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Scotland's groundwater monitoring network: its effectiveness for monitoring nitrate

Groundwater Programme

Commissioned Report CR/05/205N

BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

COMMISSIONED REPORT CR/05/205N

Scotland's groundwater monitoring network: its effectiveness for monitoring nitrate

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Front cover

Pasture fields in the Scottish Borders.

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Summary

Scotland has had a national groundwater quality monitoring network since the year 2000. One of the main functions of this network is to monitor nitrate concentrations. Nitrate can be elevated in the environment due to modern agricultural practice. Initially there were 150 monitoring sites, but these have been added to, and in 2005, the number of groundwater monitoring points for nitrate was 219, comprising 139 boreholes, 51 springs and 27 wells; 67% of these sites are in agricultural areas.

In order to have confidence in the interpretation of data gathered from the network it is important to know the context of the sample points, and in particular whether any sites are compromised by surface contamination or nearby point sources. Prior to this study, many of the sites had not undergone a formal risk assessment and their condition was unclear. In order to improve confidence in the network, and to help act as a baseline before improving the network, the British Geological Survey and the Macaulay Institute were commissioned by the Scottish Executive to carry out a review during the period February-July 2005.

The core of the project was to undertake field assessments for 151 sites where no formal assessment had been made previously. Using criteria developed in this project, a judgement was made as to whether the monitoring point was adequate, required improvement or further assessment, or should be considered for removal. For all 219 sites on the network, a zone of influence was estimated using a semi-quantitative method. These zones were used to help focus the field surveys and also to characterise each site using national datasets; for example the monitoring site would be assigned the land use that occupied more than 60% of the zone. These data were then used to conduct an analysis of the factors controlling nitrate concentrations across the network and to help evaluate how effective the network is at monitoring nitrate in Scottish groundwater.

Below is a summary of the main results from the project:

1. The fieldwork and analysis of the 151 previously unassessed sites indicated that:

   - 61 of the 151 sites are adequate and can continue to be monitored with no improvements.
   - There are serious concerns about 29 of the 151 sites (19% of the sites assessed and 13% of the total nitrate network). These sites should be considered for removal from the network. The sources found to be least reliable were shallow large diameter wells. However, there is little evidence to suggest that the data from these sources collected from 2000 – 2005 has been seriously compromised by point source pollution.
   - 30 sites require further assessment before being judged suitable. Most of these sites are springs and require additional work to identify the precise source.
   - 31 sites require improvements to the monitoring points – the improvements range from better sampling protocols to improving the headworks through simple engineering.

2. There is a clear difference between nitrate concentrations measured in the areas designated as nitrate vulnerable zones (NVZs) and other areas. Within the NVZs, the mean concentration is 25 mg-NO_3 l^{-1} and the median 17 mg-NO_3 l^{-1}; outside the NVZs, the mean concentration is 9 mg-NO_3 l^{-1} and the median 4.4 mg-NO_3 l^{-1}.

3. The data from the network indicate that land use has a large influence on the nitrate concentrations measured in the monitoring network: arable areas, mixed cultivation of both arable and grassland, and areas where dairy, pigs and poultry are reared contribute to the highest nitrate concentrations, with 18% of sites in these areas exceeding 50 mg-NO_3 l^{-1}. The most significant control on nitrate concentrations in the monitoring network is the presence of dairy, pigs or poultry within the zone of influence.

4. A considerable number of monitoring sites have lower nitrate concentrations than would be expected from the nitrate pressure. This can be attributed to dilution from rainfall, mixing with older low nitrate waters, denitrification, or the presence of low permeability soil and superficial deposits which slow the movement of high nitrate water into the aquifers.

5. A “gaps” analysis which compared the current network with an idealised network based on nitrate pressures across Scotland indicated that overall the distribution of the current network is generally good. However, there are significant gaps in the improved grassland areas of the Midland Valley and Ayrshire and in the arable areas of Aberdeenshire, while Mid and East Lothian and the Borders are currently over-represented.

The following recommendations are made for the nitrate groundwater quality network in Scotland:

1. Consideration should be given to **removing or replacing 29 of the 219 sites**, and undertaking further assessments on 30 sites. A further 31 sites would benefit from improvements to the headworks or sampling arrangements.

2. **Further statistical analysis** should be undertaken to help understand the factors that control the nitrate concentrations in groundwater – particularly the environmental factors that help to reduce the measured nitrate.

3. The network should continue to be **concentrated on nitrate pressured areas** in Scotland, with approximately 75% of the network in high nitrate areas, and 25% used to monitor background nitrate concentrations in less pressured areas.

4. Any **future sites added to the network must undergo a risk assessment** similar to the one developed for this study to ensure that the network remains of good quality.

5. The network must continue to **reflect the diverse hydrogeological, soil and land use conditions** in Scotland. Therefore, both bedrock and superficial aquifers should be monitored in a variety of soil conditions. The network should continue to include different types of sources, although less emphasis should be given to wells, which are generally poor monitoring points.

6. In the future, the data from the network will require to be **actively interpreted**: an inevitable outcome from having a diverse network is that the results of the monitoring must be interpreted not only in terms of agricultural practice, but in light of the other factors such as geological and environmental conditions. In practice this could mean a regular detailed review (maybe every 2-3 years) of the data from the network.

7. The network will also need to be **actively managed** to account for various changes in monitoring sites, for example the land use, the condition of the headworks and the pumping rate. This will involve SEPA hydrogeologists having an overview of the network; individual sources being periodically reviewed using a simple checklist; and

additional new sources being sought, possibly through the ongoing BGS/SEPA study of baseline groundwater chemistry across Scotland.

8. **Wellhead measurements** should be taken periodically to help identify denitrification or mixing with older waters. The limited samples taken during this study proved invaluable for interpreting apparently anomalous nitrate concentrations. To undertake this successfully, dedicated sample taps may have to be introduced.

9. A separate **programme of focussed monitoring** should be developed in tandem with the national groundwater monitoring network to give information on the effects of the action programmes within the NVZs. These sites should be in a controlled environment that will respond rapidly to changes in agricultural practice. The results from these studies can then be upscaled to help interpret changes in the national network as well as be used on their own to help understand the success of the Action Programmes.

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- Angela Paul and Francis Brewis at the Scottish Executive.
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1 Background

1.1 INTRODUCTION

Nitrate derived from agricultural activity is a threat to Scotland's water environment. The contamination of groundwater by nitrate can impact on drinking water in aquifers and also the quality of base-flow to streams, rivers and wetlands. Increased nitrate concentrations in water have been associated with eutrophication (the nutrient enrichment of water bodies), which may lead to increased algal growth, a reduction in oxygen, and loss of biodiversity (Lack 1999). With respect to human health, there is still debate over whether the consumption of potable groundwater containing significant amounts of nitrate over a prolonged period may be detrimental to the health of certain vulnerable groups (Addiscott & Benjamin 2004).

In 1991, in response to growing concerns over the impact on the environment of increasing levels of nitrate from agriculture throughout Europe, the European Community issued the Nitrates Directive (91/676/EEC) to protect aquatic ecosystems and potable groundwaters. The Directive stated that waters exceeding, or likely to exceed, a nitrate concentration of 50 mg-NO_3 l^{-1} should be identified and their recharge areas designated as Nitrate Vulnerable Zones (NVZs). Scotland designated approximately 14% of its land area as NVZs in 2002, based on an assessment of the risk of, and vulnerability to, nitrate contamination, and on existing data on nitrate concentrations in groundwater (Lilly et al. 2001; Ball & MacDonald 2001a, Ball et al. 2005).

Within the NVZs, measures have been put in place to reduce the amount of nitrate leaching from agricultural activities. These action programmes promote good agricultural land practice and restrict the use of inorganic and organic fertiliser (Scottish Executive 2003). The aim is to closely match nitrogen input with crop requirements, therefore minimising the risk of nitrate leaching.

To characterise the scale of nitrate contamination in Scottish groundwaters, and any improvement as a result of the measures taken in the action programmes, it is necessary to monitor groundwater quality. The EU Nitrates Directive issued draft guidelines in 1999, updated in 2003 (EC 2003), to help member states develop appropriate monitoring strategies. These guidelines stress the importance of monitoring for the characterisation of water quality and also to monitor the effectiveness of the action programmes. There is obviously overlap with the more recent Water Framework Directive (2000/60/EC) for which widespread monitoring of groundwater is required.

1.2 BACKGROUND TO THE EXISTING MONITORING NETWORK

Management of groundwater has only recently been considered seriously in Scotland (Clews et al. 2005). A national groundwater monitoring network was established in 2000, many years after most other European countries had monitoring systems in places (Fraters et al. 2005). At the start of the current project in February 2005, there were 219 water points across Scotland monitored for nitrate four times per year. Below is a summary of the history of network development.

1. The initial Scottish groundwater monitoring network established in 2000 included 150 sites. All were pre-existing water points and most were private supplies. This network was designed to be objective and representative of Scotland's environment: the sample points were spread over 39 biophysical classes based on aquifer permeability, soil leaching potential, and land use (Lilly et al. 2003). The specific

sample points were chosen by SEPA, with no time set aside to audit the condition of the sources chosen to be monitored.

2. In 2001, twelve of the sites with consistently high nitrate were reviewed, and six dropped from the network after being identified as locally contaminated (Ball & MacDonald 2001b).

3. As part of the process of designating NVZs in 2002, a further 70 sites were chosen in agricultural areas with high nitrate leaching and mainly vulnerable aquifers (Ball and MacDonald 2002). Monitoring of these sites continued after the NVZs had been designated.

4. A further 10 boreholes were drilled in 2003 in areas which were thought to be at risk of nitrate contamination, but where there were no existing sources, to be used as monitoring sites.

5. Monitoring points in the Nithsdale NVZ in southwest Scotland were reviewed in 2004 and several shallow sites identified for future monitoring (MacDonald & Abesser 2004).

In addition to the work carried out above, some sites have been removed due to various circumstances, such as a change of ownership, pumps breaking down, or sources drying up.

1.3 AIMS AND OBJECTIVES OF THE PROJECT

In order to have confidence in the interpretation of data gathered from the network, it is important to know the setting of the sample points, and in particular whether any sample points are compromised by surface contamination or nearby point sources. Many of the initial 150 sites had never been subject to a formal risk assessment and their condition was unclear. In order to improve confidence in the network, and to help act as a baseline before improving the network, the British Geological Survey and the Macaulay Institute were commissioned by the Scottish Executive to carry out a review during the period February-July 2005. The aim of the project was specifically:

> *"to assess the effectiveness of the Scottish groundwater nitrate monitoring network and recommend improvements."*

To achieve the project aim the following objectives had to be met:

1. Develop a database of existing data.
2. Delineate capture zones for all 219 monitoring sites.
3. Assess the validity of 120 of the sites which have not yet been subjected to any validation (this increased to 151 sites during the course of the project).
4. Undertake an interpretation of data for the 219 sites to assess effectiveness of the network and make recommendations for improvements.

Table 1 shows the work programme designed to meet these objectives. The three outputs from the project are: (1) a database of information from all the sites, including digital photographs and maps; (2) a GIS layer of capture zones for the whole network, and (3) this research report discussing the result of the project.

An interdisciplinary team was drawn together for the project including soil scientists (from the Macaulay Institute), GIS specialists, hydrogeologists and chemists.

Table 1 Activity chart for the nitrate monitoring project.

	J	F	M	A	M	J	J
1. Project management	■	■	■	■	■	■	■
2. Delineate capture zones	■	■					
3. Establish criteria and methodology for site assessment		■					
4. Prepare access and desk reports		■	■				
5. Land use and soil data and interpretation	■	■	■	■	■		
6. Visit 120 sites				■	■		
7. Databasing and interpretation				■	■		
8. Recommendations for effective Network					■	■	■
9. Final Reporting and QA						■	■
Monthly project meetings		■	■		■	■	
Steering group meetings	■			■			■

2 Methodology for assessing existing sites

2.1 OVERVIEW

Prior to this study, for many of the original 150 sites of the Scottish groundwater quality monitoring network, little was known about the condition of the individual sites or the surrounding and underlying environments. Therefore, visiting each site, and carefully collecting key data, was fundamental to judging the condition of each site. Figure 1 outlines the approach taken in this project to assess the network:

1. Existing data on each site were gathered from various databases held at SEPA and BGS. National datasets from BGS and the Macauley Institute were also used, such as digital geology and groundwater maps, soil maps, and land use.
2. A zone of influence was estimated for each site. This was based on the pumping rate, recharge and direction of groundwater flow.
3. Criteria were determined that each site had to be judged against. These included information on the source construction and surrounding risks.
4. Each site was visited, and a proforma completed from a visual inspection. The information was then entered into a database.
5. A judgement on each site could then be made (this is reported in Chapters 3 and 4).

Two points are important to note:

- Only sites that had not been assessed before were subject to review. Originally, this was thought to be about 120 sites, but by the end of the project 151 monitoring points had been assessed (see Chapter 3).
- The aim of this part of the project was to assess the *condition and quality* of each source for monitoring purposes, not the *relevance* of the source to the monitoring network. The effectiveness of the network was subject to a separate review (see Chapters 6 and 7) which took in all 219 sites, not just the 151 that were visited.

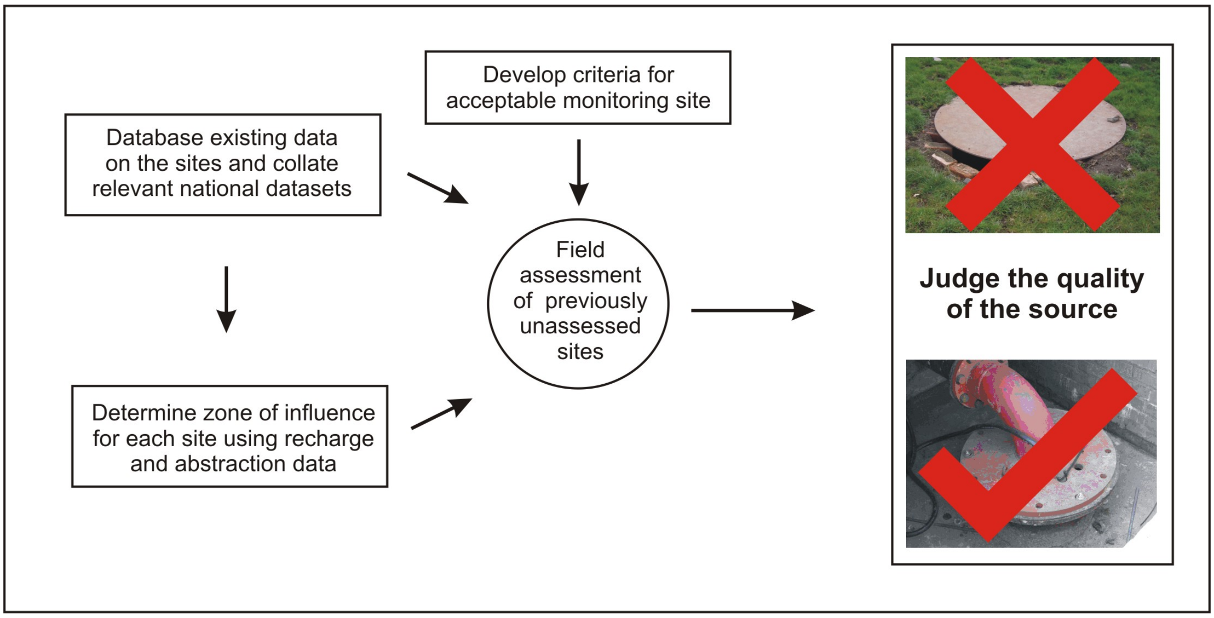


Figure 1 Overview of the method used to assess the quality of the sites previously unassessed.

2.2 ESTIMATING ZONES OF INFLUENCE

2.2.1 Introduction

In order to assess the potential impact of land activities or sources of pollution on a water point, its catchment must be determined. However, unlike a surface water catchment, which can be directly observed or measured, a groundwater catchment is hidden and almost impossible to delimit accurately.

Several different methodologies can be adopted to address this uncertainty, depending on both the information and time available. These range from arbitrary circles drawn around a source, to sophisticated time variant groundwater modelling (Ball et al. 1997). Uncertainty is due to:

- Heterogeneity of aquifers (particularly in fractured rocks, such as occur over much of Scotland).
- Time variant factors, such as the patterns of pumping, or recharge throughout the year.
- The direction of groundwater flow.

To highlight the difference in certainty between the extent of surface water and groundwater catchments, we refer to the estimated groundwater catchment as the *zone of influence.*

The zone of influence was used in the project to help focus the field assessments, and also to combine with the national datasets to help characterise each site.

2.2.2 Methodology

A compromise between sophisticated modelling and arbitrary circles was used to estimate the zone of influence for each source. The method used standard shapes and analytical solutions based on simplified hydraulic assumptions at the source.

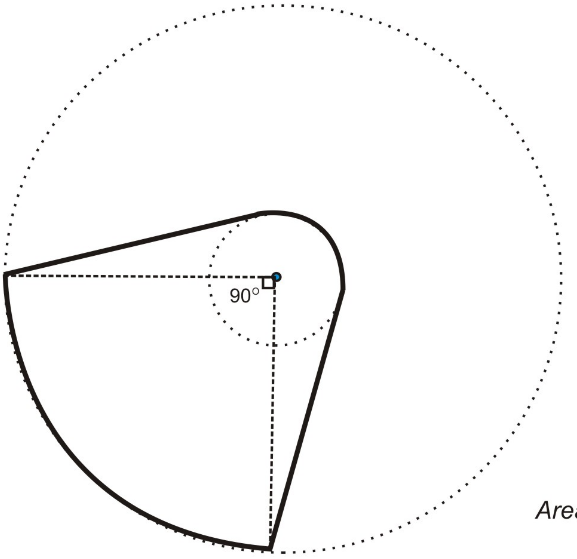
The standard shape adopted was a shuttlecock (see Figure 2 for details). This comprises an inner circle around the site and a longer tail which extends upslope forming an arc with an angle of 90 degrees. The advantages of this shape are:

- It allows for uncertainty in flow path (unlike some numerical models which give “tadpole” shapes, which narrow upslope).
- The inner circle allows for flow from down gradient of the borehole, which occurs in pumping boreholes.
- The shape can be easily scaled according to the pumping rate of the source, and estimated recharge (see Figure 2).
- The shape could be applied to the 219 sites within the timescale of the project.

The limitations of such a method are:

- It assumes that a groundwater gradient can be inferred across the site.
- The extent and nature of superficial deposits, or confining layers are ignored.
- River-aquifer interaction is not included.
- Interference with other abstraction boreholes may change the shape of the zones.

