WICKLOW COUNTY COUNCIL
GROUNDWATER PROTECTION SCHEME

GROUNDWATER QUALITY REPORT

An Assessment of the Quality of Public Groundwater Supply Sources in County Wicklow

Revised March 2003

Louise Woods
Geoff Wright
Groundwater Section
Geological Survey of Ireland
Beggars Bush, Haddington Road, Dublin 4

Groundwater Quality Report

An Assessment of the Quality of Public Groundwater Supplies in County Wicklow

1 Introduction

This report contains a brief assessment of the readily available groundwater chemistry and quality data for public and group scheme supply sources in County Wicklow. It consists largely of the assessment of chemical and bacteriological data carried out as part of the Groundwater Protection Scheme (1997), County Council data (1995-97), and some GSI data, together with a brief appraisal of more recently published data on nitrates (EPA, 1997). The report describes both the natural hydrochemistry of the groundwater and the water quality situation. (Hydrochemistry uses the inherent water signature and variations in parameters over space and time, to gain an understanding of the dynamic flow system. Groundwater quality, on the other hand, refers to the chemical, physical and microbiological characteristics of groundwater, relative to a standard or to the requirements of its intended use (Ball, 1994)). The report gives a number of recommendations for consideration by Wicklow County Council.

2 Sources of Information

Hydrochemical and water quality data were compiled primarily from the three phases of groundwater sampling from puplic schemes, carried out during 1997 and with some data from GSI files and also County Council files. A detailed sampling programme of private supplies around Brittas Bay was also carried out in July 1997. The County Council analyses are required by the EC (Quality of Water Intended for Human Consumption) Regulations, S.I. No. 81 of 1988.

As part of the groundwater protection scheme prepared for Wicklow County Council by the Geological Survey of Ireland, three full suites of analyses including all major anions and cations, and the more important heavy metals, were carried out by the State Laboratory; samples were taken in February, May and August 1997. Bacteriological analyses (Total Coliforms and *E. coli.*) were carried out concurrently at the County Council Laboratory in Wicklow. The samples taken were of raw water except in sources at where pre-chlorination could not be avoided. A spread of nine different aquifer types were sampled, including: the Maulin Formation, the Ballylane Formation, the Wicklow Head Formation, the Kilmacrea Formation, the Butter Mountain Formation, the Pollaphuca Formation, the Tipperkevin Formation, the Glen Ding Formation and the Granites. The analyses are given in Table 1.

In July 1997 a detailed groundwater sampling programme was undertaken in the Brittas area to assess the water quality and the vulnerability of the area as a result of the developing holiday resort.

In March 1997, the EPA produced a draft report on nitrates in groundwater in County Wicklow (EPA, 1997) in which data for 22 sources were compiled. These data are given in Table 2.

3 Hydrochemistry

3.1 Groundwater characteristics

Total hardness, i.e. the sum of the concentrations of calcium and magnesium ions, varies depending upon rock type and overlying subsoils. The following classification was used for hardness levels:

• **soft**	<50 mg/l as $CaCO_3$	• **moderately hard**	151–250 mg/l as $CaCO_3$
• **moderately soft**	51–100 mg/l as $CaCO_3$	• **hard**	251–350 mg/l as $CaCO_3$
• **slightly hard**	101–150 mg/l as $CaCO_3$	• **very hard**	>350 mg/l as $CaCO_3$

Groundwater in the county is mainly moderately soft with average total hardness of 50–100 mg/l (as $CaCO_3$), as the bedrock mainly comprises sandstones and shales generally overlain by limestone-poor subsoils. Softer waters (as low as 20 mg/l) are found in the higher upland areas of central Wicklow. Moderately hard to hard waters are found only where the overlying subsoils are limestone-rich.

The low concentration of ions in the Wicklow groundwaters indicate a short residence time within the ground, resulting in many of the analysis showing similarities to rain water.

The hydrochemistry of the groundwater in Co. Wicklow is discussed below under the headings of the different main rock types. Sources which are considered to show significant contamination by a local point source at the time of sampling are excluded from the hydrochemical assessment.

3.2 Maulin Formation

Six Council sources were sampled; data are also available for several other areas. Groundwaters are generally of calcium bicarbonate type, and **soft** to **moderately soft** (20–80 mg/l $CaCO_3$). Some areas in east Wicklow, around Enniskerry and Ashford, show slightly higher hardness and alkalinity, probably because the overlying tills, sands and gravels include limestone clasts which chemically alter the recharge.

