AN ASSESSMENT OF GROUNDWATER QUALITY IN COUNTY CLARE

Prepared by:

Colette Cronin and Jenny Deakin
Groundwater Section
Geological Survey of Ireland

In collaboration with:

Clare County Council

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AN ASSESSMENT OF GROUNDWATER QUALITY IN COUNTY CLARE

1. Introduction

This report contains an assessment of the readily available groundwater chemistry and quality data for public and private supplies in County Clare. It also gives a number of recommendations for consideration by Clare County Council.

2. Sources of Information

Data on hydrochemistry and water quality were obtained from the following sources:

- Two rounds of chemical analyses (October 1997, February 1998) carried out for the GSI by the State Lab on all major groundwater supplies in Clare. The location of these supplies is shown in Figure 1. The State Lab analyses comprised all major cations and anions, hardness and trace metals (Tables 1, 2). At the request of the local authority, mercury was analysed during the Oct 1997 round of sampling. The County Council carried out raw water bacteriological analyses during both sampling rounds.
- Chemical and bacteriological analyses for over 50 private supplies submitted for the Water Supply Improvement Grant Scheme (Table 3) (Data for 1998–1999).
- Source reports for Ballyvaughan, Whitegate, Mountshannon, Pouladower, and Drumcliff Public Water Supplies (GSI, 1999)
- Geological Survey of Ireland water quality and hydrochemistry files.
- ‘Water Quality in Ireland for the period 1995 to 1997’ (EPA, 1999).
- ‘An Investigation into Elevated Lead Concentrations in Groundwater’. Carried out as part requirement of an M.Sc. at Trinity College Dublin (Jones, 1998).
- ‘Nitrates report for County Clare’ (MacCarthaigh, 1997).
- ‘Environmental Impact Statement for Kilbreckan Calcite Mine’ (Clare Calcite Ltd, 1995).
- ‘Summary Report of Hydrometric and Water Quality Data (October 1995–July 1996)’ (Drew, 1996).
- ‘Report on Cloonoolia North Springs’ prepared for Clare County Council (K.T. Cullen & Co., 1993).
- Hydrogeological Investigation of Drumcliff Springs. Preliminary report to Clare County Council (K.T. Cullen & Co., 1989).
- Further Hydrogeological Investigations of Drumcliff Springs. Report to Clare County Council (K.T. Cullen & Co., 1990).

3. Hydrochemistry

The inherent water signature and variations in chemical parameters over space and time were assessed to gain an understanding of the groundwater flow system in the various rock types. There are few long term data available for County Clare therefore the assessment is based largely on sampling carried out in 1997 and 1998. Although this does not allow a full overview of the hydrochemistry, it does provide some indication of spatial variations across Clare. Hydrochemistry data for all major supplies are given in Tables 1 and 2. Water types are plotted on a Piper diagram in Fig 2. (A description of Piper diagrams is given in Appendix 1).

3.1 Carbonate Rock Units

Much of County Clare is underlain by carbonate limestone rock. The groundwater chemistry of the various limestone formations are similar and will be treated collectively in this section. The hydrochemistry of the carbonate rocks is dominated by calcium and bicarbonate ions. As a result many of the sources in Clare plot as a cluster on a Piper diagram (Fig. 2). Hardness is in the range of 132 to 387 mg/l ($CaCO_3$), i.e. slightly hard to very hard. Spring waters tend to be softer as throughput is quicker and there is less time for the dissolution of minerals into the groundwater.

Groundwater alkalinity is high, ranging from 132 to 392 mg/l ($CaCO_3$) (Oct 1997). Alkalinity is less than hardness indicating that ion exchange (where calcium or magnesium are replaced by sodium) is not a significant process. Electrical conductivities range greatly from 274 to 713 µS/cm. Typical limestone water conductivities are of the order 500–700 µS/cm. Lower values suggest that the residence times of some of the sources are very short, for example at Ballyvaughan where a rapid response to rainfall results in low conductivities at the public supply (see Section 11.2).

The magnesium/calcium ratio is used in limestone aquifers to indicate possible dolomitisation where the calcium ions have been replaced by the magnesium. A ratio of greater than 0.3 (where parameters are expressed in milliequivalents per litre) indicates conditions which may be due to the presence of dolomite, or the result of ion exchange or may be an indication of some form of contamination. Crusheen PWS for example is located within the Tubber Limestone which is crinoidal cherty limestone containing some dolomite. Groundwater at Crusheen had a Mg/Ca ratio of 0.35 in 1997 which may be due to the presence of thin dolomite beds within this limestone. Dolomitisation is caused when magnesium is introduced into limestone ($CaCO_3$) forming dolomite ($CaMg[CO_3]_2$)

3.2 Non Carbonate Rock Units

The non carbonate rock units in County Clare include all the Silurian, Devonian and Namurian sandstone/shale formations. Alkalinity ranges from 114 to 242 mg/l ($CaCO_3$) and hardness ranges from 163 to 219 mg/l (moderately hard).

The Silurian and Devonian (Old Red Sandstone) formations largely contain calcium bicarbonate type water (Fig 1). This suggests that these groundwaters have short residence times and largely contain the more readily dissolved ions such as calcium and bicarbonate. Conductivities in these units are low ranging from 313 to 416 µS/cm.

The groundwater samples taken from the Namurian shales contain a mixed water type (Fig. 2). These samples have variable conductivity readings ranging from 465 to 727 µS/cm.

Cation exchange is occasionally evident in groundwater samples taken from non carbonate rocks. The most important exchange reactions are the replacements of both calcium and magnesium by sodium which show up in the analyses where total alkalinity is greater than total hardness. A large reservoir of exchangeable sodium (provided chiefly by clay particles in the shales) and sufficient residence time within the aquifer are the main requirements for the process to occur.

Iron (Fe) and manganese (Mn) are a common occurrence in groundwater derived from sandstone and shale formations. This is due to the dissolution of Fe and Mn from the sandstone/shale where reducing conditions occur.

3.3 Sand and Gravel Deposits

The hydrochemistry of groundwater in sand and gravel deposits tends to reflect the predominant lithology of the clasts. ‘Limestone gravels’ for example will have harder groundwater than ‘sandstone gravels’. Where a mixed gravel is present the signatures may be variable. Groundwater analyses are available for three sources located in gravel deposits. Hardness ranges from 68 to 218 mg/l ($CaCO_3$) i.e. moderately soft to moderately hard. At Montpelier (a Clare PWS located in Limerick) the groundwater is slightly hard, whereas the Bridgetown and Killaloe springs have moderately soft water.

Alkalinity ranges from 34 to 242 mg/l ($CaCO_3$). Carbonate and bicarbonate are the main ions which contribute to alkalinity. The spring sources have a lower alkalinity than the Montpelier well possibly because the shallower water has had less time to dissolve these ions. Conductivities range from 174 to 437 μS/cm.

Natural iron and manganese levels are occasionally elevated in gravely deposits where the clasts are largely sandstone and shale lithologies. One private supply located in gravels contained very high manganese levels (Grant Scheme records, 1998–1999).

4. Background Factors in Assessing Groundwater Quality

In assessing groundwater quality, the approach taken in the GSI is to distinguish between the terms 'contamination' and 'pollution'. Groundwater becomes 'contaminated' when substances enter it as a result of human activity. The term 'pollution' is reserved for situations where contaminant concentrations are sufficiently high to be objectionable i.e. above the EU maximum admissible concentration (MAC).

As human activities have had some impact on a high proportion of groundwater in Ireland, there are few areas where the groundwater is in pristine condition. Consequently most groundwater is contaminated to some degree although it is not necessarily polluted. In assessing groundwater quality there is often 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 and when monitored over time can be helpful in isolating potential sources of contamination before major incidents occur. Consequently, thresholds for certain parameters can be used to help indicate situations where significant contamination but not pollution is occurring. The thresholds for assessing water quality in County Clare are given below.

Parameter	**Threshold** mg/l	**EU MAC** mg/l
Nitrate	25	50
Potassium	4	12
Chloride*	25-50	250
Ammonia	0.15	0.3
Faecal bacteria	0	0
K/Na ratio **	0.4	

* Refer to Section 7.
** Refer to Section 8.
Indicators of groundwater contamination are discussed in Appendix 2.

5. Faecal Bacteria

Escherichia Coli (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. coil are an excellent indicator of pollution, they can come from different sources - septic tank effluent, farmyard waste, landfill sites, birds.

The natural environment, in particular the soils and subsoils, can be effective in removing bacteria and viruses by predation, filtration and adsorption. 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 karstified 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 giving sufficient time for them to die off.

Two rounds of raw water sampling were carried out on all major groundwater supplies in Clare as part of the Clare Groundwater Protection Scheme Project (Deakin, 1999). In Oct 1997, 56% (13 of 23 samples) of the supplies contained E. coli and total coliforms (see Table 1). Eight of those sources are located in karst limestone aquifers. In Feb 1998, 37% (7 of 19 samples) contained E. coli and total coliforms (see Table 2). Six of those supplies are located in karstified limestone aquifers. In karst areas where the vulnerability is extreme, rapid recharge and flushing of coliforms from the land surface, septic tank systems and farmyards into groundwater can readily occur.

25% (13 of 53 samples) of private wells sampled for the well improvement grant scheme contained some general coliforms (usually < 5) however no E. coli were detected (Table 3). A private well located in the Old Red Sandstone at Dromindoora, North Clare had 31 E. coli detected on 9/9/97 (GSI files). The cause of contamination was not clear but it was likely to be the owners septic tank system or from contaminated surface runoff. A number of wells located in karst limestone were sampled in the Kilbreckan area (Clare Calcite Ltd., 1995) during the period Oct 1992 to Oct 1993. 42% (15 of 36 samples) contained general coliforms and 36% (13 samples) contained faecal coliforms. A number of wells contained coliforms in Oct 1993 following a period of heavy rainfall which followed a dry spell. It is likely that contamination of these supplies by organic waste occurred as a result of slurry spreading too close to the wells during this dry period (Clare Calcite Ltd, 1995).

6. Nitrates in Groundwater in County Clare

6.1 Introduction

Nitrate is one of the most common contaminants identified in groundwater. 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. It poses a potential health hazard to babies.

6.2 Sources of Nitrate

Elevated levels of nitrate can be derived from the following sources: septic tank effluent; slurry and soiled water in farmyards; spreading of organic wastes and fertilisers; and spreading of inorganic fertiliser.

Septic tank effluent contains nitrogen concentrations in the range 30–45 mg/l as N. As this nitrogen 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.

While farmyards contain large volumes of organic wastes, most are landspread and do not cause significant problems. However, infiltration of soiled or dirty water into the ground beneath and in the vicinity of farmyards can increase nitrate levels (and pollution by faecal bacteria). Also the disposal of soiled water by rain guns can raise nitrate levels in underlying groundwater if they are not moved regularly. Many farm wells in Ireland have been contaminated by soiled water.

