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# Nitrate concentrations in Nithsdale groundwater, 2004

Groundwater Systems and Water Quality Programme

Commissioned Report CR/04/284N

BRITISH GEOLOGICAL SURVEY

GROUNDWATER SYSTEMS AND WATER QUALITY PROGRAMME
COMMISSIONED REPORT CR/04/284N

# Nitrate concentrations in Nithsdale groundwater, 2004

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Dairy cows in Nithsdale (photo © NERC)

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# Contents



**FIGURES**

**TABLES**



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# Summary

This report describes the results of a survey of groundwater nitrate concentrations in the Lower Nithsdale nitrate vulnerable zone (NVZ), southwest Scotland. The survey was carried out during September 2004. Rigorous field sampling techniques were used, and the samples analysed in the BGS laboratories at Wallingford. Shallow groundwater was targeted, where the effects of recent land use (within the past 10 years) would be reflected in the samples.

Twenty-one sites were sampled comprising 5 springs and 16 boreholes; all the sites were rural – thirteen were located on dairy farms. None of the boreholes showed any signs of contamination from surface water. Most were located in huts with concrete plinths, others were under manhole covers in fenced areas. The springs were more vulnerable to surface water contamination.

The median concentration of nitrate from the 21 samples was 33 mg $NO_3$ $L^{-1}$. Six samples had concentrations greater than 50 mg $NO_3$ $L^{-1}$, a further 3 sites had concentrations between 40 and 50 mg $NO_3$ $L^{-1}$. All sites with concentrations greater than 40 mg $NO_3$ $L^{-1}$ are located on dairy farms. There is broad agreement between nitrate concentrations measured in this survey and a previous survey in August 2002.

This current survey indicates much higher nitrate concentrations than monitored by SEPA from their 12 monitoring sites in Nithsdale. This is due to the nature of the sampled sources. The SEPA monitoring network in the area comprises deep boreholes in the Permian bedrock; age dating has shown that much of the water sampled is pre-1950s. In contrast, much of the groundwater sampled during the current survey is young – recharged within the past decade. By making corrections for the dilution factor from the older water at the SEPA sites, it is possible to estimate nitrate concentrations in the recently recharged groundwater. These corrected concentrations are considerably higher, and consistent with those measured from the shallow groundwater sources in this current survey.

In the light of this present survey, it is recommended that SEPA review the monitoring network in the Lower Nithsdale. Several shallow sources, which contain a high proportion of modern water, and are regularly pumped, should be adopted, and data from the existing deep sources should be interpreted in the context of the age of the groundwater sampled.

# 1 Introduction

The British Geological Survey was commissioned by the Scottish Executive to undertake a rapid sampling of groundwater sources within the Nithsdale nitrate vulnerable zone (NVZ). The purpose of the survey was to assess concentrations of nitrate in groundwater, and to compare with earlier surveys of groundwater nitrate concentrations. The sampling was carried out during the second week of September 2004. This report presents the results of the survey.

The Lower Nithsdale NVZ was designated in December 2002. The area covers the land around the Dumfries and Thornhill (see Figure 1). Much of the land in the area is used for pasture, particularly for dairy farming; the NVZ also includes the urban area of Dumfries. Earlier research (MacDonald *et al.* 2000, 2003) had indicated that nitrate concentrations in modern recharging groundwater from the agricultural land around Dumfries had concentrations of nitrate approaching 50 mg $NO_3$ $L^{-1}$ (the E.U. standard). Sampling in 2002 had confirmed that nitrate concentrations throughout Lower Nithsdale were elevated, and similar to concentrations in other, previously designated NVZs (Ball and MacDonald 2001, Ball 2002).


**Figure 1** The location of the Lower Nithsdale NVZ, as designated in December 2002.

# 2 Geological and hydrogeological setting

Much of the area within the Lower Nithsdale catchment is underlain by Permian age sedimentary bedrock. This thick sequence of sandstones and breccias forms one of the most prolific aquifers in Scotland (see Figure 2). Groundwater flow in the sandstones is primarily intergranular (i.e. through the pore spaces between grains) and in the breccias, is through fracture zones. Groundwater within the sandstone and breccia can be greater than 50 years old, and in some places may be several thousands of years old (MacDonald et al. 2003). The Permian sediments are surrounded by much poorer aquifers – Silurian age greywackes and to the southeast, granite. These rocks have little or no intergranular flow and rely on the presence of fractures in their shallow weathered zone for their ability to transmit groundwater. Consequently they have low aquifer productivity. Some Carboniferous aged sandstones are also present in the Nith catchment, most obviously around the Thornhill Permian sandstone in the north. These sandstones form moderately productive aquifers.

The bedrock is overlain by superficial deposits over much of the Lower Nith (see Figure 3). These comprise permeable sands and gravels over much of the lower-lying ground around Dumfries and the River Nith, which were deposited by meltwater from glaciers, or reworked by rivers to form alluvium. These deposits are over 30 m thick in some areas and can form an

