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Groundwater nitrate vulnerable zones for Scotland

Groundwater Systems and Water Quality

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BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/01/250

Groundwater nitrate vulnerable zones for Scotland

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Land use on the Devonian aquifer in Fife.

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Foreword

This report is the product of a study by the British Geological Survey (BGS). The work was carried out between August and December 2001 and funded by SEERAD Agricultural and Biological Research Group Flexible Fund.

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The Nitrates Directive (91/676/EEC) requires Member States to identify areas where groundwaters have nitrate concentrations of more than 50 mg/l nitrate or are thought to be at risk of nitrate contamination. Areas associated with such groundwaters are to be designated as Nitrate Vulnerable Zones (NVZs) within which Member States are required to establish Action Programmes in order to reduce and prevent further nitrate contamination.

The British Geological Survey (BGS), with funding from the Scottish Executive SEERAD Agricultural and Biological Research Group Flexible Fund, has devised a methodology for the establishment of groundwater NVZs in Scotland. The work was carried out between August and December 2001.

The methodology was based on an earlier phase of work carried out by the Macaulay Land Use Research Institute (MLURI) who produced a series of land use risk zones for the east of Scotland. These zones show where the highest risk of nitrate leaching occurs. The Scottish Executive then contracted BGS to identify aquifers associated with these risk zones.

BGS have used GIS analysis to assist the work. Digital geological line work based on the Digital Geological Map of Great Britain (DiGMapGB-50) was used to develop and apply a High, Moderate and Low permeability classification to both solid and superficial geological formations between the Borders and the Black Isle. By means of combining the solid and drift classifications, a form of groundwater vulnerability map was then constructed. Most vulnerable aquifers are in low-lying areas.

Databases containing information on the location of wells, springs and boreholes were included in the GIS. The SEPA groundwater monitoring network, the BGS groundwater database and other sources of information on private water supplies were also included to display the range of nitrate concentrations in groundwater across eastern Scotland.

Areas where highly permeable aquifers coincided with MLURI high risk leaching zones were identified using the GIS. These are the zones where the greatest risk to groundwater from the leaching of nitrogen fertilisers is thought to be present. They are the also the main surface recharge areas for the major aquifers in eastern Scotland.

The next stage in the process involved calculating surface water sub-catchments associated with these high risk aquifer/land use coincident zones. Those sub-catchments that include the coincident zones (called class 1 and 2 catchments) are distinguished from sub-catchments lying upstream, generally in upland areas, where there are no highly permeable aquifers or land risk zones (called class 3 catchments). In general the available groundwater nitrate data indicate elevated nitrate concentrations in class 1 and 2 catchments. SEPA surface water nitrate data and the available groundwater nitrate data indicate that upland catchments (class 3) are essentially low in nitrate.

For the purposes of the report, the east of Scotland has been divided into 7 areas. Descriptions of the types of aquifers present, the location of coincident zones and the extent of source nitrate data coverage are provided for each area. Data from within the highly permeable aquifer zones show that the highest proportion of groundwater sources with high nitrate concentrations are under the highest risk land use zones.

The results of the vulnerability/risk analysis are consistent with the available nitrate data for much of Scotland. There are significant discrepancies in only two catchments, Dumfries and the Upper Don (called class 4 catchments). Here, unverified private supply data show clusters of elevated nitrate. For Dumfries a separate study by BGS in 2000 also indicated rising nitrate concentrations within the main aquifer.

1 Introduction

The Nitrates Directive (91/676/EEC) requires Member States to identify areas where groundwaters have nitrate concentrations ≥ 50 mg/l nitrate, or are thought to be at risk of nitrate contamination. The recharge areas of such groundwaters are to be designated as Nitrate Vulnerable Zones (NVZs), wherein Member States are required to establish Action Programmes in order to reduce and prevent further nitrate contamination.

In Scotland, the Scottish Executive is responsible for designation and has commissioned the British Geological Survey (BGS) to aid in the identification of aquifer units that are most at risk from nitrate contamination. The area to be assessed by BGS was based on a nitrate risk assessment generated by the Macaulay Land Use Research Institute (MLURI). The area covered (200,000 km^2) stretches along the east coast from the border with England to the Black Isle. It covers some of the more productive groundwater areas in the country, particularly in Fife and Strathmore and represents approximately 25% of the land area of Scotland.

BGS's involvement with the project commenced in August 2001 and this phase is due for completion at the end of December 2001. This phase has produced the following products.

