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Nitrate concentrations in groundwater in Northern Ireland

Groundwater Systems and Water Quality Programme

Commissioned Report CR/03/051N

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/03/051N

Nitrate concentrations in groundwater in Northern Ireland

A M MacDonald and P McConvey

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Fertilizer application in Northern Ireland (photo Crawford Jordan).

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Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

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Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

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Foreword

This report was commissioned by Environment and Heritage Service (EHS), an Agency within the Department of the Environment, Northern Ireland. EHS have the regulatory responsibility for the general management and protection of water resources in Northern Ireland. It is intended by EHS that this study will contribute to determining the most appropriate management option for protection of groundwater and surface water as required under European legislation including the EC Nitrates Directive (91/676/EEC) and the recently introduced EC Water Framework Directive (2000/60/EC).

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Rob Ward: Environment Agency, England and Wales.

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Summary

The Environment and Heritage Service (EHS) commissioned the British Geological Survey to review the available groundwater nitrate data in Northern Ireland and examine relationships between groundwater nitrate concentrations and landuse or aquifer vulnerability. This forms part of work EHS is undertaking to comply with EC Nitrates Directive (91/676/EEC) and the recently introduced EC Water Framework Directive (2000/60/EC).

There are two main sources of information on groundwater nitrate concentrations in Northern Ireland. The first is the EHS regional groundwater quality monitoring network which was established in 2000. Currently, information is available for 91 sources. The second source of nitrate information is from the general survey of groundwater sources from which the EHS regional groundwater quality monitoring network was subsequently chosen. A total of 759 groundwater sources (mainly boreholes) were visited from 1992 to 1994. At 352 sites, groundwater samples were taken for analysis (including nitrate) under stringent field conditions.

1. Groundwater nitrate concentrations, where measured, are generally low:
   - 6.2% (22 sites) of the BGS 92-94 survey data exceeded 50 mg NO_3 / L; 20.1% (71 sites) exceeded 25 mg NO_3 / L (based on the average concentration at each monitoring point).
   - The current EHS regional monitoring network 91 sources have 2.2 % of sites greater than 50 mg NO_3 / L and 8.8% greater than 25 mg NO_3 / L.
   - These concentrations are considerably lower than those measured in England & Wales, and slightly lower than those measured throughout Scotland. The most likely causes of the low groundwater nitrate concentrations are: the limited extent of arable agriculture; the favourable denitrification conditions in the Northern Ireland soils; and the dilution from the high rainfall.
2. Analysis of twenty-seven sites where sampling was undertaken in both 1992-94 and 2000-02 indicate no consistent temporal trend from 1993 to 2001 in nitrate concentrations across Northern Ireland. More detailed data from two sites in Clogh Mills and Comber NVZs show a general rise from 1992 to 2002.
3. Nitrate concentrations in groundwater are highly correlated with land use.
   - Arable areas have approximately 50% of sites exceeding 25 mg NO_3 / L
   - More than 85% of sites situated in areas with no agricultural activity have less than 10 mg NO_3 / L.
   - Both the BGS Survey data and EHS monitoring data show a steady rise in groundwater nitrate concentrations as the agricultural activity becomes increasingly intensive.
4. The permeability of the superficial deposits (for example glacial till, or alluvium) affects the nitrate concentrations measured in groundwater. For example, in areas of good pasture, 34.2% of sites in high permeability areas have > 25 mg NO_3 / L compared to 18.6% in moderate or low permeability areas.
5. Groundwater nitrate concentrations are higher in shallow (< 25 m) sources.
6. During the BGS 92-94 survey, data was collected on the presence of septic tanks and the practice of slurry spreading. The data indicate that septic tanks have no statistical effect on the nitrate concentrations measured in the sample sites. However, sites where slurry was spread had higher nitrate concentrations than sites where it was not (this reflects the correlation of groundwater nitrate concentrations and agricultural activity described above).

The statistics and correlations highlighted above have several important implications for the protection of groundwater from nitrate contamination in Northern Ireland. Some recommendations are given below, in the understanding that the implementation of the EC Water Framework Directive in Northern Ireland will require a more detailed assessment of land use, groundwater quality and hydrogeological conditions over the next 2-3 years.

- Since land use is an excellent predictor of nitrate concentrations in groundwater it could be used to indicate potential concentrations in areas with no monitoring data.
- Low permeability superficial deposits offer protection to groundwater. A more detailed assessment of the permeability and thickness of superficial deposits in Northern Ireland would help to highlight areas most vulnerable to contamination.
- Areas with intensive agriculture (for example arable farming, complex cultivation patterns or intensive livestock rearing) particularly where superficial deposits are absent or highly permeable are most at risk of nitrate contamination. An approach which combines these factors may be appropriate for predicting groundwater nitrate contamination in Northern Ireland.
- Detailed information on the location of intensive livestock rearing and slurry applications across Northern Ireland would be helpful in estimating local risks to groundwater.
- The role of the gley soils and rainfall in Northern Ireland in generally reducing groundwater nitrate concentrations could be investigated further. It would be beneficial to target a small number of catchments or sub-catchments with more intensive monitoring to establish a more comprehensive local dataset.
- Ongoing monitoring of groundwater for nitrogen species is essential in Northern Ireland and any future review of the regional groundwater monitoring network should take into account this objective.

1 Introduction

The Nitrates Directive (91/676/EEC) requires Member States to identify areas where groundwaters contain, or could contain, nitrate concentrations of greater than 50 mg NO_3 / L. The areas of land which drain into these waters are to be designated as Nitrate Vulnerable Zones (NVZs), wherein the Member States are required to establish Action Programmes in order to reduce and prevent further nitrate contamination from agriculture.

Following a review of available monitoring data, three NVZ's, one located at Clogh Mills, Co. Antrim and two near Comber, Co Down, were designated in Northern Ireland (NI) in 1999. All three NVZ's were created based upon nitrate exceedences in groundwater.

In 2000, Environment and Heritage Service (EHS), established a regional groundwater monitoring network; sites within these network are monitored quarterly for nitrate. A review of data collected from the network, carried out during 2001, identified ten sites where monitoring showed nitrate concentrations in excess of 25 mg NO_3 / L in at least one sample taken between 2000-2001. More detailed assessment and further monitoring at these ten sites was undertaken by the Geological Survey of Northern Ireland (GSNI) (Geological Survey of Northern Ireland 2002a; 2002b). Following this further assessment, EHS concluded that four of the ten sites warranted designation as NVZ's under the Nitrates Directive (DOE 2002, Geological Survey of Northern Ireland 2002c).

Associated with the above review, EHS commissioned BGS to undertake a more general analysis of nitrate in groundwater using data collected both during an initial BGS reconnaissance survey between 1992-94 and from the more recent EHS monitoring in 2000-2001. This work was intended partly to review trends in groundwater nitrate concentrations between the two periods as well as examining factors such as landuse and vulnerability which may be influencing concentrations. A similar approach was recently used to designate NVZ's in Scotland (Ball and MacDonald 2001).

This report presents the findings of this work.

2 Groundwater in Northern Ireland

Groundwater can be found in most parts of Northern Ireland and is used for domestic, agricultural, industrial and public water supply purposes. With the presence of abundant surface water and the relatively high rainfall rate, exploitation of groundwater is relatively minor compared with other parts of the UK.

Northern Ireland has particularly varied and complex geology. The nature of the rock types most commonly found is such that they generally represent only poorly to moderately productive aquifers. However there are areas, such as in the Lagan and Enler Valleys, where more significant abstractions from boreholes of up to several thousand cubic metres per day can be sustained (Figure 1).

Within bedrock aquifers, groundwater flow is primarily through fractures, joints and weathered horizons. Such secondary porosity generally reduces with depth hence groundwater movement concentrated at shallow depths and discharging locally to watercourses and springs is a common scenario. Groundwater discharging to watercourses helps sustain flow during dry periods, supporting the ecological and amenity value of the waterway. The quality of this inflow hence partly influences the general chemistry of the associated surface waters.

Intergranular porosity contributes to permeability in certain bedrock aquifers such as the Sherwood Sandstone found in the Belfast and Newtownards areas. Sand/gravel glacial deposits are common throughout Northern Ireland and where they are sufficiently extensive and have sufficient saturated thickness constitute locally important aquifers (see Figure 1).

Superficial deposits mantle bedrock over more than 90% of the land area of Northern Ireland (Robins 1996). The most widespread of these deposits is glacial till (boulder clay) which comprises a matrix of poorly sorted clay, silt and sand-grade material with pebbles and boulders. Factors such as the thickness, compaction and dominant matrix grade of the till influence the degree of protection the deposit offers to groundwater within underlying aquifers from surface activities such as fertiliser use.

Soil cover is dominated by poorly draining types such as surface water gleys, partly reflecting the widespread occurrence of glacial till parent material and high rainfall rate (Cruikshank, 1997). The nature of the soil also influences where surface activities can impact on groundwater quality.