3.3 Kilmacrea Formation

This is similar to the Maulin Formation. Four Council sources were sampled, and data are available for several other areas. Groundwaters are generally of calcium bicarbonate type, and **moderately soft** to **moderately hard** (50–250 mg/l $CaCO_3$). Around Brittas Bay some show slightly higher hardness, alkalinity and conductivity, due either to salt water intrusion or retention of salt in the porespace of Quaternary deposits in once-tidal areas.

3.4 Granites

Five council sources located in the granite were sampled. The groundwater is a calcium bicarbonate type and is **soft** to **moderately hard** (50–250 mg/l $CaCO_3$).

3.5 Other Formations

Shales and Sandstone dominate the remaining formations in Co. Wicklow and produce calcium bicarbonate type waters. They are generally **moderately soft** to **moderately hard** waters, but where the overlying subsoils are more carbonate-rich, they are classed as **hard** waters (260–340 mg/l as $CaCO_3$), and conductivities are also higher, reaching over 650 μS/cm.

A major problem in shale- and sandstone-dominated rocks is the frequent presence of high concentrations of iron, up to 20 mg/l (total Fe) and manganese, up to 0.75 mg/l.

4 Background Factors in Assessing Groundwater Quality

As human activities affect most groundwater in Ireland, there are few areas where the groundwater is in pristine condition. Consequently most groundwater is somewhat contaminated but not necessarily polluted. In assessing groundwater quality, the EU maximum admissible concentrations (MAC) should not be the sole focus; the degree of contamination should also be assessed. Thresholds for certain parameters can help to indicate situations where significant contamination but not pollution is occurring. The thresholds used in assessing groundwater quality in County Wicklow are given below.

Parameter	**GSI Threshold (**mg/l)	**EU MAC** (mg/l)
Nitrate	25	50
Potassium	4	12
Chloride	15-50 (depending on proximity to sea)	250
Ammonia	0.15	0.3
K/Na ratio	0.3	
Faecal bacteria	0	0

Other useful indicators of contamination include conductivity, iron, manganese, sulphate and nitrite (See Appendix 1).

Groundwater quality problems can be due to the impact of human activities or to natural conditions. Nitrate (NO_3) and faecal bacteria are the main contaminants from human activities in Co. Wicklow. The main quality problem caused by the natural chemistry of groundwater is the presence of iron.

In the following section, the thresholds are used in assessing the general groundwater quality based on the data in Table 1; this is followed by appraisals of specific problem constituents (nitrate, faecal bacteria and iron) and the situation at selected groundwater sources.

5 General Quality Assessment of Public Groundwater Supplies

The public supplies are divided into four categories, based on the degree of contamination with respect to the major contaminant indicators nitrate, chloride, potassium and *E. coli (from raw water analyses)* and exceedances of the drinking water limits.

AI Sources in which one or more parameters exceed the EU MAC as a direct result of human influence, and which are therefore considered polluted at the time of sampling.

AII Sources in which one or more parameters (e.g. Iron and Manganese) exceed the EU MAC naturally, and which are therefore considered to be naturally polluted at the time of sampling.

B Sources which show concentrations of the contaminant indicators chloride, nitrate and potassium below the MAC, but above the thresholds (listed above), indicating significant contamination and warning that pollution may be occurring at times other than when the sample was taken, or may occur in the future.

Note: background levels of chloride and potassium may vary naturally. Chloride is generally higher in coastal areas, and a threshold of 50 mg/l may be used. Potassium levels may be higher in some sandstones and volcanic rocks, and a threshold of 4 mg/l may be used.

C Sources with slight anomalies in the analyses which may be naturally induced or indicative of some slight contamination.

D Sources which have shown no evidence of contamination

The public supply sources are listed in under each of the four categories in Table 3.

Note that many of the samples used in the groundwater quality assessment were taken before treatment. Many of the sources in Group AI have chlorination and in Group AII have iron and manganese treatment, which enable the groundwater from these sources to be supplied to the public.

6 Nitrate

6.1 General

Nitrate is one of the commonest contaminants identified in groundwater. The nitrate ion is not adsorbed on clay or organic matter, is highly mobile and under wet conditions is easily leached from the root zone and through soil and permeable subsoil. It poses a potential health hazard to babies.