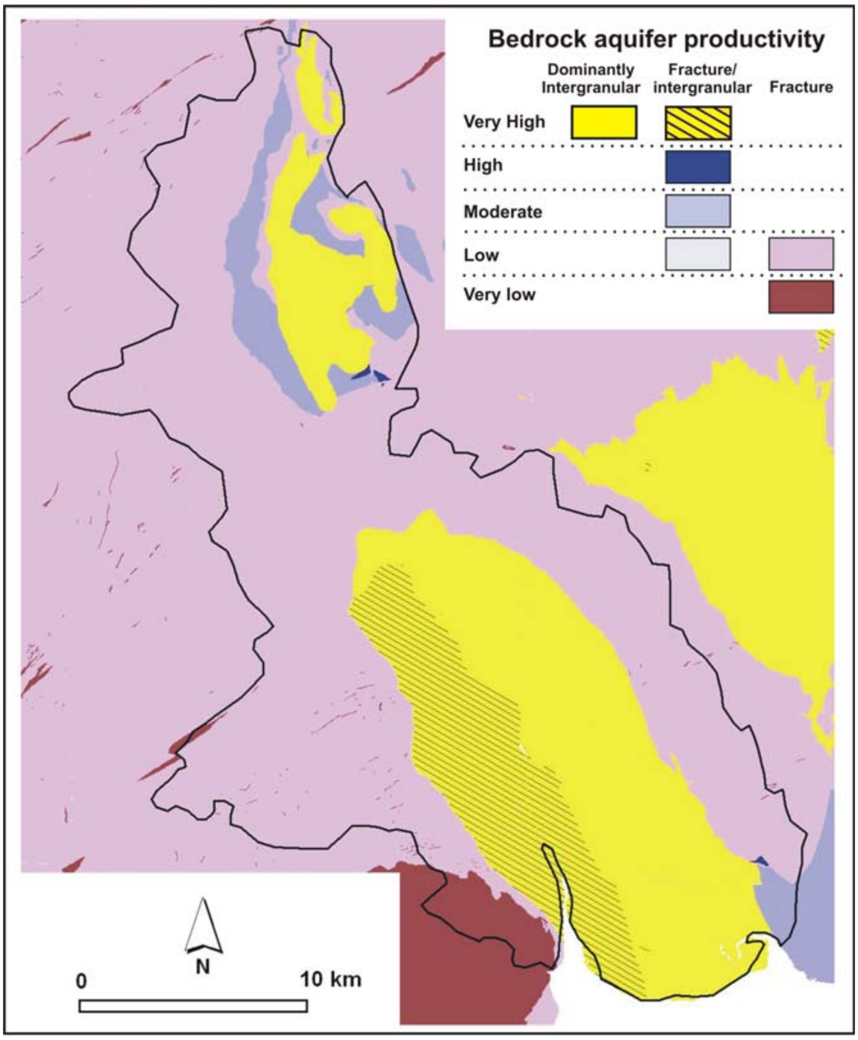


**Figure 2** Bedrock aquifer productivity for the Lower Nithsdale NVZ. Aquifer productivity is a measure of how easily groundwater can be abstracted from a certain rock (MacDonald et al. 2004).

important aquifer where the water-table is close to the surface in the valley bottoms. On higher ground, the superficial deposits are much thinner and generally comprise moderate permeability glacial till. Low permeability peat is present in some areas, particularly the low-lying area of Locharmoss to the southeast of Dumfries.

Groundwater is extensively used in the Lower Nithsdale catchment. The high productivity Permian aquifer around Dumfries is extensively used for public water supply, and also for fish farming and industrial supply. Several farms also abstract water for cattle watering. The Permian aquifer around Thornhill is also used for public water supply, but to a lesser extent than around Dumfries. Many farms make use of groundwater throughout the catchment, but particularly in the low lying ground near to the Nith. These sources, which are used for dairy washing and animal watering, often abstract water from the high permeability superficial deposits.

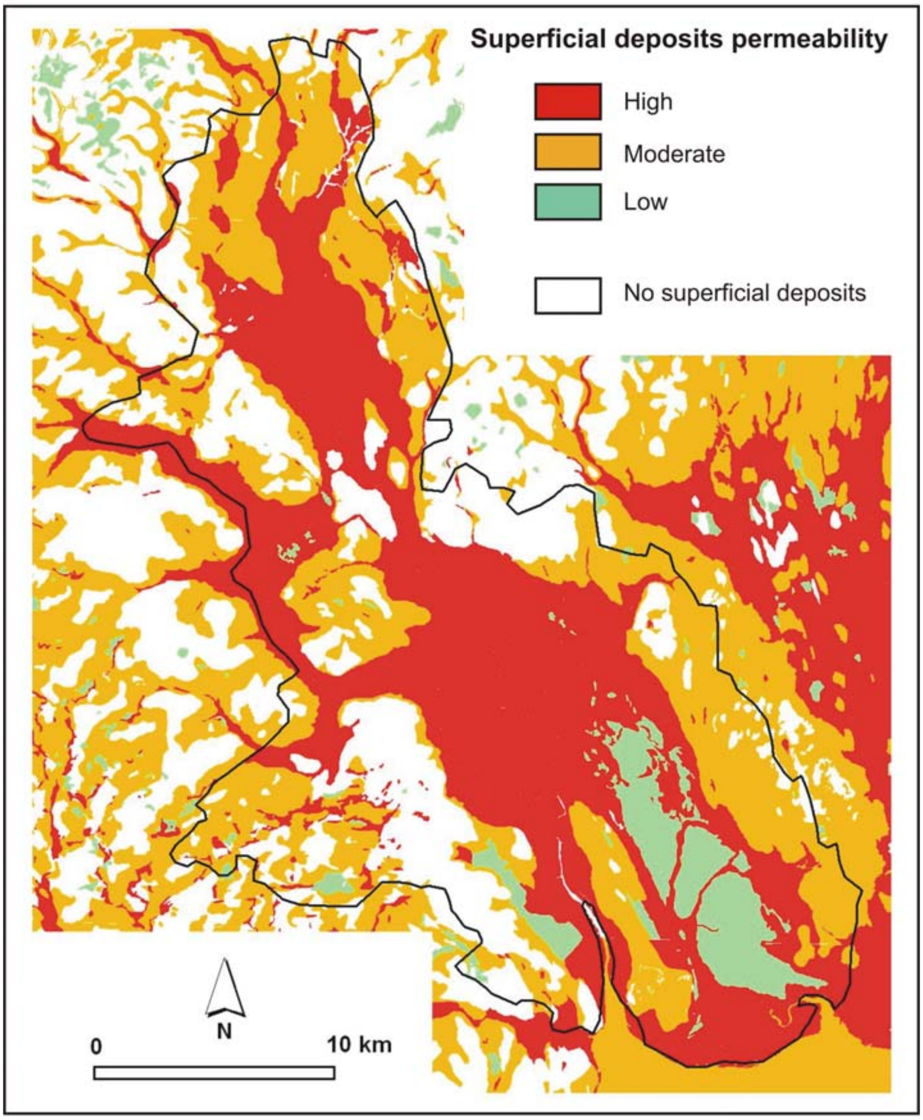


**Figure 3** Superficial deposits permeability for the Lower Nithsdale NVZ. Where saturated, high permeability superficial deposits form an important aquifer.

# 3 Sampling and data

Twenty-one sites were sampled during 6-10 September 2004 using rigorous sampling methods. All boreholes were pumped and the pH and Eh monitored to ensure the chemistry was stable prior to taking a sample. Dissolved oxygen, specific electrical conductance and alkalinity were also determined onsite, and samples taken for a full chemical analysis, and where possible for dissolved CFC concentrations to help with age dating the samples. Chemical analysis underwent routine quality-control checks and calibration against known standards. Charge imbalances for these determinations were in all cases less than 5%.

