESCRIPTION.....	29
9.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE.....	29
9.6	GEOLOGY.....	29
9.7	GROUNDWATER VULNERABILITY.....	30
9.8	HYDROGEOLOGY.....	30
9.9	CONCEPTUAL MODEL.....	33
9.10	DELINEATION OF SOURCE PROTECTION AREAS.....	35
9.11	GROUNDWATER PROTECTION ZONES.....	36
9.12	POTENTIAL POLLUTION SOURCES.....	36
9.13	CONCLUSIONS AND RECOMMENDATIONS.....	36
10	CURRAGH CAMP WATER SUPPLY.....	38
10.1	INTRODUCTION.....	38
10.2	SUMMARY OF BOREHOLE DETAILS.....	38
10.3	METHODOLOGY.....	39
10.4	BOREHOLE LOCATION & SITE DESCRIPTION.....	39
10.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE.....	39
10.6	GEOLOGY.....	40
10.7	GROUNDWATER VULNERABILITY.....	40
10.8	HYDROGEOLOGY.....	41
10.9	CONCEPTUAL MODEL.....	45
10.10	DELINEATION OF SOURCE PROTECTION AREAS.....	45
10.11	GROUNDWATER PROTECTION ZONES.....	46

10.12	POTENTIAL POLLUTION SOURCES	46
10.13	CONCLUSIONS AND RECOMMENDATIONS.....	47
11	USK - GORMANSTOWN GROUP WATER SCHEME.....	48
11.1	INTRODUCTION.....	48
11.2	WELL/SPRING LOCATION & SITE DESCRIPTION.....	48
11.3	SUMMARY OF BOREHOLE & SPRING DETAILS	48
11.4	METHODOLOGY.....	49
11.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE	49
11.6	GEOLOGY	49
11.7	GROUNDWATER VULNERABILITY.....	50
11.8	HYDROGEOLOGY.....	51
11.9	CONCEPTUAL MODEL.....	54
11.10	DELINEATION OF SOURCE PROTECTION AREAS	54
11.11	GROUNDWATER PROTECTION ZONES.....	55
11.12	POTENTIAL POLLUTION SOURCES	56
11.13	CONCLUSIONS AND RECOMMENDATIONS.....	56
12	KILKEA PUBLIC WATER SUPPLY.....	57
12.1	INTRODUCTION.....	57
12.2	BOREHOLE LOCATION & SITE DESCRIPTION	57
12.3	SUMMARY OF BOREHOLE DETAILS	57
12.4	METHODOLOGY.....	58
12.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE	58
12.6	GEOLOGY	58
12.7	GROUNDWATER VULNERABILITY.....	59
12.8	HYDROGEOLOGY.....	60
12.9	CONCEPTUAL MODEL.....	64
12.10	DELINEATION OF SOURCE PROTECTION AREAS	65
12.11	GROUNDWATER PROTECTION ZONES.....	66
12.12	POTENTIAL POLLUTION SOURCES	66
12.13	CONCLUSIONS AND RECOMMENDATIONS.....	66
13	KILTEEL GROUP WATER SCHEME.....	68
13.1	INTRODUCTION.....	68
13.2	LOCATION & SITE DESCRIPTION	68
13.3	SUMMARY OF SOURCE DETAILS.....	68
13.4	METHODOLOGY.....	68
13.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE	69
13.6	GEOLOGY	69
13.7	GROUNDWATER VULNERABILITY.....	70
13.8	HYDROGEOLOGY.....	70
13.9	CONCEPTUAL MODEL.....	74
13.10	DELINEATION OF SOURCE PROTECTION AREAS	74
13.11	GROUNDWATER PROTECTION ZONES.....	75
13.12	POTENTIAL POLLUTION SOURCES	75
13.13	CONCLUSIONS AND RECOMMENDATIONS.....	76
14	LIPSTOWN - NARRAGHMORE GROUP WATER SCHEME	77
14.1	INTRODUCTION.....	77
14.2	SPRING LOCATION & SITE DESCRIPTION.....	77
14.3	SUMMARY OF SPRING DETAILS	77
14.4	METHODOLOGY.....	78
14.5	TOPOGRAPHY, SURFACE HYDROLOGY AND LAND USE	78
14.6	GEOLOGY	79
14.7	GROUNDWATER VULNERABILITY.....	79
14.8	HYDROGEOLOGY.....	80
14.9	CONCEPTUAL MODEL.....	84
14.10	DELINEATION OF SOURCE PROTECTION AREAS	84
14.11	GROUNDWATER PROTECTION ZONES.....	85

14.12	POTENTIAL POLLUTION SOURCES	86
14.13	CONCLUSIONS AND RECOMMENDATIONS.....	86
15	REMAINING GROUNDWATER SUPPLIES IN COUNTY KILDARE.....	87
16	REFERENCES.....	88

LIST OF FIGURES

FIGURE 7-1	COMPARISON OF <i>E. COLI</i> RAW WATER ANALYSES WITH THE INHERENT RISK TO WATER QUALITY AT EACH SUPPLY.....	8
FIGURE 7-2	COMPARISON OF NITRATES ANALYSES WITH THE INHERENT RISK TO WATER QUALITY AT EACH SUPPLY	9
FIGURE 7-3	COMPARISON OF AMMONIUM RAW WATER ANALYSES WITH THE INHERENT RISK TO WATER QUALITY AT EACH SUPPLY.....	11
FIGURE 7-4	COMPARISON OF GENERAL CONTAMINANT LEVELS WITH THE INHERENT RISK TO WATER QUALITY AT EACH SUPPLY.....	13
FIGURE 8-1	PHOTOGRAPH SHOWING ATHY WELL FIELD.....	18
FIGURE 9-1	CASTLEMITCHELL - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC GROUNDWATER CONTAMINATION.	34
FIGURE 10-1	HARE PARK - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC GROUNDWATER CONTAMINATION	43
FIGURE 10-2	MCDONAGH KEY INDICATORS OF AGRICULTURAL AND DOMESTIC GROUNDWATER CONTAMINATION	44
FIGURE 11-1	GORMANSTOWN - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION	53
FIGURE 12-1	KILKEA - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC CONTAMINATION AT KILKEA PWS	63
FIGURE 13-1	KILTEEL - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC GROUNDWATER CONTAMINATION	73
FIGURE 14-1	SKETCH OF SITE AT LIPSTOWN - NARRAGHMORE	78
FIGURE 14-2	NARRAGHMORE - KEY INDICATORS OF AGRICULTURAL AND DOMESTIC GROUNDWATER CONTAMINATION.	83