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

Drawing conclusions on the source of elevated nitrate levels in any particular well depends not only on assessing the nitrate data, but also the other parameters, in particular 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. Further details on nitrate is given in Appendix 2.

6.3 Appraisal of Nitrate Data

As part of a review of draft county reports on nitrate for the EPA, the GSI have subdivided groundwater sources into four broad categories with respect to nitrate contamination.

- **Category A**: Nitrate levels regularly exceed 50 mg/l
- **Category B**: Average nitrate levels exceed 25 mg/l and peaks regularly approach or exceed 50 mg/l
- **Category C**: Average nitrate levels exceed 25 mg/l, peaks rarely approach 50 mg/l but give cause for concern
- **Category D**: Average nitrate levels <25 mg/l and peaks do not give cause for concern.

Analysis of the available data has provided the following results for Co. Clare.

- **Category A:** No public supply wells fall into this category.
- **Category B**: No public supply wells fall into this category.
- **Category C**: Three sources are in this category. Nitrate levels at Bridgetown PWS ranged from 33.5 to 38.5 mg/l (Oct 1997, Feb 1998).
  On two occasions in 1991 nitrate levels in excess of the MAC were measured at Crusheen PWS, (57 mg/l on 5/2/91 and 54 mg/l on 26/3/91). However, the source is no longer used for public supply.
  On two occasions in 1995 nitrate levels exceeded the threshold at Montpelier PWS (27.4 mg/l on 12/6/95, 32 mg/l on 8/8/95).
- **Category D**: All the remaining public supplies and private supplies are in this category. Two rounds of sampling (Oct 1997 and Feb 1998) indicate that on the whole the nitrate concentrations in Clare are well below the threshold level of 25 mg/l. Average nitrate levels for those periods was 7 mg/l.

Nitrate levels for public supply wells for Oct 1997 and Feb 1998 are given in Fig 3. Nitrates were consistently higher in February 1998 than in October 1997. This indicates that nitrates are flushed through the aquifer system during wet periods. During and after such periods higher nitrate levels are likely to be recorded. Average nitrate levels in County Clare were < 25 mg/l for 23 sources sampled between 1989 and 1995 (MacCarthaigh, 1997).

7. Chloride

Chloride like nitrate is a mobile anion i.e. the ions do not tend to get bound up by the soil/subsoil as they move toward groundwater. In coastal areas, rainwater is enriched with chloride (Cl) due to the presence of seawater in rainfall. Therefore, groundwater in areas close to the coast often contain relatively high concentrations of chloride. Chloride is also a constituent of organic wastes and fertilisers.

The GSI threshold value for chloride is generally taken to be approx. twice the background level. The average background level for chloride for East Clare is 12–15 mg/l, therefore the threshold is taken to be 25–30 mg/l. In West Clare the threshold level may be greater than 50 mg/l. At the old Kilkee PWS (shallow well) chloride levels of 157 mg/l (1997) and 139 mg/l (1998) were recorded, which would suggest that some form of contamination by organic wastes is occurring, probably seepage from septic tank systems.

8. K/Na

The 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 usually less than 0.2. Consequently a K:Na ratio greater than 0.4 can be used to indicate contamination by plant organic matter - usually from farmyards and 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. The K:Na ratio for all public supply wells in Clare sampled in October 1997 and February 1998 was < 0.4.

9. Iron and Manganese

The source of iron (Fe) can be iron minerals in the rocks or soils, pollution by organic wastes or occasionally the corrosion of iron fittings in the water system. Manganese (Mn) is frequently associated with Fe although it is less prevalent. Groundwater from certain rock types such as dark muddy limestones, shales and sandstones and from boggy areas may contain high Fe and Mn concentrations. Effluent from the wastes cause deoxygenation in the ground which results in the dissolution of Fe and Mn from the soil, subsoil and bedrock into groundwater. With reoxygenation in the well or water supply system the Fe and Mn precipitate out. The breakdown of high BOD organic wastes from farmyards and other sources can cause the formation of carbon dioxide and oxygen deficient conditions and can bring the Fe and Mn into solution in the groundwater.

High Fe concentrations have been reported in private wells in areas underlain by muddy limestone, such as the Ballysteen Limestone, and in areas underlain by shale and sandstone formations. It was found that 40 % (21 of 53 samples) of grant scheme private supplies throughout County Clare had Fe and/or Mn problems in 1998/1999. It is likely that these problems are for the most part natural as there is little evidence of other contamination in the majority of cases (only 14% of those sources experiencing Fe/Mn problems showed evidence of bacterial contamination). It has been demonstrated that at low pumping rates water does not reside long enough in the well for oxidation to occur thereby resulting in elevated Fe and Mn in small domestic supplies (Applin *et al*, 1989).

Less than 10 % of public sources sampled by the GSI in 1997 and 1998 had Fe and/or Mn problems. Kilrush PWS had high Mn levels in 1997 (60 µg/l) and 1998 (70 µg/l). Elmvale had high Fe levels in both 1997 (0.3 mg/l) and 1998 (0.211 mg/l). Kileany (Lisdoonvarna) PWS had high Fe in 1997 (0.43 mg/l). In locally important and poor sandstone and shale aquifers large drawdowns in wells are common and can result in Fe and Mn precipitation during pumping. In regionally important limestone aquifers, Fe and Mn problems may occur where surface runoff from Namurian shales infiltrates the groundwater system. This problem can be accentuated in karstified limestone where rapid groundwater flow prevents the Fe and Mn precipitating prior to pumping, resulting in elevated Fe/Mn levels. Groundwater in shaly limestones can also contain high Fe and Mn such as in the Ballysteen limestone.

High Mn was found in 25% of sites sampled as part of an M.Sc. project carried out in the Mountshannon area (Jones, 1998). In one particular supply the Mn concentration was 13 times the

MAC value. This area is underlain by Old Red Sandstone and Ballysteen Limestone both of which contain Fe and Mn mineralisation.

10. Turbidity

Turbidity in groundwater arises from the presence of very fine solids which can not be filtered by routine methods (Flanagan, 1990). The presence of turbidity in groundwater will give rise to a cloudy appearance. Turbidity regularly exceeded the EU guidelevel from 1986 to 1989 at the Drumcliff PWS (Cullen, 1990) although it does not seem to be as much of a problem at Pouladower. The source of the turbidity may be either (a) humic material and organic particles derived from soils or (b) suspended matter from Namurian Sandstones and shales which are washed into sinking streams and through the groundwater system. Turbidity fluctuations are typical of a karst environment with a rapid 'flashy' response to rainfall events and short residence times.

11. Appraisal of Water Quality in Selected Sources and Areas in County Clare

11.1 Introduction

The section contains an assessment of the water quality of sources/areas in Clare for which source reports or groundwater studies were previously carried out. Any water quality problems identified during GSI sampling rounds are also outlined below.

11.2 Ballyvaughan

- The Ballyvaughan Source is located in the Fanore Limestone which is a medium bedded limestone containing some thin shale bands. The source and much of its catchment area is extremely vulnerable to contamination.
- A water quality survey was carried out in the Ballyvaughan valley in June/July 1998 as part of a study for Clare County Council (Kelly, 1998). Over this period, temperature, conductivity and pH were monitored at the Ballyvaughan (Newtown) PWS. Temperature ranged from 10.75 to 11.75^{o}C, pH ranged from 6.75 to 7.5 and conductivity ranged from 300 to 580 µS/cm (at 20^{o}C).
  At Ballyvaughan PWS nitrate and chloride concentrations in particular are significantly less than the thresholds. Bacteriological analysis of the raw water sample indicated the presence of high total and faecal coliform counts.
- Throughout the Ballyvaughan Valley, hardness ranged from moderately hard to hard (220–297 mg/l ($CaCO_3$)) for bored wells and moderately soft to moderately hard (92-180 mg/l ($CaC0_3$)) for springs. Similarly, dissolved solids in spring waters were lower than in bored wells. Nitrate levels in the general area are also very low ranging from 0.15 to 8.9 mg/l and chloride levels range from 5 to 21 mg/l. Within the Ballyvaughan Valley, five supplies were contaminated by coliforms (Kelly, 1998). There are no iron or manganese problems in the area.
- All available data indicate that water quality throughout the Ballyvaughan Valley appears to be relatively good. The variation in temperature, pH and the conductivity drop at the Ballyvaughan PWS after heavy rainfall suggest a rapid response to rainfall and short residence times (see Fig 4). The low levels of nitrate and chloride are attributed to the absence of intense farming and landspreading in the area and the relatively rapid groundwater throughput. Bacteriological contamination is common in areas of karstified limestone where travel times can be as fast as 145 m/hr (Kelly, 1998) and there is not sufficient time for the bacteria to die off.

11.3 Bridgetown

- The Bridgetown PWS is a dug well located in a sand and gravel deposit in the middle of Bridgetown village. The groundwater at this source is extremely vulnerable to contamination.

- Groundwater at the supply is moderately soft suggesting that the sandstone may be the predominant lithology in this gravely unit. As can be seen in the Piper diagram (Fig 2) the hydrochemistry of the groundwater at Bridgetown PWS differs from most of the other major supplies in Clare which tend to be calcium bicarbonate type waters.
- Alkalinity is very low at 34 mg/l. Nitrate levels at Bridgetown PWS were 33.5 and 38.5 mg/l in Oct 1997 and Mar 1998 respectively. In July 1987, 220 E. coli and 1200 general coliforms were detected at this supply. In Oct 1997, some coliforms were detected although there were no E. coli present. In Feb 1998, there were no coliforms or E. coli detected at the source.
- The bacteriological exceedances and the high nitrate indicate a source of organic contamination which is likely to be from the large number of septic tank systems in the village.

11.4 Broadford

- The Broadford PWS is a small spring supply which is located in Silurian sandstones/siltstones. The groundwater at the source is extremely vulnerable to contamination.
- The groundwater is occasionally subject to bacterial contamination (25 Total and 13 E. coli in Oct 1997). This problem is accentuated after periods of heavy rainfall.
- The source of the contamination may be due to nearby agricultural activities.

11.5 Carron

- The Carron source comprises two springs and a backup borehole. The source is located in the Ailwee Unit of the Burren Limestone, which is a thick, clean limestone with clay bands. The groundwater over much of the catchment is extremely vulnerable to contamination.
- This source was contaminated with total (58) and faecal coliforms (46) in Oct 1997. Bacterial contamination tends to be higher following periods of heavy rainfall. Iron has also been elevated in the past (0.4 mg/l in Dec 1984) at this source.
- This contamination is probably due to nearby agricultural activities.

