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Additional Measurement of Nitrate Concentrations in Groundwater in the Nith catchment

Groundwater Systems and Water Quality Programme

Commissioned Report CR/02/262N

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/02/262N

Additional Measurement of Nitrate Concentrations in Groundwater in the Nith catchment

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Bibliographical reference

BALL D F. 2002. Additional Measurement of Nitrate Concentrations in Groundwater in the Nith catchment. *British Geological Survey Internal Report*, CR/02/262N. 17pp.

Keyworth, Nottingham British Geological Survey 2002

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Acknowledgement

The author is grateful to SEPA staff, particularly John Burns and Bruce Erikssen at Dumfries, for their assistance in this project.

Executive Summary

Twenty nine private boreholes and springs identified in earlier survey work as yielding groundwater with high nitrate concentrations have been analysed and classified according to the proximity of nitrogen sources and the degree of protection from surface run-off. Of the full data set 59% have water with a nitrate concentration greater than 25 mg/l, and by excluding those sources least protected from potential nitrogen sources, 44% exceed 25 mg/l.

1 Introduction

In order to gain further information on the distribution of nitrate in groundwater within the River Nith Catchment (Figure 1), the Scottish Executive commissioned the British Geological Survey (BGS) to carry out field investigations in the area. Site visits were made to private water supply sources that were believed to exceed 40 mg/l nitrate (see MacDonald et al., 2002). The main objective of the work was to investigate the nature of the sources and to sample them for major ion chemistry. The analyses were carried out by the Scottish Environment Protection Agency (SEPA). The field work was carried out during August 2002.