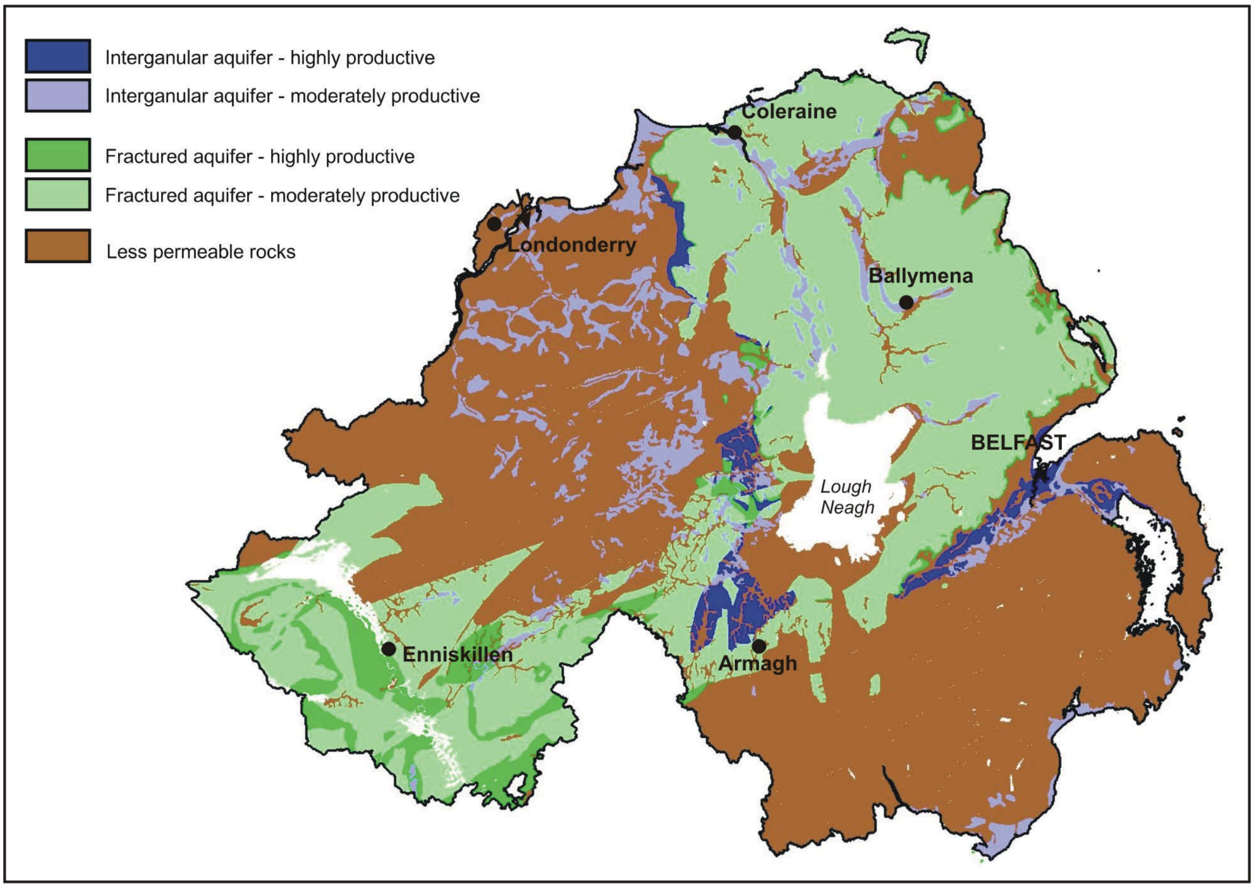


Figure 1 Simplified hydrogeology map of Northern Ireland (adapted from BGS 1994)

3 Summary of groundwater nitrate data

3.1 DATA SOURCES

There are two main sources of information on groundwater nitrate concentrations in Northern Ireland. The first is the EHS regional groundwater quality monitoring network which was established in 2000. Currently, information is available for 91 sources. Most of the sources are agricultural boreholes greater than 50 m deep although several shallower boreholes are also included. These boreholes were chosen from a much larger survey of over 700 boreholes undertaken in the early 1990s (see below). The monitoring boreholes were selected for their isolation from obvious point sources of contamination, good access and aerial distribution.

The second source of nitrate information is from the general survey of groundwater sources from which the EHS regional groundwater quality monitoring network was subsequently chosen. A total of 759 groundwater sources (mainly boreholes) were visited by the BGS and GSNI from 1992 to 1994 as part of a major project to collate hydrogeological information and to establish databases and monitoring networks. This work culminated in the production of a hydrogeological map and accompanying explanatory book (BGS 1994, Robins 1996). At 352 sites samples were taken for analysis under stringent field conditions; a sub-set of 109 sources were revisited at 3 monthly intervals for further sampling (Robins et al. 1994). This large, historic dataset can be used to help interpret the nitrate distributions observed in the current EHS monitoring network.

There are several other sources of nitrate information, for example from public water supplies and sites monitored by the Drinking Water Inspectorate. However, the sites are relatively few and add little information on the spatial distribution of nitrate. Therefore, they have been omitted from this general analysis. The monitoring data from these other sources has been taken into consideration by EHS in the designation of NVZs.

3.2 GENERAL NITRATE STATISTICS

A summary of the data from the two nitrate datasets is given in Table 1 and shown in Figure 2. Both datasets are in broad agreement, although the more widespread BGS survey shows slightly higher nitrate concentrations. Using the *average* nitrate concentration at each monitoring point, 6.2% of the BGS data set are greater than 50 mg NO_3 / L and 20.1% greater than 25 mg NO_3 / L. Using the *maximum* at each site, the percentage is slightly higher: 7.7% and 22.7% respectively. For the EHS groundwater quality monitoring network: 2.2 % of the sites have average nitrate

Table 1 Nitrate distribution for the BGS and EHS datasets.

		Number of sites in each category (percentage in brackets)			
		< 10 mg NO_3 / L	*10 - 25 mg NO_3 / L*	*25 - 50 mg NO_3 / L*	*> 50 mg NO_3 / L*
BGS	Mean[a] per site	217 (61.8)	64 (18.1)	49 (13.9)	22 (6.2)
	Max[b] per site	208 (59.2)	64 (18.1)	53 (15.0)	27 (7.7)
EHS	Mean Per site	58 (63.7)	25 (27.5)	6 (6.6)	2 (2.2)
	Max per site	52 (57.1)	23 (25.3)	13 (14.3)	3 (3.3)

[a]Nitrate measurements for each site are averaged.

[b]Only the maximum nitrate concentration measured at each site is used.

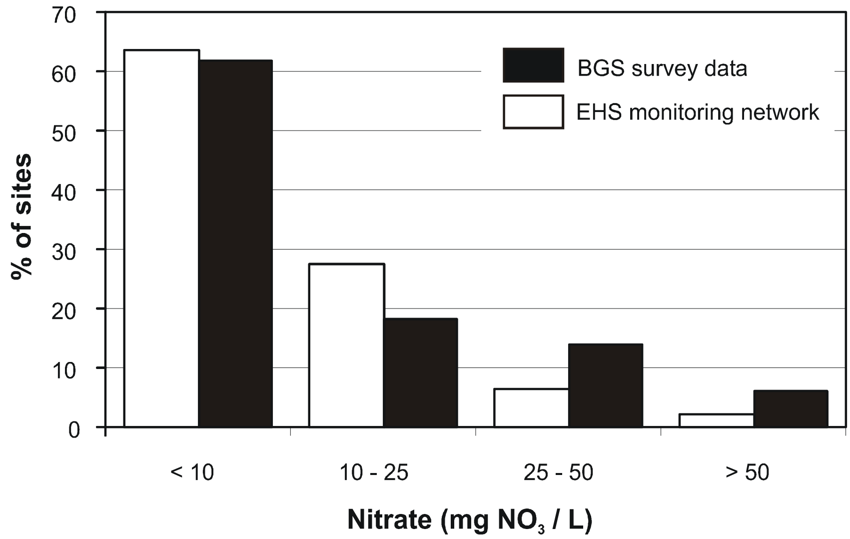


Figure 2 Distribution of mean nitrate in groundwater sources across Northern Ireland. The BGS dataset comprises 352 sources measured from 1992-94; the EHS monitoring network comprises 91 sources monitored from 2000 onwards. Data are given in Table 1.

greater than 50 mg NO_3 / L and 8.8% greater than 25 mg NO_3 / L. For the maximum at each site, 3.3% are greater than 50 mg NO_3 / L and 17.6% greater than 25 mg NO_3 / L. These data indicate that the groundwater in Northern Ireland is not widely contaminated with nitrate. More than 60% of the monitoring sites in both datasets show average concentrations less than 10 mg NO_3 / L.

To set this in a wider context, the Northern Ireland data are compared to published nitrate concentrations for the rest of the United Kingdom in Figure 3. Only tentative conclusions can be drawn since the datasets have been compiled differently. Data for 3714 sites across England and Wales were used by DEFRA for designation of NVZs in England (DEFRA 2002a) and by the National Assembly in Wales (NAW 2002). Trend analysis was used to give predicted values of nitrate in 2017 if no action was taken. Nitrate concentrations for 1997 are also available for approximately 1000 sites but these are biased to high nitrate areas and are therefore not suitable to compare with the Northern Ireland dataset (which is widely distributed across different land uses). However, the 1997 data could be used to indicate the error involved in using predicted 2017 data to compare with 1994 Northern Ireland data: 2017 concentrations were found to be on average 4 mg/l higher than the 1997 data. The error therefore is not large and the 2017 England and Wales concentrations can be used as a rough guide to compare with Northern Ireland monitoring sites. Data for 446 sites across Scotland were collated to help designate NVZs in Scotland (Ball and MacDonald 2002). These were from a variety of sources (SEPAs groundwater quality network, public water supply boreholes and a BGS survey) and measured during the time period 1980 to 2002.

Using these datasets, Northern Ireland has the lowest nitrate concentrations within the United Kingdom. Approximately 30% of sites have concentrations less than 10 mg NO_3 / L in England and Wales and 45% in Scotland; compared to 60% in Northern Ireland. In England and Wales 20% of sites exceed 50 mg NO_3 / L and 9% in Scotland, compared with 6% in Northern Ireland. There are several contributing factors to the generally low groundwater nitrate concentrations in Northern Ireland: the lack of extensive arable agriculture, the favourable denitrification conditions in the Northern Ireland soils and the dilution from the high rainfall (Robins 1998, DOE 2002). However, groundwater nitrate concentrations are not consistently low across Northern Ireland and the reasons for this merit further examination.