Table 1 gives a summary of the physical information for each site; the location of each site is shown in Figure 4.

1. Five springs, 4 boreholes greater than 40 m deep, and 12 boreholes less than 40 m deep, were sampled.
2. None of the borehole sites showed ingress of surface water; most of the boreholes are located in huts with concrete bases. Several are under manhole covers away from pasture.
3. Any potential sources of nitrate within 10 m of the source were recorded (see Table 1).
4. The springs appeared generally more vulnerable to local effects, but most are fenced around the spring collection tank.
5. All sites are located in rural areas – thirteen on dairy farms.
6. Six of the boreholes sampled groundwater from the Permian sediments; all springs are located in the Silurian greywackes; the remaining 10 sites sampled groundwater mainly derived from the superficial deposits.

Table 2 summarises the major ion chemistry for the samples. The data are also plotted on cumulative frequency plots (Figure 5 and 6) and summarised on a tri linear Piper diagram in Figure 7). The pH of the samples varies from 5.4 to 7.6. Most of the samples were aerobic (i.e. contained significant dissolved oxygen) and were oxidising. Therefore, denitrification of groundwater should not be widely significant. (Site 5 may be an exception where dissolved oxygen is low, and elevated nitrite has been measured).

Groundwater from the three different rocks types: Permian sediments, Silurian greywackes and superficial gravels could be identified by their different chemical composition:

- Permian groundwater is generally Ca-Mg $HCO_3$ type, the pH is usually greater than 7.0.
- Groundwater from the Silurian springs, although also Ca-Mg-$HCO_3$ type, is generally less mineralised than the Permian groundwaters. The pH in most samples was less than 7.0.
- The composition of the groundwater from the gravels is more varied (see Figure 7). The pH was significantly less than 7.0, usually less than 6.5.

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**Table 1.** Summary of physical information of sites sampled in September 2004.

| ID | Site name | Landuse | Source | Depth | Aquifer | Protection* | Within 10m** | Pumping | Easting | Northing | Sampled 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cleuch Head | Upland pasture | Spring | surface | Silurian | F | P | flowing all year | 282000 | 601000 | Y |
| 2 | Bellstane Sawmill Cottage | mixed arable | Spring | surface | Silurian | F | Wet | flowing all year | 283821 | 599472 | Y |
| 3 | Byreholm Farm | Dairy farm | Borehole | < 40 m | gravel | H | P, T | pumping all year | 285451 | 594239 | Y |
| 4 | Waterside Mains | Dairy farm | Borehole | < 40 m | gravel | H, F | A | pumping all year | 286444 | 592673 | Y |
| 5 | Rosehill Farm | Dairy farm | Borehole | < 40 m | gravel | H, F | P, DSh | pumping all year | 288393 | 592580 | Y |
| 6 | Kirkland Farm, Thornhill | Dairy farm | Borehole | < 40 m | gravel | H | G | pumping all year | 287969 | 593030 | Y |
| 7 | Kirkbog farm | Dairy Farm | Borehole | < 40 m | gravel | H | P | pumping all year | 287440 | 593952 | Y |
| 8 | Romesboech Farm | Dairy farm | Spring | surface | Silurian | unknown | G | flowing all year | 286154 | 574935 | Y |
| 9 | Crochmore House | Pasture | Spring | surface | Silurian | M | P, T | flowing all year | 289316 | 577738 | Y |
| 10 | Kerricks farm | Dairy farm | Borehole | < 40 m | gravel | H | P | pumping all year | 295873 | 583552 | Y |
| 11 | Guillyhill farm | Dairy farm | Borehole | < 40 m | gravel | H | G, Sh | pumping all year | 296577 | 578627 | Y |
| 12 | Abbey Farm | Dairy farm | Borehole | < 40 m | gravel | H | R | pumping all year | 295657 | 580099 | Y |
| 13 | Holmhead Farm | Dairy farm | Borehole | < 40 m | Permian | M | G, Sh, R | pumping all year | 305910 | 571339 | Y |
| 14 | Kirkland farm, Terregeles | Dairy farm | Borehole | > 40 m | Permian | H | P, Sh | pumping all year | 292985 | 576993 | Y |
| 15 | Longbridgemuir farm | Dairy farm | Borehole | > 40 m | Permian | M | Si, DSh | pumping all year | 306553 | 569494 | Y |
| 16 | Bardennoch Farm | Upland pasture | Spring | surface | Silurian | F | P | flowing all year | 277842 | 591542 | Y |
| 17 | Manse Rd Observation Bh | Pasture | Borehole | < 40 m | Permian | M | P, R | not pumping | 293925 | 576575 | Y |
| 18 | Locharmoss 1.6 | Pasture/Landfill | Borehole | < 40 m | gravel | M | P | not pumping | 301230 | 576717 | Y |
| 19 | Thornhill Golf Course | Golf Course | Borehole | > 40 m | gravel/Permian | M | G | summer | 289048 | 596002 | N |
| 20 | Kettleton treatment works | Pasture | Borehole | > 40 m | Permian | M, F | Si (bagged) | pumping all year | 290116 | 598483 | N |
| 21 | Tibbers Dairy | Dairy farm | Borehole | < 40 m | Permian | unknown | Wet | pumping all year | 286200 | 596800 | N |