The zones of influence for the network were based on a shuttlecock shape

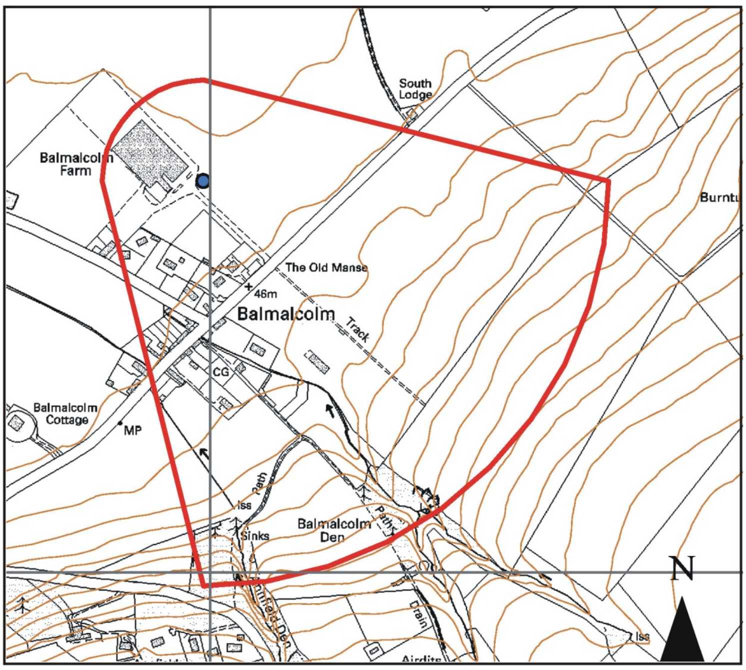


For pumping boreholes, the radius of the outer arc was 4 x the inner arc. For non-pumping boreholes (where theoretically, there should be no flow from the downstream side of the borehole) the radius of the outer arc was 8 x the radius of the inner arc (which was fixed at smaller size than for pumping boreholes).

The angle of the outer arc was 90 degrees. This allows a wide variety of flow paths to the water point, and is appropriate in fractured environments.

The overall size of the shuttlecock was determined by the recharge and abstraction using the formula:

Area (m^2) = annual abstraction (m^3) / annual recharge (m)



The inner circle shuttlecock was then centred on the source and the tail orientated roughly upslope.

Figure 2 The methodology for determining the zones of influence for the network.

2.2.3 Application

To generate the zones of influence information on the recharge and pumping rate were required for each source. An estimate of the recharge for each site was given by SEPA, using the methodology developed by Church (2005). Information on the pumping rate was gathered from a variety of sources: SEPA; BGS records; direct information from the owners, and estimates based on the use made of the water. After the sites were visited, the capture zones were revised using the new information.

For sources that were not pumping (observation boreholes – OBH), a standard shuttlecock shape, with inner circle radius of 25 m, and outer arc length of 200 m, was used for each source.

For sources that were pumped, or flowing springs, the recharge and the pumping rate were used to estimate the area of the zone of influence (see Figure 2). To make the application of the method easier, certain standard sizes were used (see Table 2), so the estimate area was always rounded up to the next standard size.

An existing capture zone had already been calculated for the Spey well field using numerical modelling by Chen et al. (1997). This was used for the two boreholes in the well field area in preference to the "shuttlecock".

Table 2 Summary of the Zones of Influence calculated for the network.

Method no.	Radius inner circle (m)	Radius outer circle (m)	Area of 'zone of influence' (m^2)	Comments	number of sources
1	25	200	36798	used for all OBH's	39
2	50	200	43256		65
3	75	300	97563		14
4	100	400	172968		20
5	150	600	389506		39
6	200	800	691874		14
7	250	1000	1081140		11
8	300	1200	1556567		7
9	350	1400	2118956		4
10	400	1600	2767053		1
11	450	1800	3502718		0
12	500	2000	4324287		1
13	750	3000	9728701		1

2.3 SITE ASSESSMENTS

There are no established international criteria for assessing the value of an individual groundwater monitoring point (Fraters et al. 2005). This is partly because a groundwater monitoring point can serve many different functions, depending on what it is measuring. The main aim of the Scottish nitrate groundwater monitoring network is to measure nitrate from diffuse agricultural sources. The survey was, therefore, designed to answer two questions:

1. Is the source compromised by local direct contamination?
2. Is the source response dominated by a local point source of nitrate contamination?

The surveys at the sites had to be rapid and non invasive. The project timetable was such that the survey had to be completed at the site within 1 to 2 hours. Additionally, there was no possibility of carrying out engineering work at the site to directly examine the condition of borehole casing, or investigate buried spring sources.

The site assessment method was modified from that developed by BGS in 2001 for assessing new sites for the Scottish groundwater monitoring network (Ball & MacDonald 2002). Other assessment methods that were referred to were: (1) cryptosporidium risk assessments, e.g. Morris & Foster (2000); (2) sanitary inspection methods, e.g. Howard (2002); (3) private water supply risk assessments for microbiological contamination (Jarman 1996; Lamb et al. 1998; Reid et al. 2001) and (4) methods used for assessment by the EA in England & Wales. Integral to the source assessment was taking photographs for future reference.

A copy of the proforma is included here as Figure 3. The aim was to collect sufficient information to help answer questions 1 and 2 above. The information collected was divided into several categories:

> *General*: confirming location details and assessing the setting of the source and what the water is used for.
>
> *Map check:* confirming that the zone of influence and maps generated for the site appear consistent with what can be seen on the ground.
>
> *Source condition:* assessing the condition of the headworks of the borehole, well or spring and what the pumping rate is.
>
> *Surrounding land use*: determining what the land use is within the surrounding 200 m of the borehole, and within the zone of influence, and identifying any point source within this area.
>
> *Immediate surrounding:* assessing the condition of the land within 10 m of the source, in particular whether there are point sources within this zone, or whether the source appears vulnerable to flooding.
>
> *Upgrading:* commenting on any additional investigations or small engineering works that would help to improve confidence in the site.

Further discussion of the data collected, and how they were used to make judgements on individual sites, is given in Chapters 3 and 4.

2.4 USE OF NATIONAL DATASETS

Integral to the project is the use of pre-existing national datasets to help characterise sites and to provide background information for future discussions on the results from individual datasets. Work over the past few years has led to the development of digital versions of several invaluable national map series, such as geology, soils and land use. Recent interpretations of these maps using additional data, has led to other derived products, such as a national groundwater vulnerability map, and nitrate loading map. The use and manipulation of large datasets requires a Geographical Information System (GIS).

There were two uses of the datasets within the project:

To act as a reference for the conditions at individual sites. To be useful in this way (and within the terms of copyright) A4 pdf maps of each dataset were produced at 1:50 000 scale for each of the 219 sites (see Table 3 for the national datasets used in the study).

To characterise the sites. This was required when assessing the overall effectiveness of the network. Statistics were calculated for the zones of influence around each site (see Figure 4). For numerical datasets (such as standard percentage infiltration (SPI) or dairy density) a numerical average was taken across the zone of influence. For datasets with different categories (such as aquifers or land use), the site was attributed to the category comprising more than 60% of the land area in the zone of influence. For landuse, some categories were combined to help provide unique values for sites (e.g. if improved grassland and arable totalled more than 60%, then it was taken as mixed cultivated).

Table 3 National datasets used in the project.

Dataset	Source	Notional Scale	Comments
Topography	OS	1:10 000	Used as a field sheet
Topography	OS	1:50 000	General location
Bedrock geology	BGS	1:50 000	Most detailed digital geological information available
Superficial geology	BGS	1:50 000	Most detailed digital geological information available
Bedrock aquifer productivity	BGS	1:100 000	Derived from bedrock geology and borehole data – an indication of where the good aquifers are.
Superficial aquifer productivity	BGS	1:100 000	Derived from the superficial geology map, well data and information on the glacial history of Scotland - a map of where the good superficial aquifers are
Aquifer vulnerability	BGS/MLURI	1:100 000	Funded by SNIFFER, a map derived from geological, geotechnical and soil data.
Depth to water-table	BGS/MLURI	1:100 000	Generally only accurate in superficial deposits, and derived from a model rather than observed data.
Landuse	MLURI	1:25 000	Derived from aerial photographs in 1988 (LCS88), still the most detailed national coverage on landuse.
Residual Nitrate loading	MLURI	1:25 000	Derived from the land use data and parish level information on animal numbers and crop types.
HOST (Hydrology of Soil Types)	MLURI	1:25 000 for eastern Scotland, 1:250 000 for the remainder	Classifies the many soil types in terms of their hydrological characteristics.
SLP (Soil Leaching Potential)	MLURI	As for HOST	Based on HOST, describes how easily nitrate can move through the soil
SPI (Standard Potential Infiltration)	MLURI	As for HOST	Based on HOST, indicates the proportion of water that will move downwards through the soil.
Soil Drainage	MLURI	As for HOST	Based on HOST, describes the natural drainage of the soil, and may infer denitrification.
Dairy Intensity	MLURI	1:100 000	Parish level stock data is disaggregated across the parish using landuse information
Pigs and Poultry density	MLURI	1:500 000	As dairy, but for pigs and poultry. Much lower resolution than for dairy, due to the difficulty of disaggregating below parish.

British Geological Survey — The Macaulay Institute

Groundwater monitoring network: nitrate assessment — Project Ref

General

Name of site	SEPA ref number	Date of assessment
NGR source	NGR sample point	
Name of assessor	Photo numbers	

Description of what is the water used for ?			
	Public supply	Domestic	Large PWS
	Industrial	Food & Drink	Mineral water
	Livestock	Irrigation	Observation

Description of water supply

Source topographical setting					
	Active floodplain	Valley floor	Hollow	Base of slope	Plain
	Steep hill slope	Hill slope	Hilltop	Coastal	Other
	Comments				

Map Check

Circle any of the maps that appear problematic or obviously contradictory to field conditions			
	Bedrock Geology	Superficial Geology	GW Vulnerability
	Bedrock Productivity	Superficial Productivity	Depth to water
	Land use	Soil	Dairy
	Comments		
Zone of influence OK ?	Explain problem – sketch better zone on 1:10 000 maps		
Yes / No			

British Geological Survey — The Macaulay Institute

Groundwater monitoring network: nitrate assessment — Project Ref

Borehole / Well

Measured Depth (m)	< 5	5 – 30	measured / estimated	Diameter (mm)	measured / estimated
	30 - 100	> 100	from owner / from records		from owner / from records
Depth of casing below ground (m)	< 5	5 – 30	measured / estimated	Height of casing above ground (m)	Is borehole/well open?
	30 - 100	> 100	from owner / from records		Yes / No / UNK

Location of source and type of headworks				Concrete Plinth / Hard standing / Grass / Not known	condition
Inside Building	Small shed	Outside	Under manhole		
Presence and condition of fence ?				Are headworks sufficient to stop surface water ingress ?	Yes / No / UNK
				Are headworks sufficient to stop direct contamination from stock?	Yes / No / UNK

Pumping rate	0 m³/d	0 - 10	measured / estimated	daily	weekly	Depth to rwl	measured / estimated
	10 - 100	> 100	from owner / from records	seasonal	Infrequent		from owner / from records

comments

Spring

Has the source been positively identified to within 10 m?	Yes	No	Prob	brick / Concrete rings	Rendered brick / Other	condition
Is the source in fenced area ?	Yes	No	UNK	Cut off ditch ?	Yes / No / UNK	
Condition of fence ?	Excellent	Adequate	Poor	Vermin proof overflow ?	Yes / No / UNK	

Flow rate	0 m³/d	0 - 10	measured / estimated	Are headworks sufficient to stop surface water ingress ?	Yes / No / UNK
	10 - 100	> 100	from owner / from records		
Seasonality?	Never changes	Reduces in summer		Are headworks sufficient to stop direct contamination from livestock?	Yes / No / UNK
	Dries in summer	Dries in drought			

Comment

British Geological Survey — The Macaulay Institute

Groundwater monitoring network: nitrate assessment — Project Ref

Surrounding land use

Land use and crops in surrounding 200 m	Market garden	potato	fruit	cereal
	dairy	pig	poultry	Other animals
	Golf course	Caravan park	woodland	Semi natural
	Urban residential	Urban industrial	Main Road	Railway line
Land use in upper zone of influence	Market garden	potato	fruit	cereal
	dairy	pig	poultry	Other animals
	Golf course	Caravan park	woodland	Semi natural
	Urban residential	Urban industrial	Main Road	Railway line

Potential Hazard	Distance (m)	In capture zone?	Comments
River or loch			
Burn or field drains			
Farm soakaways for dirty water			
Sewer (mains or domestic)			
Septic tank			
Fertilizer sheds and mixing areas			
Fuel / Oil store			
Slurry lagoon			
Slurry tank			
Silage clamp			
Silage bails			
Manure heap			
Dairy Parlour			
Animal sheds			
Slurry spreading			
Fertilised fields			
Unused wells or boreholes			
Other (e.g. landfill, railway, carcass burial, major road, cemeteries, petrol station)			

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Groundwater monitoring network: nitrate assessment — Project Ref

Immediate surroundings

Description of surrounding 10 m					
			Pasture Fields	Arable fields	Livestock assembly
			Buildings	Wood-land	Semi natural
			Farmyard	Tarmac Road	Hard-standing
Is the land liable to flooding, or surface water ingression within 10 m ?	YES	NO	UNK	List potential hazards (from before):	
Are there significant point sources of contamination within 10 m ?	YES	NO	UNK		

Sampling

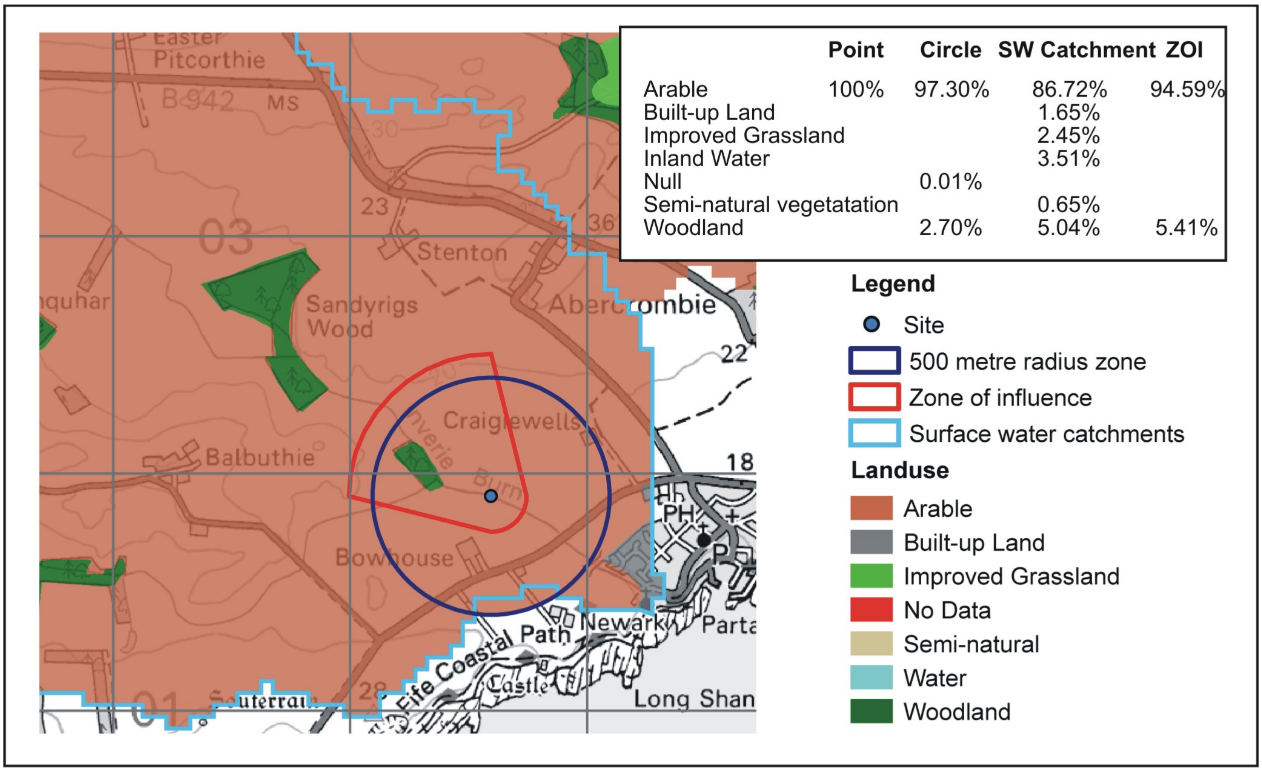
Description of sampling point			Distance from source (m)		
				Raw	After pressure vessel
				After filter	After treatment
				After header tank	Requires sampling pump
How is the sample taken?	Sample tap / Overflow	Other tap / Pipework	From tank / Sampling pump	Easy / Possibly / Difficult	
Can a sample of recently pumped groundwater be taken?	Yes	No	With difficulty	BGS sample number	
Can an unaerated sample be taken?	Yes	No	With difficulty		

Upgrading requirements

Headworks	Concrete plinth	Manhole cover	borehole cap	extend casing upwards	Other
In immediate 10 m	Fence	Cut-off Drain	Other		
Of sampling arrangements	sample tap at well head	Arrange winter pumping	Other		
Investigations	Depth of borehole	Depth and Condition of casing	Pumping rate	Other	

Comments

Figure 3 A copy of the site assessment formed used during the fieldwork.



	Point	Circle	SW Catchment	ZOI
Arable	100%	97.30%	86.72%	94.59%
Built-up Land			1.65%	
Improved Grassland			2.45%	
Inland Water			3.51%	
Null		0.01%		
Semi-natural vegetatation			0.65%	
Woodland		2.70%	5.04%	5.41%

Figure 4 Land use statistics for the Bowhouse Farm site. The statistics for the Zone of Influence were used to characterise the site. This site was characterised as “arable” since more than 60% of the zone of influence was arable.

3 Fieldwork and data for the sites

3.1 FIELDWORK

The field inspections of the monitoring sites were carried out between 20 April and 25 May 2005 by two BGS hydrogeologists, with occasional assistance from SEPA. The project proposal suggested 120 sites would need to be visited: however, 151 were eventually assessed. The reason for the discrepancy was that good information was available for fewer sites than originally thought.