LIST OF TABLES

TABLE 7.1	INVENTORY OF GROUNDWATER SUPPLY SOURCES USED IN THE WATER QUALITY ASSESSMENT	2
TABLE 7.2	GROUNDWATER QUALITY CLASSIFICATION OF SELECTED CO. KILDARE GROUNDWATER SUPPLY SOURCES	7
TABLE 7.3	GENERIC HAZARD TYPES INFLUENCING SELECTED GROUNDWATER SUPPLIES IN COUNTY KILDARE.....	14
TABLE 4	ESTIMATED AQUIFER PARAMETERS FOR THE MILFORD LIMESTONE.	24
TABLE 5	ESTIMATED AQUIFER PARAMETERS FOR BARROW SAND/GRAVEL AQUIFER.....	24
TABLE 6	MATRIX OF SOURCE PROTECTION ZONES FOR ATHY WELL FIELD.	26
TABLE 7	ESTIMATED AQUIFER PARAMETERS FOR THE BALLYADAMS LIMESTONE AT CASTLEMITCHELL SUPPLY.	33
TABLE 8	MATRIX OF SOURCE PROTECTION ZONES AT CASTLEMITCHELL.	36
TABLE 9	AQUIFER PARAMETERS FOR THE MID KILDARE SAND/GRAVEL AQUIFER.....	45
TABLE 10	MATRIX OF SOURCE PROTECTION ZONES FOR CURRAGH CAMP.	46
TABLE 11	MATRIX OF SOURCE PROTECTION ZONES AT GORMANSTOWN.....	55
TABLE 12	ESTIMATED AQUIFER PARAMETERS FOR THE ROCK UNITS IN KILKEA.	64
TABLE 13	MATRIX OF SOURCE PROTECTION ZONES AT KILKEA PWS.....	66
TABLE 14	MATRIX OF SOURCE PROTECTION ZONES AROUND THE KILTEEL SOURCE.	75
TABLE 15	MATRIX OF SOURCE PROTECTION ZONES AT NARRAGHMORE.	86

APPENDIX IV: Discussion of the key indicators of domestic and agricultural contamination of groundwater

APPENDIX V: Laboratory analytical results

APPENDIX VI: Summary of trends in water quality over time for selected supply sources in Kildare

APPENDIX VII: KT Cullen & Company. Source Protection Reports for Monasterevin, Rathangan, Johnstown Bridge and Robertstown.

- Overall conclusions are contained within Volume I -

11 Usk - Gormanstown Group Water Scheme

11.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the source.
- To outline the principal hydrogeological characteristics of the area.
- To assist Kildare 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.

11.2 Well/spring Location & Site Description

The source is located 2.5 km northeast of Dunlavin, Co. Wicklow and approximately 500 m from the border with Co. Kildare. The source comprises a borehole and spring located at Tober Demesne, approximately 650 m south of Tober cross roads, next to the burial ground. The borehole was commissioned in 1983 to meet the increasing demand, superseding and taking over from the spring. Caretaker staff indicate that the spring is no longer in use. The borehole pumps water to a reservoir situated at Grangebeg Park in Co. Wicklow. The scheme provides water for about 550 people; 137 houses and 80 farms, most of whom live in Co. Kildare.

11.3 Summary of Borehole & Spring Details

	Spring	Borehole
GSI No.	2619NEW013	2619NEW012
Grid reference	S 28855 20328	S 28859 20330
Townland	Tober Demesne	Tober Demesne
Owner	Gormanstown Group Water Scheme	Gormanstown Group Water Scheme
Elevation (ground level)	180.58 m OD (Malin Head) GSI survey 10/5/02.	181.88 m OD (Malin Head). GSI survey 10/5/02
Depth to rock	>10 m	>10m
Static water level	180.58 m OD. (GSI survey 10/5/02)	180 m OD. (GSI survey 10/5/02)
Normal consumption/abstraction		146 m ³ d ⁻¹ (32,000 gallons per day) (council figures 2000) 250-340 m ³ d ⁻¹ (55,000-75,000 gallons per day) (caretakers figures 2002)
Spring overflow	2900 m ³ d ⁻¹ (GSI 13/5/02)	
Depth		7.6 m; PVC slotted pipe. No casing.
Diameter		250mm
Depth-to-rock	>10 m	>10 m
Static water level	Ground level	1.2 m below ground 16/6/1983
Pumping test summary:		Carried out by Irish Geotechnical Services Ltd. 1982
(i) pumping rate		463 m ³ d ⁻¹ for 8 hours.
(ii) drawdown		4.3 m
(iii) specific capacity		107 m ³ d ⁻¹ m ⁻¹
(iv) transmissivity		Estimated from specific capacity~128 m ² d ⁻¹

11.4 Methodology

11.4.1 Desk Study

Details about the borehole such as depth, date commissioned and abstraction figures were obtained from County Council personnel; geological and hydrogeological information was provided by the GSI.

11.4.2 Site visits and fieldwork

This included the following;

- Water sampling in July 2002;
- Interviews with the caretakers January 2002 and June 2002;
- Levelling in the spring & borehole 10/5/02 and spring overflow measurements 13/5/02.
- Field mapping walkovers in January and May 2002 to further investigate the subsoil geology, the hydrogeology and vulnerability to contamination

11.4.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

11.5 Topography, Surface Hydrology and Land Use

The source is located in west Co. Wicklow toward the bottom of a group of three small hills amongst the foothills of the Wicklow mountains. The slopes of the hills around the source are in the order of 0.04. The elevations range from about 180 m at the source to 257 m at Wards of Tober. The source is situated toward the bottom of a westerly facing slope.