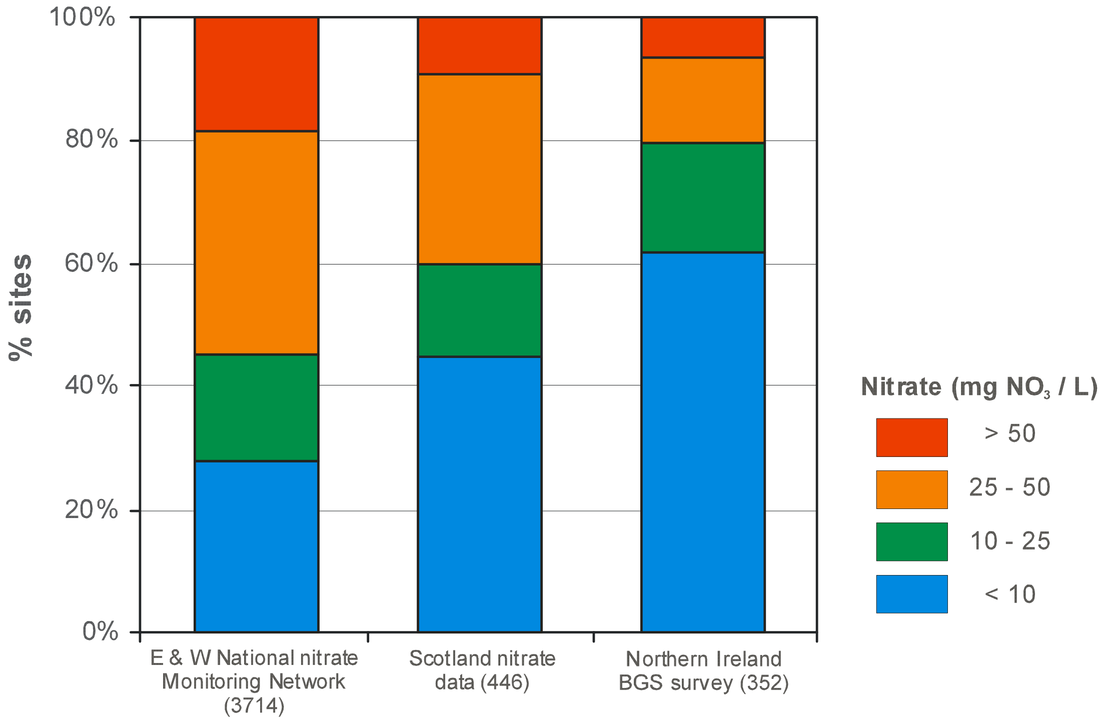


Figure 3 **Comparison of the Northern Ireland nitrate concentrations with published data for England, Scotland and Wales (numbers in brackets refer to number of sites). The England and Wales data is predicted for 2017 (DEFRA 2002a); the Scottish data is collated from 1980 to 2002 (Ball and MacDonald 2002) and the BGS 1994 survey is used for Northern Ireland.**

Figure 4 shows how the mean nitrate concentrations vary across Northern Ireland. Higher concentrations are recorded in some areas, for example to the northwest of Lough Neagh, around Ballymena and to the southeast of Belfast. Section 4 will examine some of the reasons for these variations in more detail.

Table 2 summarises the nitrate data from both the BGS and EHS datasets for the different surface water catchments in Northern Ireland. The mean groundwater nitrate concentration for each surface water sub-catchment is shown in Figure 5 to help comparison with surface water data. Only catchments with 3 or more sample points are displayed. (It should be noted that the density of available groundwater nitrate data varies significantly within the surface water catchments. This, along with natural hydrogeological complexity means that the nitrate classification assigned to groundwater within a particular surface water catchment cannot be considered as definitive). Surface water nitrate concentrations show broad agreement with groundwater concentrations, although there are some notable exceptions, for example, surface water concentrations to the south and west of Lough Neagh are higher than groundwater concentrations.

Table 2 Nitrate data in groundwater sources according to surface water catchments.

		BGS Survey Data						EHS Monitoring Data					
		No	Mean mg NO_3/L	>25 mg NO_3/l		>50 mg NO_3/l		No	Mean mg NO_3/L	>25 mg NO_3/L		>50 mg NO_3/L	
Belfast Lough & East Down	N Belfast Lough	8	19.1	2	(25.0)	0		1	56.9	1	(100)	1	(100)
	Blackwater (Ards)	3	27.9	2	(66.7)	0		0					
	Comber	7	17.4	2	(28.6)	0		0					
	Lagan	20	2.2	1	(5.0)	0		11	7.9	1	(9.1)	0	
	N Down & Ards Pen	18	22.3	9	(50.0)	3	(16.7)	5	26.0	2	(40)	0	
	Quoile	3	19.0	1	(33.3)	0		1	3.4	0		0	
	SE Down Streams	3	14.2	0		0		2	5.3	0		0	
Total		**62**	**14.6**	**17**	**(27.4)**	**3**	**(4.8)**	**20**	**14.4**	**4**	**(20)**	**1**	**(5)**
Bush & NE Coast	Bush	6	9.3	1	(16.7)	0		4	9.7	0		0	
	NE Coast	9	8.7	2	(22.2)	0		2	10.4	0		0	
Total		**15**	**8.9**	**3**	**(20.0)**	**0**		**6**	**9.9**	**0**		**0**	
Erne	Arney	1	<0.9	0		0		1	8.6	0		0	
	Ballinamallard	3	0.1	0		0		1	1.2	0		0	
	Colebrooke	4	3.3	0		0		0					
	Kesh	1	<2.2	0		0		0					
	Lower Erne	2	<1.8	0		0		0					
	Sillees	1	<2.2	0		0		0					
	Swanlinbar	1	<1.6	0		0		1	1.3	0		0	
	Upper Erne	7	0.0	0		0		1	1.0	0		0	
	Woodford	1	10.2	0		0		1	13.9	0		0	
Total		**21**	**0.7**	**0**		**0**		**5**	**5.2**	**0**		**0**	
Foyle	Camowen	6	13.1	1	(16.7)	0		0					
	Derg	8	23.5	4	(50.0)	1	(12.5)	1	1.0	0		0	
	Drumragh	4	12.4	0		0		3	11.8	0		0	
	Fairy Water	5	1.2	0		0		2	1.0	0		0	
	Foyle (with Deele)	5	20.3	2	(40.0)	1	(20.0)	3	12.6	1	(33.3)	0	
	Mourne	1	<1.5	0		0		0					
	Mourne/Strule	1	25.7	1	(100.0)	0		0					
	Owenkillew	4	12.3	1	(25.0)	0		4	10.1	0		0	
	Strule	2	1.9	0		0		1	2.2	0		0	
Total		**36**	**13.9**	**9**	**(25.0)**	**2**	**(5.6)**	**14**	**8.5**	**1**	**(7.1)**	**0**	
Lough Foyle	Faughan	4	14.5	1	(25)	0		1	6.8	0		0	
	Lough Foyle (East)	2	88.9	2	(100)	2	(100)	0					
	Lough Foyle (South)	2	8.5	0		0		0					
	Roe	5	0.0	0		0		30	1.3	0		0	
Total		**13**	**19.5**	**3**	**(23.1)**	**2**	**(15.4)**	**40**	**2.7**	**0**		**0**	
Lough Neagh & Lower Bann	Ballinderry	28	9.1	1	(3.6)	1	(3.6)	2	1.7	0		0	
	Blackwater	42	7.0	4	(9.5)	2	(4.8)	8	7.2	0		0	
	Crumlin	4	8.3	0		0		1	8.7	0		0	
	Lough Neagh & Peripherals	15	4.2	2	(13.3)	0		4	3.2	0		0	
	Lower Bann	29	23.5	8	(27.6)	5	(17.2)	8	15.2	1	(12.5)	1	(12.5)
	Main	27	16.5	7	(25.9)	1	(3.7)	6	10.1	0		0	
	Moyola	10	28.2	3	(30)	1	(10)	2	23.6	1	(50)	0	
	Six Mile Water	5	28.1	3	(60)	0		1	11.3	0		0	
	Upper Bann	20	7.2	2	(10)	1	(5)	5	1.0	0		0	
Total		**180**	**13.0**	**30**	**(16.7)**	**11**	**(6.1)**	**37**	**8.9**	**2**	**(5.4)**	**1**	**(2.7)**
Mourne & South Armagh	Castletown	1	<1.8	0		0		0					
	Fane	3	17.3	1	(33.3)	0		0					
	Kilkeel & Mourne Streams	7	28.1	2	(28.6)	1	(14.3)	2	18.0	1	(50)	0	
	Newry	14	35.6	6	(42.9)	3	(21.4)	3	15.6	0		0	
Total		**25**	**29.8**	**9**	**(36.0)**	**4**	**(16.0)**	**5**	**16.5**	**1**	**(20.0)**	**0**	
	Grand Total	**352**	**13.8**	**71**	**(20.1)**	**22**	**(6.2)**	**91**	**10.0**	**8**	**(8.8)**	**2**	**(2.2)**