11.6 Crusheen

- The Crusheen source is located in the Tubber Limestone and is highly vulnerable to contamination. It is no longer used as a public water supply source.
- Conductivity ranged from 685 to 713 (1997 and 1998) at this source. From 1989 to 1991 average nitrate levels at Crusheen were 11 mg/l (MacCarthaigh, 1997). On two occasions in 1991 high nitrate levels were measured, (57 mg/l on 5/2/91 and 54 mg/l on 26/3/91). This source was contaminated with total and faecal coliforms in Oct 1997 although it was not contaminated in Feb 1998.
- Groundwater at Crusheen had a Mg/Ca ratio of 0.35 in 1997 which may be due to the presence of thin dolomite beds within the Tubber limestone.
- There are a number of septic tanks nearby which may be contributing to contamination at the source (*Lait*, *pers comm*).

11.7 Drumcliff

- The Drumcliff Source is located in the Burren Limestone. The groundwater over much of the catchment is extremely to highly vulnerable to contamination.
- The hydrochemical analyses suggest that the Drumcliff source is a moderately hard water (151–250 mg/l ($CaCO_3$)), with alkalinities of 180–272 mg/l ($CaCO_3$) and conductivities of 290–560 µS/cm. These values are all lower than would normally be expected from a typical limestone water, suggesting that the groundwater residence time in the carbonate environment is relatively short. The large variation in conductivity also suggests a rapid response to recharge with most of the flow through large conduits.

- Water quality at Drumcliff fluctuates throughout the year with the poorer quality analyses being returned during the winter months and during periods of heavy rainfall. Colour, turbidity and iron are sometimes high in the treated water. Total coliforms and E. coli are also often present in the raw water. Three of four raw water samples taken in April 1989 were contaminated by faecal coliforms. 250 total coliforms and 230 E.Coli were detected in Feb 1998.
- High aluminium concentrations have been recorded on occasion at Drumcliff (max 0.31 mg/l Al; Sept 1994). Aluminium concentrations were less than the E.U MAC (0.2 mg/l) in both Oct 1997 and Feb 1998. Nitrate concentrations are always low (<10 mg/l NO_3) and chloride levels range from 20 to 45 mg/l. These results indicate that the water quality at Drumcliff is generally good although it is influenced by rapid recharge events, which are typical in a karst environment.
- Two sinkholes - Drumcaranmore sinkhole and Poulacorey sinkhole - have been traced to the springs. Travel times are very rapid and there is little natural purification or filtration occurring. Water sinking at these sinkholes have had high levels of iron, turbidity and colour on occasion (15/8/89 and 18/8/87 respectively) and this has implications for the water quality at the spring.
- The presence of shale within the catchment to the springs is likely to contribute to the iron problem. The Drumcliff source is highly vulnerable to contamination from a wide range of sources e.g. septic tank effluent and agricultural wastes (Deakin, 1999).

11.8 Pouladower

- The Pouladower spring is located in the Tubber limestone and groundwater is extremely vulnerable to contamination over much of the catchment.
- Hydrochemical analyses suggest that Pouladower spring has a moderately hard water (151–250 mg/l ($CaCO_3$)), with alkalinities of 140–185 mg/l ($CaCO_3$)) and conductivities of 314–462 µS/cm. These values are lower than would be expected from a limestone water, suggesting short residence times in the carbonate environment. The bacteriological analyses often show the presence of faecal coliforms, although this is to be expected in a karst spring. Colour is the main problem parameter with respect to the EU drinking water return requirements. Iron is seldom at a level which is cause for concern.
- Water quality at Pouladower is generally fairly good with low levels of chemical contaminant indicators such as chloride, nitrate and potassium.

Comments on the Water Quality at Drumcliff and Pouladower Springs

The Drumcliff and Pouladower Springs are both located in extremely to highly vulnerable, karstified limestone aquifers in mid–Clare. Some comments on the water quality problems arising at both supplies are outlined below:

- E. coli, colour and turbidity arising at both Drumcliff and Pouladower springs are typical of karst environments with a rapid 'flashy' response to rainfall events and short residence times.
- Runoff from the Namurian shales and sandstones in the Drumcliff catchment infiltrates into the karst limestones through swallow holes and travels rapidly through the groundwater system to the spring. In contrast, Pouladower spring has less problems with turbidity as the lakes in the catchment allow sediment to settle out before the spring is reached.
- Pollution incidents within the Drumcliff and Pouladower catchments could impact on the springs in a very short time due to the karstified nature of the limestone aquifer supplying the springs and the highly interconnected nature of the surface water and groundwater throughout the catchment..

11.9 Elmvale

- The Elmvale Spring is one of the largest springs in Clare and is located within the Slievenaglasha Formation which is a pale grey, clean, coarse grained limestone. The source is extremely vulnerable to contamination and is not used for drinking water.

- Elmvale Spring had high levels of iron in both Oct 1997 (300µg/l) and Feb 1998 (211 µg/l). The total coliform count was 300 in Oct 1997 and 42 in Feb 1998. The faecal count was 250 in Oct 1997 and 10 in Feb 1998.
- Surface runoff from Namurian shales located within the catchment to the springs may be causing elevated Fe and Mn levels at the supply. The presence of coliforms indicate a source of organic contamination perhaps from septic tanks/farmyards within the catchment.

11.10 Kilkee

- The Kilkee PWS is a shallow spring source which is not currently in use. The source is located in the Namurian sandstones and shales and is highly vulnerable to contamination.
- At Kilkee, sodium (Na) concentrations of >78 mg/l are much higher than the general background levels of 8 to 14 mg/l. The hydrochemistry of the groundwater at Kilkee differs from most of the other major supplies in Clare which tend to be harder limestone waters (see Fig 2). This source also has elevated chloride levels of 157 mg/l (1997) and 139 mg/l (1998) and was contaminated with total and faecal coliforms in Oct 1997.
- The presence of faecal coliforms would indicate a source of organic contamination. The chloride levels are also high which may also point to an organic source of contamination.

11.11 Kilrush

- The Kilrush source is located in Namurian sandstones and shales and is considered to be extremely to highly vulnerable to contamination.
- In Oct 1997 and Feb 1998 ammonium levels were elevated at Kilrush PWS (0.287 mg/l, Oct 1997 and 0.153 mg/l, Feb 1998). Kilrush also had high Mn levels in both Oct 1997 (60 µg/l) and Feb 1998 (70 µg/l). The supply was contaminated with some total and faecal coliforms in Oct 1997 and Feb 1998.
- The source of contamination has not been determined; however the supply has been abandoned due to the excessive ammonium levels (*Lait, pers comm*).

11.12 Kileany

- This large spring source is located in the Slievenaglasha Formation which is a pale grey, clean, coarse grained limestone. The groundwater at the spring is considered to be extremely vulnerable to contamination.
- Very high iron levels were recorded in Oct 1997 (430 µg/l). In Feb 1998 the iron levels (140 µg/l) were still elevated. This source was contaminated with total coliforms during both rounds of GSI sampling (100 in Oct 1997, 66 in Feb 1998) and faecal coliforms (110 in Oct 1997 and 45 in Feb 1998).
- It is likely that the Fe and Mn problems originate from the streams which run off the Namurian shales upgradient of the spring and sink at the limestone boundary.
- The spring water flows as a stream for a short distance before being tapped for supply making it susceptible to contamination from agriculture. Cattle congregate within a few metres of well and may be contributing to bacterial contamination at the source (*Lait*, *pers comm*).

11.13 Killaloe

- This is a shallow spring source and an infiltration gallery from the nearby river. The source is located in a sand and gravel deposit which comprises both Old Red Sandstone and Silurian sediments. The Killaloe source is extremely to highly vulnerable to contamination.
- Both faecal and total coliforms were detected at this source in October 1997. Bacterial contamination is greatest following periods of heavy rainfall (*Lait*, *pers comm*). The water quality in the river is likely to have an impact on the quality at the source.

11.14 Mountshannon Area

- There are two sources in Mountshannon, a spring source which is located to the northwest of the village and an artesian borehole which is located directly north of the village. The Mountshannon supplies are located along a large east-west trending fault zone which separates the Old Red Sandstone to the north from the Ballysteen muddy limestone to the south. Both sources are highly vulnerable to contamination.
- Groundwater at the spring and artesian supply are slightly hard and moderately hard respectively. Nitrate levels are < 5 mg/l and chloride levels are 20 mg/l at both the spring (Oct 1997, Feb 1998) and artesian supply (19/2/99). There are no bacteriological analyses available for the artesian supply. Bacteria were not detected at the spring supply in Oct 1997 or Feb 1998.
- As part of an M.Sc. thesis, a study was carried out on the presence of lead in the groundwater in the Mountshannon area (Jones, 1998). 24 sources were identified in the area and water samples taken were analysed for lead and other parameters such as Fe, Mn, Ba. The EU MAC for lead in drinking water is 50 μg/l although the new draft EU Directive proposes to reduce the MAC to 10 μg/l as lead is highly toxic.
- A small number of sources in Mountshannon had lead concentrations greater than 10 μg/l in groundwater. Lead at the Mountshannon spring source has exceeded the EU MAC on occasions e.g. 60 μg/l (6/5/97) and 70 μg/l (30/3/98). However, this source is no longer in use as a public supply. There is a group scheme to the north of the springs which has a concentration of 16.5 μg/l. Based on the analyses available to-date, the lead concentrations at the new artesian supply are low: 0.79 μg/l in summer 1998 and < 0.02 μg/l on 19/2/99.
- The Mountshannon area is an historical mining area and so other types of mineralisation such as zinc (Zn) and barium (Ba) have also been detected in the groundwater. A private borehole to the north of the fault contained a very high concentration of Zn (1086.77 μg/l) greater than the E.U. MAC of 1000 μg/l. The private group scheme also had an elevated Zn value (753.1μg/l). Ba is frequently associated with zinc and although a number of sites have elevated Ba (50–180 μg/l), concentrations do not exceed the MAC (500 μg/l).
  In 6 of the 24 sites sampled as part of the thesis, high Mn was recorded. At a private supply the Mn concentration was 13 times the MAC. Although Mn is not dangerous to health, high concentrations result in an unacceptable taste.
- A high lead anomaly in the subsoils was found over much of the area by an exploration company (AMAX, 1981) and is considered to be largely associated with the east-west fault and also disseminated in the sandstone. Sites containing elevated Ba and Zn occur north of the fault and are likely to originate in the Old Red Sandstone. The high Mn occurs in both the Old Red Sandstone and Ballysteen Limestone. It is likely to be naturally occurring in these areas owing to the siltier/shalier horizons present in both rock types.
- The water quality at the new artesian well is good with low levels of chemical contaminant indicators such as chloride, nitrate and potassium.