According to the GSI archive 1:10560 scale maps of the area there are a series of springs occurring toward the bottom of the slopes on either side of the hills. The largest of these springs is the one that group water scheme uses and is the likely to be the historical reason for the townland name (Tober) and is also the source of the River Greese.

There is a mixture of land use type in the area. Most of the land is put to pasture for sheep and cattle. There are a number of sand/gravel pits near to the spring, with one quarry less than 300 m from the source. In addition the main road passing by the source is a busy minor road [R756].

11.6 Geology

11.6.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the Tober source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

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

- Bedrock Geology 1:100,000 Map Series, Sheet 16, Kildare-Wicklow. Geological Survey of Ireland. (Mc Connell *et al.*, 1994)
- Information from geological mapping in the nineteenth century (on record at the GSI).
- Wicklow County Council Groundwater Protection Scheme (Woods and Wright, 2001).
- "Report on a groundwater investigation for Gormanstown/Kildare Group Water Scheme" Irish Geotechnical Services (IGSL) Report No.571, July 1983.
- Glanville (1997) The quaternary geology of Co. Kildare, map descriptions for relevant 1:25,000 sheets. GSI report.

11.6.2 Bedrock Geology

Greywacke² sandstones, shales and slates dominate the area. They are discussed in further detail in Sections 2 and 4 of Volume I.

11.6.3 Subsoil (Quaternary) Geology

- Sand/gravel and limestone tills are the dominant subsoil in the area. The Tober source is located near the bottom of a sand/gravel deposit that has a mapped area greater than 1 km² (one of the townlands that the deposit occupies is named "Sandyhills"). The top of the hill at Manofwar is occupied by a small sand/gravel deposit mapped at roughly 200 m² in size. The logs of the boreholes drilled close to the spring indicate 6 m of "grey sand/gravel and cobbles predominantly sub angular and sub rounded, sandy at upper levels" sitting on at least 0.7 m of "boulder clay" (IGSL, 1983).
- 'Till' or 'Boulder clay' is an unsorted mixture of coarse and fine materials laid down by ice. Till deposits in County Wicklow have a widespread distribution and occupy the area surrounding the sand/gravel deposit and also underlies the sand/gravel deposit in places (IGSL 1983).
- A depth to bedrock drilling programme was carried out to ascertain the subsoil thicknesses in County Wicklow for the Wicklow Groundwater Protection Scheme (Woods, L. & Wright, G., 2001). The thicknesses vary considerably from 0 m at Friarhill (rock outcrop) to >10 m around the source. In general the subsoil thickness increases from the hill tops down to the valley floors.

11.7 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999).

The permeability of the sand/gravel is assumed to be high. As the groundwater in the sand/gravel is regarded as the "target", the depth to the saturated zone is the key element in determining the vulnerability. This was estimated using available water level data and the estimated groundwater gradient. The distribution of interpreted groundwater vulnerability is presented in Maps 6 and 8. Areas of extreme vulnerability are constrained to where the depth to the saturated zone is less than 3m (estimated to extend 100 m from the spring/borehole) and also where rock outcrop areas are present. Thus extremely vulnerable areas have been mapped close to the spring. Highly vulnerable groundwaters are mapped in the rest of the area.

The vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. The mapping is intended only as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

² Greywacke are sandstones or siltstones that are cemented by a high proportion of mud deposited from currents loaded with sediment on seafloor slopes.

11.8 Hydrogeology

11.8.1 Introduction

This section presents our current understanding of groundwater flow in the area of the source.

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

- GSI files and archival Kildare County Council data.
- Kildare County Council drinking water returns.
- Group Water Scheme personnel.
- "Report on a groundwater investigation for Gormanstown/Kildare Group Water Scheme" Irish Geotechnical Services (IGSL) Report No.571, July 1983.
- Hydrogeological mapping carried out by GSI.
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability.

11.8.2 Rainfall, Evaporation and Recharge

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

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 and are listed as follows:

- *Annual rainfall*: 1000 mm.
 Rainfall data for gauging stations around Tober (from Fitzgerald, D., Forrester, F., 1996).

Gauging Stations	Grid reference	Elevation OD (m)	Approximate distance away from source (km)	Annual ppt 1961-1990
Donard G.S.	S930977	183	6.5	1103
Hollywood G.S.	N937070	165	5.0	992
Ballitore G.S.	S800960	99	13.0	829
Ballymore Eustace DCWW	N933092	172	8.0	932
Kilcullen G.S.	N838093	116	6.5	860

Donard and Hollywood are the closest in terms of distance, elevation and aspect to the Tober area. From the data it would appear to be reasonable to assume an annual average precipitation of 1000 mm for the Tober area. This is supported by the interpreted contour maps of precipitation presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996).

- *Annual evapotranspiration losses*: 430 mm. Potential evapotranspiration (P.E.) is estimated to be 450 mm yr.⁻¹. Actual evapotranspiration (A.E.) is estimated as 95 % of P.E., to allow for seasonal soil moisture deficits. More local measurements of evapotranspiration are not available.
- *Potential recharge*: 570 mm yr.⁻¹. This figure is based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff and is commonly referred to as "Effective Rainfall".
- *Annual runoff losses*: 170 mm. The slopes around the source and the nature of the deposits around the source need to be considered in order to give a representative value for the runoff that occurs in the area. Steep slopes usually suggest a high proportion of the rainfall would move down the hill sides as runoff (overland flow). However, the sand/gravel deposits that occur on the hill slopes above the Tober source are highly permeable, suggesting that a high proportion of the rainfall may infiltrate into the subsurface and down to the water table and in this instance may not allow runoff

to occur to the same degree if the slopes were not draped by sand and sand/gravel deposits, except during high intensity rainfall events. This view is supported by the number of small springs that occur at the base of the sand/gravel deposits around the hillsides. Typically the proportion of recharge that infiltrates to ground water in sand/gravel is around 80% (Wright *et al*, 1982), this figure has been reduced to 70% to take account of the steep slopes.