* F = fence; H = hut; M = manhole cover

** P = pasture; T = trough; A = arable; Sh = shed; Dsh = dairy shed; G = garden; Si = silage; R = road

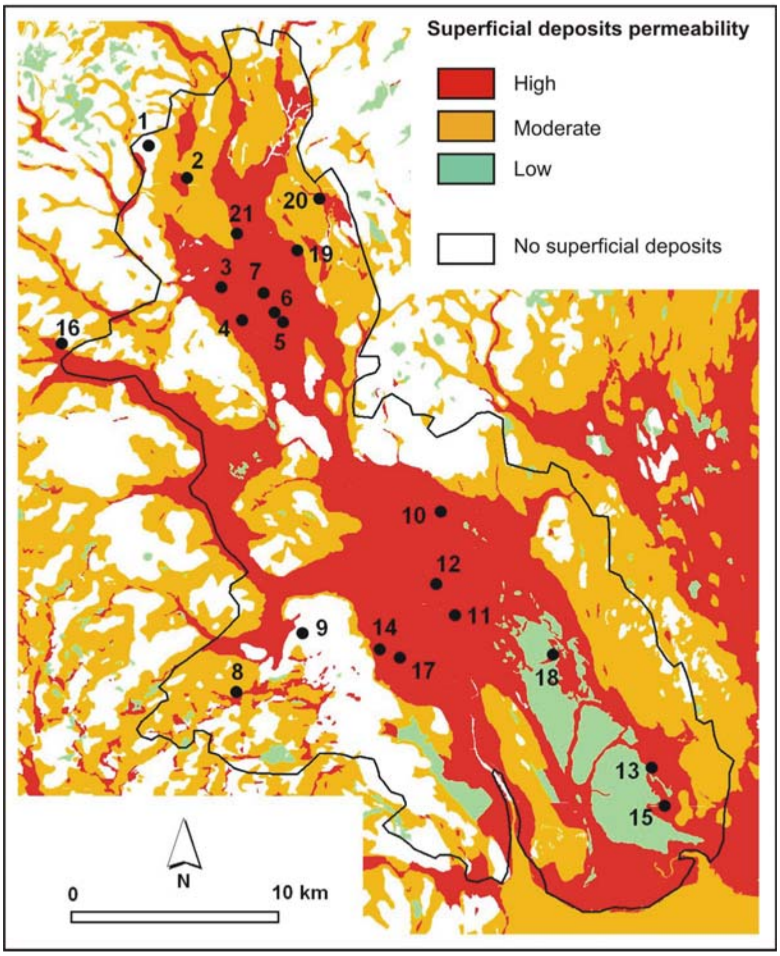


**Figure 4** Location of sample points for the September 2004 survey. A summary of the conditions at each site is given in Table 1; the permeability of the superficial deposits is used as a backdrop.

**Table 2** Summary statistics for groundwater sampled in the Nithsdale NVZ.

| | Min | 5 %ile | 25%ile | median | 75 %ile | 95%ile | max |
|---|---|---|---|---|---|---|---|
| Ca (mg $L^{-1}$) | 7.66 | 9.76 | 16.1 | 25.1 | 50.7 | 85.3 | 102 |
| Mg (mg $L^{-1}$) | 3.29 | 3.68 | 6.78 | 9.42 | 20 | 22 | 27.3 |
| Na (mg $L^{-1}$) | 5.17 | 5.59 | 6.83 | 9.64 | 12 | 18.4 | 25.6 |
| K (mg $L^{-1}$) | 0.52 | 0.55 | 1.42 | 1.91 | 2.86 | 5.51 | 5.66 |
| $HCO_3$ (mg $L^{-1}$) | 12 | 16 | 54 | 67 | 165 | 207 | 283 |
| $SO_4$ (mg $L^{-1}$) | 5.05 | 5.43 | 10.2 | 12.8 | 16.4 | 66.9 | 153 |
| Cl (mg $L^{-1}$) | 5.17 | 6.94 | 9.63 | 14.5 | 20 | 31.1 | 33.3 |
| $NO_3$ (mg $L^{-1}$) | 5.8 | 6.2 | 16.4 | 32.7 | 51.8 | 86.3 | 112.4 |
| pH | 5.4 | 5.6 | 6.2 | 6.4 | 6.8 | 7.6 | 7.6 |
| SEC (µS $cm^{-1}$ @ 25 °C) | 125 | 134 | 195 | 285 | 458 | 681 | 707 |
| Temperature (°C) | 9.3 | 10.4 | 10.8 | 11.4 | 12.9 | 13.3 | 13.5 |
| Eh (mV) | 341 | 385 | 404 | 442 | 469 | 484 | 505 |
| DO (mg $L^{-1}$) | 0.81 | 1.31 | 2.73 | 6.13 | 7.86 | 10.8 | 11.19 |

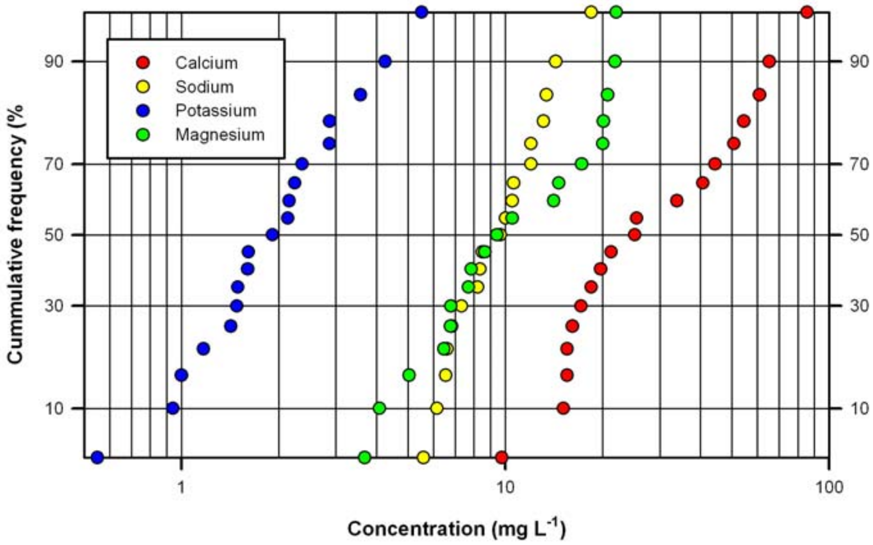


**Figure 5** Cumulative frequency diagram for the cations measured in samples from the Nithsdale NVZ. The bimodal distribution of calcium and magnesium illustrates the different chemistry from the samples taken from the Permian aquifer (higher magnesium and calcium) and the gravel aquifers (lower magnesium and calcium).

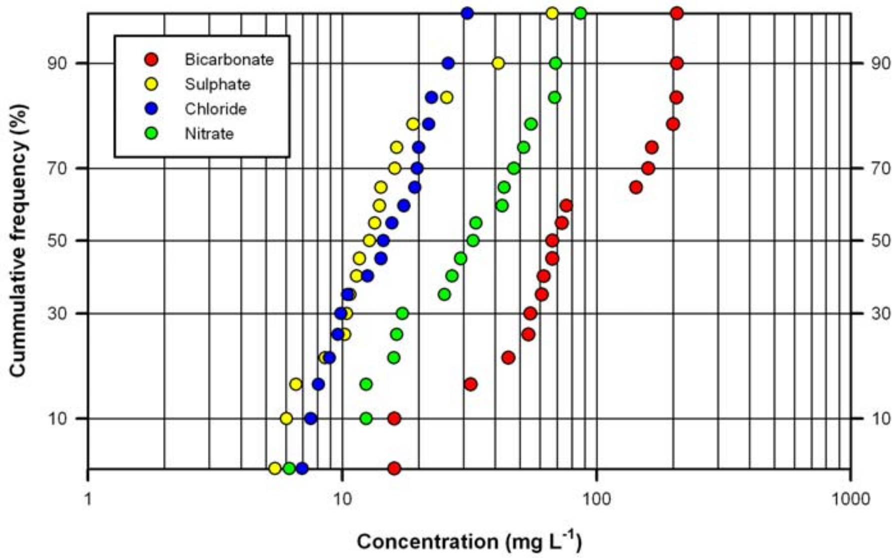


**Figure 6** Cumulative frequency diagram for the anions measured in samples from the Nithsdale NVZ. The bimodal distribution of bicarbonate follows that of calcium and magnesium and illustrates the different chemistry from samples taken from the Permian, Silurian and gravels.