6.2 Sources of Nitrate

Septic tank effluent contains 30-45 mg/l of nitrogen. As this is usually converted to nitrate, it poses a risk to groundwater and can significantly raise nitrate levels in the vicinity of the septic tank system.

Farmyards produce large volumes of organic wastes, but most are landspread and cause no significant problems. However, infiltration of soiled or dirty water into the ground beneath and around farmyards can increase nitrate levels (and pollution by faecal bacteria). Many farm wells in Ireland have been contaminated by soiled water.

Landspreading of slurry from cattle does not usually pose a significant risk to groundwater as the nutrients are recycled. In contrast, organic wastes from piggeries and hatcheries do pose a significant risk unless the rates and timing of spreading match crop needs.

Inorganic fertilisers are a hazard, particularly in tillage areas (leaching of nitrates from tillage crops is generally greater than from grassland) and intensive dairying areas.

Identifying the source of elevated nitrate levels in any particular well depends on assessing not only the nitrate data, but also other parameters, particularly faecal bacteria, ammonia, potassium, chloride and the potassium/sodium ratio. It also requires some knowledge of the zone of contribution (ZOC) of the well, the vulnerability and potential hazards in the ZOC.

Nitrate data for sources with large abstractions give the best indication of general nitrate levels in groundwater because they draw water from large catchment areas where the impact of nearby point sources is less likely to make the concentrations unrepresentative. In contrast, nitrate levels in small sources are more likely to reflect the impact of nearby farmyards and septic tank systems.

Table 3 Groundwater Quality classification of Wicklow County Council public supplies

CATEGORY AI (13% of analysed supplies)	Parkmore Springs (*E. coli*) Rathdrum (*E. coli*, Fe, Mn)	Kilballyowen (K, *E. coli*)
CATEGORY AII (23% of analysed supplies)	*Roundwood (Mn) Thomastown (Fe, Mn) Kirikee (Fe, Mn)	Threewells (Fe, Mn) Annacurragh (Mn)
CATEGORY B (32% of analysed supplies)	Redcross (NO_3) Tinoran (NO_3) Knockananna (NO_3) Coolboy (NO_3, Coliforms)	Barndarrig (NO_3) Freynestown (NO_3) Rathnew (NO_3)
CATEGORY C (18% of analysed supplies)	Lathaleere (Coliforms) Valleymount (Coliforms) Dunlavin (Coliforms)	Grangecon (Coliforms)
CATEGORY D (14% of analysed supplies)	Kiltegan Ballycoogue	Eadestown

* Based on GSI analyses only.
Rathdrum is used as a backup supply only; Rathnew and Lathaleere have been decommissioned.

6.3 Appraisal of Nitrate Data

In County Wicklow the nitrate situation is relatively good, with no sources above the MAC (50 mg/l). Nine (Rathnew, Redcross, Tinoran, Parkmore, Knockananna, Coolboy, Barndarrig, Kilballyowen, and Freynestown) have nitrate levels above the guide level (25 mg/l) but below 50 mg/l. Four sources (Roundwood, Lathaleere, Thomastown, Dunlavin) have nitrate values around the guide level. The remaining nine sources have nitrate values below the guide level (Kiltegan, Valleymount, Kirikee, Rathdrum, Threewells, Annacurragha, Ballycoogue, Eadestown and Grangecon). Some statistical analyses of the EPA nitrate data are given in Table 2 and are not further commented on here.

7 Faecal Bacteria

In general, faecal bacteria in groundwater samples indicate contamination by organic wastes originating from septic tank effluent and farmyards. However, animals and birds in the vicinity of uncovered springs or poorly constructed wells can have some impact.

Raw waters in public groundwater supplies in Co. Wicklow (1997 analyses only) are generally of good microbial quality. Only three sources showed the presence of *E. coli* (Parkmore, Rathdrum and Kilballyowen) while six others showed total coliforms greater than 10/100 ml (Coolboy, Valleymount, Thomastown, Freynestown, Dunlavin, Grangecon). The presence of small numbers of coliforms in an open spring is not considered crucial, as slight contamination (e.g. by birds) is inevitable, and chlorination is generally adequate to eliminate it. However, the situation with bored wells is far less satisfactory, particularly as the water from these sources is often not chlorinated.