These calculations are summarised as follows:

Average annual rainfall (R)	1000 mm
Estimated P.E.	450 mm
Estimated A.E. (95% of P.E.)	430 mm
Potential Recharge (R – A.E.)	570 mm
Runoff losses (30% of recharge)	170 mm
Estimated Actual Recharge	400 mm

11.8.3 Groundwater levels, Flow Directions and Gradients

Water levels in the vicinity of the source are generally close to or at the ground surface. Water levels in the supply borehole are approximately 1 m below ground. The water table coincides with the ground surface where the springs emerge. Information on the water levels elsewhere is limited.

The water table in the area is generally assumed to be a subdued reflection of the topography, with groundwater flowing from the sub-catchment watersheds and discharging into the Liffey and Greese Rivers. Topography around the spring forms a horseshoe, which drives groundwater westwards to discharge at the point where the sand/gravel deposits pinch out (i.e. the spring). The borehole is located beside the spring presumably intercepting groundwater discharging at the spring.

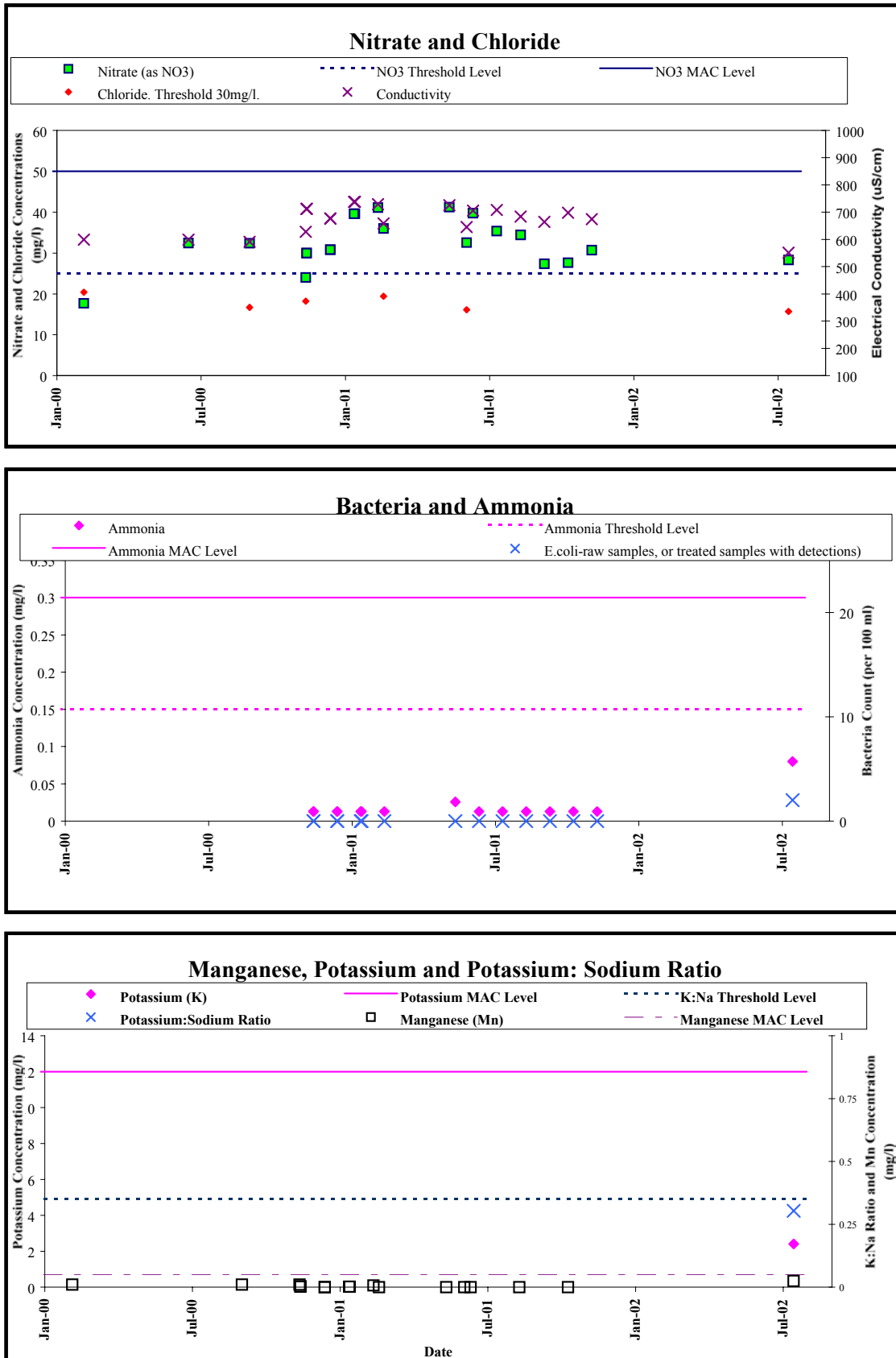
There are not enough hydrogeological data to calculate precise groundwater gradients, however low gradients are typical of sand/gravel and it is assumed to be less than the topographic gradient. For the purposes of calculations it is assumed to be 0.001.

11.8.4 Hydrochemistry and Water Quality

The data is summarised graphically in Figure 11-1 and the following key points have been identified from the data:

- The water is hard to very hard, with total hardness values of 306-405 mg l⁻¹ (as CaCO₃) and electrical conductivity values of 591-628 μS cm⁻¹. These values are indicative of groundwater from limestone or from sand/gravel deposits. The logs given by IGSL and a field examination of the sand/gravel pits show that the majority of clasts are derived from limestones. Thus the hydrochemistry suggests that the groundwater is derived from the sand/gravel deposits, with only minor amounts from the bedrock below.
- Nitrate concentrations appear to be elevated, typically 20-40 mg l⁻¹.
- On the basis of eighteen available results from the last two years, faecal bacteria are generally low with only one raw water analysis slightly exceeding the EU MAC.