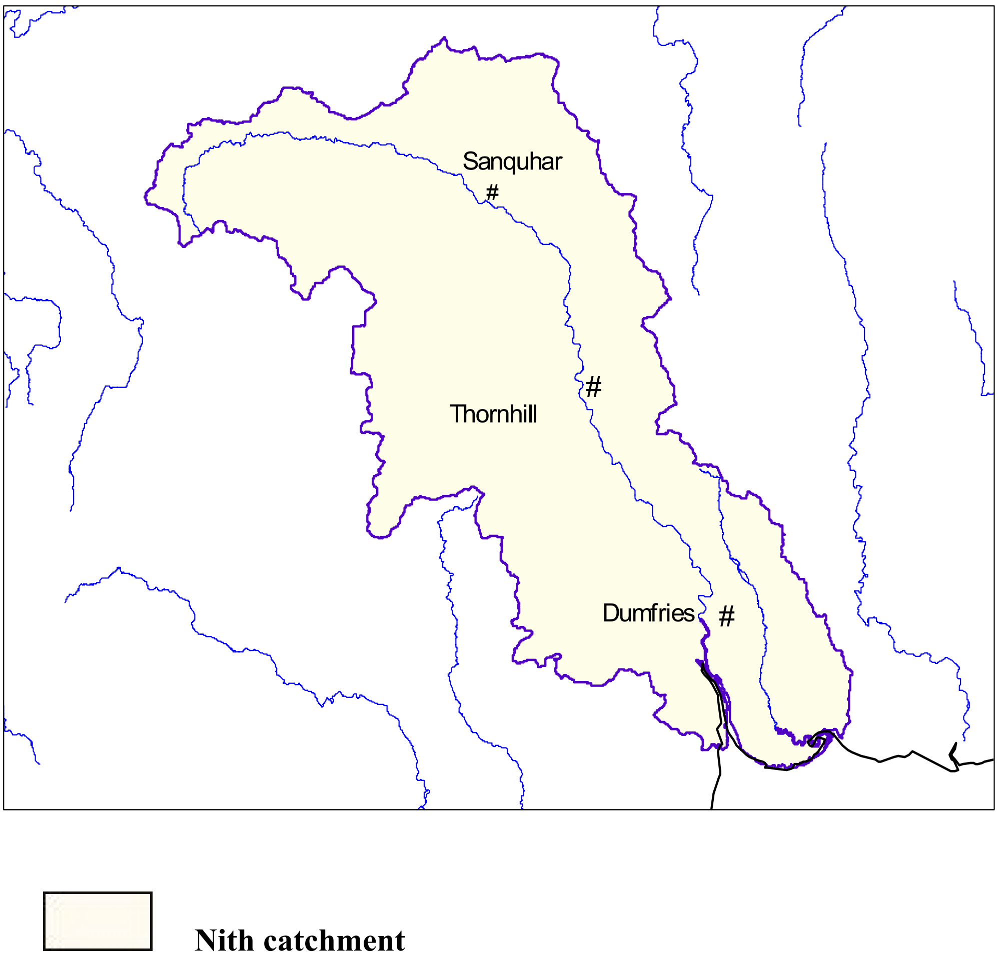

Figure 1 The River Nith catchment

2 Methodology

An earlier survey (MacDonald et al., 2002) identified 39 sources in the Nith catchment which had nitrate concentrations in excess of 40 mg/l. A letter was written to each of the owners of these sources requesting permission to visit and resample each source; access was granted by all respondents. A pro forma which had been designed for an earlier investigation of nitrate occurrence in groundwaters in the Nith catchment in November 2001 (Ball and MacDonald, 2002) was completed for each source; all details relating to source type, location and land use were recorded. Water samples were delivered daily to the East Kilbride laboratory. Sampling was in accord with the SEPA sampling protocol.

3 Hydrogeological setting

Figures 2 and 3 show the distribution of solid and drift geology across the catchment.