Data are also available from 22 private wells, mainly in the Brittas Bay area, with four having *E. coli* (one testing clear on re-sampling) and a further two having total coliforms greater than 10/100 ml. It appears that a significant proportion of wells intermittently contain faecal bacteria in areas where the groundwater is highly to extremely vulnerable. The primary origins of bacterial pollution in Co. Wicklow are likely to be septic tank systems and organic wastes in farmyards.

8 Iron and Manganese

The source of iron can be iron minerals in rocks (shales and sandstones) or soils (boggy areas), pollution by organic wastes (from farmyards, etc.), or occasionally the corrosion of iron fittings. Manganese is frequently associated with iron although it is less prevalent.

Iron and/or manganese concentrations exceeded the EU MAC in six public supplies, listed below:

Table 4 Groundwater Sources with High Iron Concentrations

Geological Formation	Public Supplies	Comments
Maulin	Roundwood	Manganese only (1997)
	*Kirikee	
	Rathdrum	
	Threewells	
	Annacurragha	Manganese only
Kilmacrea	*Thomastown	

*Iron and Manganese treatment installed in pump house

There is no evidence that iron problems in Co. Wicklow are due to anything other than the rock type or natural conditions. In particular, high iron is prevalent in the shale-dominated rock formations.

9 Appraisal of Groundwater Quality in Selected Sources

9.1 Roundwood

The water is moderately soft (50-64 mg/l $CaCO_3$), and of calcium bicarbonate type with low alkalinity (32-45 mg/l $CaCO_3$). While the quality is generally good, some parameters may be increasing slightly. There is intermittent natural contamination from iron and manganese which seems to coincide with high turbidity and suspended solids. Chloride is low (c. 15 mg/l) and conductivity ranges 130-170 µS/cm. Nitrate (mean 19 mg/l) is below the EU guide level, with no apparent increasing trend.

The aquifer is unconfined and is assessed as ‘extremely’ to ‘highly’ vulnerable to contamination. Point sources, particularly farmyards and septic tank systems, probably pose the main threats to the well. A survey of point sources in the ZOC was carried out. In view of the vulnerability and the potential sources of contamination in the ZOC, the risk to this source is relatively high.

9.2 Redcross

The analyses indicate a moderately soft (58–62 mg/l $CaCO_3$) calcium bicarbonate type water with low alkalinity (38-56 mg/l $CaCO_3$). Conductivities range 200-220 µS/cm, with chloride 20-25 mg/l.

Nitrate levels are fairly high and have exceeded the EU guide level of 25 mg/l NO_3 with an average of 27 mg/l, but have never exceeded the EU MAC of 50 mg/l NO_3

The aquifer is unconfined and of ‘low’ to ‘moderate’ vulnerability. The main potential sources of contamination appear to be Redcross village and the surrounding houses and farmyards. There is no sewerage scheme and there is a concentration of septic tanks adjacent to the source. Although the ZOC appears to exclude the main residential area, it includes the new Council estate to the west of the well.

9.3 Baltinglass

Tinoran

The analyses indicate a calcium bicarbonate water type, moderately soft (82-94 mg/l $CaCO_3$) with low alkalinity (70 mg/l $CaCO_3$). Water quality is very good except for nitrate, which is 25-39 mg/l. Chloride averages 17 mg/l and conductivity 210-250 μS/cm.

The water quality in the adjacent Tinoran stream is very variable with high ammonium, iron, nitrite and potassium together with high numbers of bacteria which all indicate farmyard contamination.

The main risk to the source is from surface runoff from farmyards and landspreading of organic wastes. Well construction details are unavailable; the boreholes may not be sealed against contaminated surface water. Steep local gradients allow substantial and rapid runoff to occur. Septic tanks may threaten the groundwater quality. Point sources in the ZOC have been surveyed (see source report).

The Tinoran groundwater is ‘extremely’ to ‘highly’ vulnerable.

Lathaleere

The hydrochemical analyses indicate a moderately hard (204-216 mg/l $CaCO_3$) calcium bicarbonate water with a moderate alkalinity (178-190 mg/l $CaCO_3$).

The quality of the groundwater is good. There are some background coliforms which are below levels which cause concern. Nitrate levels are just below the guide level – mean 19 mg/l, max. 23 mg/l.