11.15 Mullaghmore Area

- A number of wells and springs adjacent to the proposed site for an interpretative centre at Mullaghmore, Burren National Park were monitored over a 4 year period from 1992 to 1996 (Drew, 1996). These wells are located in the Burren Limestone which is a pale to medium grey, pure limestone. The subsoils in the area are generally thin and vulnerability is extreme to high.
- In general it was found that springs exhibit bacterial contamination in all seasons. Borehole contamination by bacteria is more sporadic and less predictable. Fe and Mn are prevalent in the groundwater in this area and occasionally exceed the MAC at many of the sampling sites. Mean pH readings for the period 1992–1996 range from 7 to 7.9. Mean hardness varies from moderately soft to moderately hard (60–152 mg/l $CaCO_3$). Mean conductivites range from 36 to 132 μg/l.

- There is a wide temporal and spatial variation in water chemistry between adjacent boreholes emphasising the highly karstified nature of the groundwater system in the Mullaghmore area.

11.16 Turlough

- The Turlough PWS is located in the Burren Limestone and is extremely vulnerable to contamination.
- Nitrate levels of 10.1 mg/l were recorded at the Turlough source (Feb 1998). A high nitrite value of 0.12 mg/l was recorded in Aug 1998. In recent years this source has experienced high ammonium levels (0.746 mg/l in Feb 1998) although in 1999 ammonium levels have been lower. Sodium levels of 405 mg/l were excessively high in Feb 1998. Calcium was low in Feb 1998 (1.391 mg/l) as was chloride (17.7 mg/l). A high total coliform count of 50 was recorded in Oct 1997. 10 faecal coliforms were detected in Feb 1998.
- It is likely that the water at Turlough had been softened prior to testing in Feb 1998. In the softening process Ca and Mg are replaced by Na to prevent a build up of limescale ($CaCO_3$) in pipes and kettles. This would account for the high Na and low Ca and Mg levels in the analysis.
- Although nitrates are not elevated at Turlough the high ammonium and occasional high nitrite reported indicates an organic source of nitrogen which may be due to nearby cattle farming in the area and the use of round feeders close to the supply (*Lait*, *pers comm*). Monitoring of the water at this source is ongoing.

11.17 Whitegate

- The Whitegate PWS is located in the Old Red Sandstone. The groundwater around the source is highly vulnerable to contamination.
- The groundwater at the Whitegate Springs is a moderately hard (169 mg/l $CaC0_3$) with a pH of 7.08. The groundwater is characterised by relatively low calcium (54.66 mg/l) and magnesium levels (6.425 mg/l). Nitrate levels at Whitegate for the period 1989 to 1995 were very low (< 10 mg/l NO_3). Chlorides were also relatively low (18.5 mg/l) in 1997, 1998. Faecal coliforms were detected in the untreated spring water on the 12/1/93 (Cullen, 1993) although in October 1997 none were present.
- Lead concentrations at the Whitegate source and surrounding areas are low (<0.02 mg/l) although the springs are located close to the faulted contact between the Ballysteen Limestone and the Old Red Sandstone.
- The water quality in the Whitegate PWS appears to be good. The low calcium and magnesium indicate that the supply is derived from the sandstone bedrock or the overlying sandstone till.

12. Water Quality of Lakes

Eutrophication is caused by the input of nutrients, principally phosphorus, at concentrations significantly in excess of natural levels. It results in excessive open water production of planktonic forms of algae and cyanobacteria the growth of which is regulated by the supply of phosphate and nitrogen. The principal sources of phosphate and nitrogen compounds in Ireland are from agricultural activities and municipal/industrial waste discharges.

The quality of some of the larger lakes in County Clare was assessed by the Environmental Protection Agency for the period 1995 to 1997. Chlorophyll concentrations were measured in the summer and autumn months; the maximum concentrations give an indication of the annual maximum levels of planktonic algal growth which aids in the assessment of the degree of eutrophication.

The degree of eutrophication is defined as follows:
Oligotrophic: This trophic status reflects low algal growth which is consistent with a low probability of pollution.

Mesotrophic: This trophic status reflects moderate to substantial algal growth which implies moderate to significant level of pollution respectively.
Eutrophic: Algal growth in these lakes is high. *Strongly Eutrophic* lakes are considered to be strongly polluted. *Highly Eutrophic* lakes are considered to be highly polluted.

Phosphorus (P) does not generally present a problem for groundwater however groundwater can provide a pathway for P. to reach targets such as lakes, streams and wetlands (see Appendix 2). There are a number of lakes in the karstified limestone areas of the Drumcliff and Pouladower Spring catchments which are highly interconnected with the groundwater system. Within the Pouladower Spring catchment, Lough Inchiquin and Dromore Lough are classed as unpolluted and significantly polluted respectively. Within the Drumcliff Spring catchment, Ballycullinan Lough is classed as strongly polluted. Ballybeg Lake, also fed by groundwater flow in a karstified limestone aquifer, is classed as strongly polluted. The eutrophic status of these lakes may have implications for water quality at the sources and indeed other groundwater sources in this lowlying karstic region of Clare, particularly in times of low flow.

13. Overall Assessment

♦ The hydrochemistry of groundwater in County Clare is primarily influenced by the nature of the subsoil and bedrock that it passes through. The groundwater in the limestone areas (north and central Clare, and the lowlying areas of east Clare) is hard and can be classed as calcium bicarbonate ($Ca(HCO_3)_2$) type water. Softer waters are found in the remaining areas (west Clare and the upland areas of east Clare), where the bedrock comprises mainly sandstones, siltstones and shales.

♦ The main groundwater quality problems in County Clare are as follows:
- high iron (Fe) and manganese (Mn);
- bacteriological pollution;
- high turbidity in some spring supplies;
- high lead (Pb) levels in the Mountshannon area.

♦ The high iron (Fe) and manganese (Mn) concentrations are caused mainly by the natural conditions in the ground and the natural chemistry of the groundwater. This may occur in areas underlain by peat, muddy limestones, the Old Red Sandstone and the Namurian rocks, where reducing conditions result in solution of Fe and/or Mn from the geological materials. This causes taste and aesthetic problems. High manganese levels may also occur from pollution by silage effluent. High Fe concentrations are sometimes associated with high turbidity in karst springs. Two large springs – Elmvale and Kileany – had high Fe concentrations in the samples analysed for the GSI by the State Laboratory, and one – Kilrush – had high Mn. Ennis UDC report occasional high Fe levels at Drumcliff spring.

♦ The most important groundwater quality issue in County Clare is the presence of faecal bacteria in public and private water supplies. A significant proportion of the public groundwater supplies (10 out of 15) contained faecal bacteria during GSI sampling of raw waters. In certain areas, a high proportion of private wells (>50%) are also likely to be polluted, at least intermittently. While the presence/absence of faecal bacteria is considered to be the most reliable indicator of microbiological water quality, they are not reflective of the presence/absence of other non bacterial pathogens in a supply.

♦ The bacteriological pollution of a relatively high proportion of groundwater supplies in Clare is due to the following:

- the ‘extremely’ vulnerable conditions in large areas, where either bare rock or thin subsoils provide only limited protection;
- the karstic nature of much of north and mid-Clare, where groundwater flow velocities are rapid, purification in the limestone is minimal and microbes can be carried large distances;
- poorly designed, located and constructed septic tank systems and farmyards;
- landspreading of organic wastes;
- poor siting and construction of wells.

♦ In some springs and boreholes in karst areas, high turbidity occurs after heavy rainfall. This is caused where (a) sediment that has collected in fissures and cavities is washed out at the start of recharge events, and (b) where there is a direct link between the source and a swallow hole into which surface water containing sediment is flowing. For example, runoff from the Namurian shales and sandstones in the Drumcliff catchment infiltrates into the karst limestones through swallow holes and travels rapidly through the groundwater system to the spring. In contrast, Pouladower spring has less problems with turbidity as the lakes in the catchment allow sediment to settle out before the spring is reached.

♦ Lead (Pb) problems occur in the Mountshannon area and are considered to be largely associated with the east-west fault and also disseminated in the sandstone. Although only 3 out of 24 supplies in the Mountshannon area had high Pb concentrations (Jones, 1998), it is possible that other areas along the fault may experience similar problems. The new artesian supply at Mountshannon had low Pb concentrations when sampled.

♦ Nitrate concentrations are generally low in County Clare. Nitrate levels were less than the EU MAC (50 mg/l NO_3) in all public supply wells monitored apart from Bridgetown PWS and Crusheen PWS. The latter had high nitrate in 1991 (57 mg/l on 26/3/91); however since then levels have been low. Also, it is no longer used as a public water supply source. All the other supplies, apart from Montpelier, had less than 25 mg/l in all samples analysed. Nitrate contamination is likely to be caused by point sources, such as septic tank systems.

14. Recommendations

♦ As a good database on groundwater quality is required to enable an improved and continuing assessment, 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 background situation and trends in each source are defined).
- full analyses (including all major ions) should be carried out on at least some of the samples from each source to enable a fuller picture of groundwater quality and contaminant movements to be obtained.
- where there is evidence of contamination, the sampling frequency should be increased and the source of contamination should be investigated.

- A high level of disinfection should be maintained at all public supplies to protect against health risks from microbial pollution. In extremely vulnerable areas, disinfection of private supplies is recommended.

♦ It is recommended that the existing programme of delineating groundwater protection zones around public and group scheme supplies, using the DELG/EPA/GSI guidelines, be continued.

♦ A programme of checking the sanitary protection at each well and spring site (i.e. on Co. Co. property in the immediate vicinity of the source) would help to ensure that contaminated shallow

- groundwater and surface water is not entering the source and that accidental spillages would not contaminate the source.