The site visits were prefaced by consultation with the SEPA area hydrogeologists and other relevant staff to obtain details of the monitoring network in each area, including details of site owners and any particular access arrangements, and, where available, location maps for each of the sites. The fieldwork proceeded at an average rate of approximately 4 sites per day per fieldworker. At each site, the following work was undertaken:

- The location of the source was confirmed using a GPS. In many instances, the grid reference recorded in SEPA's database referred to the *sample point*, not to the *source*. This was particularly common for spring sources, where in many cases the exact source location is unknown. For some sites, the true source could not be accurately determined, although considerable time was spent searching.
- Where possible, the landowner or other person responsible for the source was consulted to obtain the required information.
- Where possible, there was a visual inspection of the headworks: for example, manhole covers were lifted to inspect the casing. This was not possible at all sources because some buildings were locked, or the covers too heavy to lift;
- There was a detailed visual inspection of the land within 10 m of source.
- Photographs were taken of the setting of each source.
- The land use and any obvious point sources of contamination within about 200 m of each site were assessed by a visual inspection from around the source.
- The site assessment form was completed for each site (see a copy of the form in Figure 3).

A total of 146 sites were visited during the fieldwork phase of the project, most of which had not previously been assessed in detail by BGS and for which BGS did not hold sufficient information to complete a desk assessment.

A further five sites on Orkney & Arran were assessed using desk studies and information from other projects. Four of these sites had previously been visited by BGS as part of other projects, and desk assessments were completed on each site using data collected by BGS and the SEPA area hydrogeologists.

The 70 sites added to the monitoring network in 2002 were assessed by BGS during 2001 and 2002 and sufficient information is available for each of the sites to enable them to be assessed using the criteria developed during the current project. Only one of these sites, Peacehill Farm, was revisited during the current phase of fieldwork: this site shows an upward trend in nitrate concentrations and a further visit was warranted to determine whether there had been significant change at the site or whether there were factors that had been missed in the first review.

For selected sites, groundwater samples were collected for major and trace chemical analysis. There were resources in the budget to sample 54 sites, and these were collected semi-randomly, to give an impression of the network as a whole. Samples were collected in polyethylene bottles. Those for major and trace elements were filtered through 0.45 µm membrane filters; the aliquot to be used for cation and trace element analyses was acidified with 1% v/v HNO_3 to minimise adsorption onto container walls.

Age dating was used specifically at sites where a source was low in nitrate and the risk factors suggested the concentration should by high. However, age dating using CFC and SF6 can only be used where a sample can be collected without coming into contact with the atmosphere. Eight sites were sampled for CFC and six for SF6 analysis.

A suite of wellhead chemistry measurements was made wherever a water sample was collected. Where there was a suitable tap the parameters pH, dissolved oxygen (DO) and redox potential (Eh) were measured on-site in an anaerobic flow-through cell (Figure 5). Other on-site measurements included temperature, specific electrical conductance (SEC) and alkalinity. If it was not possible to connect a flow-through cell then well head measurements were usually made in a bucket, or in some cases directly in a well or spring.

Figure 5 Making well-head measurements using a flow through cell.

3.2 DATA HANDLING

The project has generated much data for the groundwater monitoring network, particularly the sites visited during the fieldwork. The data have been handled in a variety of ways.

MS Access database. All the data gathered from the fieldwork have been digitised and entered into an Access Database. The database is relational and has 10 tables holding different information about the 151 monitoring sites assessed. Data from the earlier assessment of the additional boreholes added to the monitoring network in 2002 were reorganised so that they are held in the same format as the new data. The statistics for each site generated using the national datasets and the zone of influence have also been entered into the database, as have the chemistry data for the 54 sites sampled.

Photographs. Photographs were taken for most of the sites visited during fieldwork. These photographs were taken primarily to illustrate the setting of the site. These should be considered confidential, as they have been taken on individual properties, and should be used only by the Scottish Executive and SEPA in relation to the monitoring network.

Maps. A suite of 16 maps was produced for each of the 219 sites in the network to help with the analysis (See Table 3). These maps have been printed as pdf A4 maps, at 1:50 000 scale around each site. An example of one of the maps is shown in Figure 6. These maps are covered by copyright and again should only be used by SEPA and the Scottish Executive in relation to the monitoring network and should not be made publicly available.

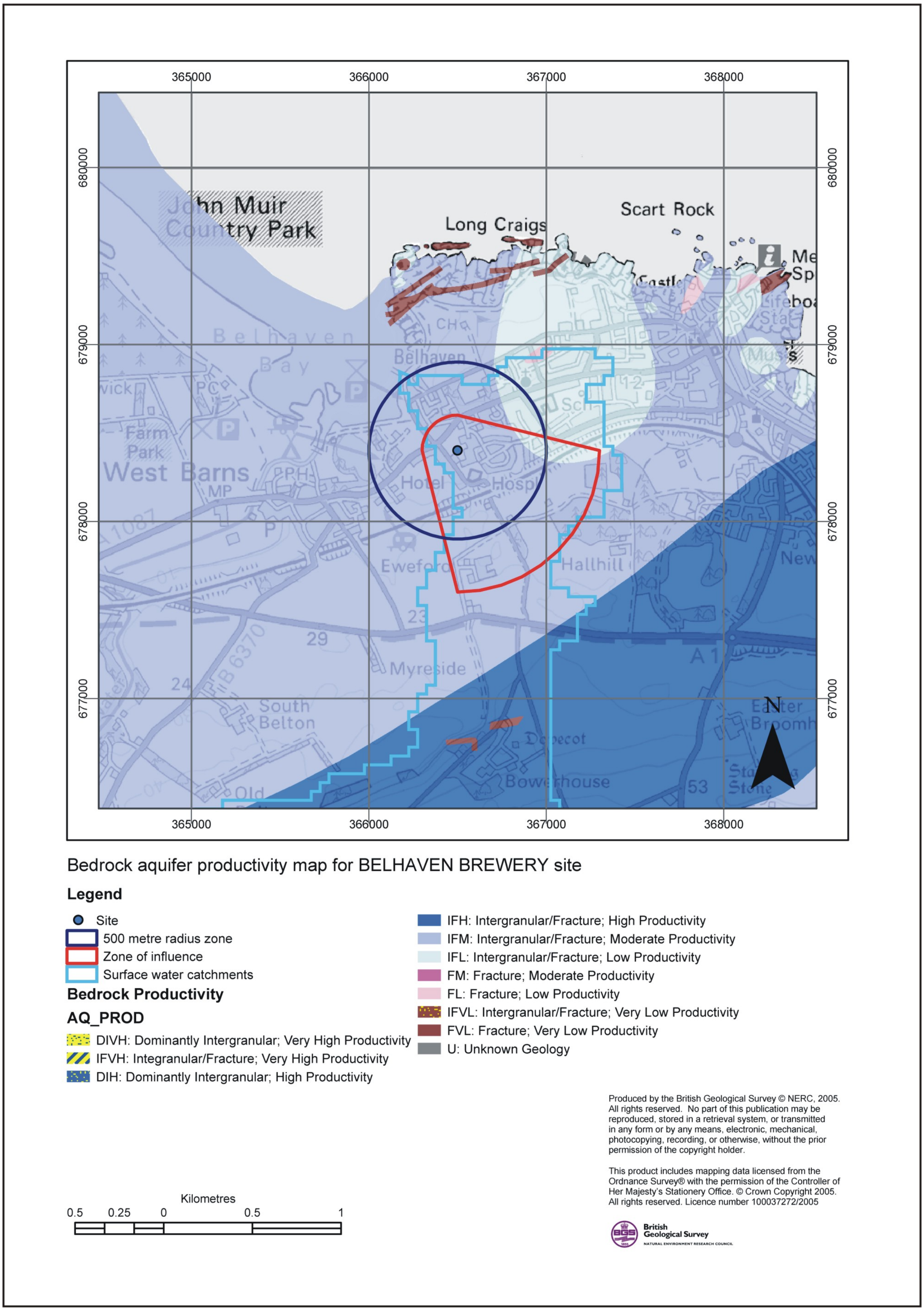


Figure 6 An example of a bedrock aquifer productivity map for the Belhaven Brewery monitoring site. Sixteen such maps were generated for each of the 219 sites as part of the project.

4 Scotland's groundwater monitoring network in 2005

4.1 AN OVERVIEW OF THE NETWORK

The current groundwater nitrate monitoring network in Scotland comprises 219 sites. This is a subset of a larger network (approximately 300 sites) that is monitored for other parameters such as the presence of sheep dip. The locations of the currently monitored sites are shown in Figure 7. It is immediately apparent that the network is skewed towards the east of the country. There are two reasons for this: (1) the original design of the network weighted it towards agricultural areas where the risk of contamination is greatest; and (2) the 70 extra sites added in 2002 were all in potential NVZ areas in the east.

Within the network there is a large diversity in types of source (see Table 4). The majority of the sources (139 sites) are boreholes; springs (51 sites) are the next common. There are 27 sources that are called "wells". However, some of these "wells" may actually be springs, and *vice versa*. The terms spring and well have often been used interchangeably in Scotland – field evidence often suggests this to be the case. Most of the boreholes are between 30 and 100 m deep, and few of them are shallower than 30 m deep.

Table 5 gives an indication of the variety of land uses that the groundwater nitrate monitoring network covers. Arable areas and improved pasture (without dairy, pigs or poultry) are the most represented areas; however many of the sites are still in areas where they may not be monitoring diffuse agricultural contamination. This is discussed in more detail in Chapter 6.

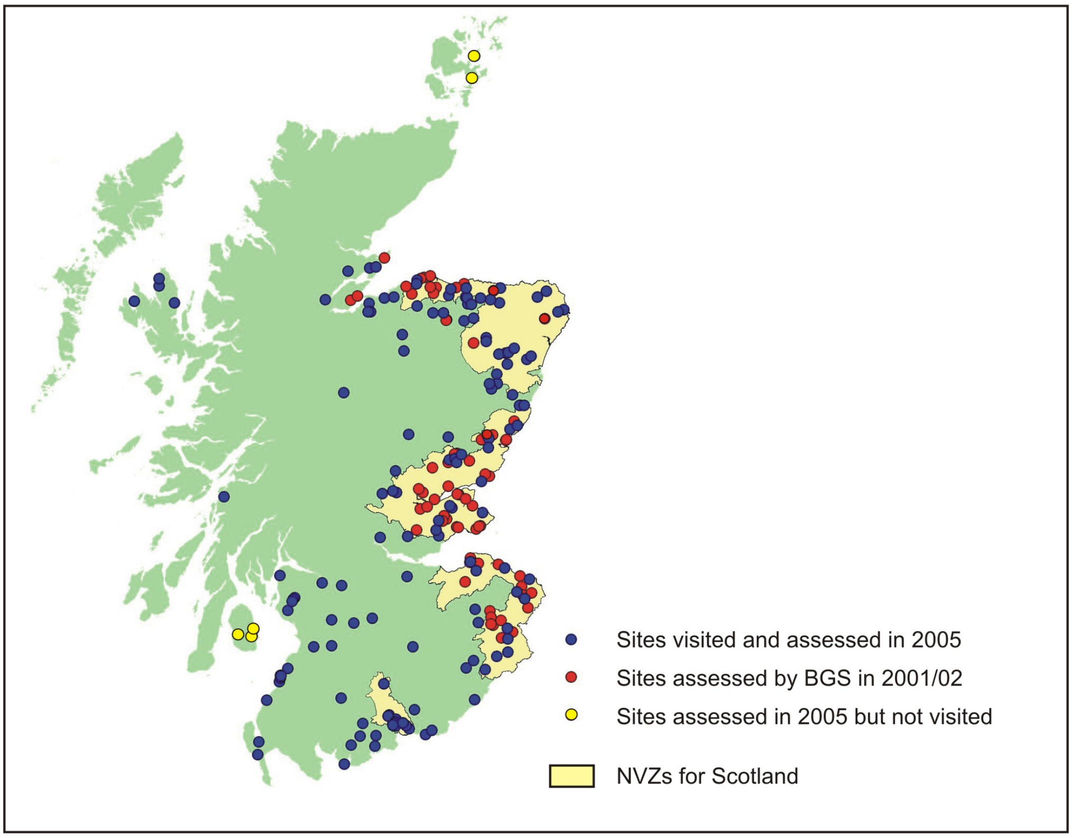


Figure 7 The Scottish groundwater monitoring network in 2005. The diagram also indicates which sites were assessed during this project.

Table 4 Number of sites by source type.

Source type	Number of sites
Shallow borehole (< 30 m depth)	21
Borehole (30 – 100 m depth)	94
Deep borehole (> 100 m depth)	24
Well	27
Spring	51
Unknown source type*	2
Total	**219**

* Considerable uncertainty about the exact location or nature of the source.

Table 5 Number of sites by land use.

Land use type[1]	Number of sites
Arable	55
Dairy/Pigs/Poultry[2]	27
Improved grassland	52
Mixed cultivated[3]	18
Mixed landuse[4]	24
Built-up land	8
Recreational	4
Semi-natural vegetation	5
Woodland	26
Total	**219**

Notes

[1]Calculated as the land use that covers >60% of the zone of influence.

[2] Dairy/Pigs and Poultry is a site where dairy cows, pigs or poultry were noted within the zone of Influence.

[3]Mixed cultivated is where the combination of arable and improved grassland is > 60%

[4]Mixed land use is where no land use dominates the zone of influence.

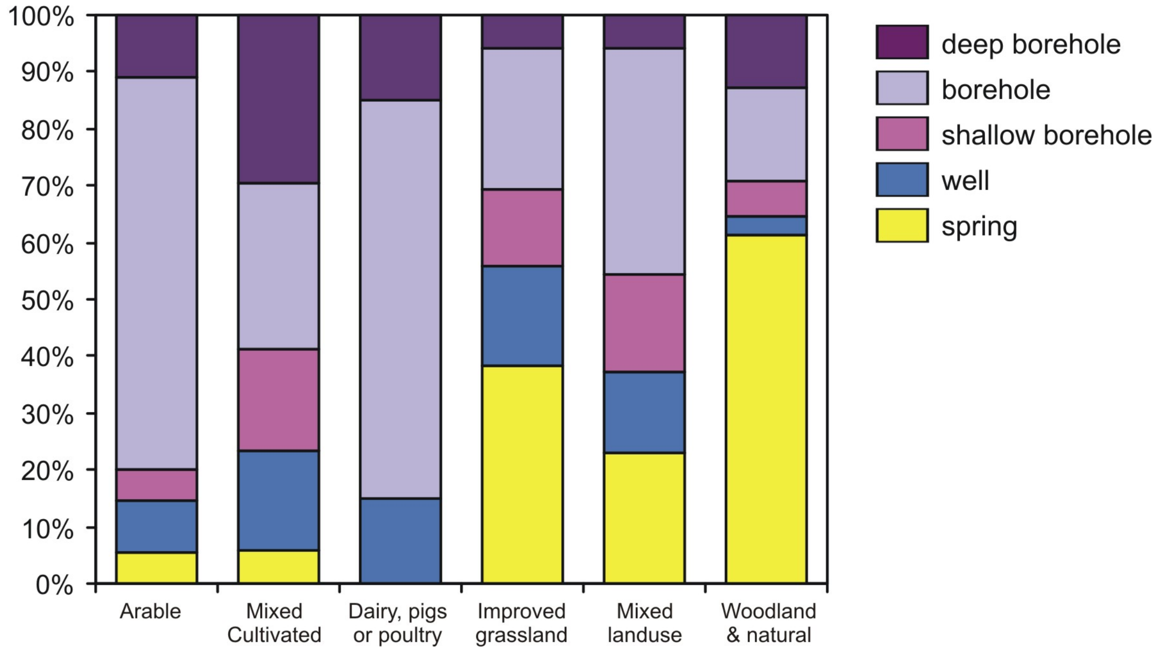


Figure 8 The proportion of different source types in different land uses. Note that some land use categories from Table 5 have been combined: *Mixed landuse* includes built up and recreational areas; *Woodland & natural* includes woodland and areas with semi natural vegetation.

The different source types are not distributed evenly across land use types (see Figure 8). Boreholes are concentrated in areas with a high proportion of arable land (i.e. arable or mixed cultivated) or intensive livestock (dairy, pigs or poultry). Springs are the most common source in woodland or areas with semi-natural vegetation; springs and wells also comprise about half of the sources in areas of improved pasture. The few shallow boreholes on the network are distributed evenly among the different land uses. Likewise, there is no pattern to the distribution of deeper boreholes across land use types.

4.2 EXAMPLES OF DIFFERENT KINDS OF MONITORING SITES

The type of monitoring point (borehole, well or spring) can potentially impact on the measured nitrate. This is largely because of the different depths from which groundwater is sampled, and the different ways in which each type of site is protected from contamination. In this section we give examples of various types of monitoring point.

4.2.1 Springs

Springs are useful sampling points. The issues surrounding their use as monitoring points are different from boreholes (see Figure 9).

They are continually flowing. This is a considerable advantage as a monitoring point, since no pump is required and the source is naturally purged.

It is difficult to accurately work out exactly where the source is. Often what is observed in the field is a spring box, with a pipe entering the box coming from an unknown source. In some springs, particularly in upland areas, the source can be very close to the spring box (several metres); however, in other locations the source may be kilometres away (see below).

The sampling point is often far from the source. The tap sampled at the house or farm, may be from a spring several kilometres away. If the inflow to, or overflow from the spring box cannot be directly sampled, it is necessary for the source to be regularly used so that the pipes are flushed and the sampled water is fresh.

Springs are difficult to protect from direct contamination. To be certain that there is no direct contamination, the source should be fenced off, sealed above, and have a bypass surface drain or bund above it. This is often not the case. Fortunately, many springs are in upland wooded areas where there is little risk of direct nitrate contamination.

Springs often sample shallow groundwater from a small catchment. Sampling shallow groundwater must be an integral part of a national network. However, springs with low flows often have highly localised catchments, and can sometimes be difficult to distinguish from field drains.

Figure 10 shows some pictures of typical springs in the network.

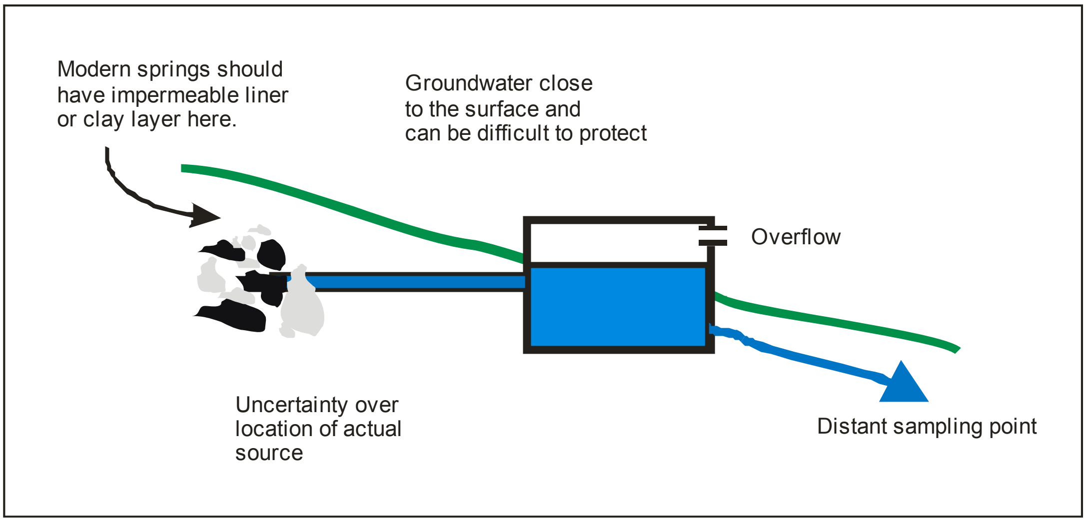


Figure 9 Uncertainty surrounding using small springs as monitoring points.