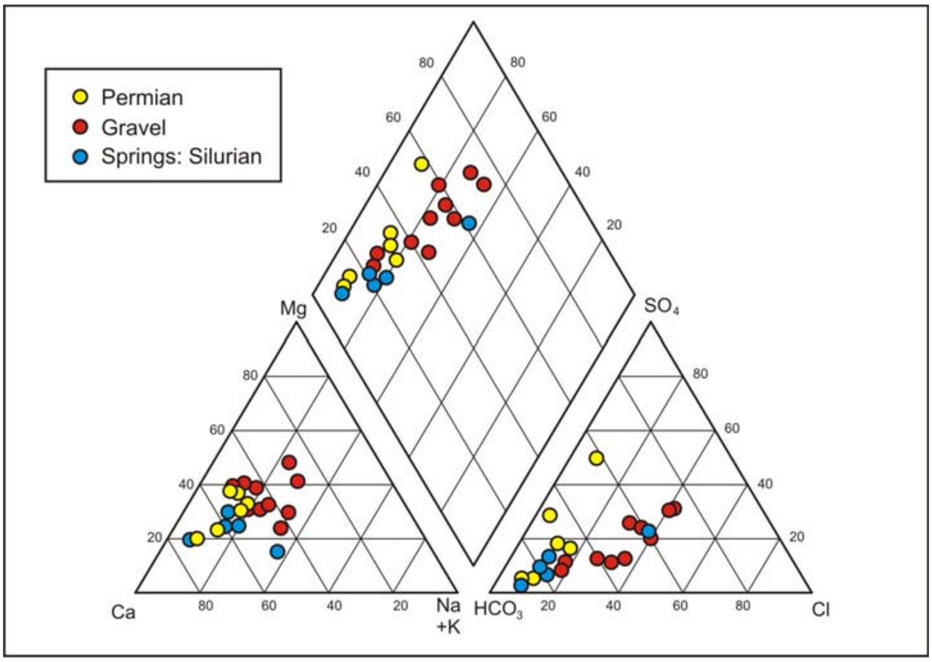


**Figure 7** Piper diagram of groundwaters sampled in the Nithsdale NVZ. The sampled Permian and Silurian groundwaters are general Ca-$HCO_3$ type waters; groundwater in the gravels is more varied.

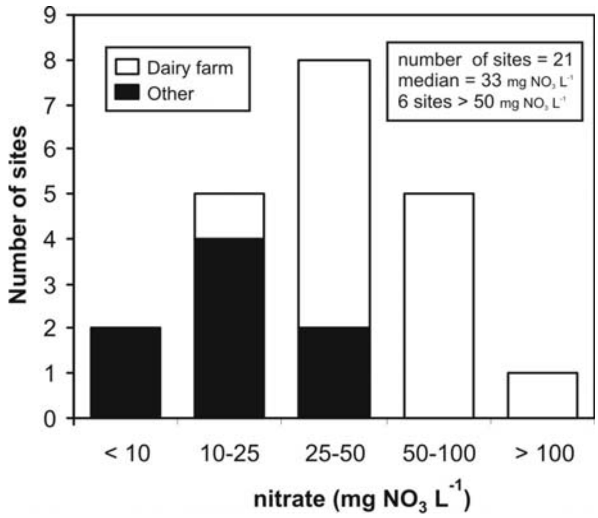


**Figure 8** Histogram of the nitrate concentrations measured in the 21 sites sampled in Nithsdale, September 2004.

# 4 Nitrate data

## 4.1 NITRATE FROM THE 2004 SAMPLING

The nitrate data for the 21 samples are summarised in Figure 8 and plotted on Figure 9. Elevated concentrations of nitrate have been measured in many of the samples.

1. The median concentration of nitrate from the 21 samples is 33 mg $NO_3$ $L^{-1}$.
2. Six samples have concentrations greater than 50 mg $NO_3$ $L^{-1}$, a further 3 sites have concentrations between 40 and 50 mg $NO_3$ $L^{-1}$.
3. All sites with concentrations greater than 40 mg $NO_3$ $L^{-1}$ are located on dairy farms (the median concentration of nitrate for the 13 samples taken on dairy farms is 47 mg $NO_3$ $L^{-1}$; the median nitrate concentrations of the remaining 8 sites is 16 mg $NO_3$ $L^{-1}$).
4. At most sites, the samples are believed to be representative of groundwater quality in the vicinity of the sample point. Only the samples from the springs, and in particular site 8, are believed to be at risk from direct surface water contamination.