1. GIS-based maps showing the locations of high, moderate and low vulnerability aquifers associated with MLURI high risk zones.
2. GIS-based maps of surface water catchments associated with the vulnerable aquifers.
3. GIS maps showing all data points from the diverse databases in Scotland that have information on groundwater nitrate concentrations.
4. A report discussing the methodology for defining areas and discussing individual areas in detail.
5. An assessment of the suitability for monitoring of 12 sites from the SEPA nitrate network in Scotland where nitrate regularly exceeds 50 mg/l.

The methodology for the work has been developed and evolved throughout the project through weekly progress meetings between BGS, the Scottish Executive and SEPA. The requirement to incorporate surface water catchments and nitrate data with areas where highly vulnerable aquifers coincide with MLURI moderate and high risk zones has been the single most important development during the project.

This report is intended for use with the GIS (enclosed as a CD ROM). The GIS contains maps of aquifer vulnerability, the MLURI risk zones and associated catchments. Also included are several datasets containing information on nitrate concentrations in groundwater and surface water. These include the SEPA groundwater monitoring network, Water Authority data and information from private water supplies.

BGS continues to be involved in the process. In a later phase to the project, approximately 70 new nitrate monitoring sites are being identified both in and around the vulnerable aquifers identified during the current work programme. First results from this work will be available in February 2002.

2 Data Sources

Data used in the present study have been derived from various sources. Geological and hydrogeological data and information from BGS have been used in conjunction with datasets held by SEPA and the Scottish Executive. The following is a description of each data set used within the project.

DiGMapGB-50 (BGS dataset). This is a digital version of all the published 1:50 000 scale geological maps for Scotland. These maps are of various ages and have been produced by many different geologists dating back to the primary survey in the late 1800's. Hence there are significant variations in the detail, quality and density of information used to construct individual maps. As a consequence, differences can arise at the boundary between adjacent sheets. These have been resolved through discussions with Land Survey geologists. There are two different geological datasets: the solid (bedrock) geology; and the drift (superficial) geology. The basic geological information is not included in the GIS, only the necessary interpretations.

Nitrate leaching risk zones (MLURI dataset). A conceptual model has been developed by MLURI which predicts relative nitrate concentrations leaching from agricultural activity (Lilly *et al.* 2001). The model uses Parish data on main crop types, the soil type (using the HOST classification) and rainfall. The output of the model is a 100 m grid covering Scotland. Classifications of moderately high, high and very high are most likely to cause groundwaters to exceed 50 mg/l (Lilly *et al.* 2001). However, since the data are averaged over parishes, localised sources of nitrate contamination (such as dairy, poultry or pig farms) may be underestimated. The moderately high, high and very high areas are included in this study and on the GIS.

Borehole Geology (BGS dataset). This digital dataset has approximately 205 000 records from site investigation and deep boreholes in Scotland. This information was used to estimate the thickness of superficial deposits and identify areas of thick clay. The dataset is not included on the GIS.

River network. (SEPA dataset). Digital linework of the river network was provided by SEPA and is an updated and verified version of the Centre for Ecology and Hydrology (CEH) network for the UK. Rivers are divided into three different classes: (1) rivers with a catchment of > 100 km^2; (2) rivers with catchment between 10 and 100 km^2; and (3) rivers with a catchment smaller than 10 km^2.

Digital Terrain Model (SEPA/Ordnance Survey/CEH). This digital terrain model (DTM) was used by SEPA under licence to generate surface water catchments associated with vulnerable aquifers. The grid interval of the DTM is 50 m. The generated catchments are included in the GIS, but not the DTM.

Nitrate groundwater datasets. Data on nitrate concentrations in groundwater in Scotland come from five main databases:

1. SEPA groundwater monitoring network.
2. Water Authority groundwater monitoring information.
3. Private water supplies – EnviroCentre. Nitrate information from local councils, many of the grid references are unreliable.
4. Private water supplies – MLURI with additional information from local councils.
5. BGS dataholdings. Limited data from various projects, some protected by commercial confidentiality.

The quality of individual monitoring points have not been verified, therefor, much of these data may not be a reliable indication of true nitrate concentrations in groundwater. This is discussed in more detail in section 4. All datasets are included in the GIS.