15. Acknowledgements

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Oct. 1997																	
Source	NO_3	Ca	Mg	K	Na	Cl	NO_2	SO4	Alk	Hard	Cond	Al	Fe	Mn	NH_4	NH_4 (Co. Co.)	TC	EColi
Whitegate	4.3	54.66	6.425	1.721	10.66	18.5	<0.1	4.7	158	162.9	340	0.023	0.01	<.005	<0.015	0.04	0	0
Turlough	10.4	85.71	3.052	1.681	9.11	15.1	<0.1	5.5	226	226.6	441	0.021	0.007	<.005	<0.015	0.04	50[b]	0
Scarriff old	5	50.6	8.606	1.302	14.6	21.2	<0.1	5.9	160	161.8	351	0.033	0.038	<.005	<0.015	0.04	0	0
Scarriff new	5.2	72.99	11.27	1.53	10.65	18.2	<0.1	6.9	226	228.7	446	<0.02	0.005	<.005	<0.015	0.05	0	0
Pouladower	2.9	65.08	4.081	1.833	11.88	18.8	<0.1	7.5	178	179.3	371	<0.02	0.054	<.005	<0.015	0.03	35[b]	19[b]
Newtown	4.5	71.53	2.713	1.597	9.103	11.4	<0.1	4.6	196	189.8	375	0.03	0.017	<.005	<0.015	0.04	110[b]	150[b]
Mountshannon	2.93	50.19	4.843	1.505	11.43	19.4	<0.1	4.9	146	145.3	318	<0.02	0.011	0.007	<0.015	0.03	0	0
Mountpellier	9.4	77.57	6.006	1.335	11.01	19.6	<0.1	9.8	212	218.4	437	0.022	0.007	<.005	<0.015	0.05	0	0
Lisdoon spa	<0.1	34.54	23.45	1.544	49.99	31.1	<0.1	7.9	242	182.8	510	<0.02	0.034	0.009	0.357	0.4	0	0
Knockaculla N.	19.9	17.06	5.916	2.992	32.82	47.5	<0.1	38.5	26	66.96	299	0.129	0.129	0.013	0.026	0.07	400[b]	300[b]
Kilrush	0.3	44.18	19.23	1.584	41.17	44.5	<0.1	18.8	212	189.5	508	<0.02	0.07	0.07[b]	0.287[a]	0.19[a]	25[b]	19[b]
Kilkee	3.62	46.25	18.14	2.834	88.54	156.5[a]	<0.1	38	114	190.2	727	<0.02	<0.005	<.005	<0.015	0.03	5[b]	2[b]
Killeany	1.65	49.2	2.17	0.701	10.66	12.8	<0.1	5.7	132	131.8	274	0.098	0.43[b]	0.007	<0.015	0.03	100[b]	110[b]
Killeady/Tubber	11.2	97.55	21.15	2.033	13.15	23.8	<0.1	11.1	320	330.7	607	0.027	0.01	<.005	<0.015	0.03	11[b]	2[b]
Killaloe	8.3	23.17	3.758	1.217	7.927	11.9	<0.1	7.1	66	73.34	176	<0.02	0.013	<.005	<0.015	0.03	10[b]	7[b]
Feakle new	3.1	62.91	14.23	1.112	11.91	14.6	<0.1	5.5	220	215	416	0.032	0.011	<.005	<0.015	0.04	0	0
Feakle old	3.1	58.43	8.766	0.996	9.215	13.1	<0.1	6.4	182	182	358	<0.02	<0.005	<.005	<0.015	0.04	0	0
Elmvale	5.2	62.87	3.334	2.044	13.43	18.8	<0.1	8.6	164	170.7	355	0.113	0.3b	0.006	<0.015	0.03	300[b]	250[b]
Drumcliff	5.2	84.69	4.863	2.817	12.92	21	<0.1	9.1	228	231.5	461	0.028	0.068	0.006	0.026	0.03	40[b]	65[b]
Crusheen	2.22	115.5	24.02	2.372	15.57	24.9	<0.1	9.7	392	387.3	713	0.025	0.029	<.005	na	0.03	14[b]	9[b]
Carron	4.7	62.86	2.078	0.676	9.046	9.1	<0.1	4.8	176	165.5	326	0.024	0.012	<.005	<0.015	0.04	58[b]	46[b]
Broadford	6.7	55.85	4.861	1.581	9.022	15.1	<0.1	7.5	150	159.5	320	0.023	0.017	<.005	<0.015	0.03	25[b]	13[b]
Bridgetown	38.5[a]	19.81	4.5	4.49[a]	11.82	19.4	<0.1	8.6	34	68.01	207	0.048	0.029	<.005	<0.015	0.03	7[b]	0

Elmvale and Lisoonvarna are not drinking water supplies. Knockacullee is a small private source.
x^a denotes levels higher than GSI threshold levels.
x^b denote EU MAC exceedances.
All units for chemical parameters are mg/l; TC and EColi are numbers/100 ml
All chemical analyses were carried out by the State Lab.

Table 1: Hydrochemical and Bacteriological Analyses for Groundwater Sources in County Clare

Oct. 1997																
Source	**Ba**	**B**	**Cd**	**Cr**	**Cu**	**F**	**Pb**	**Hg**	**Ni**	**PO4**	**P**	**Se**	**Ag**	**Sr**	**Z**	**Ant**	**Ar**
Whitegate	0.075	0.014	<.005	<.005	0.006	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.105	0.086	<0.02	<0.05
Turlough	0.005	0.022	<.005	<.005	0.006	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.1	0.019	<0.02	<0.05
Scarriff old	0.059	0.035	<.005	<.005	0.01	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.124	0.172	<0.02	<0.05
Scarriff new	0.04	0.012	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.172	0.022	<0.02	<0.05
Pouladower	0.009	0.016	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.089	0.01	<0.02	<0.05
Newtown	0.005	0.014	<.005	<.005	0.009	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.076	0.052	<0.02	<0.05
Mountshannon	0.069	0.011	<.005	<.005	<0.005	<.25	0.032[a]	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.1	0.018	<0.02	<0.05
Mountpellier	0.43	0.019	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.143	0.019	<0.02	<0.05
Lisdoon spa	1.518[b]	0.073	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	2.08	0.031	<0.02	<0.05
Knockaculla N.	0.007	0.034	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.064	0.037	<0.02	<0.05
Kilrush	0.071	0.069	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	1.179	0.081	<0.02	<0.05
Kilkee	0.012	0.05	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.207	0.006	<0.02	<0.05
Killeany	0.008	0.016	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.056	0.008	<0.02	<0.05
Killeady/Tubber	0.01	0.02	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.164	0.057	<0.02	<0.05
Killaloe	0.096	0.012	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.057	0.039	<0.02	<0.05
Feakle new	0.034	0.014	<.005	<.005	0.009	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.183	0.012	<0.02	<0.05
Feakle old	0.101	0.017	<.005	<.005	0.006	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.14	0.007	<0.02	<0.05
Elmvale	0.012	0.026	<.005	<.005	0.008	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.087	0.122	<0.02	<0.05
Drumcliff	0.011	0.019	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.121	0.107	<0.02	<0.05
Crusheen	0.019	0.023	<.005	<.005	0.018	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.103	0.03	<0.02	<0.05
Carron	0.004	0.012	<.005	<.005	0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.074	0.016	<0.02	<0.05
Broadford	0.112	0.013	<.005	<.005	<0.005	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.08	0.085	<0.02	<0.05
Bridgetown	0.32	0.018	<.005	<.005	0.011	<.25	<.02	<.001	<.01	<0.5	<0.25	<0.05	<0.005	0.055	0.35	<0.02	<0.05

NB: Elmvale and Lisdoonvarna spa well are not drinking water supplies.
Knockacullee is a small private source not currently being used as a public supply.
x[a] denotes levels higher than GSI thresholds.
x[b] denote EU MAC exceedances.

Table 1
(Cont)

Feb -98																	
Source	**NO3**	**Ca**	**Mg**	**K**	**Na**	**Cl**	**NO2**	**SO4**	**Alk**	**Hard**	**Cond**	**Al**	**Fe**	**Mn**	**NH4**	**Total Coliforms**	**E. Coli**
Whitegate	4.5	56.76	6.56	1.641	10.53	18.5	<0.1	5	164	168.7	334	<0.02	0.013	<0.005	<0.015	0	0
Turlough **	10.1	1.391	0.753	1.994	404.9[b]	17.7	<0.1	6.6	910	6.573	3110[a]	0.025	<0.005	<0.005	0.746[b]	77[b]	10[b]
Scarriff old	5.9	52.38	8.772	1.302	11.62	17.6	<0.1	5.9	160	166.9	332	<0.02	0.015	<0.005	<0.015	0	0
Scarriff new	5.7	75.53	11.49	1.488	10.49	17	<0.1	7	222	235.9	430	<0.02	<0.005	<0.005	<0.015	0	0
Pouladower	6.2	72.23	4.369	1.765	11.15	21.7	<0.1	7.5	184	198.3	384	<0.02	0.033	<0.005	<0.015	23[b]	12[b]
Newtown	5.7	80.7	3.195	1.279	9.263	17	<0.1	6.6	202	214.7	401	0.052	0.015	<0.005	<0.015	6[b]	3[b]
Mountshannon	3.9	51.71	4.88	1.434	11.88	20.9	<0.1	5.1	144	149.2	313	<0.02	0.027	0.015	<0.015	0	0
Mountpellier	5.1	34.27	7.347	1.352	10.36	15.1	<0.1	6.2	112	115.8	249	112[a]	0.031	<0.005	<0.015	0	0
Lisdoon spa	<0.1	37.11	24.02	1.557	49.69	34	<0.1	51.5	198	191.6	521	0.021	0.037	0.01	0.179	0	0
Kilrush	0.25	42.05	17.43	1.371	40.28	43	<0.1	18.7	190	176.8	465	0.024	0.115	0.059b	0.153[a]	2[b]	0
Kilkee	5.1	40.64	15.91	2.481	78.43	139[a]	<0.1	35.5	104	167	660	<0.02	0.006	<0.005	<0.015	0	0
Killeany	2.5	52.23	2.344	0.681	10.85	19.6	<0.1	7.2	128	140.1	287	0.077	0.144	<0.005	<0.015	66[b]	45[b]
Killeady/Tubber	10.6	96.58	22.64	1.554	13.6	24.3	<0.1	11.2	316		595	<0.02	0.01	<0.005	<0.015		
Killaloe	7.2	24.09	3.79	1.151	7.59	10.6	<0.1	6.5	68	75.76	174	<0.02	0.011	<0.005	<0.015	0	0
Feakle new	4.2	63.85	14.49	1.12	11.94	14	<0.1	5.5	220	219.1	401	0.031	0.046	<0.005	<0.015	0	0
Feakle old	3.6	60.77	8.964	0.975	8.843	12.3	<0.1	6.8	182	188.6	347	0.023	0.021	<0.005	<0.015	1[b]	1[b]
Elmvale	6.7	70.09	3.392	1.497	12.93	20.9	<0.1	8.4	168	189	366	0.052	0.211b	0.008	<0.015	42[b]	10[b]
Drumcliff	7.2	78.61	4.521	2.978	12.63	23.2	<0.1	9.1	202	214.9	423	0.026	0.143	0.007	<0.015	250[b]	350[b]
Crusheen	4.2	112.8	24.48	2.349	16.96	30.5	<0.1	10.2	370	382.4	685	<0.02	0.008	<0.005	<0.015	0	0
Bridgetown	33.5[a]	19.99	4.355	4.425[a]	11.31	19.4	<0.1	9.2	36	67.85	200	<0.02	0.034	<0.005	<0.015	0	0

** May not represent true groundwater quality in Turlough area.
NB: Elmvale and Lisdoonvarna spa well are not drinking water supplies.
Knockacullee is a small private source not currently being used as a public supply
x[a] denotes levels higher than GSI Guidelevels.
x[b] denote EU MAC exceedances.
All chemical analyses were caried out by the State Laboratory.
All units for chemical parameters are mg/l; TC and EColi are numbers/100 ml