Figure 10 Two different springs on the monitoring network. Even where sources are fenced, the fence is often in disrepair. Spring boxes are generally brick lined with a cement screed, and are best sampled from an inflow.

4.2.2 Wells

As mentioned above, in Scotland there is often overlap in definition between sources called springs and those called wells. In this report we tend to define wells as large diameter holes in the ground, from which water is pumped, but does not overflow naturally. Figure 11 shows a diagram of a well, and Figure 12 some examples from the network. Below are some of the main issues to consider when using wells as monitoring points.

Wells sample shallow groundwater, often only 2 to 3 m deep. As with springs, this can be a distinct advantage, but makes wells more responsive to nearby hazards.

It can be difficult to effectively purge wells before sampling, as they contain a large volume of water. This is particularly important where wells are no longer in continual use. Even if they are purged, this can disturb sediment at the bottom of the well which may affect the results.

Wells are often poorly protected at the surface and are often located close to potential areas of contamination (such as on a farm steading).

Sometimes wells have inflows into them from sources that are unknown. What is known as a well can often be a holding tank from a spring further up the catchment. If the well has an inflow, then it should be treated more as a spring. Because wells were often constructed many years ago, the current owners may not know much about the true nature of the source.

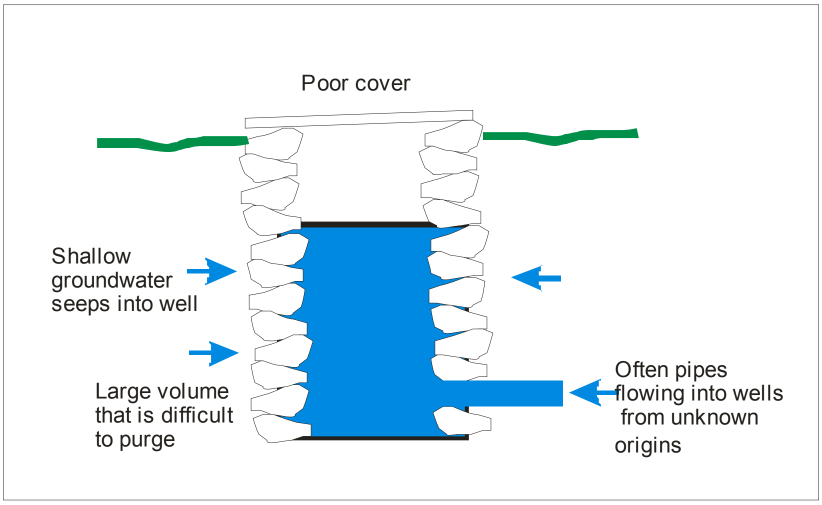


Figure 11 Schematic of a typical Scottish well.

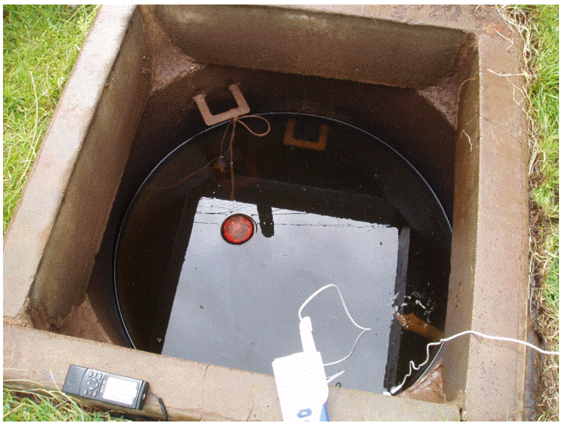


Figure 12 Two wells on the groundwater monitoring network.

4.2.3 Boreholes

Boreholes are by far the most numerous type of source in the groundwater nitrate monitoring network in Scotland. They are often the most controlled way to sample groundwater. However, their major disadvantage is that, once constructed, it is difficult to obtain information on the geometry and construction of a borehole. Below is a summary of the issues surrounding using boreholes as monitoring points.

Depth. Deep boreholes can intersect deeper fractures and therefore tap older groundwater, which tends to have lower nitrate concentrations than more recently recharged groundwater. However, the depth of the borehole is often no indication of the depth of groundwater – for example, a 100 m deep borehole may be obtaining most of its water from an 8 m deep fracture.

Mixing of waters. Linked to the depth of the borehole is the issue of mixed samples. There is often more than one inflow into a borehole: for example, fractures at 20 m, 40 m and 80 m depth. Therefore, the pumped sample can be a mixture of different ages of groundwater, with significantly different nitrate concentrations. This has been demonstrated in the Dumfries basin (MacDonald et al. 2003, MacDonald & Abesser 2004), where mixed samples from deep boreholes consistently underestimate the nitrate concentrations in modern recharging groundwater.

Boreholes must be pumped to get a sample. This is relatively easy where a borehole is equipped with a pump, but for unused boreholes, samplers must carry a pump. If the borehole has not been pumped for some time, the standing water in the borehole must be purged so that a representative sample of groundwater from the surrounding aquifer can be obtained. Shallow, narrow diameter boreholes have a relatively small volume, and can be easily purged within a short space of time. Deeper and/or large diameter boreholes require much larger volumes of water to be purged.

Protection from direct contamination. Boreholes are relatively easy to protect against direct contamination, since they are a narrow, well-defined source, and can be housed in a manhole cover or small shed. Important issues are whether the casing stands proud of the ground surface, the presence of concrete around the wellhead, and whether the borehole is open at the top. Pumping boreholes are generally not in areas where they can be interfered with by animals, since this could damage the pump.

Protection from indirect contamination. The only way to protect a borehole against indirect contamination (leakage of contaminated shallow groundwater down the borehole casing) is to construct it with a suitable depth of steel casing from the ground surface that is effectively sealed. There are only two ways of knowing the borehole construction at depth: from the availability of good quality construction logs from the time of drilling, or the use of downhole geophysics. For most of the boreholes in the monitoring network, some information on borehole depth is available. However, detailed information on borehole construction is not generally available. For the purposes of this assessment, two assumptions have been made: that public water supply boreholes are always effectively constructed, and that high yielding, usually deep industrial boreholes and recently drilled boreholes are likely to be effectively constructed. For all other boreholes where data are not available, no attempt has been made to assume details of construction.

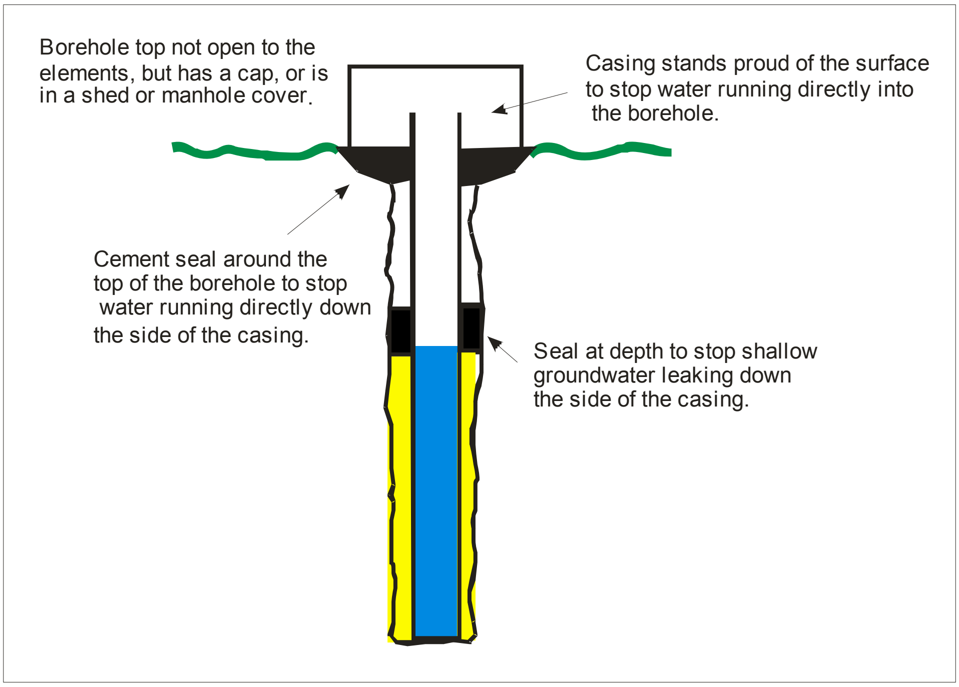


Figure 13 Schematic of an effectively constructed borehole.

Figure 14 A purpose drilled observation borehole (left) and the headworks of an effectively constructed pumping borehole (right).

5 Identifying poor monitoring sites

In this chapter we review the 151 sites on the network that were assessed during the fieldwork, and discuss the criteria used to judge whether the site is compromised. At the outset several points are of fundamental importance:

1. The judgement made here is whether the site itself is compromised, not whether it is in a suitable location – this is dealt with later (chapter 6 and 7) in our assessment of the overall effectiveness of the network for monitoring nitrate.
2. Sources that are judged to be compromised are both vulnerable to local contamination, and exposed to a source of contamination. Therefore, a poorly constructed source is still deemed acceptable if there is a low probability of local point sources contaminating the sites.

5.1 GENERAL CRITERIA

The criteria used to judge the sites were broadly based around several key questions:

The condition of the source

- Is the source vulnerable to direct contamination into the borehole or down the side of the casing?
- Is it vulnerable to indirect local contamination? For example could shallow groundwater enter the source, contaminating the deeper groundwater which has a longer flow path.

Hazards around the source

- Are there any hazards within 10 m of the source?
- Are there potential hazards within 50 m of the source or within the zone of influence of the source?

Sampling arrangements

- Is the existing sampling procedure adequate? For example, can a purged sample be easily taken? Could the water chemistry change between source and sample point?
- Are arrangements with owners adequate? For example, is it particularly difficult to arrange to take a sample?

These questions were used only as a guide, and not used mechanistically to produce a judgement on each source. Fundamental to the process was the field assessment of the hydrogeologist who noted whether there were any mitigating circumstances for sources, or whether improvements could be easily made to rectify any shortcomings.

Figure 15 illustrates how these questions were used to judge the quality of individual monitoring points. The following sections describe the criteria used to answer these questions for springs, wells and boreholes.

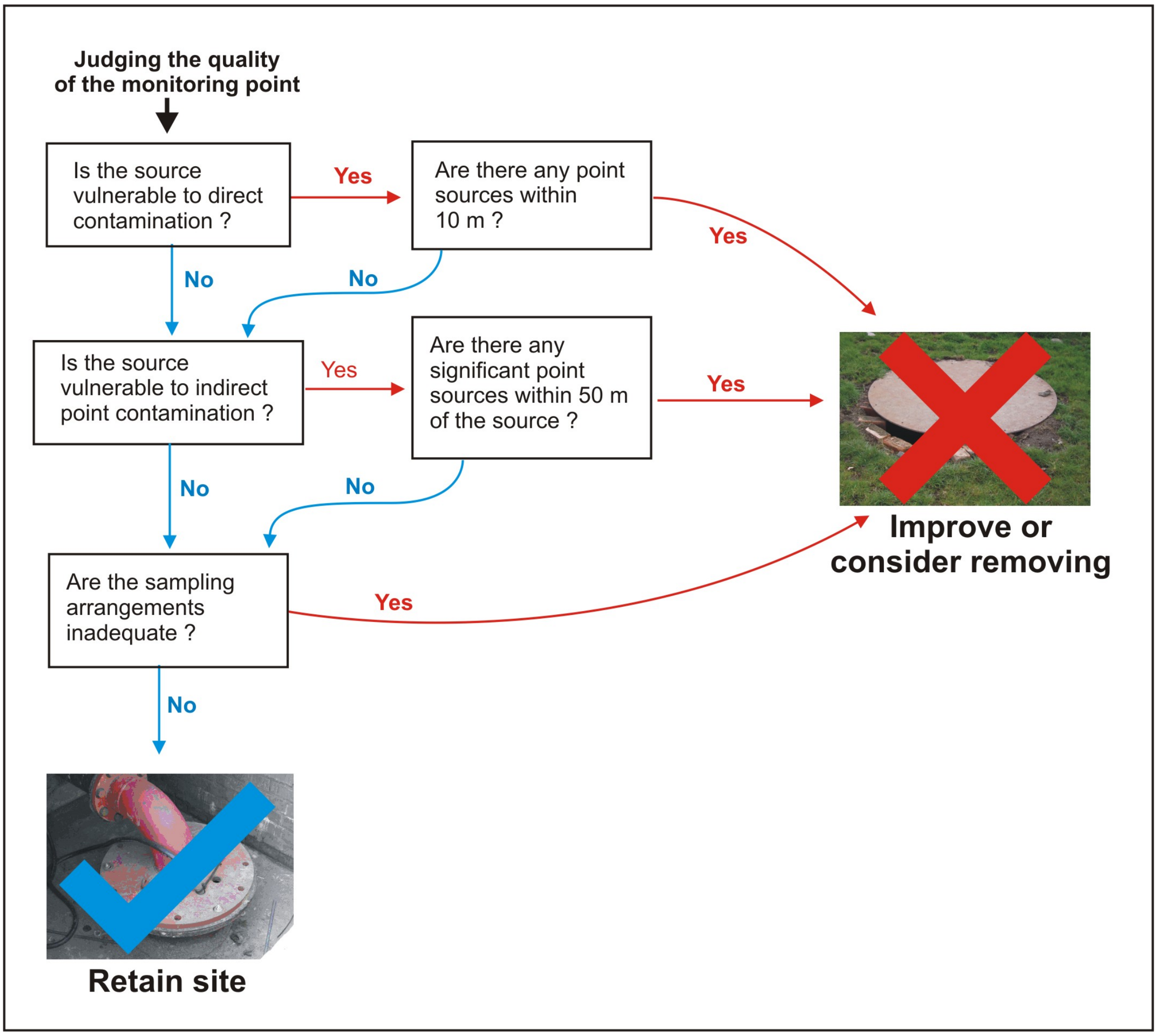


Figure 15 An outline of the methodology for assessing the quality of individual monitoring points for the Scottish nitrate groundwater monitoring network.

5.2 SPRINGS

5.2.1 Criteria

(i) The source of the spring must be accurately identified (see Figure 9). Many spring boxes will have an inflow pipe to them, so the assessing hydrogeologist must also judge whether the pipe is tapping a source in the vicinity or is taking water from another spring hundreds of metres away.

(ii) There must be no significant point source hazards within 10 m of the source.

(iii) The spring must have a reliable flow throughout the year. High flows are more desirable as the spring will be less dominated by any point sources in the catchment.

(iv) The springs must be protected from direct contamination from livestock – for example be in a fenced off area and capped.

(v) The area above the spring should not be wet.

(vi) The spring must be able to be sampled with confidence. For example, a tap in a house will suffice if the flow to the house is regular. However, if the distance from spring to sample tap is several kilometres and the usage low, then the spring would need to be sampled at the source.

5.2.2 Improvements and further assessment

- If there is uncertainty about the location of the spring then further work may be required to identify the actual source. If the source can be judged to an area of several tens of metres that is likely to be sufficient, since any potential point sources can be identified.
- Some springs may require fencing to keep out animals, or an improvement to the construction of the spring box.
- A properly constructed cut-off drain or bund could be installed to stop the sample being contaminated by runoff.
- Improved access to sample the spring at its source, or a sample tap downstream.

5.3 WELLS

5.3.1 Criteria

(i) The well must be in regular use all year, so that purged samples can be taken. An unused well cannot be satisfactorily purged prior to sampling.

(ii) The source of the water in the well must be clearly identified (see Figure 11). If there are inflow pipes to the well, then their source must be identified.

(iii) The well must be in a fenced off area away from livestock and protected at the top, preferably with a cover.

(iv) There should be no point source hazards within 10 m. Point source hazards at greater distances can be acceptable if the pumping rate from the well is sufficient to dilute the effect of the point source.

(v) The sample arrangements must be satisfactory and the sample point close to the source. If the abstraction from the well is sufficient to purge the pipework then a sample point far from the well is acceptable.

5.3.2 Improvements and further assessments

- If the well is not used regularly, has a nearby point source of contamination or has unidentified inflows, then there is little that can be done to improve the source.
- The two areas that can be improved, are fencing around the source, and improved sampling arrangements, such as a sample tap close to the well, or adequate purging of pipework.
- It is difficult to materially alter the headworks of a well – however, small improvements (such as covers) may be possible.

5.4 BOREHOLES

5.4.1 Criteria

(i) The location of the borehole must be clearly identified. For example some boreholes have been buried under tarmac etc. and their exact location is uncertain.

(ii) The depth of the borehole should be known, or estimated with a degree of confidence.

(iii) The borehole must not be susceptible to *direct* contamination if there are any hazards within 10 m (Figure 13). For example: the borehole must be covered (e.g. under a manhole cover, or in a small shed), there should be a concrete seal around the top of the borehole, and the borehole casing should protrude above this plinth. Where the pumping rate is high, some of these criteria can be relaxed slightly.

(iv) The borehole must not be susceptible to *indirect* contamination if there are significant point source hazards within 10 m (or 50 m if the borehole is not pumping). Therefore, there must be reasonable confidence that the casing has been sealed at depth (see Figure 13) to stop shallow groundwater leaking down the side of the casing.

(v) If the borehole is not pumping, there should be no major point sources of contamination within 10 m even if the construction is excellent. This is to prevent the results being dominated by a local point source.

(vi) The sampling arrangements for the borehole must be adequate. For example, the borehole must be able to be adequately purged and a sample taken before treatment or retention in a large storage tank. Preferably a sample should be able to be taken four times a year. However, an exception could be made for some irrigation boreholes if they are in suitable locations.