Figure 11-1 Gormanstown - Key indicators of agricultural and domestic contamination



11.8.5 Aquifer Characteristics

Bedrock: The bedrock units are classed as **Poor Aquifers which are generally unproductive (Pu)** (Woods and Wright, 2001).

Subsoil: The sand/gravel deposit is termed the "Tober" sand/gravel deposit in the Wicklow Groundwater Protection Scheme and is classed as a **Locally Important sand/gravel aquifer (Lg)** (Woods and Wright, 2001).

The occurrence of springs toward the bottom of the sand/gravel deposits, the poor nature of the bedrock aquifer, and the hydrochemistry suggest that the sand/gravel deposit is the main aquifer feeding the spring and borehole. The aquifer tests carried out by IGSL are summarised in the following table.

Test	Yield (m ³ d ⁻¹)	Duration (hrs)	Drawdown (m)	Specific capacity (m ³ d ⁻¹ m ⁻¹)
27/6/1983	218	4	0.8	273
6/7/1983	273	8	2.3	119
7/7/1983	463	8	4.3	108

Transmissivities are estimated from specific capacity calculations using analytical methods by GSI giving a range of values of 130-150 m²d⁻¹. There is no site specific data on the porosity of the sand/gravel, however porosities calculated for sand/gravel in other parts of the country tend to be about 0.07-0.08. Permeability tends to be high in sand/gravel, ranging from 20-70 m d⁻¹. The borehole intercepts groundwater that is discharging to the spring. From inferences of transmissivity and aquifer thickness, the permeability is estimated to be approximately 20 m d⁻¹.

11.8.6 Spring Discharge

The spring flows were estimated by personnel from the group scheme using a V-notch weir in September 1977 to be about 1000 m³ d⁻¹ and was then estimated to be in the region of 3000 m³ d⁻¹ when measured by GSI staff in May 2002. The spring is classed as a **high** yielding spring under the GSI classifications for spring discharge.

11.9 Conceptual Model

- The Gormanstown Group Water Scheme abstracts 300 m³ d⁻¹ (66,000 gallons per day) from a borehole located beside a high yielding spring.
- A **Locally important sand/gravel aquifer (Lg)** feeds the spring and borehole.
- Groundwater levels are close to or at the ground surface in the vicinity of the spring and borehole.
- Topography around the spring forms a horseshoe, which drives groundwater westwards to discharge at the spring which is located at the point where the sand/gravel deposits pinch out.
- Groundwater is generally unconfined.
- The groundwater quality is hard to very hard.

11.10 Delineation of Source Protection Areas

11.10.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, and are presented in Map 8.

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) to the spring and borehole.

11.10.2 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)**, which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the sand/gravel permeability and (d) the recharge in the area.

The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations and the conceptual model and are shown in Map 8. The ZOC catchment boundaries are discussed as follows:

The **northern, southern and eastern** boundaries are based hydrogeological mapping and the limits of the sand/gravel with an additional arbitrary buffer zone of 50 m which extends into the till.

The **western** boundary is defined by the furthest point downstream of the spring discharge area, as it is assumed that groundwater will not flow upstream to the spring. This distance is greater than the downgradient distance that the borehole is estimated to be able to draw water (50 m), thus providing an extra precaution.

The area delineated by the boundaries described is approximately 1 km². The area needed to provide water to the borehole can be estimated using a water balance. The water balance uses the average recharge and average abstraction figures to determine the area. The abstraction figure has been increased by 50% to 525 m³ d⁻¹ to allow for increases in usage and for dry periods in summer. The area required to balance is estimated to be about 0.5 km², which is less than the area delineated using the above boundaries.

11.10.3 Inner Protection Area

According to “Groundwater Protection Schemes” (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (ToT) to the supply. Estimations of the extent of this area are made by hydrogeological mapping and semi-analytical modelling.

A permeability (K) value of 20 m d⁻¹, porosity (n) of 0.07 and a gradient (i) of 0.001 were used to calculate the velocity (V) as follows:

$$V = (K.i) / n$$

$$V = 3 \text{ m d}^{-1}$$

Thus, in 100 days most groundwater will move approximately 300 m.

11.11 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. 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. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination. The source protection zones as shown in Table 11 and Map 8.

Table 11 Matrix of Source Protection Zones at Gormanstown.

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

11.12 Potential Pollution Sources

Land use in the area is described in Section 11.5. The land around the source is grassland dominated, used for cattle and sheep. In addition there are a number of sand and sand/gravel pits (some disused) within the zone of contribution to the spring. The main potential sources of pollution within the ZOC are farmyards, septic tank systems, hydrocarbon wastes, runoff from the roads, leaky sewers and landspreading of organic wastes and inorganic fertilisers.

11.13 Conclusions and Recommendations

- ◆ The source comprises a small production borehole abstracting about $80 \text{ m}^3 \text{ d}^{-1}$ which is located in a **locally important sand/gravel aquifer (Lg)**.
- ◆ The vulnerability in the vicinity of the source varies from extreme to high.
- ◆ Septic tank systems, farmyards, landspreading and runoff from the roads are the main hazards in the area.
- ◆ 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:
 1. the potential hazards in the ZOC should be located and assessed.
 2. a full chemical and bacteriological analysis of the **raw** water is carried out on a regular basis.
 3. particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well; particularly in relation to nitrates.

Usk – Gormanstown PWS

COUNTY KILDARE GROUNDWATER PROTECTION SCHEME

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
-  Zone of Contribution of Wells (SO)
-  Inner protection area (SI)
-  K.T. Cullen & Co. Ltd.
-  GSI Sources

This Source Protection Zone map is designed for general information and strategic planning usage. The boundaries are based on the available evidence and local details have been generalised to fit the map scale. Evaluation of specific sites and circumstances will normally require further and more detailed assessments and will frequently require site investigations to determine the risk to groundwater.