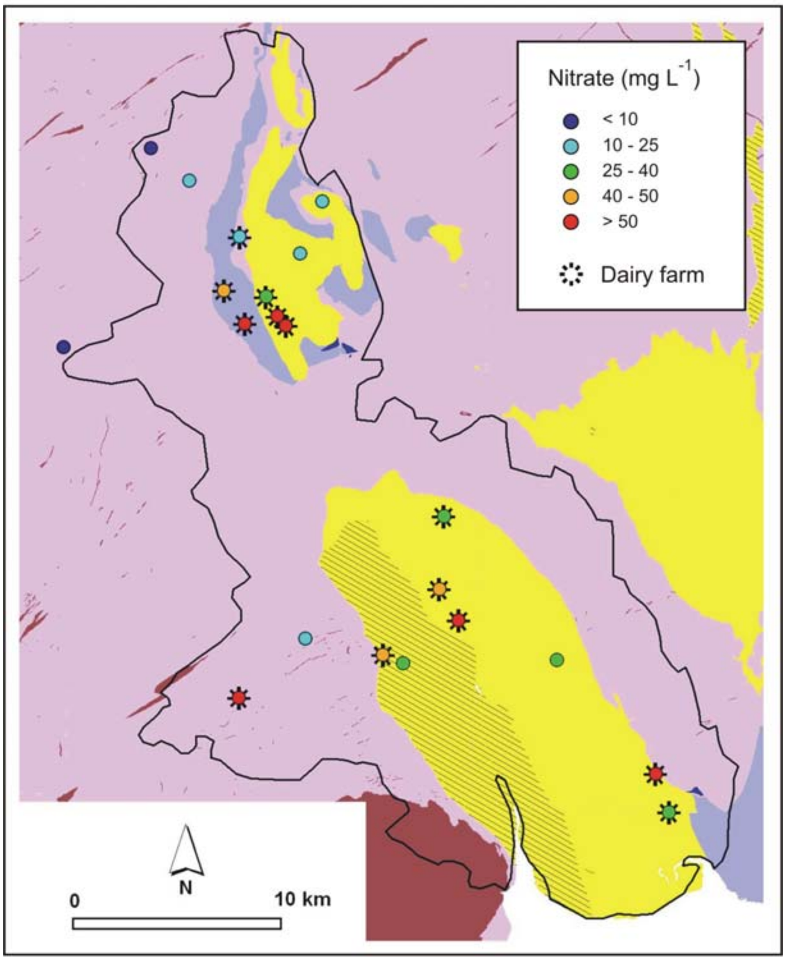


**Figure 9** Measured nitrate concentrations in groundwater sampled during September 2004. The bedrock aquifer productivity is used as a backdrop (see Figure 2 for key).

### 4.2 COMPARING 2004 AND 2002 SAMPLING

Sixteen of the sites sampled in September 2004 had previously been sampled in August 2002 for nitrate concentrations (see Ball 2002 for details). The 2002 sampling methods were less rigorous and analysis of the data had been carried out from unfiltered samples at the SEPA laboratories in East Kilbride. A comparison of the data from the sixteen sites sampled in both 2002 and 2004 is given in Figure 10.

1. There is a broad relation between nitrate concentrations measured in August 2002 and September 2004 ($r^2 = 0.8$), excluding site 5.
2. In 2004, 6 sites exceeded 50 mg $NO_3$ $L^{-1}$, compared to 2002, where 4 sites exceeded 50 mg $NO_3$ $L^{-1}$
3. Site 5 shows a significant increase in nitrate concentrations from 2002 to 2004. The most likely explanation is a sampling or analysis error in 2002. Ball and MacDonald (2002) demonstrated that nitrate reduction can occur in unfiltered samples if they are not analysed within 24 hours.

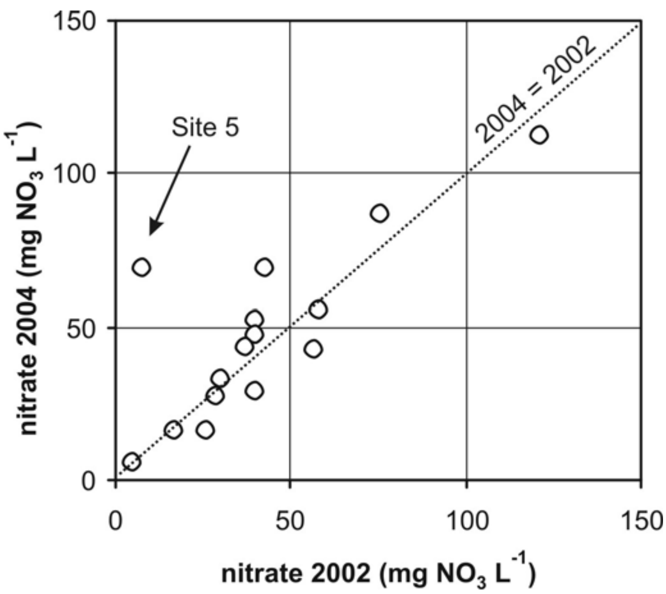


**Figure 10** Comparison of nitrate concentrations for sites that were sampled in both September 2004 and August 2002.

### 4.3 NITRATE DATA FROM THE SEPA NETWORK

Twelve sites are currently monitored by SEPA in the lower Nithsdale NVZ. The details of the sites are given in Table 3, and their locations in Figure 11. These sites are sampled 4 times a year to monitor nitrate concentrations. All of the sites sample groundwater from the Permian bedrock aquifer; eleven of them are from the Dumfries basin.

The measured nitrate concentrations from the network are significantly lower than those from the current survey. No sites exceed the 50 mg $NO_3$ $L^{-1}$ standard, and none are greater than 40 mg $NO_3$ $L^{-1}$.

The discrepancy can be explained by taking into account the age of the groundwater sampled at each site. By measuring the concentration of dissolved CFC gas in the groundwater (see

MacDonald et al. (2003) for an explanation of the technique) it is possible to estimate the proportion of groundwater in the sample that has been recently recharged (i.e. in the past 10 years). Much of the groundwater abstracted from the gravels is from recent recharge, and, therefore, reflects the nitrate leaching from land use over the past decade. However, groundwater abstracted from the Permian bedrock aquifer is considerably older, and has a high proportion of pre-1950s groundwater. This older water contains negligible nitrate and, therefore, dilutes the concentrations of nitrate measured from pumping boreholes.

By measuring the relative proportions of recent and pre-1950s groundwater in samples from the Permian bedrock it is possible to estimate what the nitrate concentrations are in the recently recharged groundwater. Table 3 shows the proportions of recent groundwater in bedrock samples from the SEPA network in the Lower Nithsdale NVZ. Using this information and the measured nitrate concentrations from the sample, an estimate has been given of the likely nitrate concentrations in the recently recharged groundwater (Table 3). These concentrations are much more in line with those measured in the gravel boreholes as part of this current survey.

Thus, there is general agreement between the data from the current survey of shallow groundwater in the Lower Nithsdale NVZ, and data from the SEPA monitoring network, when adjusted to take account of the dilution from the older, pre-1950s water.