Table 2 Hydrochemical and Bacteriological Analyses for Groundwater Sources in County Clare

Feb '98															
Source	**Ba**	**B**	**Cd**	**Cr**	**Cu**	**F**	**Pb**	**Ni**	**P**	**Se**	**Ag**	**Sr**	**Z**	**Ant**	**Ar**
Whitegate	0.079	0.009	<0.005	<0.005	0.008	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.109	0.05	<0.02	<0.05
Turlough	<0.001	0.017	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.013	0.004	<0.02	<0.05
Scarriff old	0.064	0.016	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.127	0.049	<0.02	<0.05
Scarriff new	0.041	0.012	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	1.488	<0.05	<0.005	0.176	0.018	<0.02	<0.05
Pouladower	0.007	0.021	<0.005	<0.005	0.009	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.092	0.015	<0.02	<0.05
Newtown	0.005	0.012	<0.005	<0.005	0.008	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.084	0.033	<0.02	<0.05
Mountshannon	0.068	0.014	<0.005	<0.005	0.014	<0.25	0.044[a]	<0.01	<0.25	<0.05	<0.005	0.099	0.023	<0.02	<0.05
Mountpellier	0.157	0.02	<0.005	<0.005	0.02	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.063	0.065	<0.02	<0.05
Lisdoon spa	1.516[b]	0.074	<0.005	<0.005	<0.005	2.25[b]	<0.02	<0.01	<0.25	<0.05	<0.005	2.116	0.018	<0.02	<0.05
Kilrush	0.064	0.066	<0.005	<0.005	0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	1.084	0.103	<0.02	<0.05
Kilkee	0.01	0.053	<0.005	<0.005	0.008	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.184	0.015	<0.02	<0.05
Killeany	0.007	0.01	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.058	0.014	<0.02	<0.05
Killeady/Tubber	0.009	0.027	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.165	0.022	<0.02	<0.05
Killaloe	0.102	0.01	<0.005	<0.005	<0.005	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.059	0.044	<0.02	<0.05
Feakle new	0.036	0.016	<0.005	<0.005	0.016	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.185	0.212	<0.02	<0.05
Feakle old	0.106	0.013	<0.005	<0.005	0.006	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.146	0.018	<0.02	<0.05
Elmvale	0.014	0.016	<0.005	<0.005	0.011	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.093	0.047	<0.02	<0.05
Drumcliff	0.009	0.037	<0.005	<0.005	0.025	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.11	0.04	<0.02	<0.05
Crusheen	0.018	0.021	<0.005	<0.005	0.009	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.097	0.026	<0.02	<0.05
Bridgetown	0.306	0.034	<0.005	<0.005	0.021	<0.25	<0.02	<0.01	<0.25	<0.05	<0.005	0.054	0.049	<0.02	<0.05

Elmavale and Lisdoonvarna Spa are not drinking water supplies.
x[a] denotes levels higher than GSI thresholds.
x[b] denotes EU MAC exceedances.

Table 2 (Cont)

Townland	Rock Type	pH	Fe/Mn	Coliforms	Conductivity uS/cm
Barefield	Ballysteen Limestone	7.2	x	x	814
Feakle	Ballysteen Limestone		> MAC	x	648
Meelick	Ballysteen Limestone	6.7	> MAC	x	440
Scarrif	Ballysteen Limestone	7.3	x	x	680
Scarrif	Ballysteen Limestone	7.7	x	x	422
Tulla	Ballysteen Limestone	7.6	Fe > MAC	x	473
Feakle	Ballysteen/ORS	7.3	x	x	330
Boston	Limestone	7.3	> MAC	x	623
Clonlara	Limestone	7.1	x	x	721
Corrofin	Limestone	7.4	x	x	754
Crusheen	Limestone	7.4	x	x	493
Killaloe	Limestone	7.6	Mn > MAC	x	378
Killaloe	Limestone	8.4	x	x	382
Maghera	Limestone	7.4	Fe > MAC	x	686
O'Callagh's Mill	Limestone	7.6	x	x	527
Reinskea	Limestone	7.5	Elev Mn	x	866
Tubber	Limestone	7.3		x	740
Tubber	Limestone	7.6	x	x	552
Tulla	Limestone	7.1	x	x	713
Fanore	Maumcaha Limestone	7.5	x	x	622
Milltown-Malbay	Namurian Shale	8.9		x	
Ennistymon	Namurian Shales	7.8	> MAC	1 General	847
Bodyke	ORS	7.4	Fe > MAC	x	644
Crusheen	ORS	7.4	x	1 General	
Feakle	ORS		x	1 General	
Ogonnelloe	ORS	7.1	x	x	437
Sixmilebridge	ORS	6.9	x	x	416
Tulla	ORS	7.9	x	x	492
Feakle	Sandstone	7.5	x	x	532
Killaloe	Sandstone	7.3	x	x	371
Kilmihil	Sandstone	6.9	x	1 General	287
Kylemore	Sandstone	7.6	> MAC	x	797
Middlelane	Sandstone	7.1	x	x	349
Tuamgraney	Sandstone	7.6	Mn > MAC	1 General	620
Kilfenora	Shale	7	Elev Mn	x	741
Lisdoonvarna	Shale over Limestone	7.8	> MAC	x	370
Caher	Silurian	7	x	x	447
Caher	Silurian	7.3	Fe > MAC	x	567
Caher	Silurian	8.5	x	x	536
Caher	Silurian	6.6	Fe > MAC	x	220
Flagmount	Silurian	7.7	x	x	
Scarrif	Silurian	6.9	x	x	393
Scarrif	Silurian	7.1	Mn > MAC	x	401
Scarrif	Silurian	7.5	x	x	449
Bodyke	Silurian Sandst/Shale	7.1	x	x	590
Broadford	Silurian Sandst/Shale	7.2	Mn > MAC	x	
Carrakyle	Silurian Sandst/Shale	0.1	Mn > MAC	5 General	521
Meelick	Silurian Sandst/Shale	7.2	x	x	341
Renahamara	Silurian Sandst/Shale	7.5	Mn > MAC	x	561
Ennis	Tubber Limestone		> MAC	x	
Newmk-Fergus	Visean Limestone	7.5	x	x	727
Quin	Waul. Limestone	7.5	x	1 General	640
Tubber	Waulsortian Limestone	7.1	Fe > MAC	x	813

Table 3: Well Improvement Grant Scheme Data (1998, 1999)

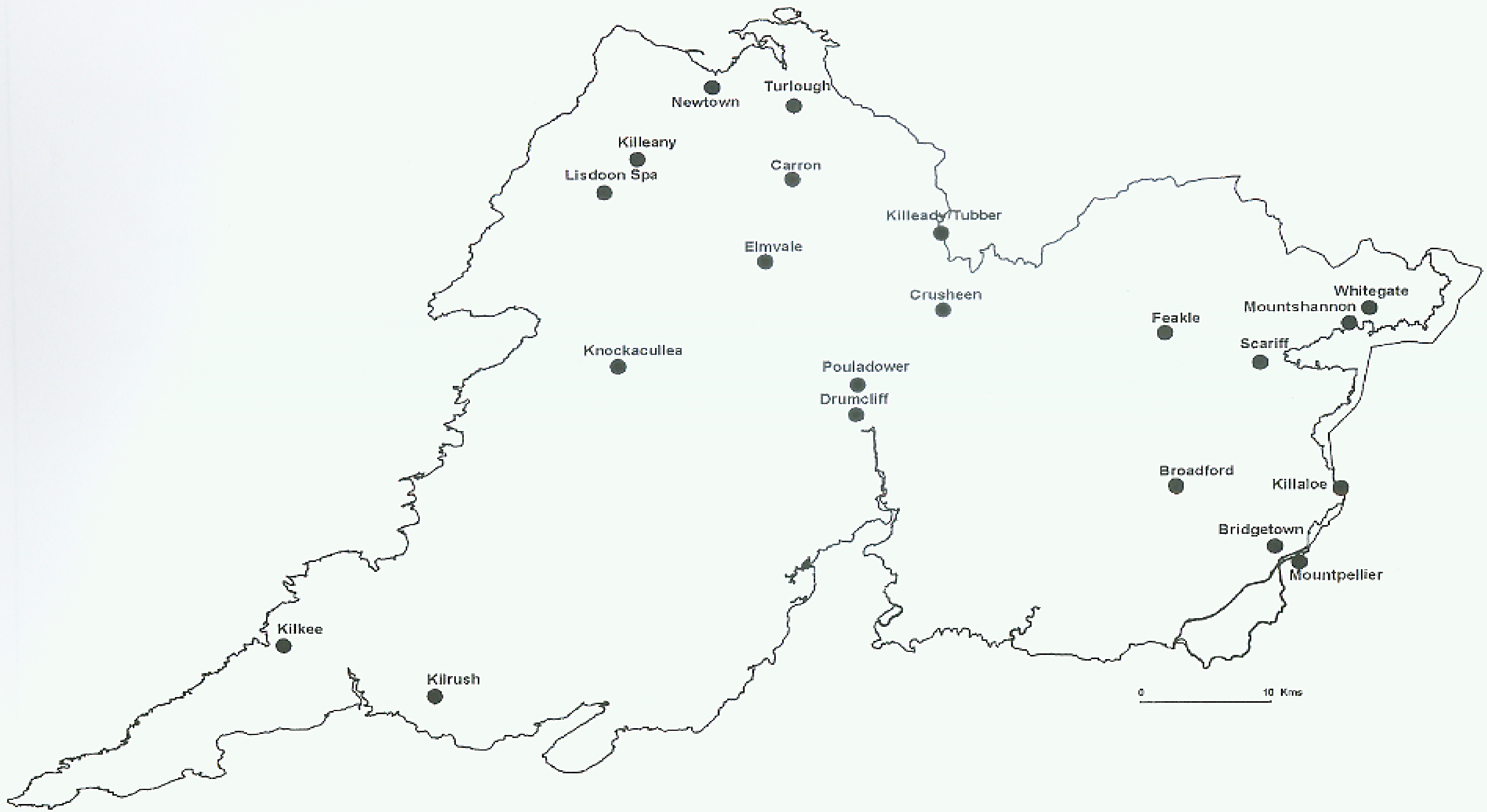
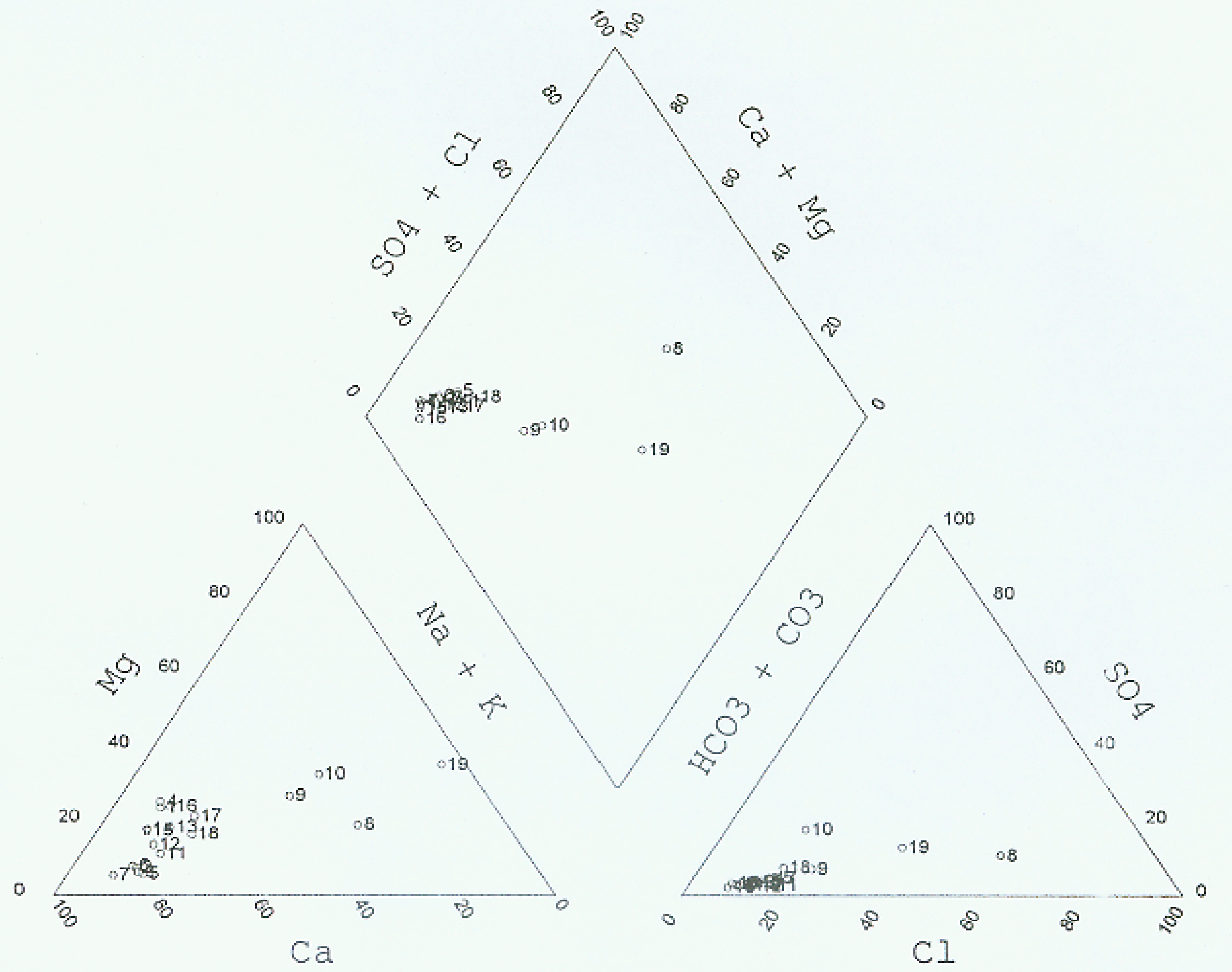