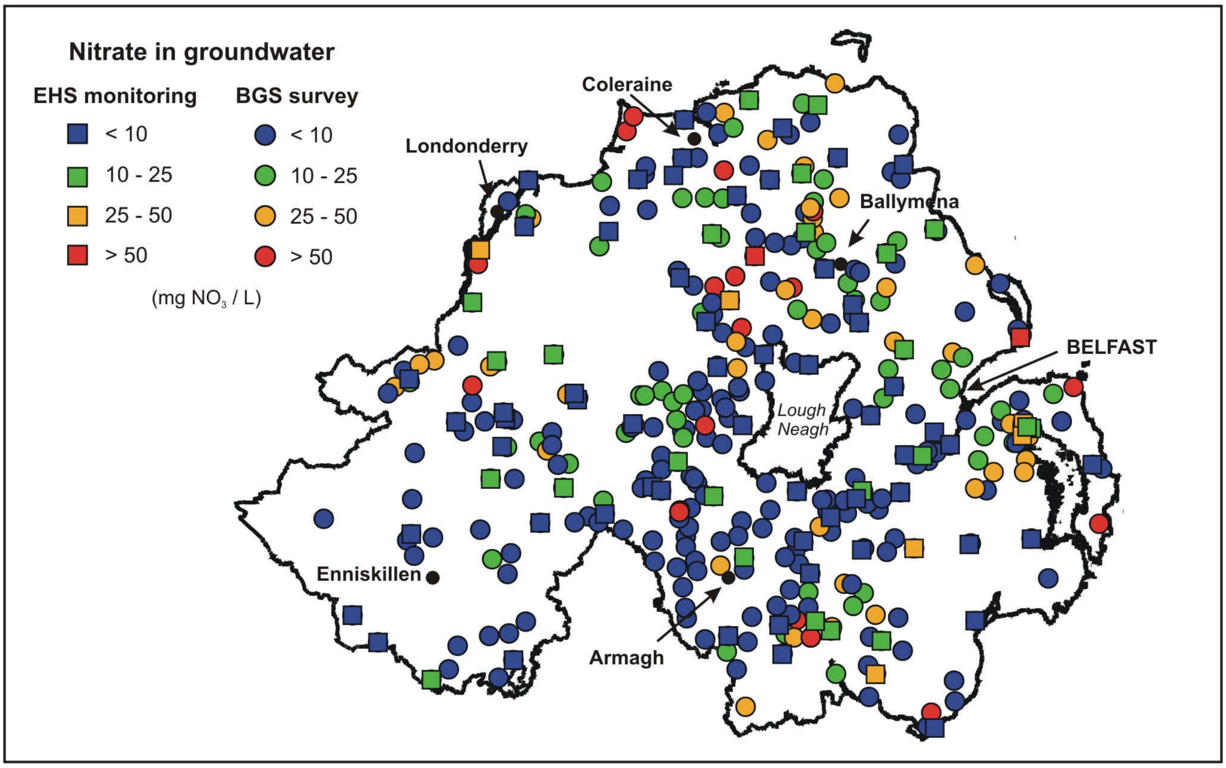


Figure 4 Mean nitrate measured in groundwater sources across Northern Ireland.

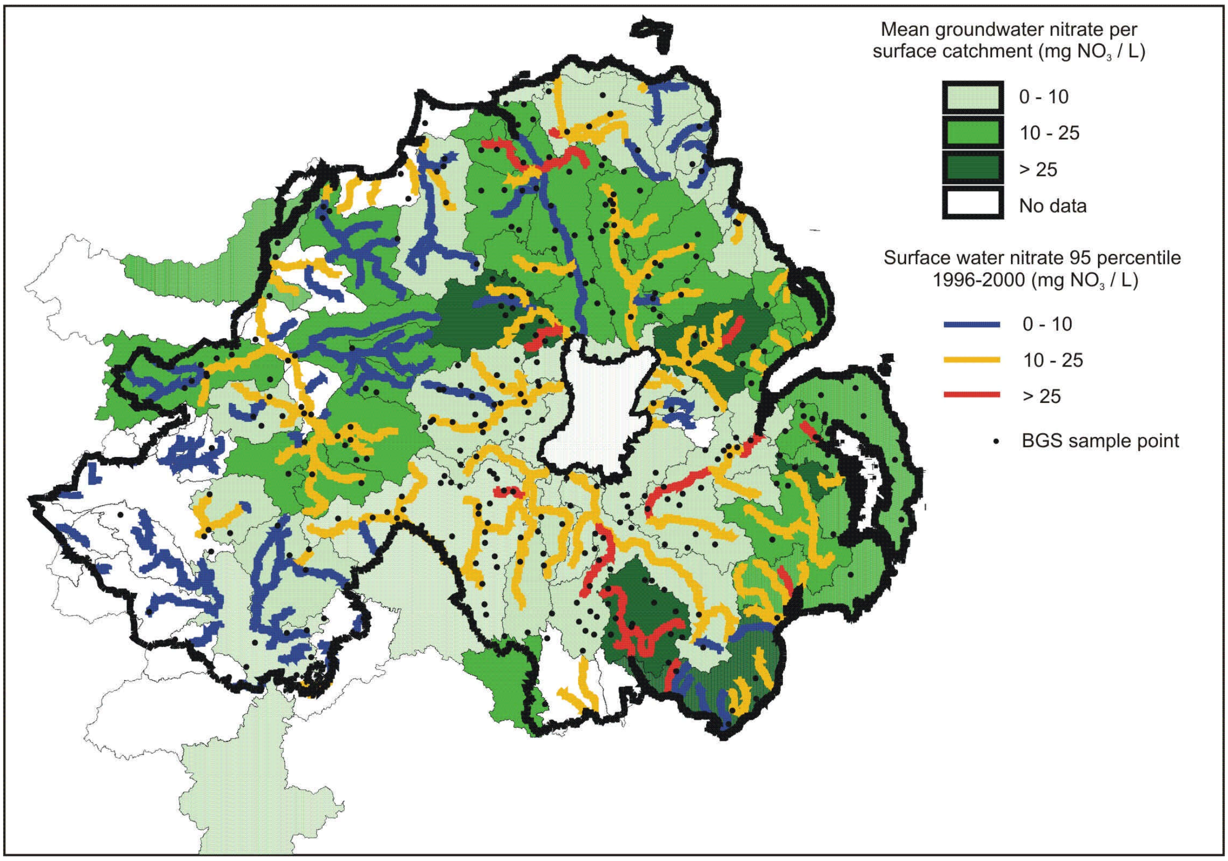


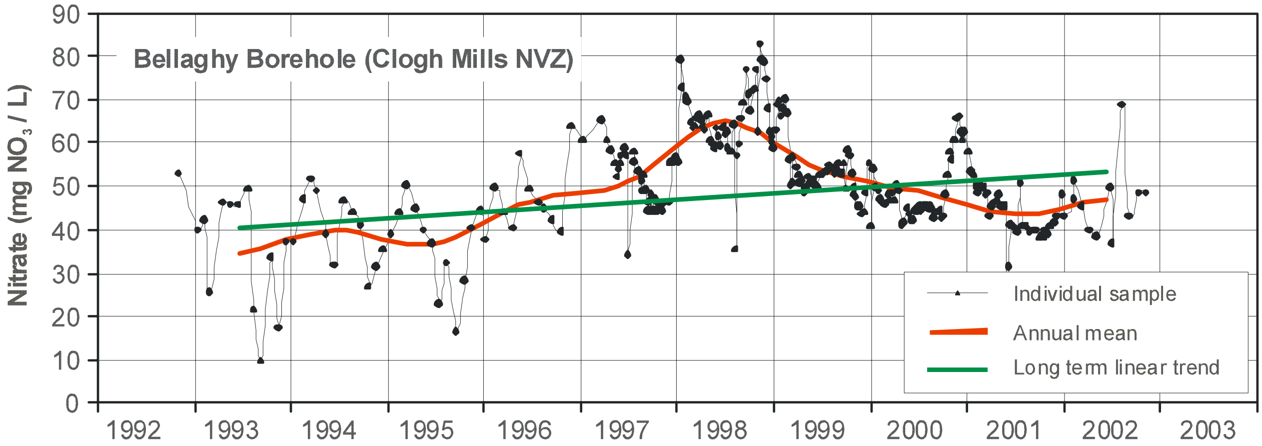
Figure 5 Mean groundwater nitrate concentrations per surface water catchment for the BGS Survey data compared to surface water nitrate.

3.3 NITRATE TRENDS

Long-term monitoring of groundwater nitrate concentrations has been carried out for selected monitoring points in the existing NVZ's at Clogh Mills and Comber. The data are shown in Figure 6. In both areas nitrate concentrations show an overall increase between 1992 and 1997-1998. From this time, nitrate concentrations at the Comber NVZ remained relatively steady up to 2002. At the Clogh Mills NVZ, concentrations varied more with some decrease following the 1997-1998 peak although concentrations still remain high and intermittedly exceed the 50 mg NO_3 / L.

In addition to these long term monitoring data it is possible to give some indication of temporal trends by comparing the EHS monitoring data (2000 – 2001) with the BGS survey data (1992 – 1994). Only sites that were sampled in both surveys could be used. To minimise sampling errors, only sites that had 4 or more samples taken in each monitoring period (the 92-94 period, and 00-02 period) were chosen (27 sites in total). The change in mean between the periods for each site is shown in Figure 7.

The data shown in Figure 7 show no consistent trend in nitrate concentrations. Eight sites have an increase in average nitrate of more than 5 mg NO_3 / L and 5 sites decrease more than 5 mg NO_3 / L over the 8 year period. The remaining 14 sites have changed less than 5 mg NO_3 / L in the time period. Three sites with the largest increases have been proposed as NVZs (Geological Survey of Northern Ireland 2002c).



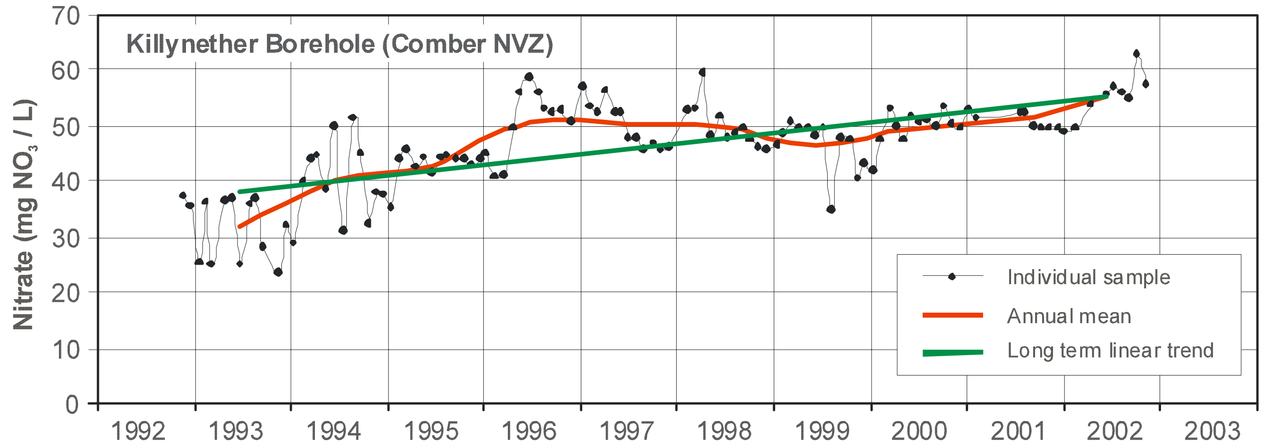


Figure 6 Nitrate data from two existing NVZs in Northern Ireland: Clogh Mills NVZ (in sand and gravel) and the Comber NVZ in the Sherwood Sandstone. The location of the two boreholes is shown in Figure 7.