5.4.2 Improvements and further assessments

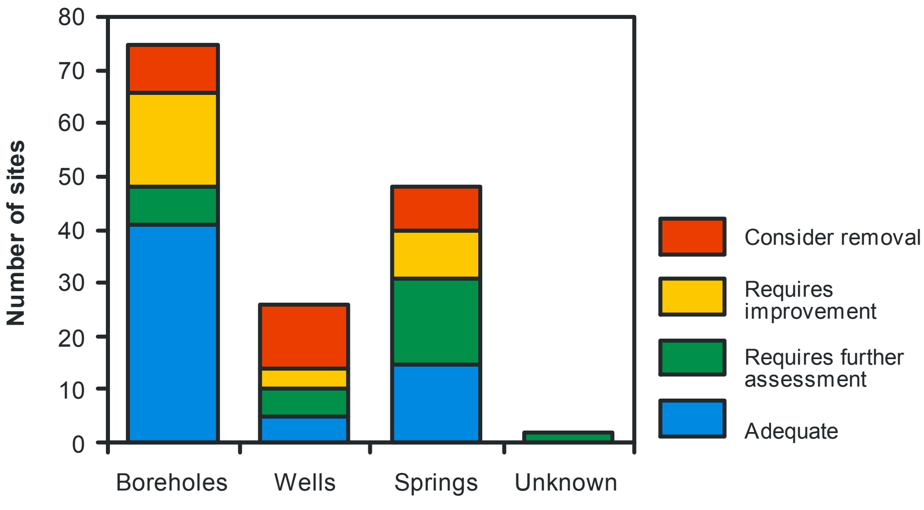
- It is difficult to find out more about a borehole once construction has been completed. The only reliable way is to pull out the pump and rising main, and carry out downhole geophysics, including CCTV scans. This can then give information about the depth of the casing, the condition of the grout, the inflow levels etc. However, there are considerable risks with carrying this out in an existing borehole – particularly if it is several years old, and of narrow diameter. The geophysical equipment can get stuck, or the borehole damaged by removing the pump, or running the geophysical equipment.
- Fitting a sample tap to the borehole at the headworks would be an excellent improvement to most boreholes. A sample is best taken before the water has had contact with air, therefore a purpose built sample tap allows a proper sample to be taken, and parameters such as dissolved oxygen, or the age of the water (using CFC or SF_6) to be measured.
- Minor improvements to the headworks could be carried out to improve the protection against direct contamination. This may be installing or improving a manhole cover, concrete plinth, fence or borehole shed.
- All sources must be properly purged before sampling. In some cases, better sampling arrangements must be put in place, to enable the borehole to be purged and a reliable sample to be taken.

5.5 RESULTS OF THE 2005 SURVEY

The above criteria were applied to the 151 monitoring points assessed during the current survey. The detailed results are given in the appendix and a summary in Figure 16. In brief:

- 61 of the 151 sites (40%) are adequate and can continue to be monitored with no improvements.
- There are serious concerns about 29 of the 151 sites (19% of the sites assessed and 13% of the total nitrate network). These sites should be considered for removal from the network. The sources found to be least reliable were shallow large diameter wells. This is consistent with observation from the Macaulay Institute which indicates that shallow wells in agricultural land have nitrate concentrations that vary throughout the year.
- 30 sites (20%) require further assessment before being judged suitable. Most of these sites are springs and require further time to try to identify the source.
- 31 sites require improvements to the monitoring points – the improvements range from better sampling protocol to additional engineering works to the headworks.

Although not formerly assessed this time, the other 68 sites on the network were chosen in 2001 after going through an assessment exercise using similar criteria (see Ball & MacDonald 2002). Therefore, many of these sites would be considered adequate.



	Boreholes	Wells	Springs	Unknown	Total
Adequate	41	5	15		**61**
Requires further assessment	7	5	16	2	**30**
Requires improvement	18	4	9		**31**
Consider removal	9	12	8		**29**
Total	**75**	**26**	**48**	**2**	***151***

Figure 16 A summary of the assessment of 151 sites on the Scottish groundwater monitoring network.

6 Interpreting nitrate data from the network

6.1 NITRATE CONCENTRATIONS ACROSS SCOTLAND

The nitrate data for the 219 sites have been interpreted in the light of the information gathered during this project. Although this was not one of the aims of the project, some initial analysis was required to help understand whether the monitoring network was being effective. Further analysis and interpretation of the data can be done at a later stage, in another project.

Figure 17 shows the nitrate data from the monitoring network. Most of the data are from sampling during the summer of 2003; however, later data have been used for some sites, where 2003 data are not available.

1. There is a wide range of nitrate concentrations measured across the Scottish network: the mean concentration is 18 mg-NO_3 l^{-1} and the median 10 mg-NO_3 l^{-1}; the 25 and 75 percentile are 1.5 and 25 mg-NO_3 l^{-1} respectively.

2. There is a clear difference between nitrate concentrations measured in the NVZs and outside the NVZs (see Figure 17):

   - Within the NVZs, the mean concentration is 25 mg-NO_3 l^{-1} and the median 17 mg-NO_3 l^{-1}. The 25 and 75 percentiles are 5 and 33 mg-NO_3 l^{-1} respectively.

   - Outside the NVZs, the mean concentration is 9 mg-NO_3 l^{-1} and the median 4.4 mg-NO_3 l^{-1}. The 25 and 75 percentiles are 0.9 and 15 mg-NO_3 l^{-1} respectively.

3. It is clear that, although the average nitrate concentrations in the NVZs are high, there is considerable variation, with 37% of the sites having less than 10 mg-NO3 l^{-1}.

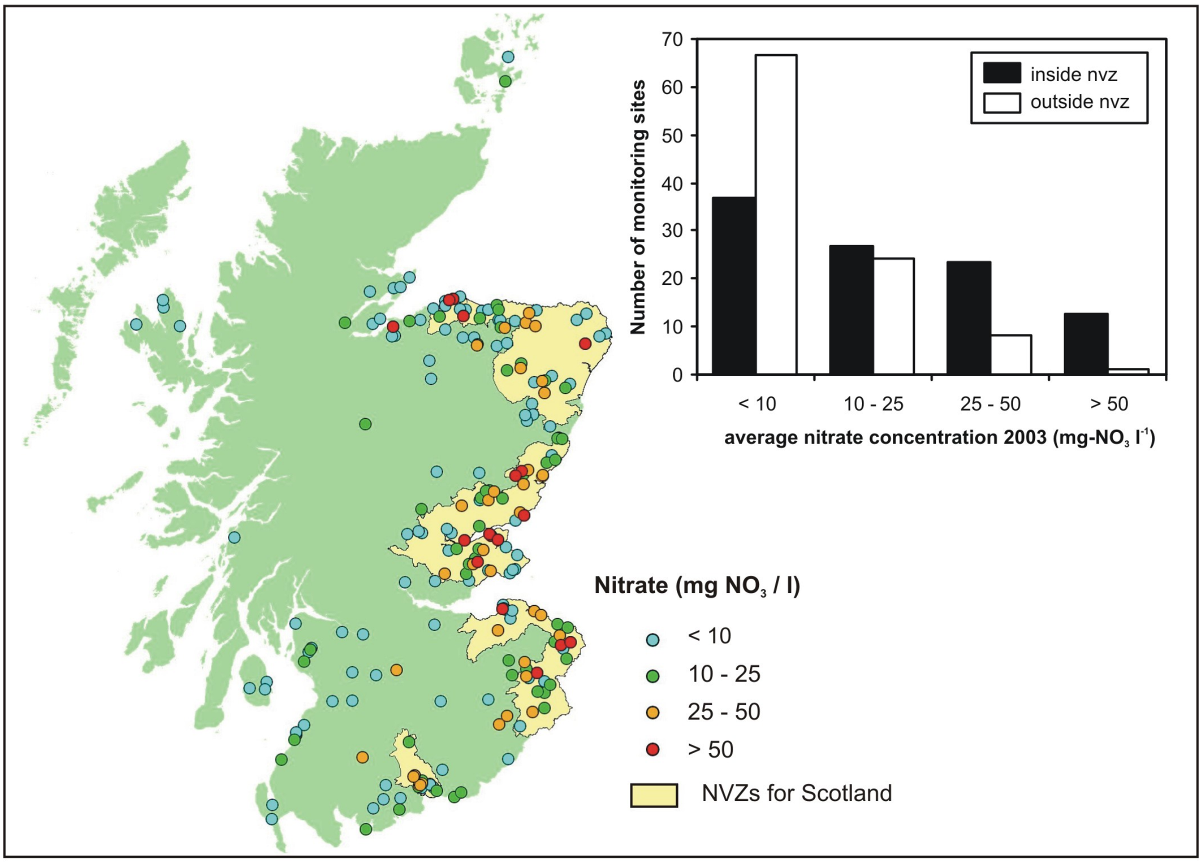


Figure 17 Nitrate data from the Scottish groundwater monitoring network. The data shown are the average results for the summer of 2003, or for sites without such data, those taken during 2005 sampling.

6.2 FACTORS INFLUENCING NITRATE CONCENTRATIONS

6.2.1 Agriculture

Many of the elevated nitrate concentrations found in Scottish groundwater are due to modern agricultural practice. Additional sources of both organic and inorganic fertilisers are required to maintain high levels of production; to be used by the crops, nitrogen has to be in the form of ammonia or nitrate, which is highly soluble. Any nitrate that remains in the soil after the crop has ceased to grow, or has been harvested, is easily leached.

Therefore, we would expect a good correlation between land use and measured nitrate concentrations in groundwater. This has been demonstrated at a catchment scale for Scotland for surface water (see Dunn *et al.* 2004). It is also inferred in Figure 17 for groundwater: nitrate concentrations are elevated in the NVZ areas, where much of the intensive agriculture takes place.

Figure 18 shows the relationship between groundwater nitrate concentrations and land use within the monitoring points' zone of influence (as identified using GIS, modified by the field assessments of 2005 and 2001).

- Arable areas, mixed arable and grassland, and dairy, pigs and poultry have the greatest nitrate concentrations, with 18% of sites in these areas exceeding 50 mg-NO_3 l^{-1}.
- Improved grassland by itself (i.e. where not mixed with arable, and with no identifiable pig, poultry or dairy farming) has intermediate nitrate concentrations. This reflects the lower intensity farming of cattle production.
- Woodland and semi-natural areas have the least nitrate concentrations with virtually all sites below 10 mg-NO_3 l^{-1}.
- There is still variance that is not explained by the land use – for example, more than 50% of the sites in arable, and dairy areas have less then 25 mg-NO_3 l^{-1}.

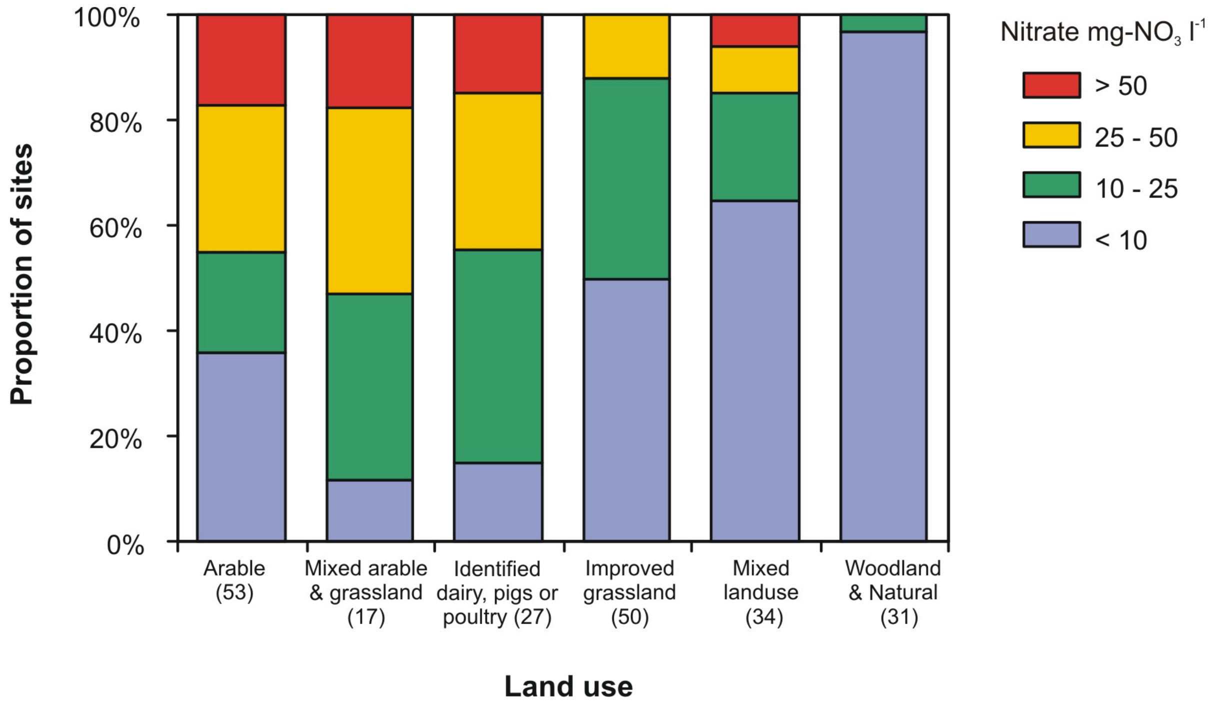


Figure 18 The relation between land use and measured nitrate concentrations in the Scottish groundwater monitoring network. The number of sites for each category is in brackets.

6.2.2 Other factors

Analysis of the relationship between land use and nitrate can be taken further by using estimates of *residual nitrogen* across Scotland. Residual nitrogen is nitrogen that that is left in the soil (and is available for leaching) after crop requirements have been met. A method to estimate and spatially distribute residual nitrogen has been developed for Scotland (Dunn *et al.* 2004) which uses landcover data from the LCS88 dataset (MLURI 1993) and the results of the annual Agricultural and Horticultural census.

If hydrological systems were simple, the concentration of nitrate in runoff and groundwater could be determined by factoring the residual nitrogen by the *dilution effect* of rainfall. Assuming that all residual nitrogen can be leached (which is likely in most of Scotland in all but the driest winters), the measured nitrate concentrations would be the residual nitrogen divided by the annual volume of effective rainfall. In areas with high residual nitrogen and low rainfall, the nitrate concentrations in runoff and groundwater would be expected to be high; however if the rainfall was greater, or the residual nitrogen less, measured nitrate concentrations would be lower.

However, this simple direct relationship between predicted groundwater nitrate concentrations (from residual N and rainfall) and actual groundwater nitrate concentrations is often poor due to a number of different factors (Figure 19) including:

Point source contamination. If there is a point source of nitrate close to the borehole (for example a fertiliser store or manure heap), then nitrate concentrations measured from the monitoring point may be greater than expected from diffuse agricultural sources.

Soil processes. In some conditions, denitrification can occur within the soil, changing nitrate to nitrogen or nitrous oxide gas. Poorly permeable soils also help route the nitrate to surface water, making less available to infiltrate to groundwater, and delaying the time it takes for changes in activity to effect changes in groundwater.

Unsaturated zone. If the superficial geology, and unsaturated part of the bedrock geology, is poorly permeable then the recharging high nitrate groundwater cannot reach the water-table

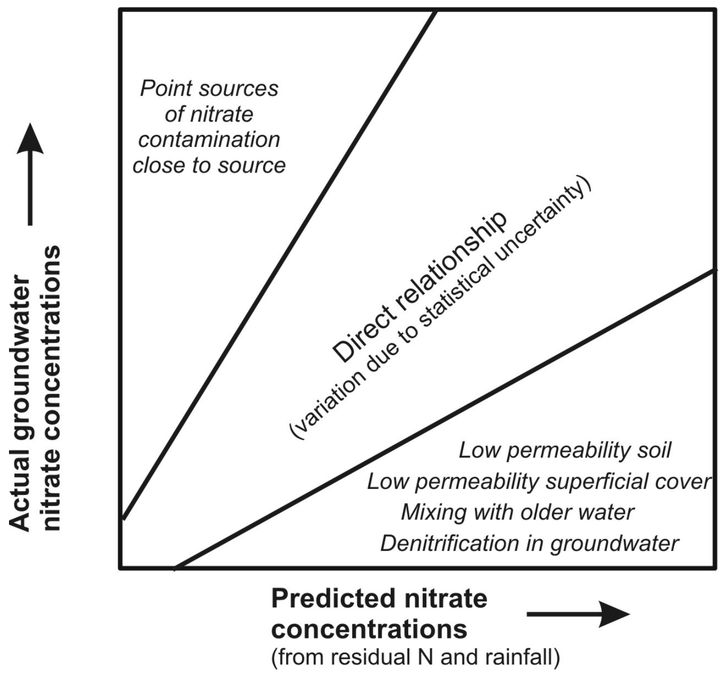


Figure 19 The factors that affect the measured concentration of nitrate in groundwater. The direct relationship is between measured nitrate concentrations and that predicted from the residual N and rainfall.

but is diverted into shallow groundwater, or runoff. The groundwater directly beneath the site therefore will have much of its origin from elsewhere in the catchment where the superficial deposits are more permeable. In addition, the low permeability will slow the downward movement of high nitrate recharge, meaning that recent increases in nitrate loading may not be observed for several years or decades (see below).

Mixing with older waters. Extensive use of nitrogen fertiliser started in the 1950s; hence, groundwater older than about 1950 generally contain little nitrate. In aquifers containing older groundwater (for example the Permian and Devonian sandstones) the effect of the modern high nitrate recharge is diluted and the monitored nitrate concentrations appear low.

Denitrification in groundwater. Processes within aquifers can reduce nitrate to nitrogen gas, thus removing it from groundwater. This can occur when there are reducing conditions within the groundwater (e.g. there is no dissolved oxygen present). This is a particular issue in the Netherlands, Belgium and Denmark where much of the deeper groundwater is reducing, and thus contains no nitrate.

6.3 THE SCOTTISH DATA

6.3.1 Overview

The large database of information collated for each monitoring point can be used to further interpret the measured nitrate concentrations from the network. Figure 20 shows the measured nitrate concentrations plotted against the expected nitrate given the modelled residual nitrogen and the effective rainfall from 1989-98 (based on a method developed by Dunn *et al.* 2004). The calculation ensures that both the measured and predicted concentrations are in the same units, mg-NO_3 l^{-1}. This analysis has considerable statistical uncertainty within it, given the scale at which the residual N has been calculated, and local variability over rainfall. However it is a useful illustration of the impact of other factors on the measured nitrate concentrations.