The map is intended for use in conjunction with groundwater protection responses for potentially polluting activities, which sets the degree of acceptability of these activities in each zone and describes the control measures necessary to prevent pollution.

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 Project Manager: Vincent Fitzsimons
 Digital Map Production: Sinead Smyth & Denise Taylor

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KILDARE COUNTY COUNCIL
 Comhairle Chontae Chill Dara



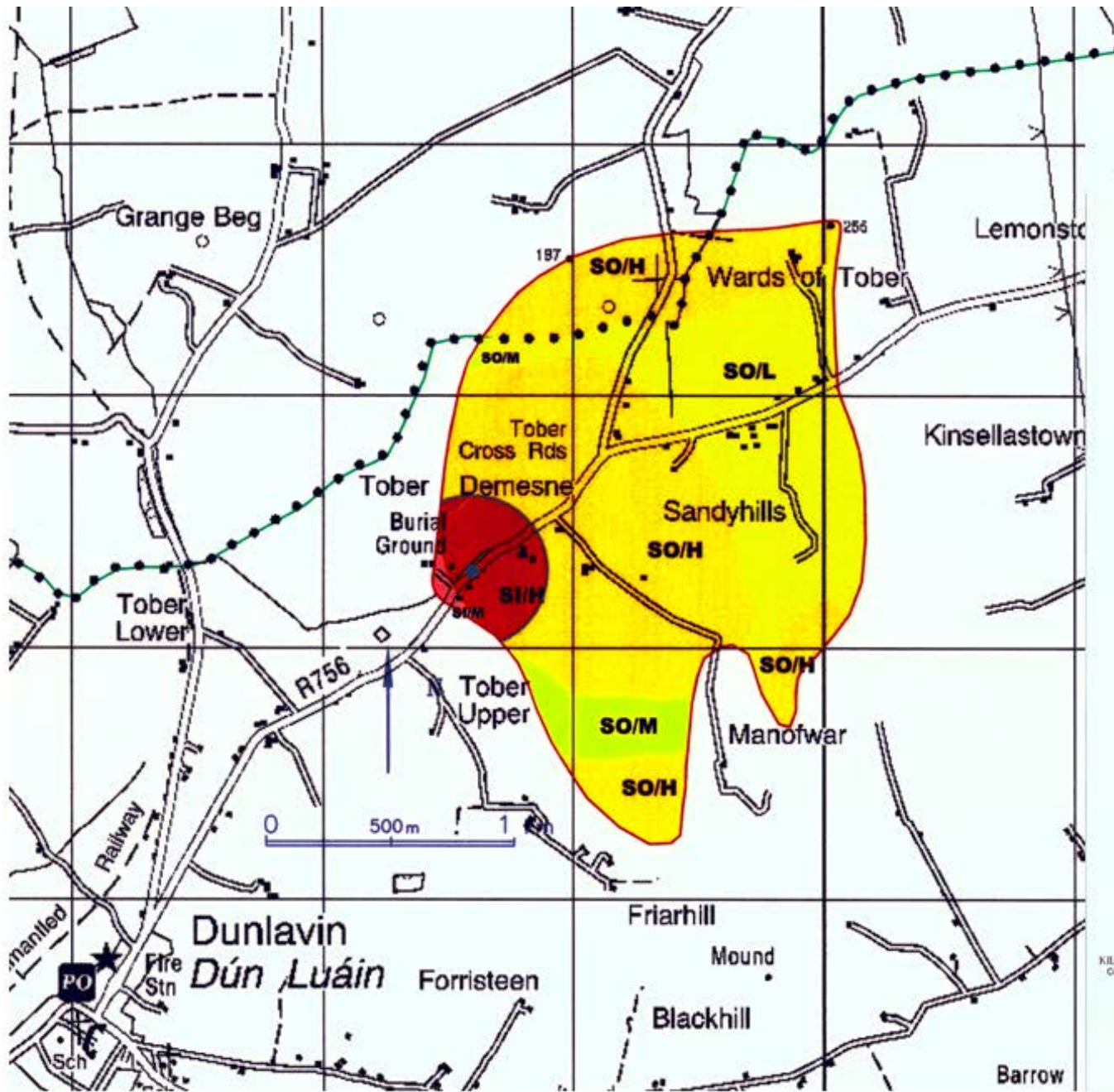
Dr. John Lavelle
 Director of Sanitary Services
 St. Mary's, Naas, Co. Kildare

SOURCE PROTECTION ZONES				
SI/L	SI/M	SI/H	SI/E	EX

GEOLOGICAL SURVEY
 OF IRELAND
 Sárthreasaigh Ombudsána Eireann



Groundwater Services
 Beggan Bush, Harold's Cross Rd.,
 Dublin 4



Map 8 Gormanstown Source Protection Zones

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Appendix IV: Discussion Of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

A.1 Introduction

This appendix is adapted from Daly, 1996.

There has been a tendency in analysing groundwater samples to test for a limited number of constituents. A "full" or "complete" analysis, which includes all the major anions and cations, is generally recommended for routine monitoring and for assessing pollution incidents. This enables (i) a check on the reliability of the analysis (by doing an ionic balance), (ii) a proper assessment of the water chemistry and quality and (iii) a possible indication of the source of contamination. A listing of recommended and optional parameters are given in Table A1. It is also important that the water samples taken for analysis have not been chlorinated - this is a difficulty in some local authority areas where water take-off points prior to chlorination have not been installed.

The following parameters are good contamination indicators: E.coli, nitrate, ammonia, potassium, chloride, iron, manganese and trace organics.