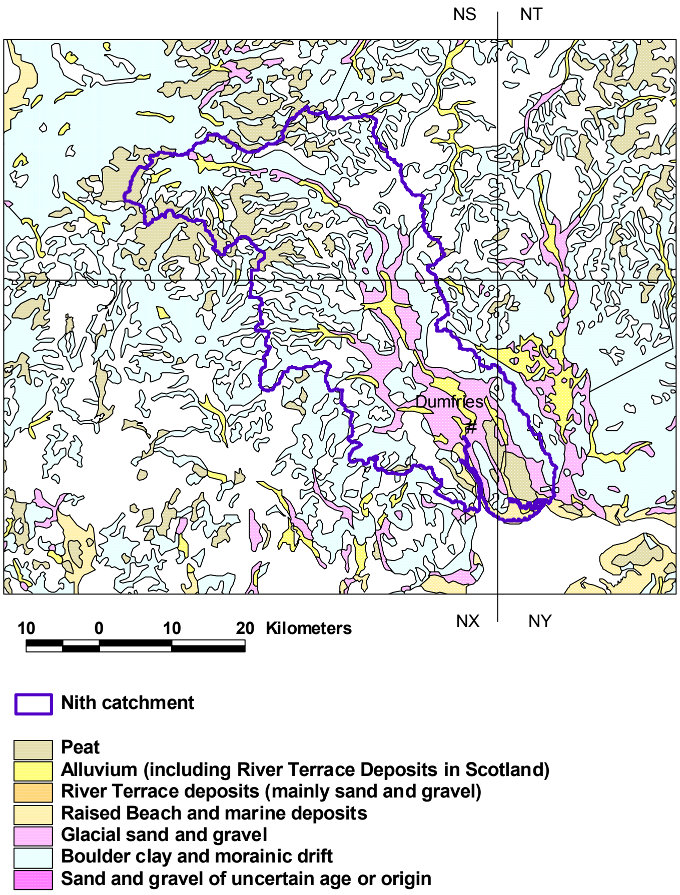

Figure 2 Drift geology in the Nith catchment

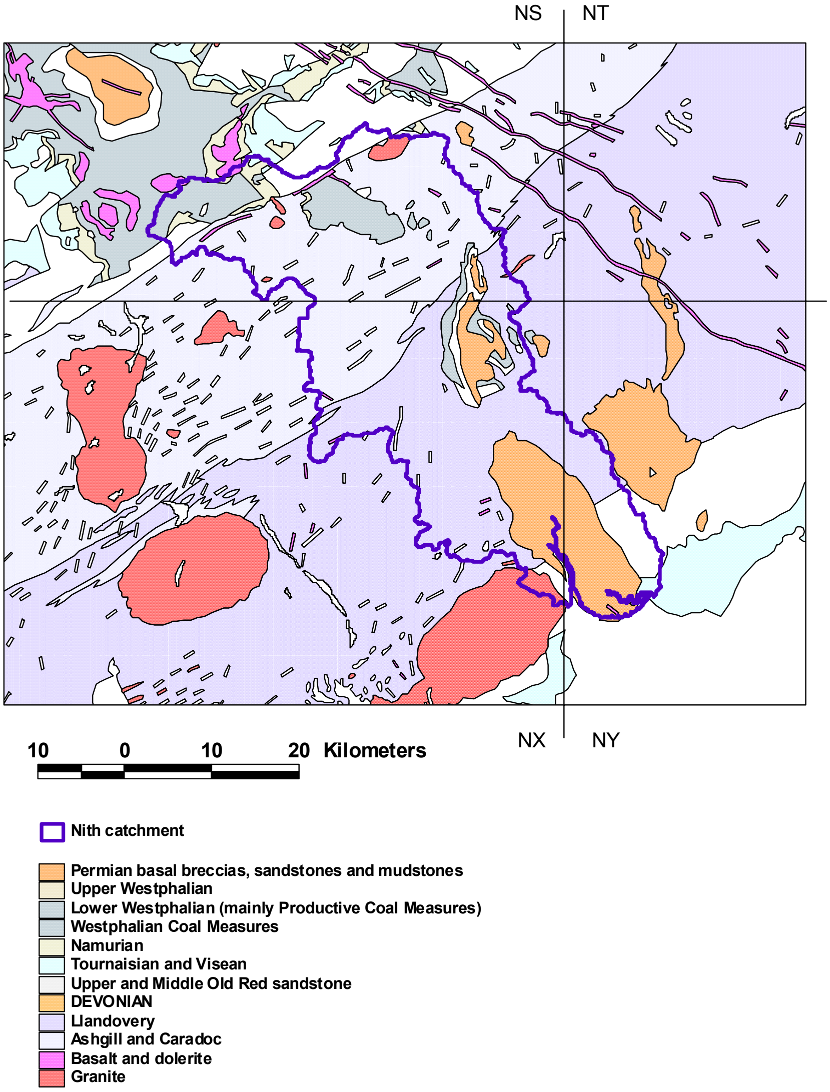

Figure 3 Solid geology in the Nith catchment

Glaciofluvial sand and gravel deposits are widespread in the lower parts of the catchment. Much of the lower-lying ground around Dumfries is underlain by this granular material or by river alluvium, the latter mostly being reworked glacial gravel. These deposits are up to 30 m in thickness near Dumfries. The water table is generally close to the ground surface in the sand and gravel beneath the river flood plain of the Nith. Several boreholes exploit this resource, including some livestock farms.

Much of the area around Dumfries and Thornhill is underlain by permeable Permian sandstone and breccia which is a significant groundwater source (Figure 3). The sandstone and breccia are overlain by deposits of superficial sand and gravel across much of the lower ground in the basin and there is hydraulic connection between them.

The middle and upper slopes of the valleys within the main catchment are covered by thin stony clays, or tills, whilst other areas have thin soils and exposed bedrock comprising Silurian shales and greywackes, granite or weakly permeable Carboniferous sediments. In these higher areas there is little groundwater, but the presence of many small springs indicates shallow groundwater storage and transport through gravelly beds within otherwise clayey superficial deposits. Few boreholes have been drilled into bedrock, and yields are in any case generally less than 1 l/s, drawing only from the uppermost weathered zone in these rocks.

4 The Survey

The boreholes and springs are classified according to the degree of protection with which each source is provided, and the pressures from nitrogen availability locally. Boreholes are divided into 2 classes:

1. Boreholes (shallow and deep) well constructed, with a concrete sanitary seal near surface. Sources of nitrate may be present nearby (such as, for example, a silage clamp or dairy unit). These sources are considered to be valid monitoring sites.
2. Poorly protected boreholes, close to obvious sources of nitrate. These sources have been rejected as valid monitoring sites.