The groundwater is ‘moderately’ to ‘highly’ vulnerable. The main potential sources of contamination appear to be developments at the eastern edge of Baltinglass village and the surrounding houses and farmyards. A sewerage scheme exists but not all the houses are connected and there are some septic tanks adjacent to the source. The ZOC extends under some residential estates and industrial developments. The main sewer runs along the main road within 20 m of the wells.

There is also a risk from surface runoff from farmyards and landspreading of organic wastes. A survey of point sources has been carried out in the zone of contribution of the well (details in source report).

The Lathaleere source was closed in November 2002 due to the concentrations of Uranium found in the water. A new well drilled at Carsrock will be commissioned in the summer of 2003 to augment the supplies from the Tinoran and Parkmore sources.

Bawnoge (Parkmore) Springs

The hydrochemical analyses indicates a calcium bicarbonate water type which is hard (286-324 mg/l $CaCO_3$) with a moderate alkalinity (238-280 mg/l $CaCO_3$).

The water tends to have intermittent contamination from *E. coli*. Chloride ranges 16-19 mg/l. Conductivity is high (524-605) due to dissolution of $CaCO_3$ from the limestone-dominated subsoils. Nitrate levels are generally above the EU Guide Level, ranging 23-39 mg/l with a mean of 27 mg/l.

The main risk is posed by surface runoff around the two springs following landspreading of organic wastes. The aquifer is unconfined and ‘highly’ to ‘extremely’ vulnerable, due to the gravelly subsoils.

9.4 Kilballyowen

Groundwater at Kilballyowen is **moderately soft** (216-255 mg/l $CaCO_3$), calcium bicarbonate type water with very low alkalinity (10–38 mg/l $CaCO_3$) and electrical conductivity around 240 μS/cm.

In general the quality is fair, but slight contamination occurs at times. Chloride was above background, (average 30 mg/l). Nitrate was slightly above EU guide level (average 32 mg/l) but seems not to be increasing with time. Potassium was above EU MAC on 3/2/97 at 13 mg/l, and on 12/5/87 and 12/8/97 was over the threshold level. The water shows very high levels of coliforms and occasionally *E. coli*.

The aquifer is unconfined and is assessed as 'extremely' to 'highly' vulnerable to contamination. Point sources of contamination, in particular septic tanks, pose the main threats to the well, and investigation should be undertaken to eliminate the source of high potassium and coliforms.

10 Relationship between Vulnerability and Groundwater Quality

A comparison between the mapped groundwater vulnerability and water quality suggests that sources showing contamination were usually in areas where the groundwater was mapped as extremely and/or highly vulnerable.

11 Overall Assessment and Conclusions

- The hydrochemistry of groundwater in Co. Wicklow is primarily influenced by the non-limestone dominated bedrock geology.
- The groundwater in most of the county is soft to moderately hard and is of a calcium bicarbonate water type. The softer waters are generally found in the upland areas of central Wicklow.
- The presence of limestone dominated subsoils around the margins of Co. Wicklow permits the dissolution of the calcium carbonate, producing a much harder calcium bicarbonate water.
- The main groundwater quality problems due to natural conditions in the ground and the natural chemistry of groundwater are caused by iron (Fe) and manganese (Mn).
- The main water quality problems caused by the impact of human activities are due to faecal bacteria and nitrate (NO_3). Chloride and potassium provide good indicators of contamination.
- Mean nitrate levels were greater than the EU guide level in nine out of 22 public sources (41%). None of the sources had a level above the EU MAC.
- There may be slight evidence of a trend of increasing nitrate concentrations in some of the sources. Further sampling is required to confirm this.
- Groundwater quality from the smaller and shallower sources tends to be poorer than from the larger and deeper sources.
- The presence of faecal bacteria in some sources is a major concern. The location of these wells close to septic tank systems and/or farmyards is likely to be the main reason for the relatively poor quality.
- The smaller sources are more likely to be affected by point source contamination than by diffuse contamination.
- There is a good correlation between groundwater vulnerability and groundwater quality.

In general, groundwater quality in County Wicklow is relatively good and contamination is not extensive. However, some groundwater sources are polluted by faecal bacteria and there is some nitrate contamination. The pollution and most of the significant contamination is probably caused by point sources, particularly farmyards and septic tanks, and by poor sanitary protection of wells.