TABLE A1

Recommended Parameters		
Appearance	Calcium (Ca)	Nitrate (NO ₃)*
Sediment	Magnesium (Mg)	Ammonia (NH ₄ and NH ₃)*
pH (lab)	Sodium (Na)	Iron (Fe)*
Electrical Conductivity (EC)*	Potassium (K)*	Manganese (Mn)*
Total Hardness	Chloride (Cl)*	
General coliform	Sulphate (SO ₄)*	
E. coli *	Alkalinity	
Optional Parameters (depending on local circumstances or reasons for sampling)		
Fluoride (F)	Fatty acids *	Zinc (Zn)
Orthophosphate	Trace organics *	Copper (Cu)
Nitrite (NO ₂)*	TOC *	Lead (Pb)
B.O.D.*	Boron (B) *	Other metals
Dissolved Oxygen *	Cadmium (Cd)	
* good indicators of contamination		

A.2 Faecal Bacteria and Viruses

E. coli is the parameter tested as an indicator of the presence of faecal bacteria and perhaps viruses; constituents which pose a significant risk to human health. The most common health problem arising from the presence of faecal bacteria in groundwater is diarrhoea, but typhoid fever, infectious hepatitis and gastrointestinal infections can also occur. Although *E. coli* bacteria are an excellent indicator of pollution, they can come from different sources - septic tank effluent, farmyard waste, landfill sites, birds. The faecal coliform : faecal streptococci ratio has been suggested as a tentative

indicator to distinguish between animal and human waste sources (Henry *et al.*, 1987). However, researchers in Virginia Tech (Reneau, 1996) cautioned against the use of this technique.

Viruses are a particular cause for concern as they survive longer in groundwater than indicator bacteria (Gerba and Bitton, 1984).

The published data on elimination of bacteria and viruses in groundwater has been compiled by Pekdeger and Matthess (1983), who show that in different investigations 99.9% elimination of *E. coli* occurred after 10-15 days. The mean of the evaluated investigations was 25 days. They show that 99.9% elimination of various viruses occurred after 16-120 days, with a mean of 35 days for Polio-, Hepatitis, and Enteroviruses. According to Armon and Kott (1994), pathogenic bacteria can survive for more than ten days under adverse conditions and up to 100 days under favourable conditions; enteroviruses can survive from about 25 days up to 170 days in soils.

Bacteria can move considerable distances in the subsurface, given the right conditions. In a sand and gravel aquifer, coliform bacteria were isolated 100 ft from the source 35 hours after the sewage was introduced (as reported in Hagedorn *et al.*, 1981). They can travel several kilometres in karstic aquifers. In Ireland, research at Sligo RTC involved examining in detail the impact of septic tank systems at three locations with different site conditions (Henry, 1990; summarised in Daly, Thorn and Henry, 1993). Piezometers were installed down-gradient; the distances of the furthest piezometers were 8 m, 10 m and 9.5 m, respectively. Unsurprisingly, high faecal bacteria counts were obtained in the piezometers at the two sites with soakage pits, one with limestone bedrock at a shallow depth where the highest count (max. 14 000 cfu's per 1000 ml) and the second where sand/gravel over limestone was present (max 3 000 cfu's per 100 ml). At the third site, a percolation area was installed at 1.0 m b.g.l; the subsoils between the percolation pipes and the fractured bedrock consisted of 1.5 m sandy loam over 3.5 m of poorly sorted gravel; the water table was 3.5 b.g.l. (So this site would satisfy the water table and depth to rock requirements of S.R.6:1991, and most likely the percolation test requirement.) Yet, the maximum faecal coliform bacteria count was 300 cfus per 100 ml. Faecal streptococci were present in all three piezometers. It is highly likely that wells located 30 m down gradient of the drainage fields would be polluted by faecal bacteria.

As viruses are smaller than bacteria, they are not readily filtered out as effluent moves through the ground. The main means of attenuation is by adsorption on clay particles. Viruses can travel considerable distances underground, depths as great as 67 m and horizontal migrations as far as 400 m have been reported (as reported in US EPA, 1987). The possible presence of viruses in groundwater as a result of pollution by septic tank systems is a matter of concern because of their mobility and the fact that indicator bacteria such as faecal coliforms have been found not to correlate with the presence of viruses in groundwater samples (US EPA, 1987).

The natural environment, in particular the soils and subsoils, can be effective in removing bacteria and viruses by predation, filtration and absorption. There are two high risk situations: (i) where permeable sands and gravels with a shallow water table are present; and (ii) where fractured rock, particularly limestone, is present close to the ground surface. The presence of clayey gravels, tills, and peat will, in many instances, hinder the vertical migration of microbes, although preferential flow paths, such as cracks in clayey materials, can allow rapid movement and bypassing of the subsoil.

A.3 Nitrate

Nitrate is one of the most common contaminants identified in groundwater and increasing concentrations have been recorded in many developed countries. The consumption of nitrate rich water by young children may give rise to a condition known as methaemoglobinaemia (blue baby syndrome). The formation of carcinogenic nitrosamines is also a possible health hazard and epidemiological studies have indicated a positive correlation between nitrate consumption in drinking

water and the incidence of gastric cancer. However, the correlation is not proven according to some experts (Wild and Cameron, 1980). The EC MAC for drinking water is 50mg/l.

The nitrate ion is not adsorbed on clay or organic matter. It is highly mobile and under wet conditions is easily leached out of the rooting zone and through soil and permeable subsoil. As the normal concentrations in uncontaminated groundwater is low (less than 5 mg/l), nitrate can be a good indicator of contamination by fertilisers and waste organic matter.

In the past there has been a tendency in Ireland to assume that the presence of high nitrates in well water indicated an impact by inorganic fertilisers. This assumption has frequently been wrong, as examination of other constituents in the water showed that organic wastes - usually farmyard waste, probably soiled water - were the source. The nitrate concentrations in wells with a low abstraction rate - domestic and farm wells - can readily be influenced by soiled water seeping underground in the vicinity of the farmyard or from the spraying of soiled water on adjoining land. Even septic tank effluent can raise the nitrate levels; if a septic tank system is in the zone of contribution of a well, a four-fold dilution of the nitrogen in the effluent is needed to bring the concentration of nitrate below the EU MAC (as the EU limit is 50 mg/l as NO₃ or 11.3 mg/l as N and assuming that the N concentration in septic tank effluent is 45 mg/l).