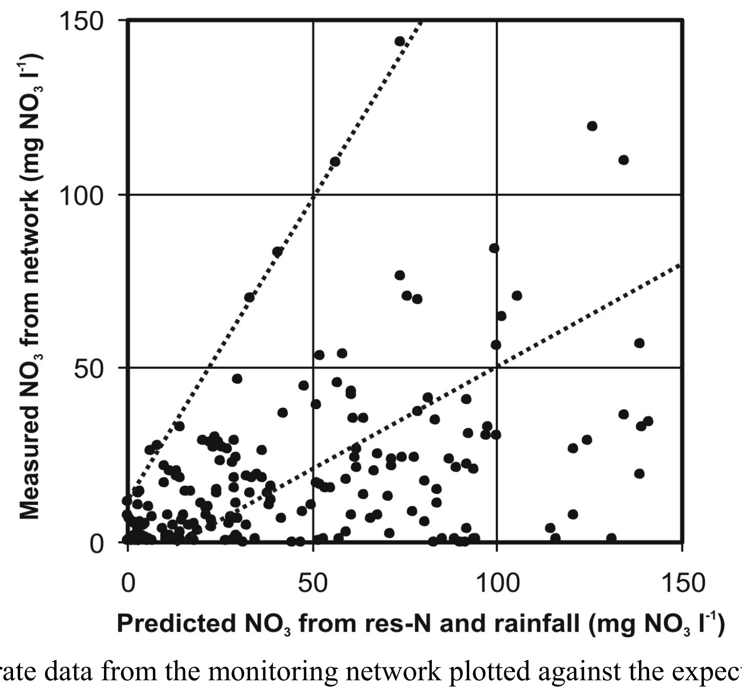


Figure 20 Nitrate data from the monitoring network plotted against the expected nitrate concentration given the modelled residual nitrogen and meteorological data from NIRAMS. Dotted lines are for comparison with Figure 19 and indicate the likely statistical uncertainty of a direct relationship. Datapoints plotting on the upper limit of this uncertainty are mostly sites with dairy, pigs or poultry in the zone of influence.

Several points about the groundwater quality network can be noted from Figure 20:

1. There are some data which conform to the broad direct relation between predicted nitrate (from residual-N & rainfall) and measured nitrate concentrations.
2. There are few data that indicate high nitrate concentrations where the nitrate concentrations are predicted as being low. This suggests that most of the data from the monitoring network has not been compromised by point source contamination. The datapoints that plot at the upper limit of uncertainty in the direct relationship are mostly associated with the presence of dairy, pigs or poulry in the zone of influence.
3. A considerable number of monitoring sites have lower nitrate concentrations than predicted from residual N and rainfall. Figure 19 shows various factors that can account for this. The importance of these factors in Scotland is discussed in more detail in the remainder of this section.

Denitrification. Groundwater samples with no measurable nitrate from sites in areas where there are many nitrate pressures may have undergone denitrification. Chemistry samples were taken for a third of the sites visited; redox potential and dissolved oxygen were measured and minor element chemistry analysis undertaken. From this, it was possible to infer which sites were likely to have undergone denitrification. Figure 21 indicates that all these site lie close to the x-axis on the graph. It is likely that the other sites close to the x-axis (for which no detailed chemistry data was available) will also have undergone denitrification.

Mixing with older waters. Previous studies in the Dumfries area have demonstrated that the presence of older groundwaters decreases the measured nitrate concentrations in groundwater. The few sites for which residence time indicators were measured are plotted in Figure 21. For all the sites, the measured nitrate is less than predicted. This technique may be particularly useful if applied to sites with predicted nitrate greater than 50 mg-NO_3 l^{-1}.

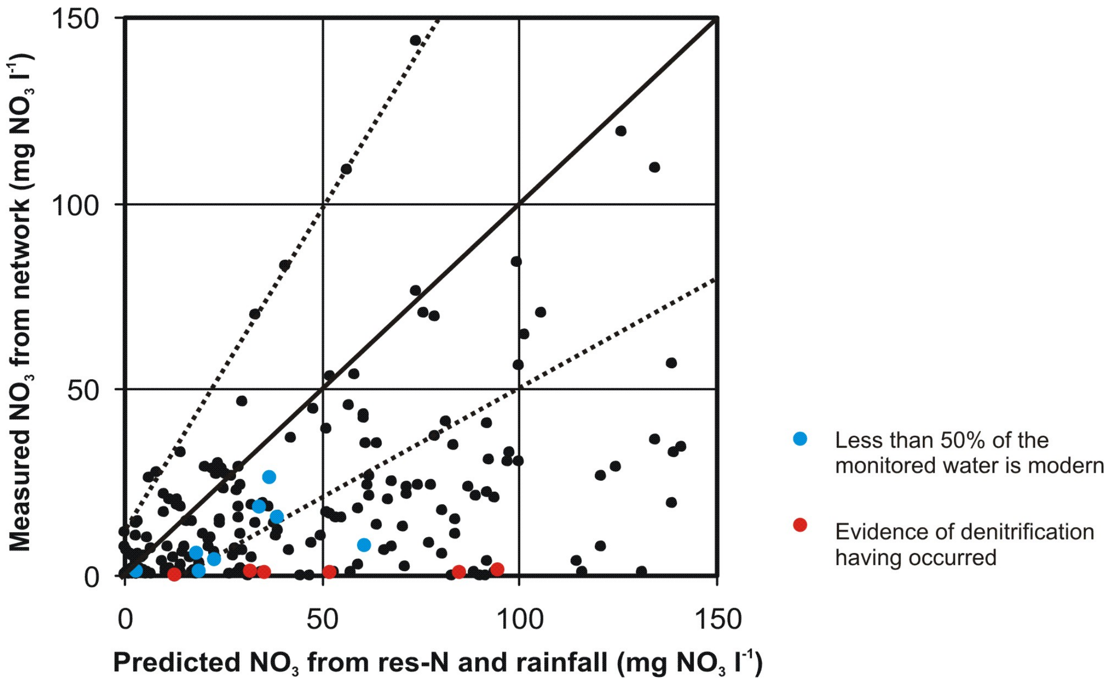


Figure 21 The effect of denitrification and mixing with older water on the measured nitrate concentrations. The data shown in colour are from a subset on which chemistry analysis was undertaken. Refer to Figure 19 for an explanation of the lines on the graph.

6.3.2 Initial analysis

Some preliminary statistical analysis was undertaken using information from the database constructed for the project. Various techniques were used, including multiple regression, ANOVA, stepwise regression and simple regression. The bullet points below indicate initial results and should be used as a starting point for further analysis.

- As discussed above, the greatest predictor of nitrate concentrations in groundwater is the presence of dairy, pigs or poultry within the zone of influence of the source. Other hazard factors, such as the land use and the average residual nitrogen within the zone of influence are also highly significant.
- There is no discernable relationship between the source depth or type, and nitrate concentrations. This is different to what has been observed in many other countries, and may be due in part to the dominantly fractured nature of aquifers in Scotland.
- The superficial permeability and to a lesser extent the bedrock permeability have some influence on the measured nitrate concentrations. Poorly permeable aquifers generally have lower nitrate concentrations. There was little discernable trend, however with aquifer vulnerability. This is not unexpected since nitrate is generally conservative in Scotland (apart from the sites where denitrification takes place) and widely dispersed over space and time. All aquifer vulnerability classes are vulnerable to this type of pollution (Ó Dochartaigh 2005). A large study in the US also found that aquifer vulnerability (using the DRASTIC method) was not a good predictor of nitrate (Canter 1996).
- The soil parameters SPI (standard potential infiltration) and soil drainage both have an effect on measured nitrate concentrations. SPI apportions soil water between groundwater and surface water, therefore high SPI means more of the soil water in the zone of influence will leach to groundwater. The soil drainage indicates how wet the soil is and may infer denitrification in the soil – monitoring sites with drier soils in their zone of influence were found to have greater nitrate concentrations.

The data collected for all 219 sites of the monitoring site can be used to carry out further analysis on the factors controlling nitrate concentrations in Scotland.

7 Improving the Scottish nitrate monitoring network

7.1 SCOPE

Part of the remit of this review was to make recommendations for improving the groundwater nitrate monitoring network in Scotland. This is looking beyond the quality and suitability of different sites as detailed in Chapter 5 to what the characteristics of the overall network should be. Two provisos apply: (1) the costs of improving the network must be taken into consideration and (2) the network will also be drawn on for other uses, such as monitoring under the water framework directive.

The recommendations made here are only a starting point for discussion with SEPA and the Scottish Executive, and are not a point-by-point workplan for future implementation.

7.2 DIVERSE NETWORK

Scotland is a diverse country: land-use, climate, geology, soil and groundwater all vary considerably across the country. Chapter 6 has illustrated that all these factors can affect the measured nitrate concentrations in groundwater. Therefore, any network that seeks to characterise and understand nitrate concentrations in Scottish groundwater must reflect this variability (see Figure 22).

- Since the network is focussed on monitoring *nitrate*, monitoring points should first be targeted to areas where nitrate in groundwater is expected to be elevated (cultivated areas) with some background monitoring points for reference. Lilly et al. (2003), when designing the original network, suggested that a suitable division would be 75% of the network in cultivated areas and 25% of the network in areas where nitrate is expected to be low. This approach appears reasonable.
- Groundwater resources are diverse within the cultivated areas (Figure 22). There are many different aquifers in Scotland – from shallow sands and gravels where groundwater has a low residence time, to deep aquifers where groundwater may be thousands of years old. An effective network must seek to monitor groundwater in these different environments.
- Groundwater sources are diverse. Groundwater is abstracted from boreholes, wells and springs in Scotland. There are in excess of 4000 boreholes in Scotland and over 20 000 springs and wells in regular use for private supply (MacDonald *et al.* 2005). Much of the 330 megalitres abstracted every day from Scottish groundwater is from high yielding boreholes and large springs. However the 20 000 private supplies from small springs and wells are significant and should form part of the monitoring network.
- The monitoring network should also reflect other important factors, such as the effects of different soils on measured nitrate concentrations.

The Scottish groundwater monitoring network was first devised in a manner that would reflect this diversity (Lilly et al. 2003). However, when SEPA first set up the network not enough emphasis was placed on choosing good quality sources (hence the requirement for this project). Therefore, a balance should be struck between the availability of good quality sources and reflecting the diversity of Scottish conditions, and a pragmatic approach taken to any system devised to reflect diversity.

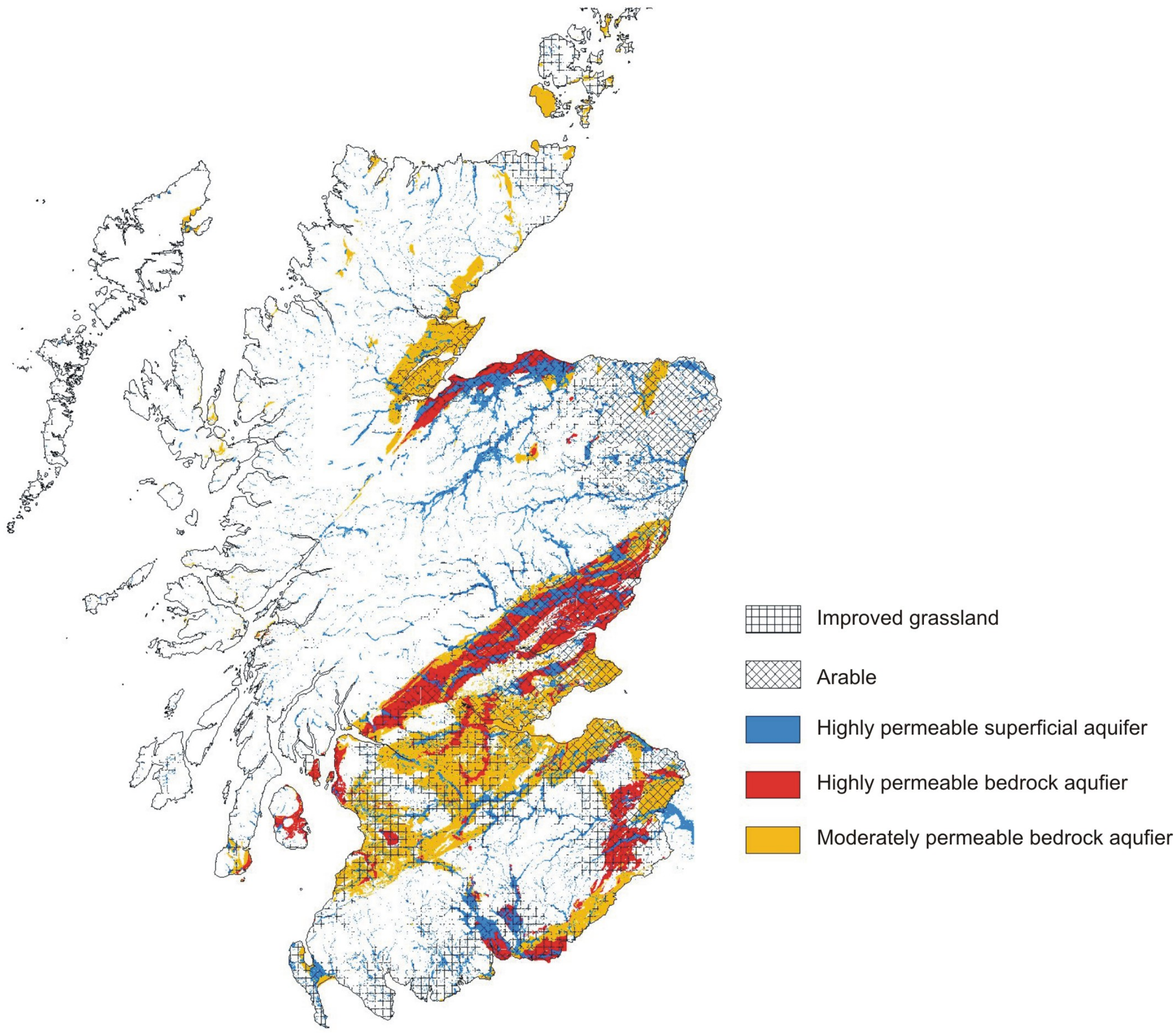


Figure 22 Agricultural areas in Scotland in relation to the main aquifers. This diagram illustrates the diversity of hydrogeological conditions within the agricultural areas. Soil conditions and climate also varies considerably.

7.3 ACTIVE INTERPRETATION AND MANAGEMENT

7.3.1 Interpretation

The data from the network will require to be actively interpreted. An inevitable outcome from having a diverse network is that the results of the monitoring cannot be interpreted only by referring to agricultural practice. The data must be interpreted in light of the other factors that affect nitrate concentrations in groundwater: dilution, mixing of groundwaters, denitrification, time lags due to aquifer permeability, elevated concentrations in shallow systems etc. All data can be useful if interpreted judiciously and within context. This approach is in line with current thinking in other European countries (see Figure 23). The context for monitoring data is required to help understand whether policy measures are actually working.

An example of this approach for Scotland is the data from the Nithsdale NVZ. Within the Nithsdale NVZ is one of Scotland most prolific aquifers – the Permian sandstone basin around Dumfries. The aquifer comprises a large groundwater resource with some of the water being thousands of years old (MacDonald et al. 2003). However, there are also shallow sands and gravels which overlie this aquifer. It is necessary to monitor both the shallow and the nationally important deeper aquifer. However, a simple interpretation of the monitoring data which does not take into account the aquifer conditions would indicate that some boreholes in the area had moderate nitrate concentrations (< 25 mg-NO_3 l^{-1}), and others very high concentrations (> 50 mg-NO_3 l^{-1}). Further interpretation of the data using age dating demonstrated that the data were consistent. Some of the samples from boreholes penetrating the sandstone were a mixture of modern high nitrate water and older low nitrate water; therefore, their overall nitrate concentration was low with a slowly rising trend as the older water is depleted.

7.3.2 Active Management

Once the monitoring network has been extended and invigorated in the coming years, it will require ongoing management. Various aspects of a monitoring point can change, for example the land use, the condition of the headworks, pumping rate etc. In addition, some sources may become decommissioned, or change owners. Therefore, the monitoring network will require be actively managed by SEPA and periodically reviewed.

1. The network should be actively managed by SEPA hydrogeologists, who have some

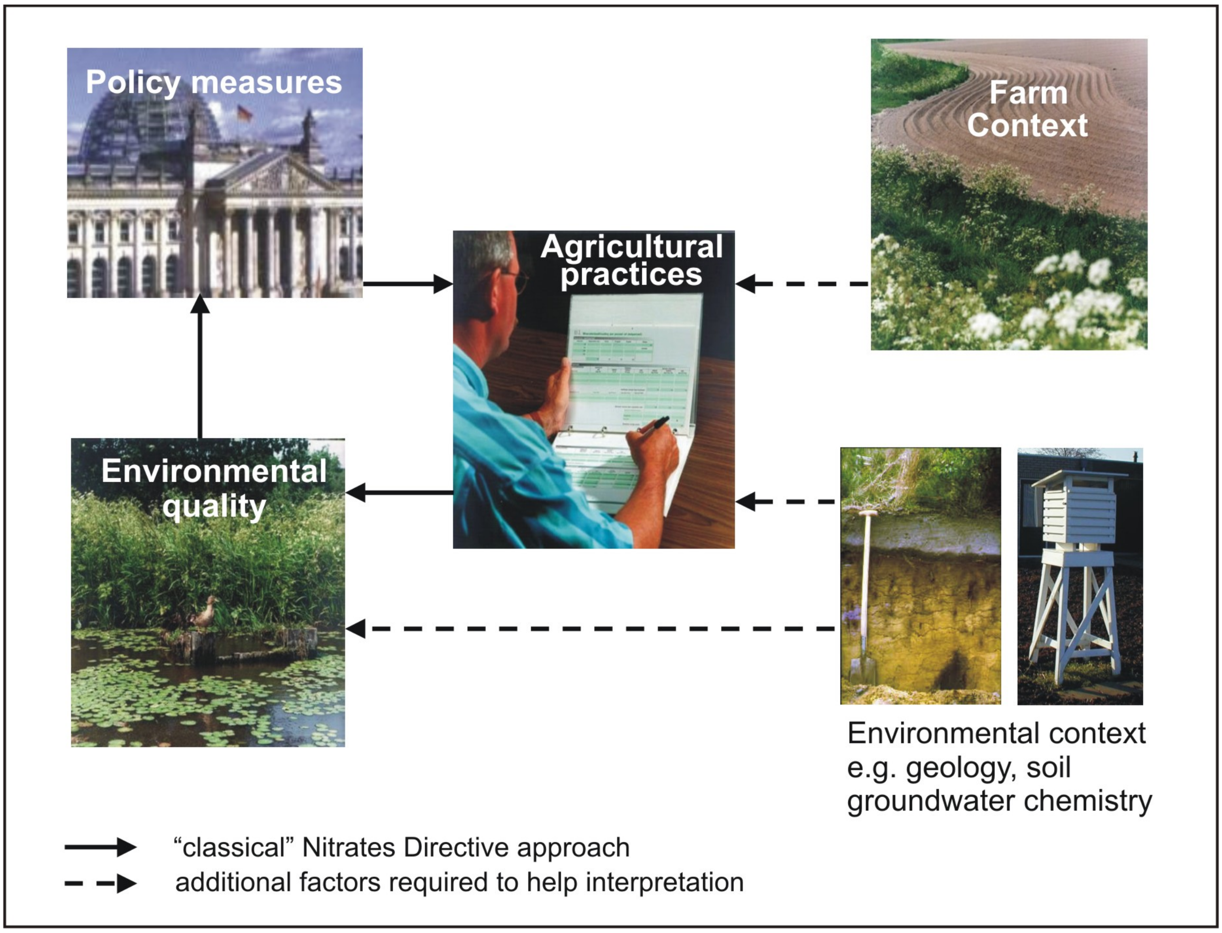


Figure 23 Monitoring the effects of policy measures on environmental quality. Solid lines reflect factors that must be monitored according to EU guidelines. Dashed lines are the additional factors that should be monitored to help interpret data and understand whether policy measures are working (amended from Fraters *et al*. 2005).

practical experience of the network.