12 Recommendations

- To improve the groundwater quality database, it is recommended that:
  - analyses of raw water rather than treated water should be carried out on a regular basis (at least twice a year until the situation and trend in each source is confirmed);
  - full analyses (including all major ions) should be carried out on these samples;
- Particular attention should be given to the Group A and Group B sources listed in Table 6.3.

- A continued review of the most recent nitrate data for the sources listed in Group B is recommended; with increased monitoring of untreated water, monitoring and assessment of other parameters, surveys of potential contamination sources, and assessment of the likely source(s) of nitrate; using vulnerability zones and groundwater protection zones in the assessment process
- Boreholes indicating coliforms should be disinfected and a chlorination system installed.
- A programme of groundwater protection zone delineation around public and group scheme supplies, using the GSI guidelines, over the next few years is recommended.
- A programme of checking the sanitary protection at each well and spring site (i.e. on Council property immediate around the source) would help to ensure that shallow groundwater and surface water is not entering the source and that accidental spillages would not contaminate the source.

13 Acknowledgements

The assistance of Council staff, in particular Ms. Breege Kilkenny, Mr Tom Griffin and Mr Eamon Dillon, and State Laboratory staff, in particular Ms. P. Bonnar and Ms Elizabeth Kinsella, is greatly appreciated.

14 References

Aldwell, C. R. & Burdon, D.J. (1987). *Outline of the hydrogeology of the Dinantian volcanics, Co. Limerick*. Internal report, Geological Survey of Ireland, 24 pp.

Ball, D. M. (1994). *The value of hydrochemistry and the confusion with water quality*. The GSI Groundwater Newsletter, Geological Survey of Ireland, No. 24, p. 11–12.

Casey, S. (1997). *Groundwater Vulnerability and Water Quality for Brittas Bay*. Unpublished MSc (Research) thesis, Trinity College Dublin.

Casey, S., Woods, L., & Wright, G.R. (1998). *Groundwater Vulnerability and Water Quality for Brittas Bay*. Geological Survey of Ireland, Report to Wicklow County Council.

EPA (1997). *Nitrates in groundwater in County Wicklow*. Draft report, Environmental Protection Agency.

Woods, L. (1998). *Roundwood Public Supply: groundwater source protection zones*. Geological Survey of Ireland, Report to Wicklow County Council.

Woods, L. (1998). *Redcross Public Supply: groundwater source protection zones*. Geological Survey of Ireland, Report to Wicklow County Council.

Woods, L. (1998). *Baltinglass Public Supply: groundwater source protection zones*. Geological Survey of Ireland, Report to Wicklow County Council.

Appendix 1: Indicators of Groundwater Contamination : A Discussion

(from Daly, 1996)

Introduction

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 ($N0_3$)*
Sediment	Magnesium (Mg)	Ammonia (NH_3)*
pH (lab)	Sodium (Na)	Iron (Fe)*
Electrical Conductivity (EC)*	Potassium (K)*	Manganese (Mn)*
Total Hardness	Chloride Cl)*	
General coliform	Sulphate ($S0_4$)*	
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 ($N0_2$)*	TOC *	Lead (Pb)
B.O.D.*	Boron (B) *	Other metals
Dissolved Oxygen *	Cadmium (Cd)	
*** good indicators of contamination**		

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 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; entertoviruses 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 (Hagedorn, 1983). 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 bgl; 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 bgl. (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 streptocci 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 (Keswick and Gerba, 1980; 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 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.

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 fertilizers 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 fertilizers. 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 NO_3 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 suggest that diffuse sources – landspreading of fertilizers – is having an impact on groundwater.

To counteract the threat posed to health and the environment by rising nitrate levels, the EC prepared a directive to control diffuse inputs of nitrate from agricultural sources to groundwater (Thorn and Coxon, 1992). This directive (Commission of the European Communities, 1991) allows for the designation of "nitrate vulnerable zones" (NVZs), which are areas of land that drain into surface or groundwaters which are intended for the abstraction of drinking water and which could contain more than 50mg/l nitrate if protective action is not taken. If areas are designated as NVZs in Ireland, it will have repercussions for farmers in these areas as the application of livestock manure/slurry and inorganic fertilizers will be restricted.

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.