Surface water quality (SEPA). This dataset has been compiled by SEPA from databases of monitoring in the three SEPA regions. The data are of varying quality and include current ie.

after 1992, monitoring points. A rapid verification process has been carried out to eliminate effluent outflows etc and statistical anomalies. Only sites with more than 48 samples have been included. The 95 percentile is calculated for each site. (Included in the GIS).

Scottish groundwater database (BGS dataset). This has records of many water boreholes drilled in Scotland. There is a legislative requirement for details of boreholes drilled to greater than 50 feet (16 m) to be lodged with BGS. Currently the database has details of 4000 water boreholes. Information on borehole productivity and aquifer properties in the database was used to help assign a hydrogeological classification to each rock type (Not included in the GIS).

3 Methodology

3.1 INTRODUCTION

This section describes the methodology established to identify areas of Scotland where groundwater is at risk of nitrate contamination. The methodology is based on a risk analysis combining groundwater vulnerability and risk of nitrate leaching. Section 4 describes the data used in parallel with the risk analysis.

A summary of the methodology is given in Figure 3.1. This section describes the stages for which BGS was responsible – stages 2, 3 and 4. The development of stage 1 (risk of nitrate leaching from agricultural activity) is described in a separate report (Lilly *et al.* 2001).

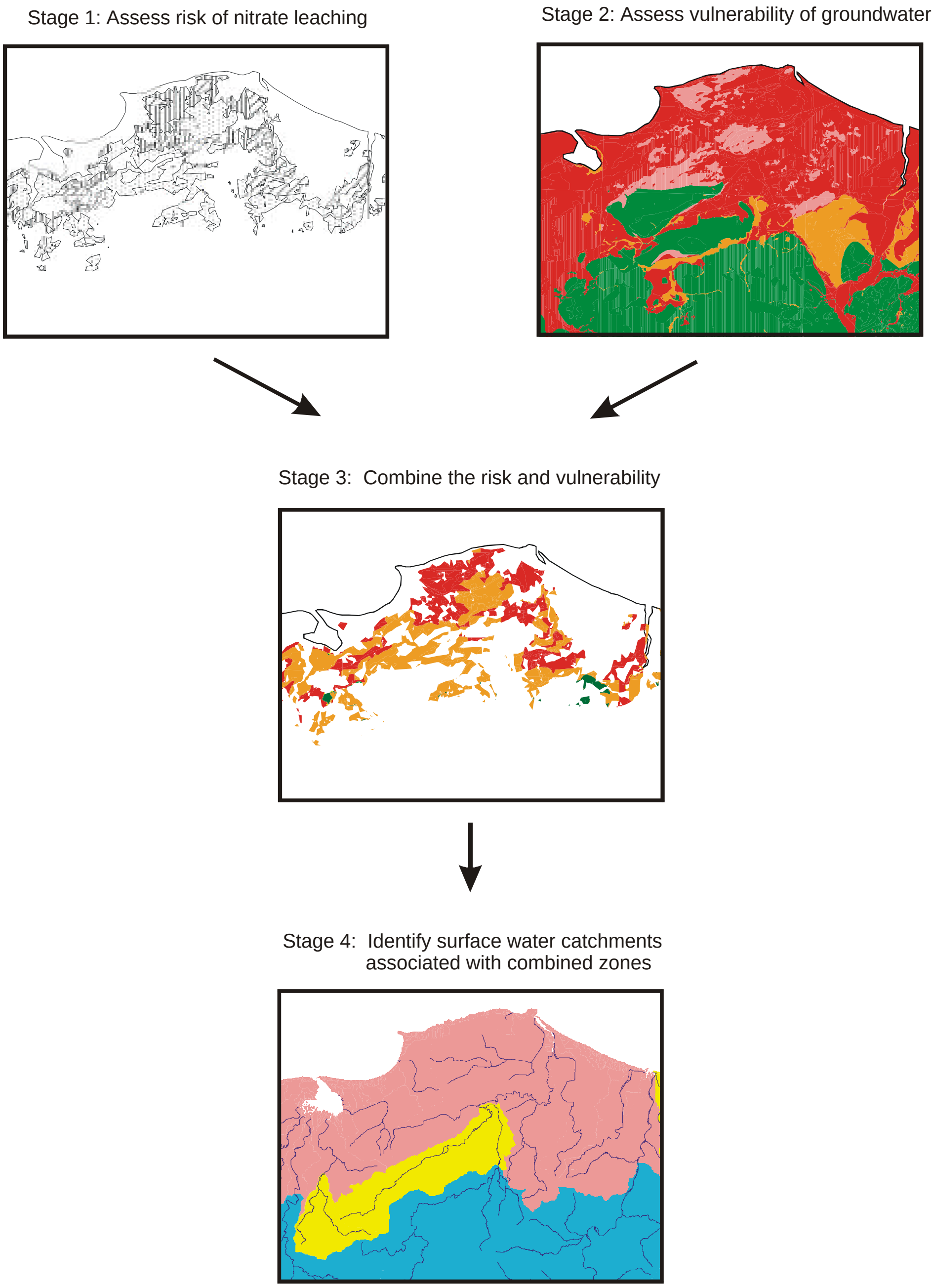

Figure 3.1 A summary of the methodology for identifying groundwater NVZs in Scotland.