The recently produced draft county reports by the EPA on nitrate in groundwater show high levels of nitrate in a significant number of public and group scheme supplies, particularly in south and southern counties and in counties with intensive agriculture, such as Carlow and Louth. This suggests that diffuse sources – landspreading of fertilisers – is having an impact on groundwater.

In assessing regional groundwater quality and, in particular the nitrate levels in groundwater, it is important that:

- (i) conclusions should not be drawn using data only from private wells, which are frequently located near potential point pollution sources and from which only a small quantity of groundwater is abstracted;
- (ii) account should be taken of the complete chemistry of the sample and not just nitrate, as well as the presence of *E. coli*;
- (iii) account should be taken of not only the land-use in the area but also the location of point pollution sources;
- (iv) account should be taken of the regional hydrogeology and the relationship of this to the well itself. For instance, shallow wells generally show higher nitrate concentrations than deeper wells, low permeability sediments can cause denitrification, knowledge on the groundwater flow direction is needed to assess the influence of land-use.

A.4 Ammonia

Ammonia has a low mobility in soil and subsoil and its presence at concentrations greater than 0.1 mg/l in groundwater indicates a nearby waste source and/or vulnerable conditions. The EU MAC is 0.3 mg/l.

A.5 Potassium

Potassium (K) is relatively immobile in soil and subsoil. Consequently the spreading of manure, slurry and inorganic fertilisers is unlikely to significantly increase the potassium concentrations in groundwater. In most areas in Ireland, the background potassium levels in groundwater are less than 3.0 mg/l. Higher concentrations are found occasionally where the rock contains potassium e.g. certain granites and sandstones. The background potassium:sodium ratio in most Irish groundwaters is less than 0.4 and often 0.3. The K:Na ratio of soiled water and other wastes derived from plant organic

matter is considerably greater than 0.4, whereas the ratio in septic tank effluent is less than 0.2. Consequently a K:Na ratio greater than 0.4 can be used to indicate contamination by plant organic matter - usually in farmyards, occasionally landfill sites (from the breakdown of paper). However, a K:Na ratio lower than 0.4 does not indicate that farmyard wastes are **not** the source of contamination (or that a septic tank is the cause), as K is less mobile than Na. (Phosphorus is increasingly a significant pollutant and cause of eutrophication in surface water. It is not a problem in groundwater as it usually is not mobile in soil and subsoil).

A.6 Chloride

The principle source of chloride in uncontaminated groundwater is rainfall and so in any region, depending on the distance from the sea and evapotranspiration, chloride levels in groundwater will be fairly constant. Chloride, like nitrate, is a mobile anion. Also, it is a constituent of organic wastes. Consequently, levels appreciably above background levels (12-15 mg/l in Co. Offaly, for instance) have been taken to indicate contamination by organic wastes such as septic tank systems. While this is probably broadly correct, Sherwood (1991) has pointed out that chloride can also be derived from potassium fertilisers.

A.7 Iron and manganese

Although they are present under natural conditions in groundwater in some areas, they can also be good indicators of contamination by organic wastes. Effluent from the wastes cause deoxygenation in the ground which results in dissolution of iron (Fe) and manganese (Mn) from the soil, subsoil and bedrock into groundwater. With reoxygenation in the well or water supply system the Fe and Mn precipitate. High Mn concentrations can be a good indicator of pollution by silage effluent. However, it can also be caused by other high BOD wastes such as milk, landfill leachate and perhaps soiled water and septic tank effluent.

Box A1 Warning/trigger Levels for Certain Contaminants

As human activities have had some impact on a high proportion of the groundwater in Ireland, there are few areas where the groundwater is in a pristine, completely natural condition. Consequently, most groundwater is contaminated to some degree although it is usually not polluted. In the view of the GSI, assessments of the degree of contamination of groundwater can be beneficial as an addition to examining whether the water is polluted or not. This type of assessment can indicate where appreciable impacts are occurring. It can act as a warning that either the situation could worsen and so needs regular monitoring and careful land-use planning, or that there may be periods when the source is polluted and poses a risk to human health and as a consequence needs regular monitoring. Consequently, thresholds for certain parameters can be used to help indicate situations where additional monitoring and/or source protection studies and/or hazard surveys may be appropriate to identify or prevent more significant water quality problems.

Parameter	Threshold mg/l	EU MAC mg/l
Nitrate	25	50
Potassium	4	12
Chloride	30 (except near sea)	250
Ammonia	0.15	0.3
K/Na ratio	0.3-0.4	
Faecal bacteria	0	0

Box A2 Summary : Assessing a Problem Area

Let us assume that you are examining an area with potential groundwater contamination problems and that you have taken samples in nearby wells. How can the analyses be assessed?

E. coli present ⇒ organic waste source nearby (except in karst areas), usually either a septic tank system or farmyard.

E. coli absent ⇒ either not polluted by organic waste or bacteria have not survived due to attenuation or time of travel to well greater than 100 days.

Nitrate > 25 mg/l ⇒ either inorganic fertiliser or organic waste source; check other parameters.

Ammonia > 0.15 mg/l ⇒ source is nearby organic waste; fertiliser is not an issue.

Potassium (K) > 5.0 mg/l ⇒ source is probably organic waste.

K/Na ratio > 0.4 (0.3, in many areas) ⇒ Farmyard waste rather than septic tank effluent is the source. If < 0.3, no conclusion is possible.

Chloride > 30 mg/l ⇒ organic waste source. However this does not apply in the vicinity of the coast (within 20 km at least).

In conclusion, faecal bacteria, nitrate, ammonia, high K/Na ratio and chloride indicate contamination by organic waste. However, only the high K/Na helps distinguish between septic tank effluent and farmyard wastes. So in many instances, while the analyses can show potential problems, other information is needed to complete the assessment.

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APPENDIX V: Laboratory analytical results