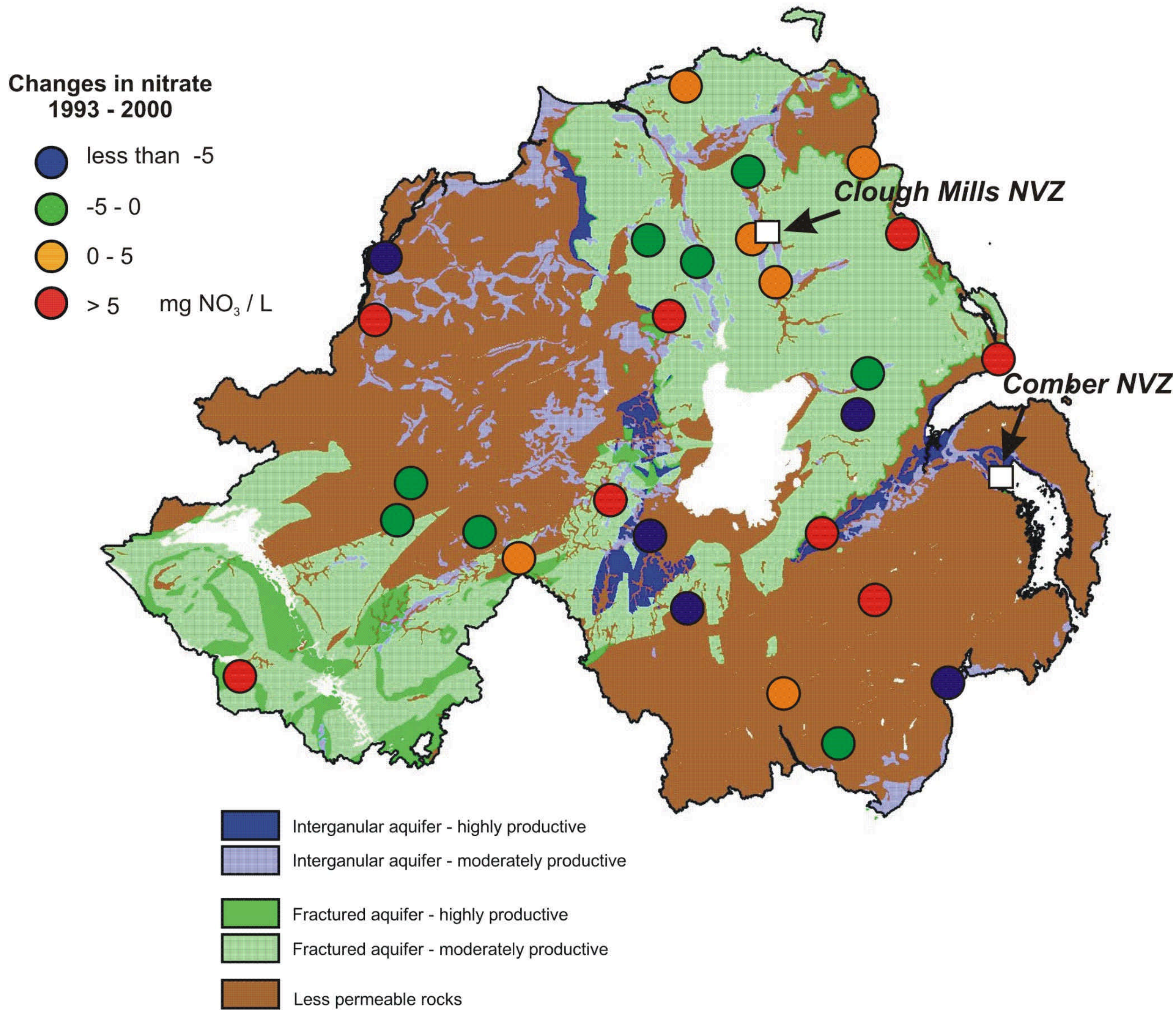


Figure 7 Change in nitrate concentrations between BGS (92-94) and EHS (00-01) monitoring for sites with more than 4 samples in each period.

4 Contributing factors to measured nitrate concentrations

4.1 INTRODUCTION

In this chapter we investigate further the spatial distribution of groundwater nitrate across Northern Ireland. In particular the main controls on nitrate distribution are examined, subject to the availability of data. This will help to interpret the monitoring data and extrapolate away from individual monitoring sites to begin to predict which areas of Northern Ireland are likely to be at risk of nitrate contamination.

Many studies have demonstrated the link between land use, and in particular arable land, and nitrate concentrations in surface and groundwater (e.g. Foster 2000; DEFRA 2002b). Other studies have shown the importance of soil type and aquifer vulnerability (Nolan 1997). The combination of land use and aquifer vulnerability can be an effective predictor of high nitrate concentrations in groundwater. For example, in Scotland, these two factors (aquifer vulnerability and nitrate leaching) explained much of the nitrate concentrations in groundwater and were used to help delineate additional NVZs (Ball and MacDonald 2001).

The two main groundwater datasets in Northern Ireland (EHS monitoring dataset and BGS survey) have been used to examine the relationships between groundwater nitrate concentrations, land use, aquifer vulnerability and borehole depth. Some other relationships are then examined, for example the effect of septic tanks.

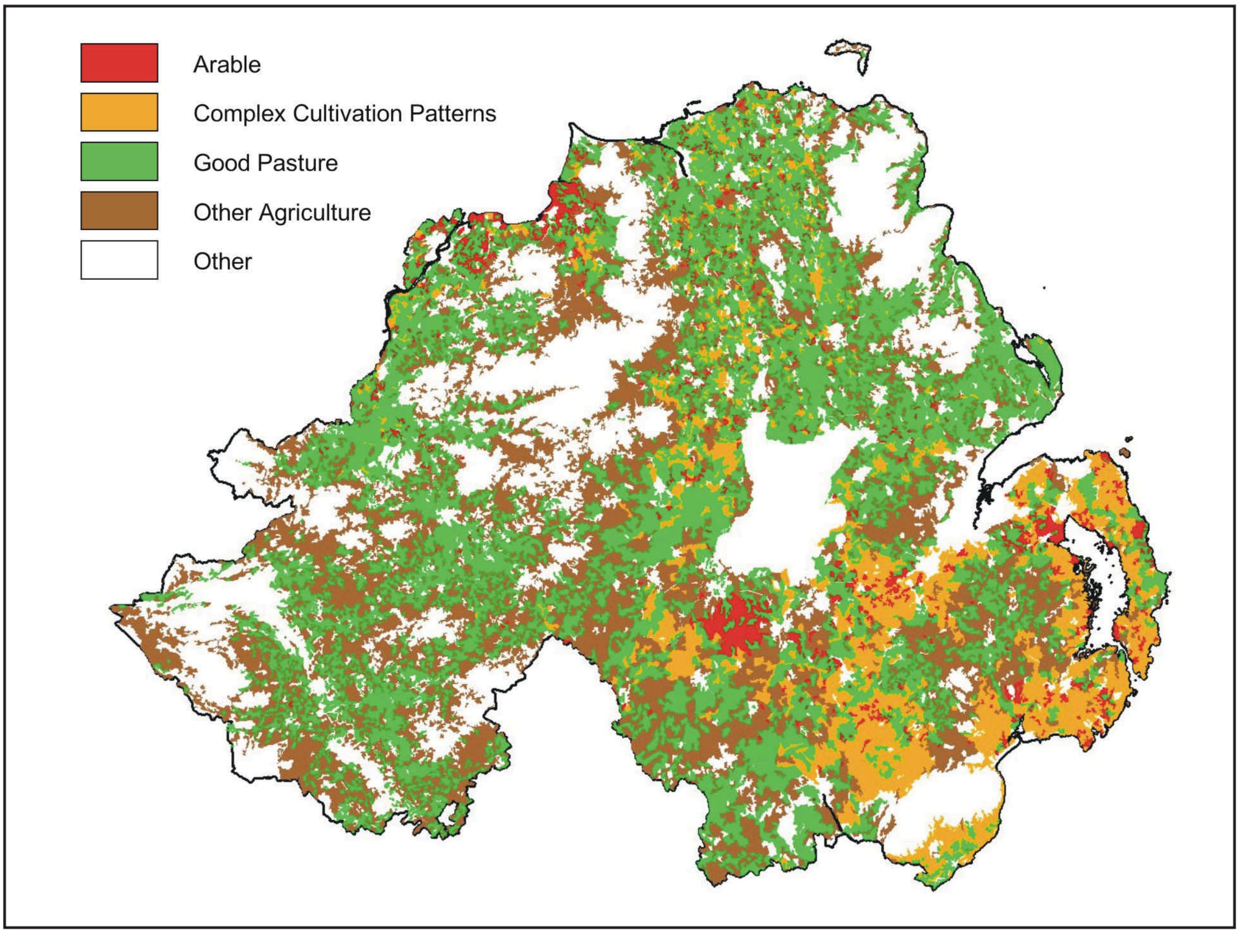


Figure 8 Simplified land use for Northern Ireland taken from the Corine dataset.

4.2 LAND USE

There are two main sources of land use information available in Northern Ireland: Landcover 2000 and the Corine dataset. For the purposes of this analysis, the Corine dataset was found most suitable. The various agricultural subdivisions provided a better correlation with nitrate than the Landcover 2000. A simplification of the Corine dataset is given in Figure 8.