**Table 3** SEPA monitoring sites in the Lower Nithsdale NVZ.

| ID | Site Name | Grid Reference | Pumping | Average monitored nitrate (mg $NO_3$ $L^{-1}$) | Proportion of modern water (1990s) with respect to pre-1950 water | Predicted nitrate in modern water (mg $NO_3$ $L^{-1}$) |
|---|---|---|---|---|---|---|
| a | Cargen Production | NX9616772303 | pumping all year | 25 | 45% | 56 |
| b | Crichton Bh | NX9783373275 | pumping all year | 28 | no age data | |
| c | Greenmerse | NX9781370445 | pumping all year | 8.5 | <10% | unsuitable |
| d | Hardthorn Road | NX9357578096 | pumping all year | 25 | 60% | 42 |
| e | Ironhirst Moss | NY0496670790 | not pumping | <0.5 | <10% | unsuitable |
| f | Kettleton Production | NX9010698674 | pumping all year | 17 | 60% | 28 |
| g | Larchfield Production | NX9803075093 | pumping all year | 22 | 30% | 73 |
| h | Longbridgemuir Farm | NY0703368891 | not pumping | 28.5 | 30% | 95 |
| I | Pleasance Farm | NX9702572314 | pumping all year | 29 | no age data | |
| j | Pow Bridge | NX9608171320 | not pumping | 18 | no age data | |
| k | Racks Moss Deep | NY0293672768 | not pumping | <0.5 | <10% | unsuitable |
| l | Terregles Fish Farm | NX9292977323 | pumping all year | 27 | 70% | 39 |

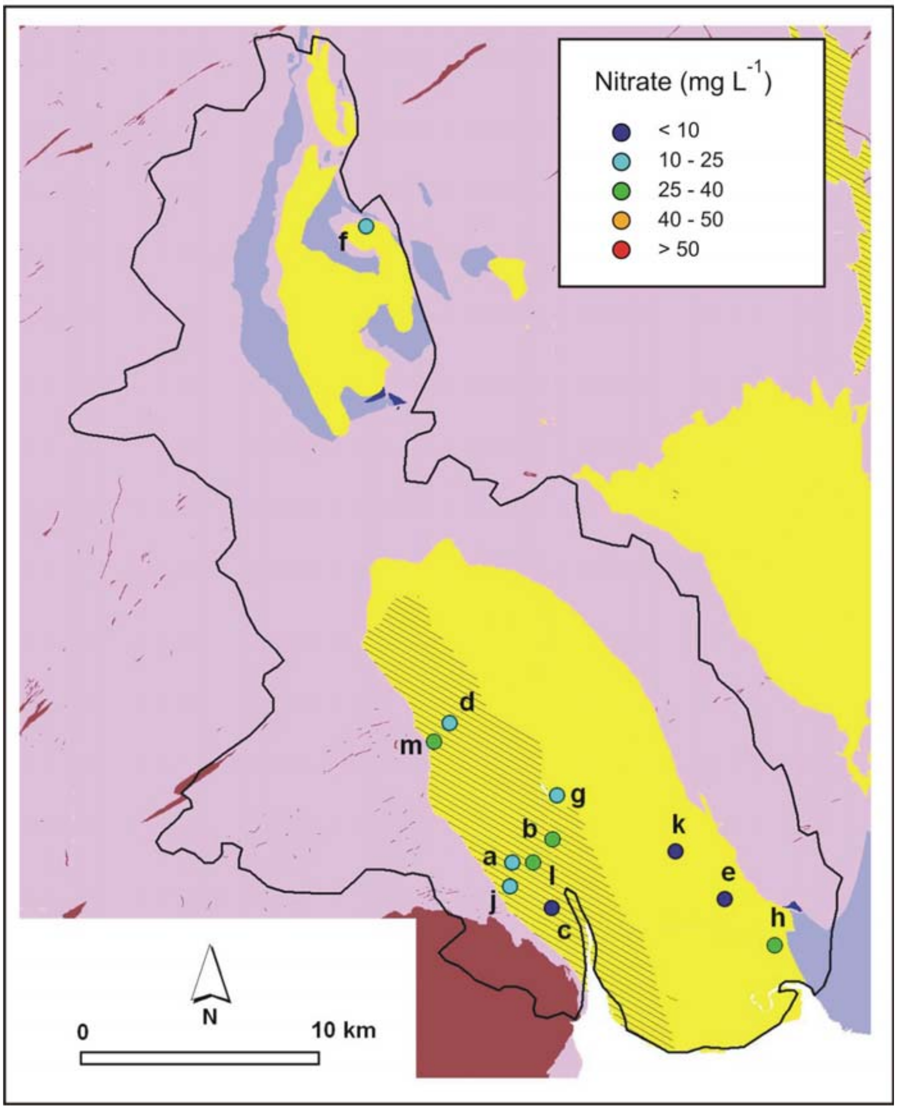


**Figure 11** Average nitrate concentrations from the SEPA monitoring network. Table 3 has the details of the individual sites.

# 5 Summary and recommendations

Nitrate concentrations across the Lower Nithsdale NVZ were sampled during 6-10 September 2004 from 21 sites. The aim of the survey was to get a widespread view of current nitrate concentrations from *shallow* sources, which are generally more representative of current land use practice than deeper sources. Five springs were sampled (all from Silurian bedrock), 4 boreholes greater than 40 m deep and 12 boreholes less than 40 m deep.

- All the sites are rural; thirteen are located on dairy farms.
- 5 sites (all springs) sample groundwater from the Silurian greywackes; six boreholes sample water from the Permian sediments in the Dumfries and Thornhill basins; the remaining 10 boreholes sample groundwater from the superficial gravels.
- Rigorous hydrogeochemical sampling techniques were used to take samples; all the boreholes were pumped and the chemistry monitored to ensure it was stable before taking samples.
- None of the boreholes showed any signs of contamination from surface water. Most are located in huts with concrete plinths, others are under manhole covers in fenced areas. The springs appeared more vulnerable to surface water contamination.
- Samples were sent for major and minor ion analysis; age-dating using CFC concentrations was used at selected sites.

The nitrate concentrations from the 21 sites have been interpreted in the context of the aquifer hydrochemistry and land use.