2. Individual sources should be reviewed, possibly annually, by using a simple checklist. This could be based on the proforma used in this study.
3. The ongoing BGS/SEPA study of baseline groundwater chemistry across Scotland can help to identify good new sites for monitoring. These can be incorporated into the network or used as reserves, if others in the vicinity fail.

7.4 WELL HEAD MEASUREMENTS

Given the importance of denitrification, and dilution from mixing with older groundwaters, it is essential that wellhead monitoring is conducted on the network. Sites should be improved so that samples can be taken without contact with air, and dissolved oxygen, pH and Eh (redox potential) measured. This will indicate whether the groundwater has undergone natural denitrification. Sampling should also be undertaken to determine the residence time of the groundwater sampled. This will help to explain situations where the measured nitrate is different to that expected from the agricultural practices.

A dedicated sample tap would also ensure that samples are taken from the same place every time. With the current network there is some confusion over where samples are taken, and sometimes even if they are from the same source. It is important that a sampling protocol is developed such that a good groundwater sample is always taken, even if the sampler has little knowledge of groundwater resources. A dedicated sample tap is a fundamental part of this protocol.

7.5 FOCUSSED EFFECTS MONITORING

Given the diverse nature of the Scottish groundwater monitoring network, it is not suitable as the primary dataset for monitoring the effects of the Action Programmes developed to limit nitrate contamination. For this it is important to have sites that are in a controlled environment and that will respond rapidly to changes in agricultural practice. A separate programme of focussed monitoring should be developed in tandem with the national groundwater monitoring network. The results from these studies can be scaled up to help interpret changes in the national network as well as be used on their own to help understand the success of the Action Programmes.

Below are some of the advisable characteristics of these focussed monitoring points:

- They should be in areas where the environmental and farm factors can be characterised.
- They should tap generally shallow groundwater so that changes can be observed within a matter of years; deeper groundwater sources could also be used to help characterise the system as a whole.
- They should be used as investigation boreholes and data collected from them as they are drilled – such as pore-water nitrate concentrations and groundwater inflows.

7.6 GAP ANALYSIS

Some preliminary analysis has been undertaken on what the ideal spatial spread of a national nitrate monitoring network should be for Scotland and how the current network compares. The analysis is based on the assumption that the network should be primarily targeted on the parts of Scotland where nitrate pressures are greatest. The following methodology was used.

- Scotland was divided into seven areas to ensure a geographical spread of sources (Figure 24). These areas comprised the existing NVZs and other areas with high nitrate loading and account for 97% of the residual nitrogen produced in Scotland. To ensure the network is monitoring the high nitrate areas in Scotland, 75% of the network should be targeted to these areas. The remaining 25% could be used as a baseline against which the rest of the network is compared.
- The total residual nitrogen was calculated for each of the areas, and expressed as a percentage of the whole. For each area, the land use was divided between arable and improved grassland and the total residual nitrogen calculated for each. This indicates whether crops or livestock are the greater nitrate pressure in each area (see Table 6).
- If the network is to be targeted on areas with highest nitrogen pressures, then the proportion of residual nitrogen in each area can be directly related to the number of monitoring sites; e.g. areas with highest residual nitrogen should have the most monitoring points.

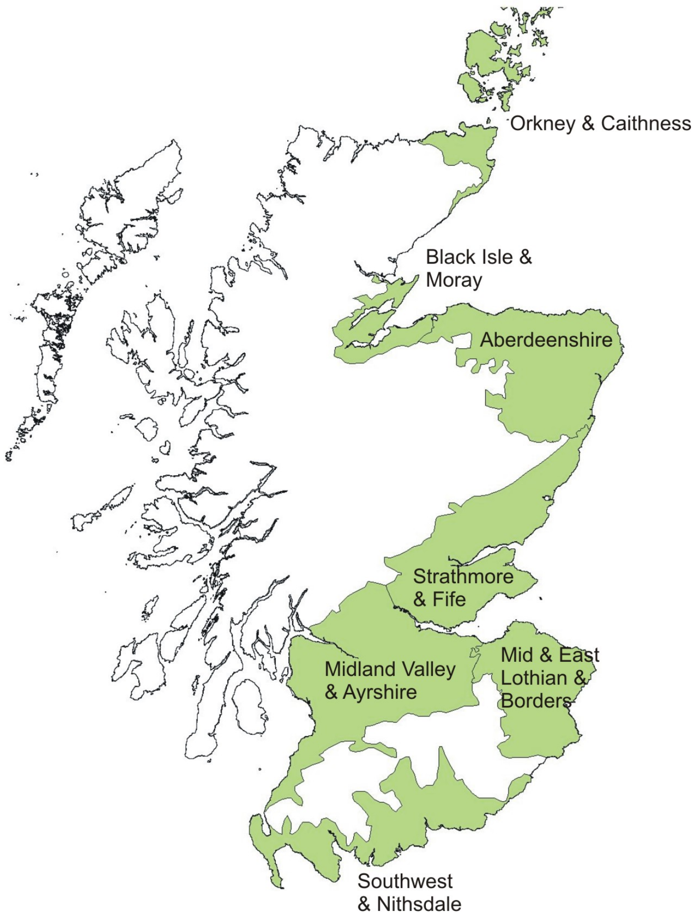


Figure 24 The seven areas used as a base for estimating the distribution of Scotland's nitrate groundwater monitoring network. These seven areas encompass 97% of the residual nitrogen produced in Scotland.

Table 6 gives the results of this analysis. In Example 1, the current network is compared to a network with the same total number of sites, but distributed using the above methodology. In Example 2, the network has been increased by 50% to 329 sites. The following observations can be made:

1. Overall the spread of the current network is generally good and covers most of the nitrate pressured areas in Scotland.
2. There are significant gaps in improved grassland areas of the Midland Valley and Ayrshire and in the arable areas of Banff, Buchan and Aberdeenshire.
3. Mid and East Lothian and the Borders are over-represented (particularly for arable sites) if the current total of 219 sites are to be kept.

Further analysis was undertaken to further divide the areas into different geology and soil types. However, this quickly becomes unmanageable and statistically difficult. It is probably adequate to ensure that the hydrogeological and soil conditions should be represented across the country, but not necessarily within each region.

Given the analysis in Chapter 6, which identified dairy, pigs and poultry as the main predictor of nitrate concentration in improved pasture areas, monitoring sites within the improved pasture should be biased towards these areas.

Table 6 Comparison of the current Scottish groundwater monitoring network against an ideal network, based on the distribution of residual nitrogen in Scotland.

			No of monitoring sites		
REGION	**Landuse**	**% of Scottish residual N**	**SEPA network 2005**	**Example 1**	**Example 2**
Orkney & Caithness	Arable	0.0	0	0	0
	Improved Grassland	2.7	2	4	7
Black Isle & Moray	Arable	3.0	4	5	7
	Improved Grassland	0.7	3	1	2
Aberdeenshire	Arable	20.2	18	33	51
	Improved Grassland	3.9	13	6	10
Strathmore & Fife	Arable	24.9	37	41	63
	Improved Grassland	2.0	5	3	5
Mid & East Lothian & the Borders	Arable	9.5	28	16	24
	Improved Grassland	4.1	10	7	10
Southwest & Nithsdale	Arable	1.3	4	2	3
	Improved Grassland	9.3	15	15	24
Midland Valley and Ayrshire	Arable	3.1	2	5	8
	Improved Grassland	11.9	10	20	30
	Total	96.7%	151 of 219	159 of 219	244 of 329

Note: Example 1 is based on 219 sites (the current network) but with 75 % of sites in high nitrate areas.
Example 2 is based on 329 sites (an increase of 50% on current network) with 75% of sites in high nitrate areas.

8 Summary and recommendations

Scotland has had a national groundwater quality monitoring network since the year 2000. One of the main functions of this network is to monitor nitrate concentrations; nitrate can be elevated in the environment due to modern agricultural practice. Initially there were 150 monitoring sites, but these have been added to and the current number of groundwater monitoring points for nitrate is 219.

In order to have confidence in the interpretation of data gathered from the network it is important to know the context of the sample points, and in particular whether any sample points are compromised by surface contamination or nearby point sources. Many of the initial 150 sites had never been subject to a formal risk assessment and their condition was unclear. In order to improve confidence in the network, and to help act as a baseline before improving the network, the British Geological Survey and the Macaulay Institute were commissioned by the Scottish Executive to carry out a review during the period February-July 2005.

8.1 SUMMARY OF WORK UNDERTAKEN

The aim of the project was to assess the effectiveness of the Scottish groundwater nitrate monitoring network and recommend improvements. The project was split into two main parts:

1. To assess the validity of sites which have not yet been subjected to any validation.
2. To undertake an interpretation of data for the 219 sites to assess the effectiveness of the network and make recommendations for improvements.

To undertake the **assessment and validation of the 151 sites**, the following work was undertaken:

- A risk assessment proforma was developed, drawing on experience from previous assessment. This included information about the source, surrounding hazards and sampling arrangements.
- Zones of influence were estimated for each monitoring point using a semi-quantitative method developed specifically for the project.
- Considerable background data was collated for each site from key national datasets and databases held at SEPA and BGS.
- Each site was visited and a field assessment made using the proforma. Samples for further chemical analysis were taken at certain sites.
- All the data for the 151 sites were put into an MS-Access database. Existing data for the 68 sites not visited were also put in the database.
- Criteria were developed for judging the quality of a source. The criteria were based around several key questions:
    - Is the source vulnerable to direct contamination from the surface?
    - Is the source vulnerable to indirect localised contamination?
    - Are there hazards within 10 m of the source, or significant point sources within 50 m?
    - Are the sampling arrangements adequate and safe?

To assess the **effectiveness of the network** as a whole the following was undertaken:

- Summary information was provided for each of the 219 sites using the zone of influence estimated for each site and the national datasets.
- Field data from the 151 assessed sites and 68 previously assessed were combined into one dataset, and nitrate data gathered for each site.
- A summary was made of the current status of the network.
- An analysis was made of the factors governing nitrate concentrations in Scotland and consideration given to the diverse hydrogeological, soil and land use conditions in Scotland.
- A gaps analysis was undertaken of the existing network.

8.2 RESULTS

8.2.1 Quality analysis of the 151 previously unassessed sites

The fieldwork and analysis of the 151 previously unassessed sites has indicated that:

- 61 of the 151 sites (40%) are adequate and can continue to be monitored with no improvements.
- There are serious concerns about 29 of the 151 sites (19% of the sites assessed and 13% of the total nitrate network). These sites should be considered for removal from the network. The sources found to be least reliable were shallow large diameter wells.
- 30 sites (20%) require further assessment before being judged suitable. Most of these sites are springs and require additional time to identify the precise source.
- 31 sites require improvements to the monitoring points – the improvements range from better sampling protocols to improving the headworks through simple engineering.

8.2.2 Status and effectiveness of the network

The analysis of current status of the 219 sites and their effectiveness for monitoring nitrate in Scotland has shown the following.

1. There is a large diversity of source types. There are 139 boreholes, 51 springs and 27 wells.
2. There is a clear difference between nitrate concentrations measured in the areas designated as NVZs and those that are not:
   - Within the NVZs, the mean concentration is 25 mg-NO_3 l^{-1} and the median 17 mg-NO_3 l^{-1}.
   - Outside the NVZs, the mean concentration is 9 mg-NO_3 l^{-1} and the median 4.4 mg-NO_3 l^{-1}.
3. The data from the network indicate that land use has a large influence on the nitrate concentrations measured in the monitoring network: arable areas, mixed cultivation of both arable & grassland, and where dairy, pigs and poultry are reared contribute to the highest nitrate concentrations, with 18% of sites in these areas exceeding 50 mg-NO_3 l^{-1}. The most significant control on nitrate concentrations in the monitoring network is the presence of dairy, pigs or poultry within the zone of influence.

4. Further analysis of the data comparing measured nitrate concentrations with modelled predictions of the likely nitrate concentrations based on the nitrogen available for leaching at the end of the growing season and the dilution effect of rainfall indicated:
   - High nitrate concentrations are not observed where the predicted nitrate concentrations are low. This suggests that much of the data from the monitoring network has not been compromised by point source contamination.
   - A considerable number of monitoring sites have lower nitrate concentrations than would be expected from the estimated residual nitrogen and rainfall. This can be attributed to mixing with older, low nitrate waters, denitrification, the nature of the soil cover, or the presence of low permeability superficial deposits which slow the movement of high nitrate water into the aquifers.
5. A "gaps" analysis which compared the current network with an idealised network based on targeting 75% of sites to high nitrate areas indicated:
   - Overall the spread of the current network is generally good and covers most of the nitrate pressured areas in Scotland.
   - There are significant gaps in improved grassland areas of the Midland valley and Ayrshire and in the arable areas of Aberdeenshire.
   - Mid and East Lothian and the Borders are over-represented.

8.2.3 Project outputs

The following outputs were produced during the project:

1. Estimated zones of influence for each of the 219 monitoring sites;
2. A proforma and risk assessment methodology for use in assessing the quality of monitoring points.
3. A set of maps of key parameters for each of the 219 monitoring sites.
4. A database containing all available data for the 219 sites.
5. A judgement on the quality of each of the 151 sites assessed during the project.
6. This report, which includes an assessment of the current status of the monitoring network, some analysis of the factors controlling nitrating nitrate in Scottish groundwater and recommendations for moving towards an effective network.

8.3 RECOMMENDATIONS

The following recommendations are made for the nitrate groundwater quality network in Scotland:

1. Consideration should be given to removing or replacing 29 of the 219 sites, and undertaking further assessments on 30 sites. A further 31 sites would benefit from improvements to the headworks or sampling arrangements.
2. Despite the poor condition of some of these sites, there is little evidence to suggest that data from the network from 2000 to 2005 has been compromised by point source contamination. Further statistical analysis on this data should be undertaken to help understand the factors that control the nitrate concentrations in groundwater – particularly the environmental factors that help to reduce the measured nitrate.

3. The network should concentrate on nitrate pressured areas in Scotland, with approximately 75% of the network in high nitrate areas, and 25% used to monitor background nitrate concentrations in less pressured areas.

4. Any sites added to the network must undergo a risk assessment similar to the one developed for this study to ensure that the network remains of good quality.

5. The network must continue to reflect the diverse hydrogeological, soil and land use conditions in Scotland. Therefore, both bedrock and superficial aquifers should be monitored in a variety of soil conditions. The network should continue to include different types of sources – however less emphasis should be given to wells which are generally poor monitoring points.

6. The data from the network will require to be actively interpreted: an inevitable outcome from having a diverse network is that the results of the monitoring must be interpreted not only in terms of agricultural practice, but in light of the other factors such as geological and environmental conditions. In practice this could mean a regular detailed review of the data (maybe every 2 to 3 years) from the network.

7. The network will need to be actively managed: various aspects of a monitoring point can change, for example the land use, the condition of the headworks, pumping rate etc. This will include SEPA hydrogeologists having a hands on overview of the network; individual sources being periodically reviewed using a simple checklist; and additional new sources being sought, possibly through the ongoing BGS/SEPA study of baseline groundwater chemistry across Scotland.

8. Wellhead measurements should be taken periodically to help identify denitrification or mixing with older waters. The limited samples taken during this study proved invaluable for interpreting apparently anomalous nitrate concentrations. To undertake this successfully, dedicated sample taps may have to be introduced.

9. A separate programme of focussed monitoring should be developed in tandem with the national groundwater monitoring network to give information on the effects of the action programmes within the NVZs. These sites should be in a controlled environment that will respond rapidly to changes in agricultural practice. The results from these studies can then be upscaled to help interpret changes in the national network as well as be used on their own to help understand the success of the Action Programmes.