Giving a balanced view of the nitrate situation in Irish groundwater is not easy as the data availability is poor. On the one hand, many of the wells with relatively high nitrate levels examined by the GSI are being contaminated by organic waste and not inorganic fertilizers. It is essential that "nitrate vulnerable areas" under the Nitrates Directive are not delineated without the proper evidence, as this would restrict farming in these areas unnecessarily. On the other hand, inorganic fertilizers have increased the background nitrate levels significantly in some of the intensive agricultural areas - the Barrow valley, for instance.

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.

Potassium

Potassium (K) is relatively immobile in soil and subsoil. Consequently the spreading of manure, slurry and inorganic fertilizers 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 normally a problem in groundwater as it usually is not mobile in soil and subsoil).

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 cation. 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 fertilizers.

Iron and Manganese

Although naturally present 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, resulting in solution of iron and manganese 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, but can also result from other high BOD wastes such as milk, landfill leachate and perhaps soiled water and septic tank effluent.

References

Ashley, R.P. & Misstear, B.D.R. 1990. *Industrial development: the threat to groundwater quality.* Paper presented to the Institution of Water and Env. Management, East Anglia Branch.

Callery, P. 1988. *Groundwater for public supply.* In: Proceedings of International Association of Hydrogeologists (Irish Group) Seminar, Portlaoise.

Clark, L.1990. Verbal communication at lecture to IAH (Irish Group) Technical Discussion Meeting

Commission of the European Communities, 1991. *Council Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC).* Official Journal of the European Communities, No. L375/1-8.

Coxon, C. 1987. *Nitrate problems in domestic water supplies.* GSI Groundwater Newsletter, No. 5, p. 10.

Daly, E.P. 1994. *Groundwater Resources of the Nore River Basin.* Geological Survey of Ireland, Internal Report.

Daly, D. 1986. *Groundwater in County Galway, with particular reference to its protection from pollution.* Geological Survey of Ireland, Report to Galway County Council, 98pp.

Daly, D. 1996. *Groundwater in Ireland.* Course notes for Higher Diploma in Environmental Engineering, UCC.

Daly, D., & Warren, W.P. 1994. *Mapping groundwater vulnerability to pollution: GSI. guidelines.* GSI Groundwater Newsletter, No. 21, 10-15.

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. To-date there has been a tendency to focus only on the EU maximum admissible concentrations (MAC). In the view of the GSI, there is a need for assessment of the degree of contamination of groundwater as well as showing 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 significant contamination but not pollution is occurring. *So if you have to assess groundwater quality data when considering the location of a potentially polluting activity, see if the thresholds given below are of use.*

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 fertilizer or organic waste source; check other parameters.
Ammonia > 0.15 mg/l ⇨ source is nearby organic waste; fertilizer 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 contaminaton 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.

Table 2. Summary of Nitrate levels (as mg/l NO_3) in Groundwater Sources in Co. Wicklow, (after EPA, 1997, 2000).