An explanation of the Corine dataset is given in Cruickshank (1997). For the purposes of this current study *Arable* land includes all irrigated and non-irrigated arable land and also fruit growing areas. *Complex cultivation* areas is a mixture of arable and pasture. *Good Pasture* is where the pastures are sown or well managed and have uniform sward. *Other agriculture* includes all the poor pastures and areas where agriculture is interspersed with significant areas of natural vegetation. The last category, *Other*, includes all other land uses.

Figure 9 shows the distribution of nitrate for sites in each land use category. Both the EHS monitoring sites and the BGS survey sites show similar trends. The arable areas have approximately 50% of sites exceeding 25 mg NO_3 / L; more than 85% of sites in areas with no

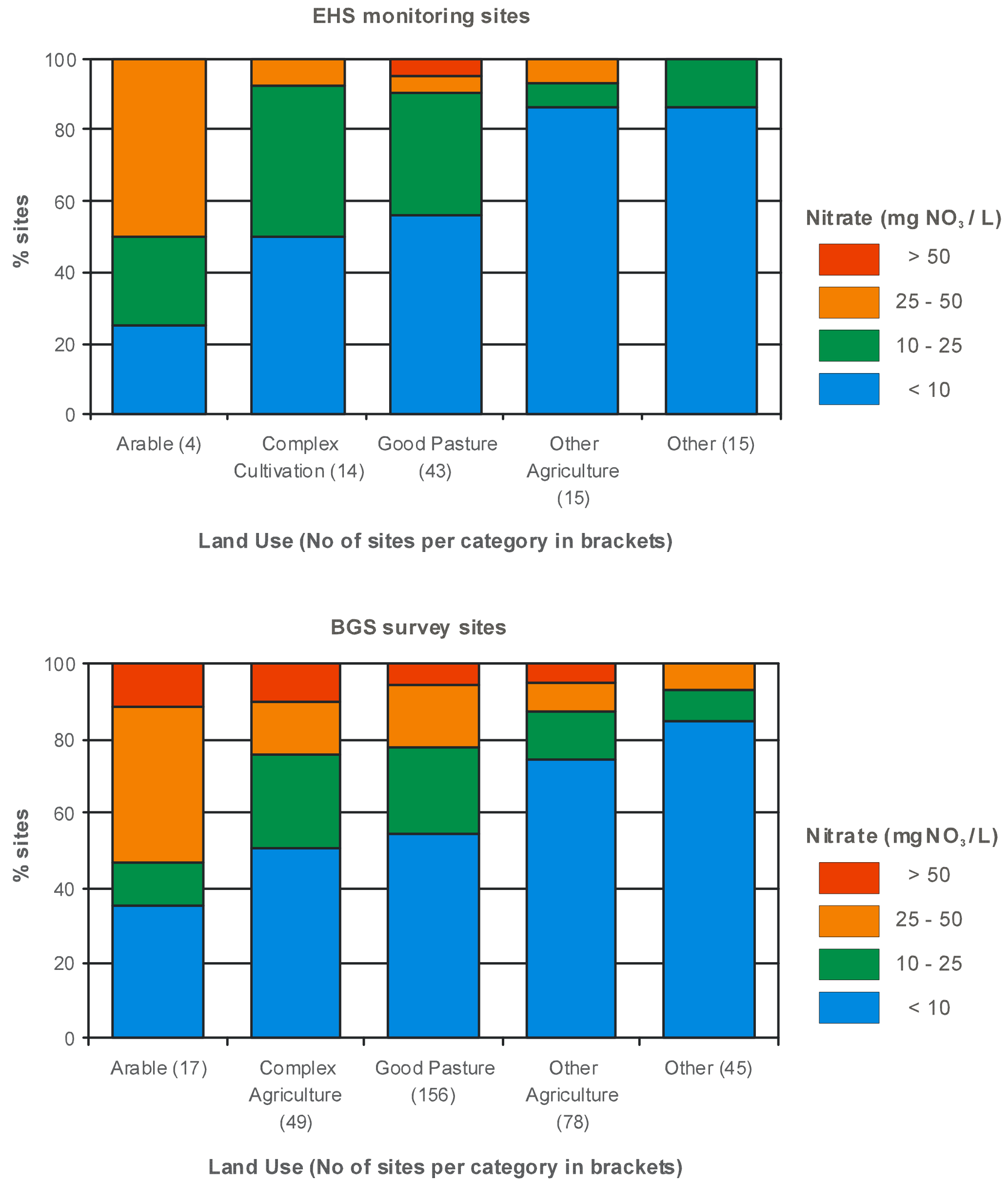


Figure 9 The proportion of groundwater sources in each landuse category exceeding 10, 25 and 50 mg NO_3 / L. Average nitrate concentrations at each site are used.

agricultural activity have less than 10 mg NO_3 / L. Both datasets show a steady rise in nitrate concentrations as the agricultural activity becomes increasingly intensive. The EHS dataset shows slightly more variability than the BGS dataset, probably because of the difference in sample size.

4.3 AQUIFER VULNERABILITY

Groundwater nitrate contamination depends not only on the availability of nitrate at the land surface, but also on aquifer vulnerability (the likelihood that contaminants can reach the water-table). Aquifer vulnerability is controlled by the composition of the soil, the composition of the unsaturated zone, and the depth to groundwater (e.g. NRA 1992). Where the soil and unsaturated zone are highly permeable, water can readily flow from the surface to the water-table and the aquifer is vulnerable. However, if the unsaturated zone and soil is clay rich, recharge is reduced and the aquifer is less vulnerable.

Superficial deposits (drift) cover much of Northern Ireland and generally offer some protection to the groundwater. Classifying the superficial deposits according to their expected relative permeability offers a rapid and simple way of estimating groundwater vulnerability. (The vulnerability classifications from the published groundwater vulnerability map for Northern Ireland (British Geological Survey 1994) do not include the permeability of superficial deposits so could not be used for this analysis). Superficial deposits can be divided into three permeability classes using the 1: 250 000 superficial geology map (Figure 10).

- High: glacial sands and gravels, blown sand, gravely raised beach deposits; absence of superficial deposits;
- Moderate: alluvium;
- Low: peat, glacial till and lacustrine clays and silt.

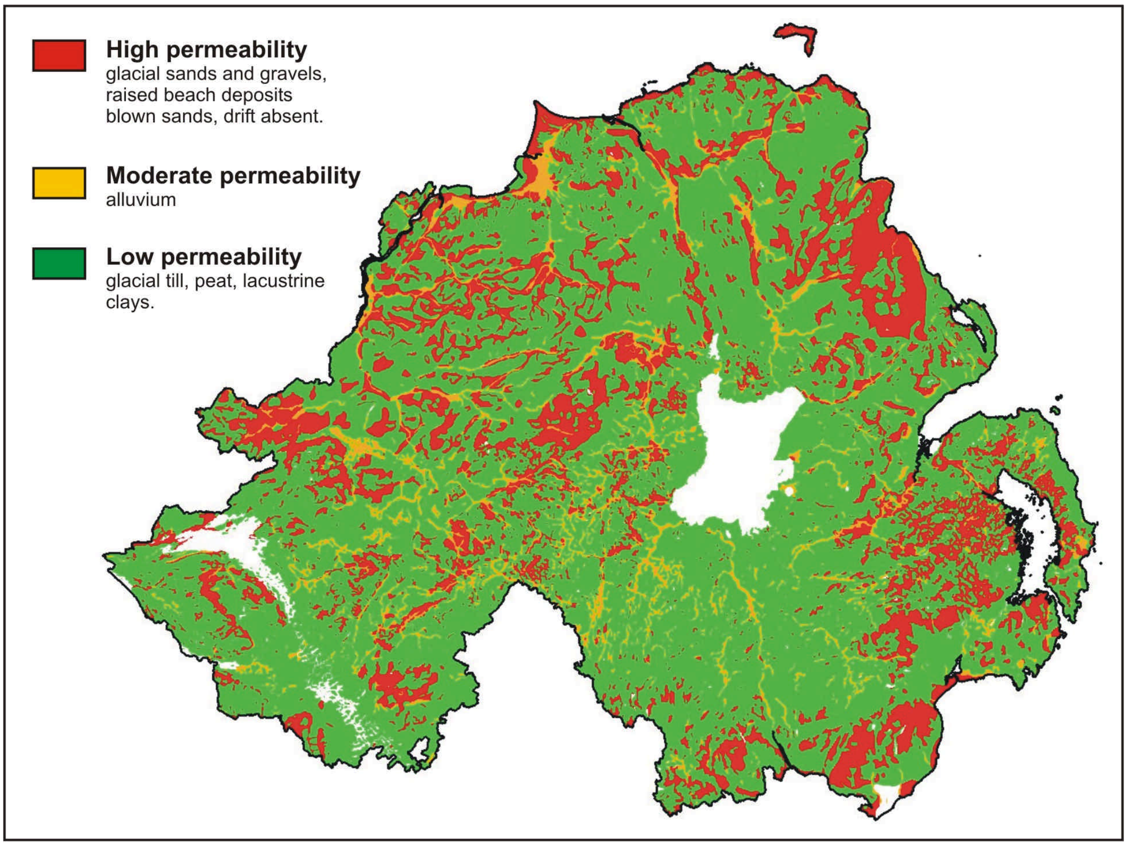


Figure 10 The permeability of superficial deposits in Northern Ireland. Note that where the superficial deposits are absent this has been classed highly permeable.

Table 3 Comparing nitrate data for BGS survey sites underlain by (1) high permeability superficial deposits and (2) moderate or low permeability superficial deposits.