Spring sources are similarly divided into classes:

1. Well-protected springs, i.e. with surface works which protect them from surface run-off and fenced to prevent access by livestock. There may be possible nitrate sources close by. These springs are considered valid monitoring sites.
2. Springs which have no surface protection with possible local nitrate sources. These springs have been rejected as valid monitoring sites.

For both boreholes and springs, Class 1 sites are likely to be the most representative of the groundwater system, although Class 2 sites will provide information on local groundwater contamination. Figure 4 shows the distribution of recent sampling results. Out of the 29 sources, 11 fall in Class 2, leaving 18 sites that are likely to be reliable ones for future monitoring. Aquifer vulnerability is also marked as Class 1, 2 or 3, relating to low, moderate or high vulnerability respectively (see Figure 5). Details of the vulnerability classification are given in Ball and MacDonald (2001).

Tables 1, 2 and 3 present summaries of the 29 sources that were sampled.

Table 1 lists 14 springs, of which 4 springs are in Class 2. Four of the 8 drift borehole sources also fall into Class 2 (Table 2). These 4 sites are located close to farm buildings and may reflect localised nitrate pollution. These boreholes should not, therefore, be included in the nitrate monitoring network. The remaining 4 sources are thought to be more representative of local groundwater conditions and are, therefore, better suited for inclusion in a monitoring network.

Table 1 Details of springs

Location	Land use	BGS sample (mg/l – NO_3)	Site Class	Aquifer vulnerability
Mabie	Wooded	7	1	2
Drumlanrig	Pasture	5	1	2
Drumlanrig	Barley	26	1	3
Moniave	Pasture	8	1	2
Tynron	Wood/pasture	13	1	2
Shawhead	Pasture	43	1	3
Irongray	Pasture	19	1	2
Irongray	Pasture	17	1	2
Irongray	Open grass	17	1	2
Irongray	Pasture	19	1	2
Durisdeer	Pasture	22	2	2
Drumlanrig	Pasture	16	2	3
Closeburn	Pasture	27	2	3
Sanquhar	Pasture	35	2	3

Table 2 Details of Drift Boreholes

Location	Land use	Depth (m)	BGS sample (mg/l - NO_3)	Site Class	Aquifer vulnerability
Thornhill	Pasture	30	40	1	3
Thornhill	Pasture	48	57	1	3
Thornhill	Pasture	?	8	1	3
Thornhill	Pasture	30	40	1	3
Duncow	Pasture	42	30	2	3
Holywood	Pasture	30	76	2	3
Holywood	Pasture	20	40	2	3
Thornhill	Pasture	19	58	2	3

The seven boreholes that penetrate bedrock are listed in Table 3. Most, if not all, are thought to abstract groundwater from the Permian aquifer. Three of the boreholes are located very close to surface sources of nitrate and are, therefore, Class 2. These should be excluded from a monitoring network. The industrial borehole in Dumfries has been drilled into the main Permian aquifer and is probably the furthest from any known nitrate source. This is reflected in the nitrate concentration of only 9 mg/l. The other Dumfries borehole is 150 m deep and is cased to 100 m below surface. The casing protects this source from modern and potentially polluted recharge, although 31 mg/l nitrate was found.

Table 3 Details of Bedrock Boreholes

Location	Land use	Depth (m)	BGS sample (mg/l - NO_3)	Site Class	Aquifer vulnerability
Dumfries	Industrial	90	9	1	2
Dumfries	Grass	150	31	1	2
Lochmaben	Pasture	30	29	1	2
Terregles	Pasture	70	37	1	3
Mouswald	Pasture	60	121	2	3
Ruthwell	Pasture	70	36	2	3
Ruthwell	Pasture	50	29	2	3

A summary of all the newly collected data is shown in Table 4. Without grouping into Classes 1 and 2, 59% of the samples have nitrate concentrations in excess of 25 mg/l, with 14% greater than 50 mg/l. When the Class 2 sites are removed, 8 out of the remaining 18 reliable sites, or 44%, exceed 25 mg/l (Table 5). This compares with the data for the NVZ designated areas in the east of Scotland where 50% of all sources exceeded 25 mg/l within mapped 'coincident zones' (Ball and MacDonald, 2001). 'Coincident zones' were identified where highly vulnerable aquifers are overlain by those land-use zones where there is potential for a high rate of nitrate leaching at surface. It should be noted, however, that no coincident zones are present in the Nith catchment due to the assumed impact of higher rainfall in this area. In addition, the recent sampling was not restricted to arable crop land, as it was in the east of Scotland, and the Nith results include many sources surrounded by pasture.