Public Supply	*GSI no.*	*Well Type*	*Aquifer (Formation)*	*No of Samples*	*Min*	*Max*	*Mean*	*Dates*	*Values*
Ballycoogue	2917SE 072	Borehole	Kilmacrea	13	<0.4	18.4	12.43	1989-2000	15.8, 13.2, 15.8, 12.3, 15.4, 10.1, 7.0, 9.7, 10.1, 14.8, 18.4, <0.44
Barndarrig	3217NW 204	Borehole	Kilmacrea	17	2.5	54.0	25.87	1989-2000	22.9, 25.5, 24.6, 22.4, 24.2, 13.6, 22.9, 21.6, 32.1, 33.1, 45.5, 41.2, 13.8, 2.5, 40.5
Carrigacurra GWS		Spring	Gravels	9	3.1	13.2	10.1	1989-1991	11.9, 11.4, 10.6, 10.6, 13.2, 12.3, 9.2, 8.8, 3.1
Coolboy/Coolfancy WS	2915NE 001	Spring	Ballylane	15	5.7	41.3	27.5	1989-2000	26.4, 24.6, 25.5, 30.4, 28.6, 30.4, 22, 26.4, 26.4, 19.8, 35.4, 25.8, 41.3, 5.7
Donard		Gallery	Gravels	10	4.6	23.1	6.1	1989-2000	5.7, 5.3, 6.2, 4.6, 5.8, 7.3, 6.7, 7.1, 7.1, 23.1
Dunlavin	2619NE 020	Springs	Tipperkevin	9	9.7	32.4	18.3	1990-2000	10.5, 15.8, 9.7, 17.4, 16.8, 9.8, 30.2, 32.4, 22.4
Grangecon	2619SE 045	Borehole	Glen Ding	6	6.2	19.8	10	1989-1992	19.8, 8.8, 8.8, 6.2, 7.9, 8.7
Hollywood WS		Spring/Gallery	Gravels	16	1.2	20.9	10.2	1989-2000	1.2, 10.1, 11.9, 9.7, 8.8, 15.8, 8.8, 8.4, 7, 10.6, 11.3, 12.2, 11.0, 4.8, 20.9, 10.8
Kiltegan	2917NW 070	Borehole	Granite	13	2.2	21.7	14.2	1989-2000	10.1, 8.8, 10.6, 16.3, 17.6, 11.4, 11.9, 16.3, 18.7, 20.7, 21.7, 18.4, 2.2
Kirikee	2917NE 076	Borehole	Maulin	17	0.1	11.0	5.1	1989-2000	6.6, 7.9, 5.7, 7.5, 10.1, 6.2, 7.5, 4, 6.2, 5.7, 0.9, 1.7, 5.2, 0.1, 0.7, 11.0, <0.4
Knockananna WS	2917NW 071	Borehole	Granite	5	11.4	29.6	20.2	1991-1998	11.4, 16.7, 17.6, 25.7, 29.6
Redcross	3217NW 217	Borehole	Kilmacrea	27	4.0	34.2	22.7	1989-2000	18.5, 26, 18, 19.8, 24.6, 25.1, 25.5, 12.8, 12.8, 15.4, 11.4, 16.3, 17.6, 4
									4, 17.6, 27.1, 30.6, 32.0, 30.9, 33.1, 34.2, 32.9, 34.1, 33.7, 29.6, 16.5,
Roundwood	2919NE 025	Borehole	Maulin	27	6.2	27.8	18.1	1989-2000	16.3, 14.5, 14.5, 15, 6.2, 6.6, 14.1, 11.9, 18, 17.8, 19.8, 18.2, 19.2, 18.3, 19.0, 19.2, 24.6, 23.9, 19.6, 20.0, 20.9, 25.6, 21.1, 21.1, 16.2, 20.6, 27.8
Stratford/Cl'money		Spring/Gallery	Gravels	13	7	37	14.6	1989-2000	8.4, 7, 9.2, 12.8, 18.9, 11.9, 7.9, 11.4, 14, 14.1, 17.4, 37.0, 20.3
Valleymount	2919NW 018	Spring	Granite	10	4.3	16.7	11.6	1992-1995	9.2, 9.6, 10.2, 11, 12.4, 12.6, 14.6, 15.7, 4.3, 16.7
Windgates/Templecarrig		Springs		21	5.8	36.4	20.3	1989-2000	24.6, 28.6, 13.6, 13.2, 13.6, 13.6, 26, 26.4, 14.5, 21.1, 20.2, 7.9, 1414.5, 16.3, 17.2
									14.5, 16.3, 17.2, 36.4, 35.8, 28.7, 15.2, 33.0, 5.8
Blessington		Borehole ?	Gravels	24	1.0	31.2	11.5	1992-2000	4, 5.3, 1.9, 1.8, 1.6, 2.2, 1.9, 2.4, 19.9, 22.1, 24.1, 24.2, 26.9, 1.0, 1.0, 4.0, 31.2, 24.5, 5.5, 2.8, 22.9, 18.1, 2.5, 24.8
Baltinglass WSS	2617NE 042, 032,	Borehole	Granite/Fault	23	14.5	26.0	21.1	1989-2000	25.5, 24.2, 26, 21.1, 21.6, 16.3, 22, 14.5, 24.6, 19.1, 19.9, 21.3, 20.8, 21.6
			Zone						21.6, 21.1, 22.7, 21.1, 23.0, 22.8, 20.1, 20.9, 15.5, 20.6
Kerry Foods (Shillelagh)		Well		1	-	-	12.6	1995	12.6
Brittas Bay (South)		Boreholes		1	-	-	3.1	1990	3.1
Thomastown	2919SE 070	Borehole	Kilmacrea	8	2.0	17.6	10.3	1989-2000	17.6, 13.6, 15, 11.9, 7.9, 2.0, 6.7, 7.6
Tober		Spring	Gravels	1	-	-	13.7	1984	13.7 (GSI Data)