Figure 1. Source Locations

Fig 2 Hydrochemical Data 1998



Sel#	Reference	Geology
1	Crusheen	Karstified Limestone
2	Drumcliff	Karstified Limestone
3	Elmvale	Karstified Limestone
4	Kileady	Karstified Limestone
5	Kileany	Karstified Limestone
6	Pouladower	Karstified Limestone
7	Newtown	Karstified Limestone
8	Kilkee	Namurian Shale
9	Kilrush	Namurian Shale
10	Lisdoon Spa	Namurian Shale
11	Mountshannon	Old Red Sandstone
12	Whitegate	Old Red Sandstone
13	Scariff Old	Silurian Seds
14	Scariff New	Silurian Seds
15	Feakle Old	Silurian Seds
16	Feakle New	Silurian Seds
17	Montpellier	Sand/Gravel
18	Killaloe	Sand/Gravel
19	Bridgetown	Sand/Gravel

Geological Survey of Ireland

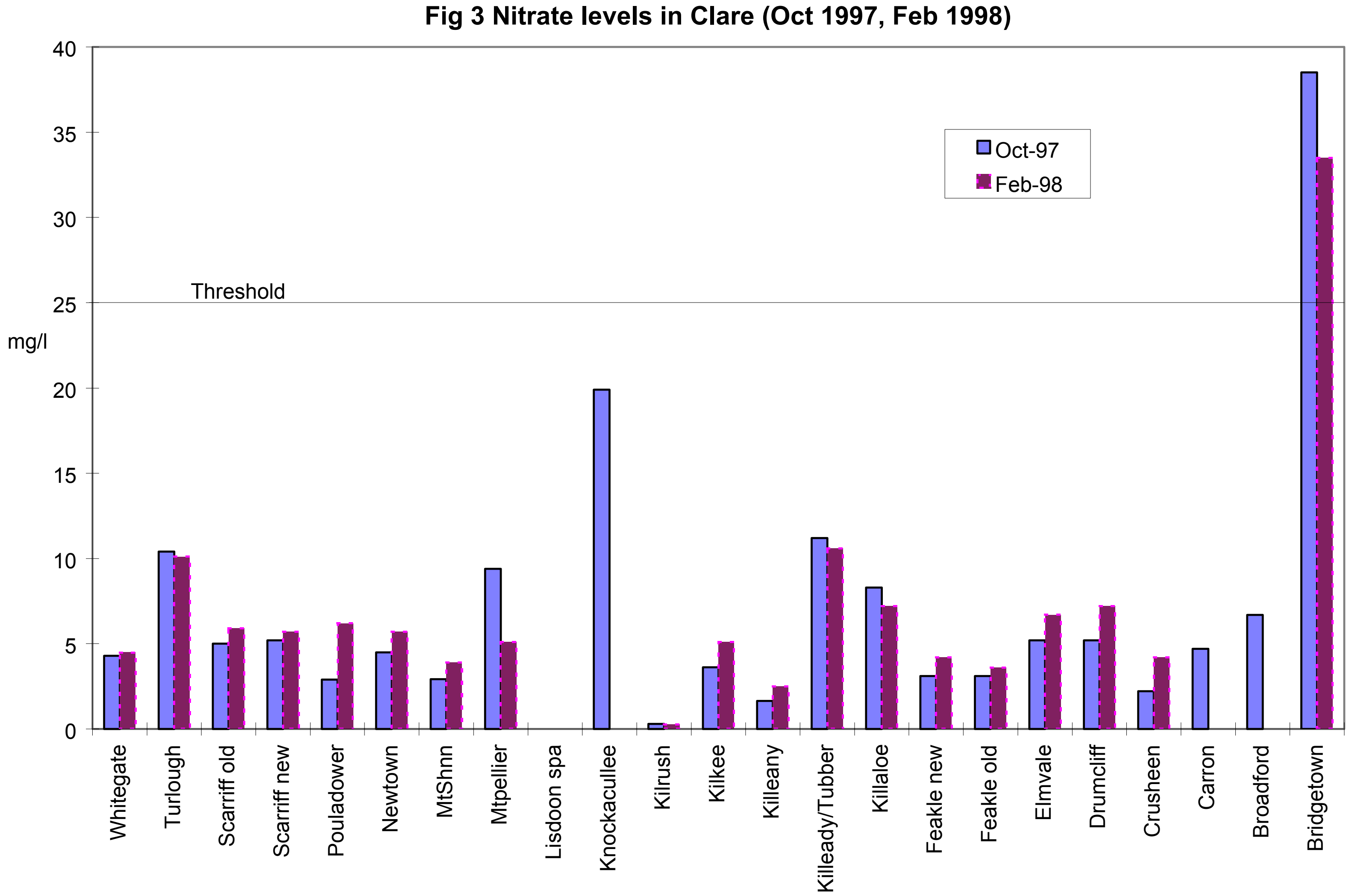
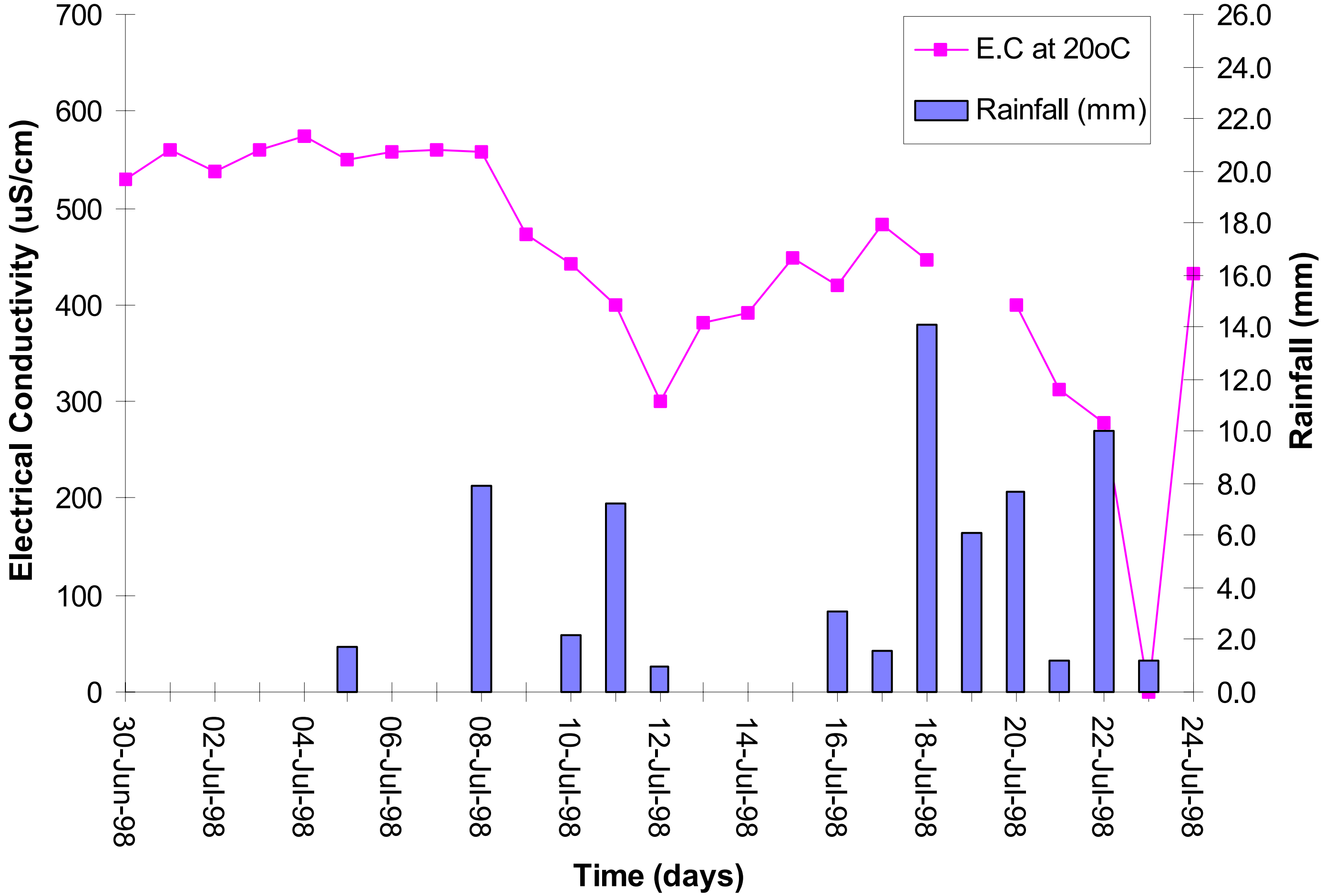
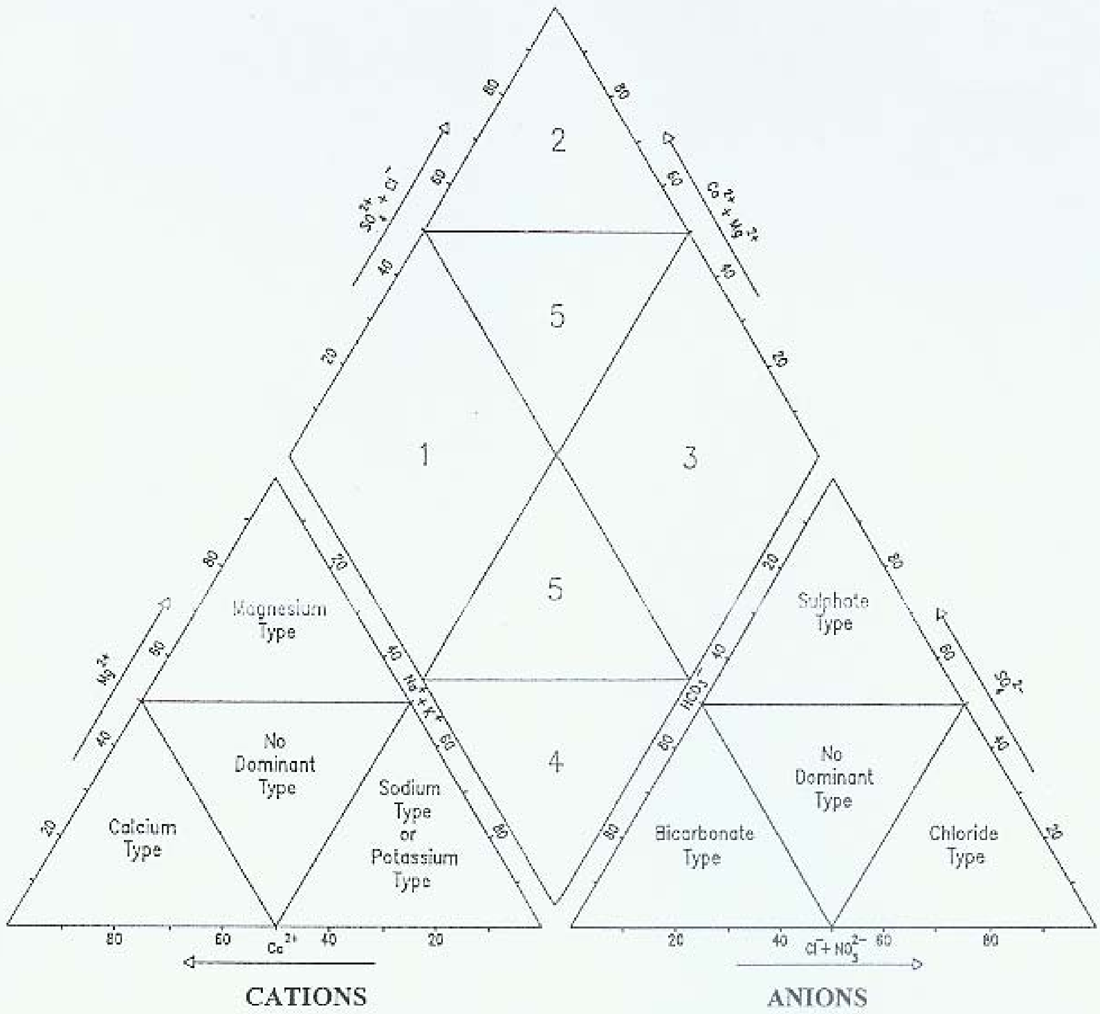