	High permeability				*Mod/Low permeability*			
Nitrate	*Mean NO_3 at site*		*Max NO_3 at site*		*Mean NO_3 at site*		*Max NO_3 at site*	
mg NO_3/L	*No sites*	*%sites*	*No. sites*	*%sites*	*No sites*	*%sites*	*No. sites*	*%sites*
< 10	14	36.9	12	31.6	71	60.2	71	60.2
10 - 25	11	28.9	12	31.6	25	21.2	20	16.9
25 - 50	11	28.9	11	28.9	15	12.7	18	15.2
> 50	2	5.3	3	7.9	7	5.9	9	7.6
	Mean NO_3 21.0		Mean NO_3 22.8		Mean NO_3 14.0		Mean NO_3 16.1	

The effect of the permeability of the superficial deposits on nitrate concentrations in groundwater was tested using the BGS survey data. To minimise bias due to land use only sites on one land class were chosen - Good pasture. This class had 156 nitrate survey sites. Thirty-eight of these are in areas of high permeability drift. There are few areas of moderate permeability and, therefore, few monitoring sites. To allow for a statistically meaningful comparison, the moderate and low permeability classes were combined.

Table 3 shows a summary of the nitrate data for sites situated in good pasture. Nitrate concentrations are higher in areas underlain by permeable superficial deposits (or where superficial deposits are absent). Taking the average nitrate concentrations measured at each site, 34.2% of sites in high permeability areas have > 25 mg NO_3 / L (average of 21 mg NO_3 / L) compared to 18.6% (average 14 mg NO_3 / L) in moderate or low permeability areas. Therefore the data indicate that the permeability of the superficial deposits does affect the nitrate concentrations measured in the groundwater.

This broad analysis does not account for the local variations that can exist with superficial deposits. Hence there may be a significant number of local areas where groundwater is vulnerable to impact from surface activities even although the superficial deposits have been classed as low permeability.

Some further analysis was undertaken to assess the effect of the soil permeability using the HOST (hydrology of soil types) classification (see Cruickshank 1997). HOST was used to

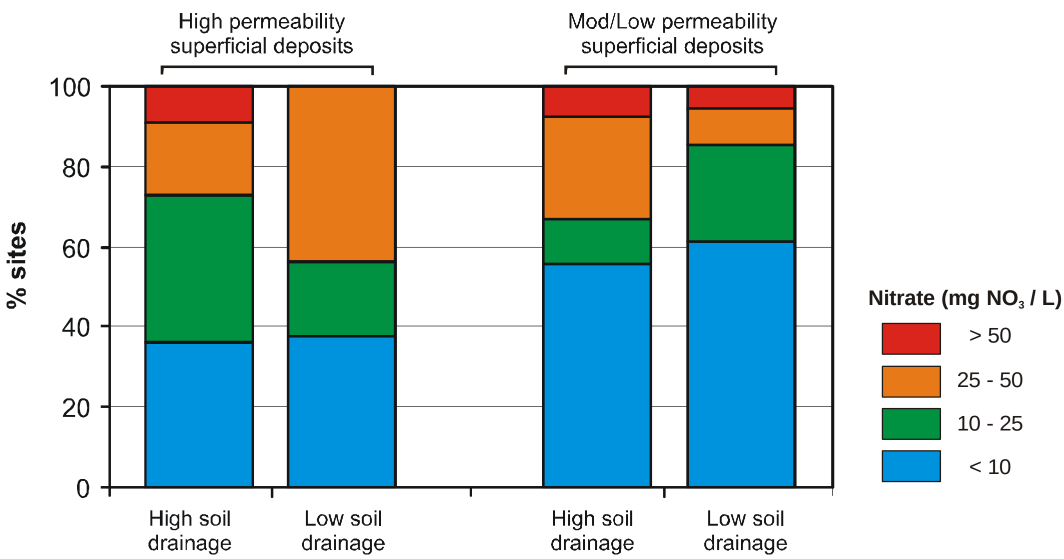


Figure 11 The relation between groundwater nitrate concentrations, soil permeability (using HOST) and the permeability of the superficial deposits. Only survey sites in areas of good pasture have been used to help minimise data bias.

divide soils into two classes: (1) low permeability (soil percentage drainage < 70%); and (2) high permeability (soil percentage drainage > 70%). Figure 11 shows the nitrate concentrations for good pasture sites classed according to the permeability of both soil and superficial deposits. The data show no correlation between nitrate in groundwater and soil permeability.

4.4 BOREHOLE DEPTH

Shallower groundwater is often more highly contaminated with nitrate than deeper groundwater. This is due to the vertical movement of shallow nitrate rich water, which moves down from the soil and mixes with older, low nitrate water. Recent research in the Dumfries Permian aquifer in southern Scotland demonstrated that the nitrate concentration measured in pumping boreholes was controlled by the mixing of shallow nitrate rich water with older (pre 1950) low nitrate water (MacDonald et al. in press).

To identify if a similar mechanism is present in Northern Ireland the nitrate concentrations were compared to the borehole depths. The mean nitrate concentration at each site was taken (a similar result was given using the maximum nitrate at each site). Figure 12 demonstrates that sources less than 25 m deep generally had higher nitrate than sources greater than 25 m deep. However, deeper than 25 m there was no discernable trend. Nearly 40% of sources shallower than 25 m had > 25 mg NO_3 / L; while only 20% of sources greater than 25 m deep had nitrate in excess of 25 mg NO_3 / L.

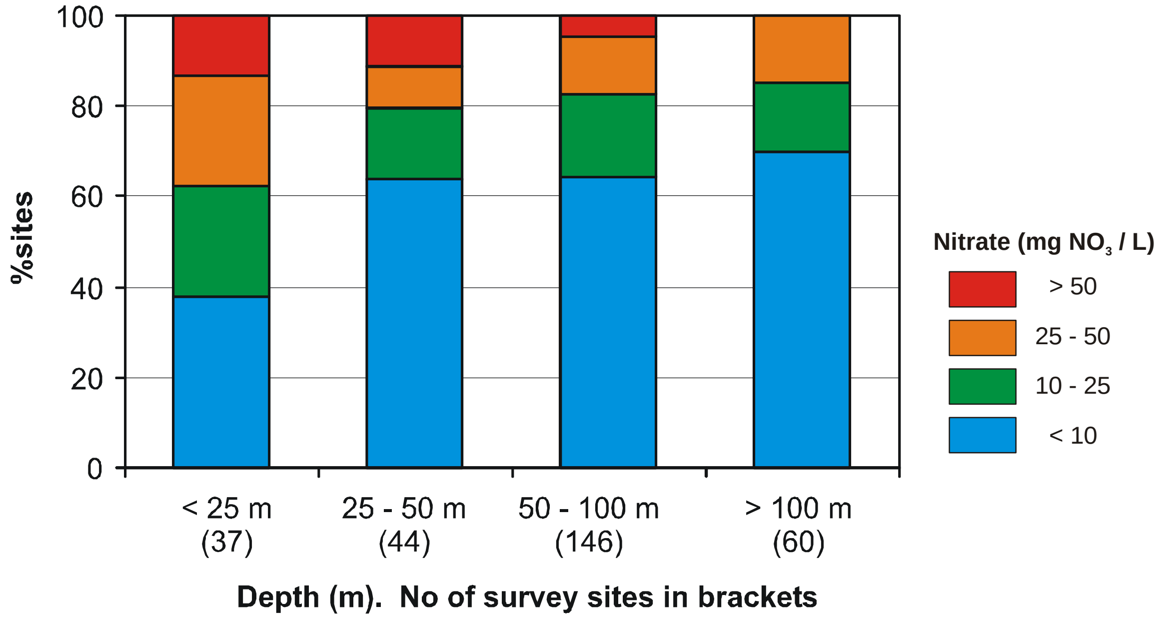


Figure 12 The relation between groundwater nitrate concentrations and the depth of the borehole/well. The BGS survey data have been used; data have been averaged for each site.

4.5 OTHER RELATIONSHIPS

Other data was collected as part of the BGS survey in 1993-1994. In particular, it was noted at each sample site whether there was a soakaway from a septic tank and also whether slurry was routinely spread on nearby fields. Two simple analyses have been undertaken using the BGS survey dataset: (1) comparison of sites having septic tanks with sites without septic tanks; and (2) comparison of sites where slurry is spread with sites where slurry is not routinely spread. For both cases the average nitrate concentration at each survey site has been used. The results are shown in Table 4. The simple analysis suggests that the presence of a septic tank makes no

Table 4 Comparison statistics for BGS survey sites with or without soakaways, and slurry spreading.

	Soakaways		*Slurry spreading*	
	present	*absent*	*present*	*absent*
No of sites	256	96	281	71
Mean nitrate (mg NO_3 / L)	15.3	14	16.5	8.6
%sites > 25 mg NO_3 / L	5.8%	7.3%	22%	11%
%sites > 50 mg NO_3 / L	20.2%	19.8%	7.50%	1.50%
t value	0.44		2.42	
t critical	1.65		1.65	

statistical difference to the nitrate measured in the groundwater. Sites where slurry is spread, however, have significantly higher nitrate concentrations than where slurry is not spread.

A first attempt at a nitrate leaching model for Northern Ireland has been developed by Crawford Jordan at the Department of Agriculture and Rural Development (Jordan et al. 1994). This takes into consideration the nitrate loading from agriculture, human and also atmospheric deposition. Agriculture is the dominant contributor. The data is available for each river catchment and gives a good correlation with measured surface water nitrate. The nitrogen loading has been estimated as kilograms of nitrogen per hectare per year. The BGS survey data show a general correlation with the model (Figure 13). However, land use data from Corine predict the nitrate concentrations better than the modelling (see Figure 9). The most likely reason is the different scale of the datasets. The nitrate leaching model is averaged over surface water catchments, but the Corine dataset is given at individual field levels. A much better correlation with the nitrate leaching model could be expected if it was disaggregated to the same scale as the land use data.