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Appendix 1 Site assessments for 151 monitoring points

SEPA ID	Site name	Assessment	Comments
14408	Aberlady Mains	Adequate	Borehole is vulnerable to direct contamination but there are currently no local hazards
206007	Achnacloich	Requires further assessment	Wellhead should be identified and assessed (not accessible during visit). IF the source is not found then it should be removed.
205987	Alliehar	Requires improvement	Should construct fence in immediate vicinity of well. It could also be worth some basic maintenance of well to remove roots growing between concrete rings
300350	Arabella Junction	Adequate	Well constructed, so hazards are not a significant risk. Should be effectively purged before sampling. Would benefit from measuring well head chemistry.
205983	Archiestown Spring	Requires further assessment	Former Scottish Water source; likely to be a good source since is high yielding and in forest. However, was not seen (2.5 km up locked forestry track) and should be further assessed by SEPA
125511	Arndarroch	Consider removing	Likely to be affected by local point source pollution. Pesticides are stored within 50 m; flow rate is low (5 m3/d); has had pesticide contamination in the past.
206012	Assich Farm	Consider removing	Small domestic supply; poor spring construction; low flow which reduces in summer
205967	Auchinhove	Requires improvement	Shallow borehole; high yield; near pig farm (high ammonia). Should install a sample tap at wellhead.
1	Auldearn Junction	Adequate	Purpose drilled borehole; well constructed. Should be effectively purged before sampling
205991	Aultmore Spring	Adequate	Several small springs draining large area of natural grassland, all fenced; supply to several houses.
205969	Backhill Farm	Requires improvement	Borehole headworks are buried; immediate surroundings (10m) not hazardous. Past hazards within 20 m, but moderate pumping rate should mitigate. Should identify and assess borehole headworks, and install manhole cover.
126196	Ballsalloch	Consider removing	Very poor site: unprotected; appears to be only a small field drain
125523	Bashaw, Kilbirnie	Adequate	Slurry spreading on adjacent field was a hazard in the past but there is no adjacent slurry spreading now, although this should be monitored. This could be a useful source for monitoring shallow groundwater response.
125522	Befern Farm	Requires further assessment	Source location was not found - would need to confirm source location before keeping in the network.
14416	Bellour Farm	Consider removing	Shallow source with large volume. Would be adequate only if effectively purged.
12905	Bermaline Mill House Borehole	Consider removing	Exact location unknown (under tarmac) and in urban area
205990	Blairmore Cottage	Adequate	Small reliable domestic source; shallow groundwater; tank fenced effectively.
12906	Blue Circle Cement	Consider removing	Borehole frequently dries - there are alternatives onsite.
12919	Bonchester Spring	Adequate	Scottish Water source; well constructed; fenced; high flow.
125505	Boundary Cottage	Consider removing	Shallow well that is not used or flowing; difficult to purge

SEPA ID	Site name	Assessment	Comments
14417	Bowmont Sawmill	Adequate	70% pre 1950s water; borehole well protected at top with no nitrate hazards close by; moderate yield
2	Brackley Junction	Adequate	Purpose drilled borehole; well constructed. Only potential hazard is adjacent road junction. Should be effectively purged before sampling
206003	Brahan Farm	Requires further assessment	Wellhead not seen during visit (in locked pump house); source is likley to be a shallow well; pumped for farm use. Probably ok, but access should be gained to the pump house to check.
12922	Brathinch Farmhouse borehole	Adequate	Well protected; no point hazards within 10 m; moderate pumping rate.
14418	Brechin Golf Course (disused bh)	Requires improvement	Is slowly artesian - requires better engineered cap for sampling. If artesian flow stops would need to reconsider this site, as it is not in use
206028	Bridgend	Requires further assessment and improvement	Source not identified, but is in area of high N inputs so could be useful shallow site; needs fence around tank.
125532	Brighouse	Consider removing	Large diameter well; only occasionally used; difficult to purge; also a dispute with neighbour
206010	Bristow Cottage	Requires further assessment	Relatively high flow rate, but source should be identified since the land use is mixed
12917	Broadhaugh Farm	Requires improvement	Must be fenced; low yielding; shallow groundwater; flow reduces in summer
125515	Brocklees Farm	Consider removing	Uncertainty over borehole depth and headworks. In a shed where chemicals are stored.
205961	Burghead	Requires further assessment	Scottish Water site; excellent protection; high yielding. However, should check sampling arrangements
205986	Burn of Aultmore Croft	Adequate	Low yielding domestic spring or well; few hazards; well constructed.
125531	Caledonian Cheese BH1	Adequate	Local hazards, but headworks and construction are good and pumping rate high. Groundwater is mostly pre1950s.
125520	Cardowan Creameries Ltd	Consider removing	Not in use; large borehole volume and so is difficult to purge; close to hazards; poor headworks
14411	Carnoustie Bh 2	Requires improvement	Hard to sample - a sample tap at the wellhead would improve sampling. Other good boreholes available on site if this one is to be replaced. Should check for denitrification.
206005	Castle Brae	Requires improvement	Shallow well in wood; no hazards; low pumping rate. Should be effectively purged before sampling
125539	Chirex	Adequate	Well constructed borehole with no immediate hazards and high flow rate. Groundwater is likely to be 50 years old.
205996	Claigan Spring	Consider removing	Very poor site: much algae; no protection; low flow
17064	Cookston Farm 1	Adequate	Purposed drilled borehole; well constructed and no hazards. Should be effectively purged before sampling
17065	Cookston Farm 2	Adequate	Purposed drilled borehole; well constructed and no hazards. Should be effectively purged before sampling

SEPA ID	Site name	Assessment	Comments
126204	Corriegills	Adequate	Public water supply used as a back up. Fine if adequately purged.
206008	Craigroy Mills	Adequate	In area of fenced woodland. Shallow source; in use; moderate flow all year
14409	Craigwalls	Requires improvement	Needs sample tap before header tank so that well head measurements can be taken (this could help explain low nitrate); high yielding borehole
125530	Crichton (Hospital?)	Requires improvement	Changed from deep source (used by "Water at Work") to old hospital source recently, slightly artesian flow, but sampling arrangements may be difficult and should be reassessed and improved if possible.
125535	Culvennan SW Borehole	Requires improvement	Manhole should be improved to stop flooding. Should be effectively purged before sampling
125513	Dalmore Works	Requires further assessment	Couldn't find the borehole or owners - needs further assessment.
12895	Dean's Food (Daylay)	Adequate	Well head good; high yield; interesting area (poultry) Could do with minor tidy up round headworks. However, groundwater is reducting (i.e. denitrification)
14407	Dirnanean House	Requires further assessment	Original SEPA monitoring point not found - believed to be old farm/house supply that is now disused. The new supply (assessed here) is probably mainly surface water and should not be part of the monitoring network. SEPA believe original monitoring point is probably also largely surface water: this site should be assessed & if mainly surface water, removed from network.
14420	Drummick Farm	Requires further assessment	Must establish pumping regime. Dirty around top of borehole, so should be removed if not pumped frequently.
206000	Dunbar, Guildhall Croft	Requires further assessment	Should identify source (thought to be up the hillside - i.e. probably a spring, not a well). If this cannot be done then remove.
205966	E Bradiestone	Requires further assessment	Confirm that the well is the actual source, not just a holding tank. Low yield; but no 10 m hazards.
205965	E Carmont	Consider removing	Not thought to be in use; low flow; uncertainty over spring source
12924	Easter Lednathie Spring	Requires further assessment and improvement	Need to identify source & make basic improvements to fence around tank
205982	Easthill	Requires further assessment	In forest, but neither source nor tanks could be found: source needs to be identified. Supplies 2 houses
12903	Elementis Specialities	Requires improvement	Should install sample point at wellhead before water treatment point. Could close borehole top and removed water treatment chemicals stored near borehole
12921	Ettrickbridge SW Borehole	Adequate	Scottish Water source next to river; well constructed; high yielding
205992	Faichfield Lodge	Requires improvement	Shallow well in wood; low yield. Should be effectively purged before sampling
206014	Falas an Duine	Requires improvement	Large diameter well in sheep field; in daily use for domestic supply. Could do with a fence to stop sheep access. Good site for information for sheep farming.

SEPA ID	Site name	Assessment	Comments
12923	Farnell Mains Spring	Adequate	Spring source likely to be well constrained; useful source for monitoring shallow groundwater in arable field
3	Feddan Junction	Adequate	Purpose drilled borehole; well constructed. Should be effectively purged before sampling. Temporary manure heap stored 30 m fropm borehole this year.
12920	Ferniehurst Mill Spring	Requires further assessment and improvement	Engineering works uncertain - brick tunnel into bank; needs to be confirmed and the area fenced (previous e-coli problem). However, if improvements made it could be useful source.
12897	Fettykill Mills (Smith & Anderson)	Requires improvement	More an urban borehole; high yield. May be useful for overall groundwater rmonitoring network. Headworks should have minor improvements to help sampling.
205974	Foggieburn	Requires improvement	Shallow source; low yielding; next to burn. Should improve fencing
206009	Forrest Springs	Adequate	Scottish Water source; high yield; recently improved to give good protection.
125524	Gardeners Cottage	Requires further assessment	Owners not happy about BGS visiting. No assessment made
205997	Garlyne Spring	Requires further assessment	Tank well fenced; good flow. However, should identify the source before continuuing to monitor.
17068	Glamis Castle Drift	Adequate	Purpose drilled borehole; no hazards (except road) and effectively sealed. Should be effectively purged before sampling
17067	Glamis Castle Solid	Adequate	Purpose drilled borehole; no hazards (except road) and effectively sealed. Should be effectively purged before sampling
17066	Glamis Petrol Station	Adequate	Purpose drilled borehole; no hazards (except road) and effectively sealed. Should be effectively purged before sampling
205988	Glassal Well Lodge Well	Consider removing	No longer used; could replace with K063B (new borehole on site)
125509	Glenlair	Adequate	Well constructed headworks; no great hazards; low yield but used all year
125507	Glenluie Farm	Consider removing	Disused; low flow; uncertainty over source; discoloured water
305189	Grant's No. 1	Adequate	Headworks appear dirty but sound. At edge of industrial site next to agricultural land use. High pumping rate (500 m3/d). Oxygen in water.
306465	Grant's No. 10	Adequate	Headworks very good. Should be effectively purged before sampling
306464	Grant's No. 4	Adequate	Headworks very good. Should be effectively purged before sampling
305191	Grant's No. 6	Adequate	Headworks very good. Should be effectively purged before sampling
305190	Grant's No. 9	Adequate	Headworks very good, although no fence. No oxygen in groundwater - probably denitrification
125508	Greenmerse	Adequate	Borehole is well constructed, but groundwater that is monitored is pre 1950s

SEPA ID	Site name	Assessment	Comments
14410	Hardiston	Requires improvement	Low yielding source in upland area; would be better if fenced, although there are no livestock in the area.
125527	Hardthorne Road 1	Consider removing	Not pumping and very difficult to purge due to large borehole volume
206071	Haremuir	Consider removing	Shallow and poorly protected with low yield; chicken coop 1 m away
300351	Hill of Fearn Farm	Adequate	Well constructed, so hazards within 10 m are not a significant risk. Should be effectively purged before sampling. Needs well head chemistry undertaken.
206015	Hillhead of Fettinear	Adequate	Shallow source; no hazards; well sited; used daily by two houses
12908	Hoardweels	Adequate	Well fenced; good flow (except in drought); good for monitoring shallow groundwater. However, there is an abandoned council tip 500 m upslope which should be taken into consideration when interpreting data.
205994	Idrigill Springs	Requires improvement	Scottish Water source; well protected; reliable flow. Sample must be taken prior to water treatment
205984	Inchtomack Bungalow	Requires further assessment	Shallow source; in woodland; domestic use; recently improved. Actual source not identified with certainty
206011	Inverey	Adequate	Domestic supply; in use; low flow; fenced; in woodland.
133761	Ironhirst Moss Observation Borehole	Adequate	Not pumping, but well constructed, and away from point sources. Should be effectively purged before sampling. Chemistry needs further analysis
12910	Kelso Racecourse Bh 1 (old bh)	Consider removing	Pumps straight into lagoon next to borehole - possible recirculation. Poor construction; pumped only seasonally; reducing groundwater
125537	Kettleton SW Production Borehole	Adequate	Sample point is a long distance from borehole (>1km); but is constantly pumping
126174	Kildonnan (S Kildonnan Farm)	Requires improvement	Headworks poor and wet around borehole. However there is a high pumping rate, and the borehole is shallow, so the site would be worth improving.
14413	Kilmaron Windmill Well	Adequate	Wellhead not seen but is within good building for protection; no nearby hazards. Used regularly and so is likely to be effectively flushed
206030	Kilmuir	Adequate	Scottish Water source; well protected; reliable flow
125526	Laigh Dykehead	Requires further assessment	Wellhead not visible, but unlikely to be sealed; but there are no real surface hazards. Should confirm borehole depth
125518	Lambhill Farm	Adequate	Good source; high yield; in a constrained area
126206	Lamlash	Consider removing	Former public water supply; now not used; difficult to sample.
125529	Larchfield SW Production Borehole	Adequate	Well constructed, Scottish Water source; high yield; immediate surroundings urban, but influenced by surrounding agriculture.
205976	Lilac Cottage	Consider removing	Shallow well; not in use; not protected
206016	Little Mill House	Requires further assessment and improvement	Not found or assessed by BGS. Should identify source and ensure that source is fenced

SEPA ID	Site name	Assessment	Comments
205998	Little Rowater	Requires further assessment	Small domestic supply; could be well or spring. Source not identified since owners absent and NGRs from SEPA wrong. Needs to be assessed before continuing to monitor
133760	Longbridgemuir Farm Observation Borehole	Adequate	Not pumping, but well constructed, and away from point sources. Should be effectively purged before sampling. Samples mixture of deep and shallow groundwater
12926	Lower Kenly Farm	Requires further assessment	General confusion over source and sample points - possibly 2 sources on site. Need to check status or remove
17156	Luffness Observation Borehole	Adequate	Good site, but does not pump, so must be purged effectively before sampling. Potential hazard is slurry spreading in nearby field
12907	Lumsdaine Farm Spring	Requires further assessment and improvement	Not a great source: low yield; uncertainty over spring location. Should investigate the spring source further; should be fenced; should sample from inflow to tank.
12909	Menzion Farm Spring	Consider removing	Although not currently a failing site, source is very small and currenly unused, so could easily fall into disrepair
205980	Milldowrie	Adequate	Shallow well in wood; good yield. Sample tap far from source, but effectively flushed.
15317	Moonzie Spring	Requires further assessment	Source is thought to be distant (probably >1km) from sampling point and not identified
12913	Mosshouses	Requires further assessment	No access during visit: should identify borehole location (which is not at sample tap) and assess headworks & immediate surroundings
125521	Muirhouse Farm	Consider removing	Shallow and large diameter well; unused; poorly constructed & protected; not fenced & animals around source
205975	Newbigging Croft	Adequate	New borehole supplying 3 houses. Good headworks; no immediate hazards.
125536	Newfields SW Borehole	Requires improvement	Manhole should be improved to stop flooding. Should be effectively purged before sampling
12928	Newton of Ballinloan	Requires improvement	Borehole under manhole cover in driveway. Because of low yield, the borehole may be susceptible to surface contamination, so manhole cover should be improved. Steep hill, so septic tank unlikely to interfere.
14419	Newton of Falkland	Consider removing	Not pumped and within sewage works - plenty of alternative sites available in area
125952	Norrel Grove	Adequate	Headworks not seen but in small pump house in good repair; adjacent LPG fuel tank (in good repair) is the only potential hazard
16494	Peacehill Farm (Wormit)	Adequate	Unknown construction, but no nearby hazards and high pumping rate.
125962	Pleasance Farm Well	Consider removing	Poor construction; no water flow observed; not fenced & animals around source
125497	Pow Bridge	Consider removing	Not pumping and very difficult to purge due to large borehole volume
205981	Putting Brae	Consider removing	Low flow; source not identified; likely to be shallow groundwater; in ditch by road.

SEPA ID	Site name	Assessment	Comments
205977	Quarry Head	Requires further assessment	Not sure that borehole was properly identified; moderate yield; pumped everyday, so it is worth finding out more information about the source before rejecting.
14415	Quest International (Kerry Bioscience)	Adequate	Large industrial user (2.4 Ml/d); probably from mine workings; well protected
133763	Racks Moss Deep Observation Borehole	Adequate	Not pumping, but well constructed, and away from point sources. Should be effectively purged before sampling. Samples pre 1950s groundwater
17069	Redford	Adequate	Purpose drilled borehole; no hazards (except road) and effectively sealed. Should be effectively purged before sampling
125533	Ringford SW Production Borehole	Adequate	Scottish Water site; well protected; pumping; shallow borehole
206057	Roseisle Maltings	Requires improvement	Good site: high yielding and deep; but should install sample tap before tank. Also need to take wellhead measurements to try & explain low nitrate
205968	Ruan, Burnhervie	Consider removing	Shallow source; 2 metres from house; low pumping rate
125519	Sandyford Abbatoir	Requires improvement	Used infrequently; high ammonium; no good for nitrate network but useful for urban. Should be effectively purged before sampling
12918	Scott (Hosiery) Well	Consider removing	Very shallow; not protected; many urban hazards
206004	Shapinsay No 11	Requires improvement	Chamber floods: an effective sump should be installed
125718	Shiol, Oban	Adequate	Small domestic source; in wooded area. Could be replaced if larger better source found
126207	Shiskine (No. 5)	Adequate	Scottish Water source; well protected; no hazards; high pumping rate
125525	South Hourat Farm	Requires improvement	Spring source area should be fenced (spring is distant from tank/sample point).
206032	Spey New	Requires improvement	In Spey wellfield; largely monitoring water from the River Spey. A robust sampling regime should be developed for the whole wellfield - preferably from pumping boreholes
205962	Spey Trial	Requires improvement	In Spey wellfield; largely monitoring water from the River Spey. A robust sampling regime should be developed for the whole wellfield - preferably from pumping boreholes
205979	Spyhill Cottage	Adequate	Shallow groundwater; in woodland; from a series of cisterns. Source is not fenced, but no hazards within woodland
125510	Terregles Fish Farm 1	Requires improvement	Should install sample tap at or close to wellhead and confirm which borehole is being sampled (currently, sampling appears to be from a tank of water mixed from all 3 boreholes). Very high yields so important to sample
125538	The Cheese Company	Adequate	Potential hazards are presence of cheese sludge within 20m, but sludge in a controlled lagoon; borehole well constructed with high pumping rate (>850 m3/d))
14414	The Ibert	Adequate	Large source; in use; well fenced
206002	Thornton	Requires further assessment	Confusion over whether borehole or well is used/sampled. The borehole is likely to be the better monitoring site

SEPA ID	Site name	Assessment	Comments
205989	Tominachi	Requires improvement	In fenced area; shallow groundwater; low flow. There is a nearly borehole which may be a better sampling point
12912	Trabrown Farm Spring	Requires improvement	Fence should be improved to keep livestock away from spring area
205985	Ugie Brae	Requires further assessment	Well has good construction and is fenced; no obvious hazards. Need more information on pumping regime: if pumping rate is low, a sample tap at the wellhead should be installed
12916	Upper Samieston Farm	Requires improvement	Fencing needs to be improved. Monitoring very shallow groundwater. Since flow is low, would benefit from monitoring flow all year to see if it dries.
205973	Upper Tillydrine	Requires further assessment	Flow rate is relatively high, and source used, however the source should be identified and protected.
205978	Upperheads of Skelmuir	Requires further assessment	No hazards; well protected at top. Should check whether the source is currently in use or not. Should be effectively purged before sampling
206020	Uryside	Consider removing	Poorly protected; close to house. Since pumping rate is high (>10 m3/d) it could be retained if further investigations show it to be deep, not a shallow well.
205964	W Carmont Spring	Requires further assessment and improvement	Source not confidently identified; tank is not fenced. If the source cannot be found and fenced, this site should be removed.
206019	Wester Balfreish	Adequate	Low yielding domestic supply, but good well head protection
125961	Will's Well, Newcastleton	Adequate	Scottish Water source; well constructed; fenced; high flow. However, is right next to burn
205963	Windyedge	Requires improvement	Should sample at wellhead or ensure that pipework is effectively flushed
125517	Woodhead Farm	Adequate	Within a dairy farm, with calves housed within 5 m; but the borehole headworks are well constructed and the flow rate is high
205995	Woodside	Consider removing	Source not effectively protected and difficult to improve
206013	Wrack PS	Adequate	Shallow source; protected; but probably largely measuring river water