Table 4 Results from both Class 1 and 2 sources in the Nith catchment (recent BGS analyses)

Range of nitrate (mg/l)	No. of sources	% per category	Cumulative % > n (mg/l)
+50	4	14	14% > 50
40-50	4	14	28% > 40
25-40	9	31	59% > 25
10-25	7	24	83% > 10
<10	5	17	100% > 0
Total	**29**		

Table 5 Nitrate data from all Class 1 sources (recent BGS analyses)

Range of nitrate (mg/l)	No. of sources	% per category	Cumulative % > n (mg/l)
+50	1	5	5%>50
40-50	3	17	22%>40
25-40	4	22	44%>25
10-25	5	28	72%>10
<10	5	28	100%>0
Total	**18**		

Table 6 shows nitrate distribution for Class 1 source type in the Nith catchment. Of the springs, only 20% had nitrate concentrations greater than 25 mg/l. This is a reflection of the sensitivity of springs to adjacent land use, as Class 1 springs do not have sources of potentially high nitrate in close proximity.

Table 6 Nitrate distribution for source type (Class 1) in the Nith catchment

Source type	No. of sources sampled	Nitrate distribution for source type (Class 1) <25 (mg/l - NO_3) %	>25 (mg/l - NO_3) %	%>50 (mg/l - NO_3) %
Springs	10	80	20	0
Drift Bhs.	4	25	75	25
Rock Bhs.	4	25	75	0

Samples tested from Class 1 boreholes drilled within drift and bedrock deposits show 75% in excess of 25 mg/l nitrate with 13% in excess of 50 mg/l. This compares to 87% >25mg/l and 27% >50 mg/l for both classes combined. The high percentage of combined sites >25 mg/l is a reflection of the preponderance of boreholes on livestock farms in lowland areas (Figure 4). These boreholes tend to be located very close to farm buildings to avoid the expense of long pipe and cable lengths. Consequently, the constant daily washing of units results in high infiltration rates to groundwater, particularly where superficial gravel is present, may form localised plumes of pollution, resulting in high nitrate concentrations. These sources are therefore not representative of the general nitrate concentration in aquifers. The results are consistent with MacDonald et al. (2000) who highlights higher nitrate concentrations in newly recharged groundwaters than in older waters. Out of the 7 reject borehole sites, 3 are in excess of 50 mg/l nitrate.

Taking other data into account it is concluded that there are significant nitrate concentrations present across the Permian aquifer. Increasing trends are demonstrated in the Manse Road public supply borehole from which records show an increase from 6 mg/l in 1978 to 26 mg/l in 1998 (Robins and Ball, 1998).

Figure 5 relates the distribution of nitrate in groundwater to the occurrence of highly vulnerable groundwater bodies, coloured red in the Figure. This Figure shows clearly a correlation between nitrate sources with >20 mg/l and the highly vulnerable aquifers. The latter comprise both Permian sandstone and glacial/alluvial gravels. By way of comparison, most of the sources with <20 mg/l nitrate are sited over low vulnerability aquifers such as the Lower Palaeozoic Silurian rocks. These sources are mainly springs located in upland areas away from farm buildings in the middle of fields. Here, nitrate usage is less compared with areas of lower-lying ground and the potential for leakage of waste farm water into the sources is smaller. In comparison, lowland sources tend to be boreholes drilled close to farm buildings.