3.2 ASSESSING GROUNDWATER VULNERABILITY

Clearly groundwater is most vulnerable where it is present in significant quantities and regularly recharged. Therefore, rock units that have high permeability and porosity are more at risk than those with negligible permeability and porosity. This is the basis on which groundwater vulnerability maps are generally constructed (National Research Council, 1993). The potential for retardation, sorption or dilution in the soil is also sometimes taken into account. However these processes had already been accounted for in the assessment of nitrate leaching potential in stage 1, so were not included again at this stage. Figure 3.2 outlines how the groundwater vulnerability maps were assembled. Much of the interpreted data which underlie the vulnerability assessment are given in the accompanying GIS.

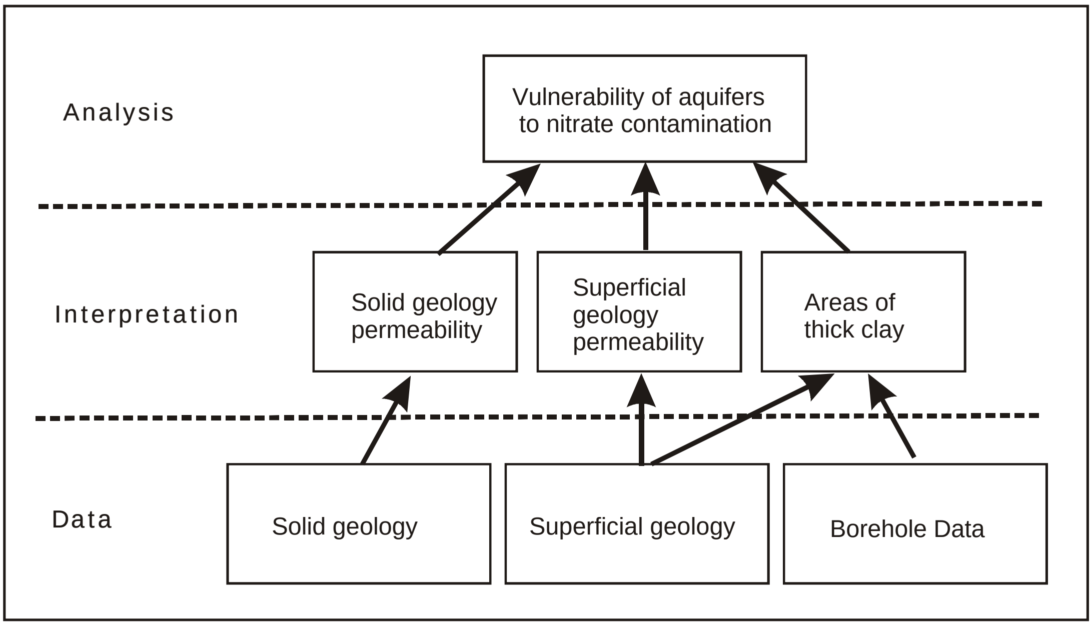

Figure 3.2 The process for assessing the vulnerability of aquifers to nitrate contamination from geological information.

Geological data at 1:50 000 scale forms the basis of the groundwater vulnerability assessment. The ongoing BGS DiGMapGB-50 project was accelerated to make sure the data were available on time. There are two complementary sets of spatial geological data. Solid geology refers to bedrock and comprises solid rocks such as sandstone and granite etc. Superficial geology encompasses deposits that overly solid bedrock (such as alluvium boulder clay or sand and gravel).

The solid and superficial geological data were then interpreted to attribute permeability classifications to each mapped geological unit (Appendix 1). These attributions were discussed and approved by BGS field geologists.