1. Groundwater chemistries in the Permian, Silurian and gravel aquifers are distinctive.
2. CFC age dating indicates that groundwater from the gravels is generally modern, much of it recharging in the past 10 years. Groundwater from the Permian bedrock generally has a high proportion (generally more than 50%) of older pre-1950s water (see MacDonald et al. 2003).
3. The median concentration of nitrate from the 21 samples is 33 mg $NO_3$ $L^{-1}$. Six samples have concentrations greater than 50 mg $NO_3$ $L^{-1}$, a further 3 sites have concentrations between 40 and 50 mg $NO_3$ $L^{-1}$. All sites with concentrations greater than 40 mg $NO_3$ $L^{-1}$ are located on dairy farms.
4. There is broad agreement between nitrate concentrations measured in this survey and a previous survey in August 2002, and no indication of a decrease in nitrate concentrations. In 2004, 6 sites exceeded 50 mg $NO_3$ $L^{-1}$; in 2002, 4 sites exceeded 50 mg $NO_3$ $L^{-1}$.
5. The 12 sites monitored by SEPA in the Lower Nithsdale NVZ indicate much lower concentrations of nitrate, with none exceeding 40 mg $NO_3$ $L^{-1}$. This is not inconsistent with the current sampling, but can be explained by the age of the groundwater sampled. The 12 SEPA sites are from deep boreholes in the Permian bedrock and contain a high proportion of pre-1950s water. By making corrections for the dilution factor of this older water, nitrate concentrations of recently recharged groundwater can be estimated from the SEPA data. These corrected concentrations are considerably higher, and consistent with those measured from the shallow sources in this current survey.

In the light of this survey, it is recommended that SEPA review the monitoring network in the Lower Nithsdale. Several shallow sources, which contain a high proportion of modern water, and are regularly pumped should be adopted (such as sites 4, 6, 7, 10, or 12). Although not pumping, site 17 could also offer a useful monitoring point. Site 13 could also merit routine monitoring because of its sustained elevated concentrations. Data from the existing network must in future be interpreted in the context of the age of the groundwater sampled.

# Appendix 1 Data for the 21 sites

| ID | Site name | temp | pH | dissolved oxygen | SEC | Ca | Mg | Na | K | $HCO_3$ | $SO_4$ | Cl | $NO_3$ | Modern Fraction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | units | $^oC$ | | mg $L^{-1}$ | uScm@ 25 $^oC$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | mg $L^{-1}$ | % 1990s water relative to pre-1950s water |
| 1 | Cleuch Head | 13.2 | 6.7 | 8.0 | 178 | 19.7 | 5.1 | 7.3 | 0.5 | 76.1 | 10.4 | 7.52 | 5.8 | |
| 2 | Bellstane Sawmill Cottage | 12.3 | 6.4 | 1.3 | 195 | 21.2 | 6.8 | 5.6 | 0.9 | 73 | 5.4 | 6.94 | 15.9 | |
| 3 | Byreholm Farm | 10.4 | 6.4 | 5.7 | 277 | 25.4 | 9.4 | 10.0 | 2.2 | 67 | 11.7 | 17.5 | 42.5 | modern |
| 4 | Waterside Mains | 10.4 | 6.2 | 2.3 | 285 | 16.1 | 14.6 | 12.0 | 1.9 | 54 | 11.4 | 21.9 | 55.3 | 66% |
| 5 | Rosehill Farm | 11.5 | 5.9 | 0.8 | 331 | 25.1 | 14.1 | 9.6 | 4.3 | 45 | 16.4 | 26.1 | 69.0 | |
| 6 | Kirkland Farm, Thornhill | 10.5 | 5.6 | 9.5 | 228 | 15.5 | 7.7 | 10.6 | 1.4 | 16 | 19.0 | 15.7 | 51.8 | 67% |
| 7 | Kirkbog farm | 12.9 | 6.0 | 2.1 | 195 | 15.5 | 6.5 | 8.4 | 2.1 | 32 | 14.2 | 14.5 | 29.2 | 75% |
| 8 | Romesboech Farm | 13.3 | 6.4 | 7.4 | 403 | 33.8 | 6.8 | 25.6 | 5.7 | 55 | 25.8 | 33.3 | 68.6 | |
| 9 | Crochmore House | 10.9 | 6.8 | 7.9 | 400 | 60.9 | 8.6 | 6.5 | 1.0 | 207 | 6.0 | 8.9 | 16.4 | |
| 10 | Kerricks farm | 12.3 | 6.3 | 5.0 | 247 | 15.1 | 10.5 | 13.4 | 1.5 | 61 | 10.2 | 19.7 | 32.7 | modern |
| 11 | Guillyhill farm | 11.6 | 7.1 | 5.4 | 458 | 44.4 | 20.1 | 10.5 | 1.6 | 143 | 16.1 | 20 | 86.3 | 70% |
| 12 | Abbey Farm | 10.9 | 6.4 | 1.4 | 444 | 40.7 | 21.8 | 13.1 | 1.6 | 165 | 13.4 | 22.4 | 47.3 | 56% |
| 13 | Holmhead Farm | 11.1 | 6.8 | 2.7 | 707 | 85.3 | 20.0 | 18.4 | 3.6 | 200 | 41.1 | 31.1 | 112.4 | 46% |
| 14 | Kirkland farm, Terregeles | 13.0 | 7.6 | 10.8 | 465 | 50.7 | 22.0 | 8.2 | 1.5 | 207 | 8.6 | 14.2 | 43.4 | |
| 15 | Longbridgemuir farm | 11.4 | 7.4 | 6.1 | 681 | 102.0 | 17.2 | 12.0 | 2.9 | 160 | 153.0 | 19.3 | 27.0 | 24% |
| 16 | Bardennoch Farm | 13.5 | 6.5 | 11.2 | 145 | 17.1 | 4.1 | 5.2 | 0.6 | 62 | 5.1 | 5.17 | 6.2 | |
| 17 | Manse Rd Observation Bh | 9.3 | 7.3 | 9.3 | 550 | 65.3 | 27.3 | 8.5 | 2.4 | 283 | 10.7 | 10.5 | 33.6 | |
| 18 | Locharmoss 1.6 | 10.7 | 5.4 | 6.5 | 125 | 9.8 | 3.3 | 6.2 | 2.9 | 12 | 6.6 | 8.05 | 25.2 | |
| 19 | Thornhill Golf Course | | 6.1 | 7.6 | 134 | 7.7 | 3.7 | 6.8 | 2.2 | 16 | 12.8 | 12.6 | 12.4 | |
| 20 | Kettleton treatment works | 13.2 | 6.5 | 7.6 | 201 | 18.4 | 7.9 | 6.6 | 1.2 | 67 | 14.0 | 9.63 | 17.3 | 64% |
| 21 | Tibbers Dairy | 10.8 | 7.6 | 6.0 | 510 | 54.5 | 20.7 | 14.3 | 5.5 | 206 | 66.9 | 9.89 | 12.4 | |

# References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.


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