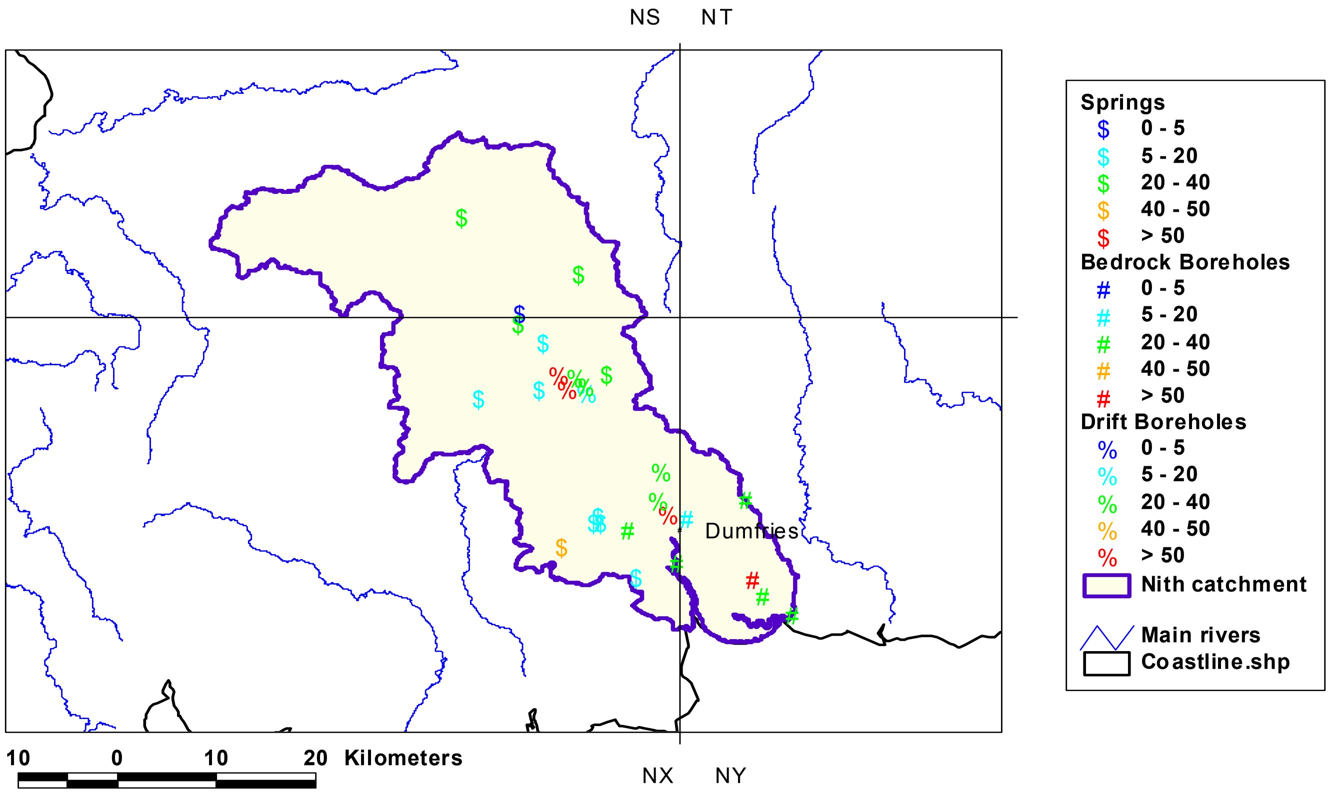

Figure 4 Nitrate distribution in the Nith catchment

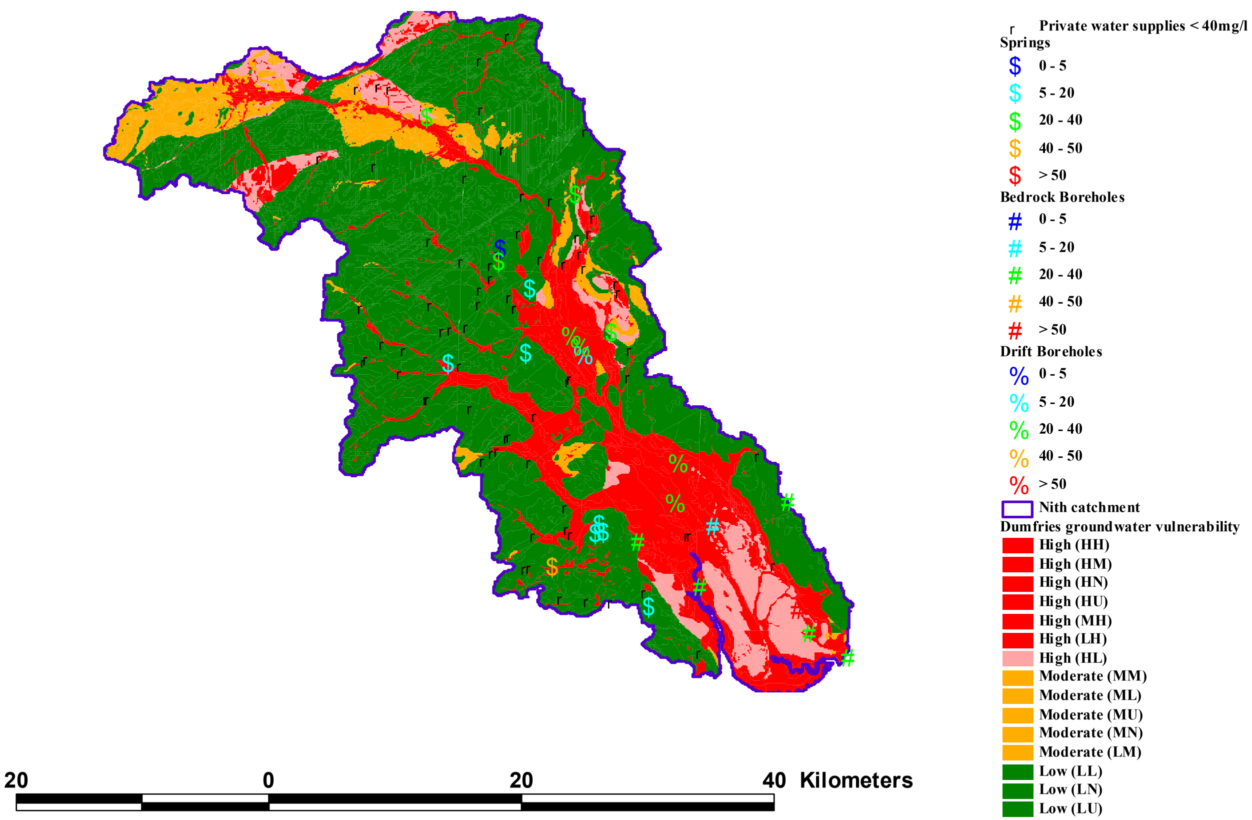

Figure 5 Groundwater vulnerability and nitrate distribution in the Nith catchment using all data sources (Ball and MacDonald, 2001)

5 Conclusions

- Springs and boreholes in the lower part of the Nith catchment are classed according to the degree they are protected from surface water ingress and the proximity of sources of nitrogen.
- Resampling of 29 of the private sources revealed that 59% of them had >25 mg/l nitrate. Eleven of these sources were poorly protected in areas of apparent abundant nitrogen availability. If these sources are excluded, 44% of the sites exceeded 25 mg/l nitrate.
- The current study reinforces earlier work on nitrate concentrations within the catchment (Ball and MacDonald, 2001, MacDonald et al, 2000).
- Springs on the sides of the main valleys generally have low nitrate concentrations reflecting local land use.
- Livestock farms and arable land located on low ground bordering the River Nith appear to provide sources of nitrate that may influence high concentrations in groundwater, particularly in drift aquifers.
- The leaching of nitrogen fertilisers from fields and the infiltration of nitrate-rich washing water from livestock farms poses a significant threat to groundwater quality in the lower parts of the Nith catchment, whereas the upper slopes of the main valleys are subject to low nitrogen applications.
- Groundwater with a nitrate concentration greater than 25 mg/l can be classed as significantly contaminated. It is now widespread within the main Permian aquifer at Dumfries as well as in many shallower superficial groundwater bodies. It is therefore recommended that at least the lower Nith catchment, to include the main Permian aquifers at Dumfries and Thornhill, be designated as an NVZ.

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