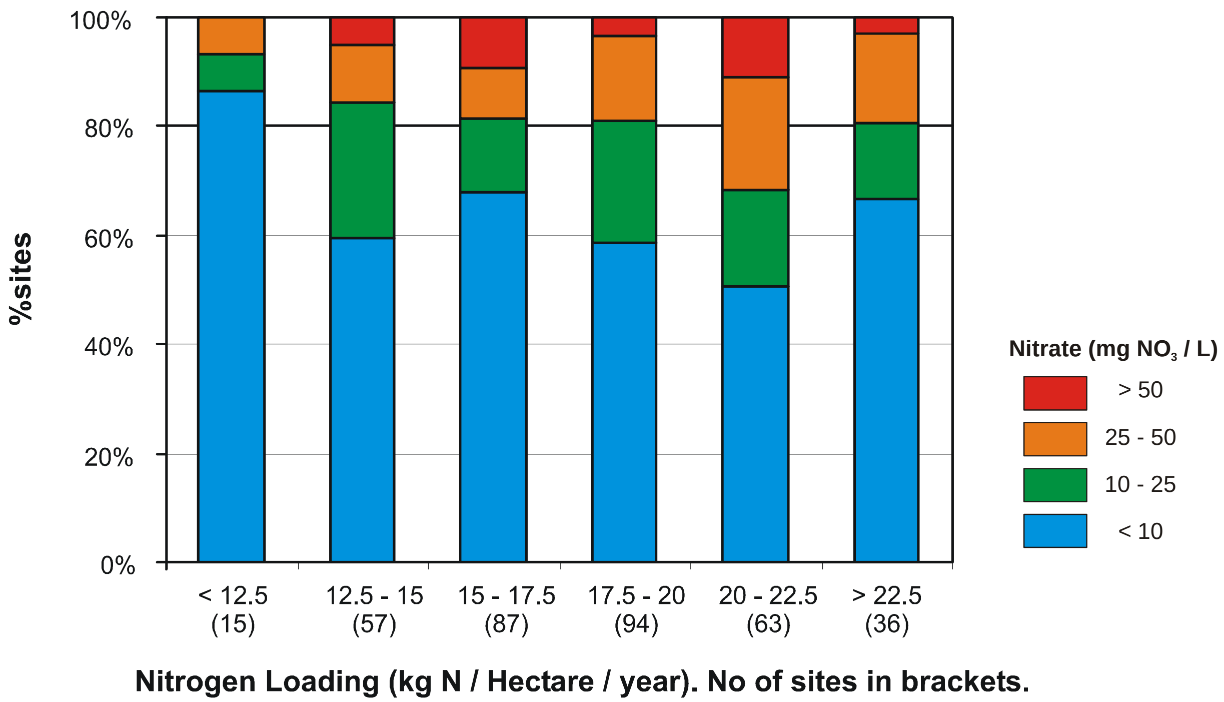


Figure 13 Comparison of groundwater nitrate concentrations and the average nitrogen load per catchment (data from Crawford Jordan, Department for Agriculture and Rural Development).

5 Conclusions and recommendations

Analysis of the groundwater nitrate data available for Northern Ireland has indicated several significant issues about nitrate in groundwater.

1. Groundwater nitrate concentrations, where measured, are generally low: mean concentrations at 6.2% of the 352 BGS 92-94 survey sites exceeded 50 mg NO_3 / L (20.1% exceeded 25 mg NO_3 / L). The current EHS regional monitoring network (91 sites) which is based upon a subset of the BGS survey sites have 2.2 % of sites greater than 50 mg NO_3 / L and 8.8% greater than 25 mg NO_3 / L. These concentrations are significantly lower than those measured in England & Wales and slightly lower than those measured in Scotland. The most likely causes of the low groundwater nitrate concentrations are: the limited extent of arable agriculture, the favourable denitrification conditions in the Northern Ireland soils and dilution from the high rainfall.
2. Analysis of twenty-seven sites where sampling was undertaken in both 1992-94 and 2000-02 indicate no consistent temporal trend from 1993 to 2001 in nitrate concentrations across Northern Ireland. More detailed data from two sites in Clogh Mills and Comber NVZs show a rise from 1992 to 2002.
3. Nitrate concentrations in groundwater are highly correlated with land use. Arable areas have approximately 50% of sites exceeding 25 mg NO_3 / L; whilst more than 85% of sites in areas with no agricultural activity have less than 10 mg NO_3 / L. Both the BGS Survey data and EHS monitoring data show a steady rise in groundwater nitrate concentrations as the agricultural activity becomes increasingly intensive.
4. The permeability of the superficial deposits also affects the nitrate concentrations measured in groundwater. For one land use category (Good Pasture) 34.2% of sites in high permeability areas have > 25 mg NO_3 / L compared to 18.6% in moderate or low permeability areas.
5. Groundwater nitrate concentrations are higher in shallow (< 25 m) sources. This is consistent with studies in Dumfries, southwest Scotland, where shallow groundwater was found to have significantly more nitrate than deeper, older groundwater.
6. During the BGS 92-94 survey, data was collected on the presence of septic tanks and the practice of slurry spreading. The data indicate that septic tanks have no statistical effect on the nitrate concentrations measured in the sample sites. However, sites where slurry was spread had higher nitrate concentrations than sites where it was not (this reflects the correlation of groundwater nitrate concentrations and agricultural activity described above).
7. The nitrogen leaching model developed by DARD for surface waters poorly predicts the nitrate concentrations in groundwater sample sites. The poor prediction is likely to be caused by the different scales of the datasets – the nitrate leaching is by catchment, while groundwater sample points are affected more by land use directly surrounding the source.

The statistics and correlations highlighted above have several important implications for the protection of groundwater from nitrate contamination in Northern Ireland. Some recommendations are given below, in the understanding that the implementation of the EC Water Framework Directive in Northern Ireland will require a more detailed assessment of land use, groundwater quality and hydrogeological conditions over the next 2-3 years.

- Since land use is an excellent predictor of nitrate concentrations in groundwater it could be used to indicate potential concentrations in areas with no monitoring data.

- Low permeability superficial deposits offer protection to groundwater. A more detailed assessment of the permeability and thickness of superficial deposits in Northern Ireland would help to highlight areas most vulnerable to contamination.
- Areas with intensive agriculture (for example arable farming, complex cultivation patters or intensive livestock rearing) particularly where superficial deposits are absent or highly permeable are most at risk of nitrate contamination. Since this is similar to that found in Scotland (Ball and MacDonald 2001), an approach, such as that developed for identifying NVZs in Scotland may be appropriate for predicting groundwater nitrate contamination in Northern Ireland.
- The role of the gley soils and rainfall in Northern Ireland in generally reducing groundwater nitrate concentrations could be investigated further. It would be beneficial to target a small number of catchments or sub-catchments with more intensive monitoring to establish a more comprehensive local dataset.
- Detailed information on the location of intensive livestock rearing and slurry applications across Northern Ireland would be helpful in estimating local risks to groundwater.
- Ongoing monitoring of groundwater for nitrogen species is essential in Northern Ireland and any future review of the regional groundwater monitoring network should take into account this objective.

References

BALL, D F. and MACDONALD, A M. 2001. Groundwater nitrate vulnerable zones for Scotland. *British Geological Survey Technical Report* CR/01/250N.

BALL, D F. and MACDONALD, A M. 2002. Additional groundwater monitoring sites for Scotland. *British Geological Survey Technical Report* CR/02/139N.

BRITISH GEOLOGICAL SURVEY. 1994. Hydrogeological map of Northern Ireland. 1:250 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1994. Groundwater vulnerability map of Northern Ireland. 1:250 000. (Keyworth, Nottingham: British Geological Survey.)

CRUICKSHANK, J G. 1997. *Soil and environment: Northern Ireland*. (Belfast: DOE)

DEFRA. 2002a. Description of the methodology applied by the Secretary of State in identifying additional NVZs in England (2002). (London: Department for Environment, Food and Rural Affairs).

DEFRA. 2002b. Agriculture and water; a diffuse pollution review. (London: Department for Environment, Food and Rural Affairs).

DOE. 2002. Report on the environmental aspects of the nitrates directive in Northern Ireland. (Belfast: DOE-DARD Scientific Working Group).

FOSTER, S S D. 2000. Assessing and controlling the impacts of agriculture on groundwater – from barley barons to beef bans. *Quarterly Journal of Engineering geology and Hydrogeology.* 263-280.

GEOLOGICAL SURVEY OF NORTHERN IRELAND. 2002a. Review and assessment of nitrate concentrations at groundwater monitoring sites, Northern Ireland. (Belfast: Geological Survey of Northern Ireland.) (Client Report for EHS).

GEOLOGICAL SURVEY OF NORTHERN IRELAND. 2002b. Investigation of nitrate concentrations at selected groundwater monitoring sites, Northern Ireland. (Belfast :Geological Survey of Northern Ireland.) (Client Report for EHS).

GEOLOGICAL SURVEY OF NORTHERN IRELAND. 2002c. Delineation of nitrate vulnerable zones for four locations in Northern Ireland. (Belfast :Geological Survey of Northern Ireland.) (Client Report for EHS).

JORDAN, C, ET AL. 1994. Modelling of nitrate leaching on a regional scale using GIS. *Journal of Environmental Management*, 43, 279-298.

MACDONALD, A M, DARLING, W G, BALL, D F, OSTER, H. (in press). Estimating groundwater quality from residence time indicators: an example from the Dumfries Permian Aquifer, southwest Scotland. *Hydrogeology Journal.*

NATIONAL ASSEMBLY FOR WALES. 2002. EC nitrates directive (91/676/EC): the protection of waters against agricultural nitrate pollution in Wales: a proposal for designating new nitrate vulnerable zones in Wales (Cardiff: National Assembly for Wales)

NOLAN, B T, RUDDY, B C, HITT, K, and HELSEL, D R. 1997. Risk of nitrate in groundwaters of the United States – a national perspective. *Environmental Science and Technology*, 34, 1156-1165

NATIONAL RIVERS AUTHORITY. 1992. Policy and practice for the protection of groundwater. National Rivers Authority, Bristol.

ROBINS, N S, TRAFFORD, J M, MCKENZIE, A A AND MATTHEWS, A L. 1994. Hydrogeochemical survey of Northern Ireland with particular reference to major ions. *British Geological Survey Technical Report* WD/94/62.

ROBINS, N S. 1996. *Hydrogeology of Northern Ireland*. (London: HMSO)

ROBINS, N S. 1998. The quality of shallow groundwaters in Northern Ireland. *J CIWEM*, 12, 163-169.