Fig 3 Nitrate levels in Clare (Oct 1997, Feb 1998)
mg/l
0
5
10
15
20
25
30
35
40
Threshold
Oct-97
Feb-98
Whitegate
Turlough
Scarriff old
Scarriff new
Pouladower
Newtown
MtShnn
Mtpellier
Lisdoon spa
Knockacullee
Kilrush
Kilkee
Killeany
Killeady/Tubber
Killaloe
Feakle new
Feakle old
Elmvale
Drumcliff
Crusheen
Carron
Broadford
Bridgetown

Fig 4 Electrical Conductivity and Rainfall at Ballyvaughan Public Supply
(30/6/98 - 24/798)



Appendix 1: Description of A Piper Diagram



Distinct groundwater types can be distinguished according to their plotted position in certain subareas of the diamond shaped field. These areas are shown on the Piper diagram (above) and are described as follows:

1. Calcium bicarbonate type waters. Carbonate hardness exceeds 50% and the chemical properties of the groundwater are dominated by alkaline earths and weak acids (typical of recharging waters in limestones).

2. Groundwater high in calcium/magnesium and chloride/sulphate. Non carbonate hardness exceeds 50% (where bicarbonate and magnesium are dominant this can indicate the presence of dolomite).

3. Sodium chloride type waters. Non carbonate alkali exceeds 50%, chemical properties are dominated by alkalies and strong acids (saline waters plot in this area).

4. Sodium-potassium bicarbonate type waters. Carbonate alkali exceeds 50%, these groundwaters are very soft in proportion to their content of dissolved solids (can indicate ion exchange)

5. No one cation-anion pair exceeds 50% (groundwaters may be mixed or may be the result of simple dissolution).

APPENDIX 2
Indicators of Groundwater Contamination : A Discussion

A1 Introduction
This appendix is taken 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: Ecoli, 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**		

A2 Faecal Bacteria and Other Pathogens
For assessment of the microbiological quality of water, it is the faecal coliform count which is the primary indicator of pollution of faecal origin in the water. While there is no absolute correlation between the coliform presence and other bacterial pathogens due to the variable and unpredictable behaviour of pathogens, the underlying principle of the test for faecal coliforms is that its presence in waters indicates the potential presence of pathogens. The usefulness of the test as indicators of protozoan or viral contamination is limited. The most common health problems arising from the presence of microbial agents include diarrohea, gastro-enteritis, giardiasis, cryptospiridiosis and hepatitis. Sources of E.coli include septic tank effluent, farmyard waste, landfill sites and birds. There is no reliable method to distinguish between animal and human waste sources. Establishing water quality criteria for viruses and protozoan pathogens is difficult as the infective dose for all strains is generally unknown. In addition, they can persist longer in natural waters than faecal coliforms and are more resistant to water treatment processes.

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.

A3 Parasitic Protozoans and viruses
During the last 20-30 years many outbreaks of waterborne giaridasis and cryptospiridosis have been reported with high frequency in USA, UK and Canada. In Britain, cryptosporidium is the fourth most common cause of water borne related diarrohea. Detailed information about different Cryptosporidium species, together with their occurrence, viability and infectivity is currently scarce. Cryptosporidia oocysts have been found in faecal material from pigs, cattle, rabbits, sheep and many birds. There is a strong body of evidence that there are identifiable "strains" of cryptosporidium and that one such "strain" appears to be restricted to humans. Current detection methods are not specific to species which are viable or pathogenic to humans. Infection by Cryptosporidium parvum causes self limiting gastroenteritis of approximately two to three weeks duration in immunocompromised hosts. In

immunosuppressed hosts the disease is much more severe. The infective dose for humans is not known with any confidence but is thought to be quite low. As yet there is no specific treatment. There is always a low level of cryptosporidosis in the community and it is unlikely that drinking water is the major cause of this background. Infection is initiated by ingestion of the oocyst with subsequent excystation and release of the organism , usually on exposure to bile salts. The organism completes its lifecycle within the host and produces oocysts which are excreted in the faeces. The oocyst is environmentally robust and can survive routine treatment of water, which will normally remove bacterial pathogens. Monitoring for presence of these pathogens is undertaken on a routine basis by Clare County Council.

A4 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 "vulnerable zones", 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 vulnerable zones 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.

A5 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.

A6 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.

A7 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.

A8 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.

A9 Phosphorus

Phosphorus is a significant contaminant and cause for eutrophication in surface water in Ireland. It is not generally a problem in groundwater and is not likely to be in the future. There are two reasons for this:

- the orthophosphate anion, which is the plant-available form of phosphorus, precipitates quickly to either calcium or iron or aluminium phosphate, depending on the nature of the soil;
- the maximum admissible concentration for drinking water (5000 μg/l P_2O_5) = 2200 μg/l P) is rarely approached except in areas of gross contamination.

However, in surface waters the concern with Phosphorus is at much lower levels; total phosphorus concentrations in excess of only 20 μg/l P may trigger eutrophication. Recent research at the Environmental Sciences unit, TCD, has pointed out that in certain hydrogeological situations, concentrations greater than this may be present in groundwater. These situations are where groundwater is extremely or highly vulnerable to contamination; in particular where fissured bedrock is at or close to the ground surface and where soils and subsoils are sandy. There may also be leaching in soils and subsoils that are saturated with phosphorus.

In conclusion, P. does not generally present a problem for groundwater; however, groundwater can provide a pathway for P. to reach targets such as lakes, streams and wetlands.

A10 Hydrogen Sulphide

Hydrogen sulphide is a gas that is recognisable by its 'rotten egg' smell. It is present only in deoxygenated water, from rocks such as black clayey limestones or shales that contain pyrite, or from evaporite beds. It is often associated with iron problems and is common. Hydrogen sulphide is likely to be a problem in parts of West Clare which are underlain by Namurian shales in.

Box A1 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 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.