1. For the **solid geology** this meant (in broad terms) that substantial sandstone formation units were classed as highly permeable; fine-grained sandstone with considerable silt/clay content and conglomerate were classed as moderately permeable; other rocks (e.g. igneous and metamorphic rocks) were classed as weakly permeable.

2. For the **superficial deposits** the classification was made as follows: deposits that comprise mainly sand and gravel were classed highly permeable (e.g. alluvium and glacial sand and gravel). Deposits that contain significant clay and silt were classed as moderately permeable (e.g. raised beach deposits). Deposits that are primarily clay and silt were attributed as weakly permeable.

The borehole data and superficial deposits were also interpreted to highlight areas where the total cumulative thickness of clay within the sequence is > 5 m. In these areas the solid aquifers may be protected from contamination by the thick clay. The areas identified were then verified by the appropriate regional geologists.

The permeability interpretations were then analysed and combined to give the overall vulnerability of Scottish groundwater to nitrate contamination. Figure 3.3 shows how this process was carried out. Where either the superficial or solid geology are highly permeable, the area was classed as highly vulnerable (coloured red on the maps). Only where both the superficial and solid geology are weakly permeable will the area be classed as low vulnerability (coloured green).

The areas of high vulnerability (for the solid aquifers only) were further subdivided on the basis of the clay cover. These classifications are (1) high vulnerability solid aquifer overlain by clayey superficial deposits of variable and unknown thickness (pink) and (2) high vulnerability solid aquifer overlain by clayey superficial deposits that are known to be greater than 5 m thick (pink and hashed).

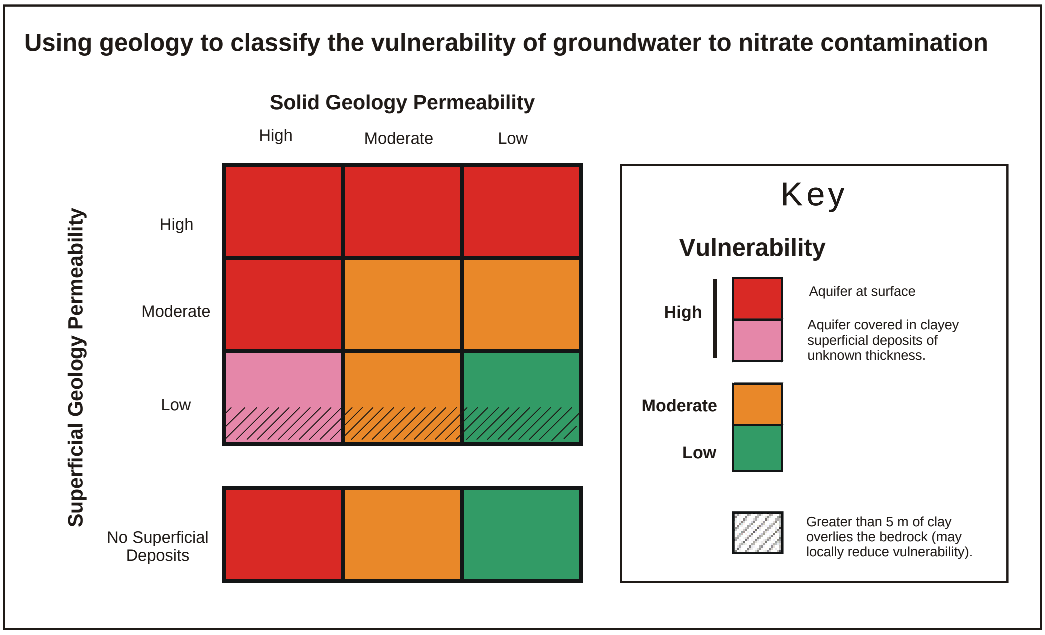

Figure 3.3 Description of groundwater vulnerability matrix based on solid and superficial geology.

3.3 COMBINING AQUIFER VULNERABILITY AND LAND USE

Stage 3 of the process is to assess which of the vulnerable aquifers are at risk from nitrate contamination. This assessment was made by combining the groundwater vulnerability maps with the risk of agricultural nitrate leaching calculated by MLURI (see Figure 3.1). In essence this is combining *receptor* (groundwater) with contaminant *source* (nitrate). Groundwater is unlikely to be contaminated where there is little or no risk of leaching of nitrate. Likewise, regional groundwater contamination is unlikely where the aquifers are not highly permeable. However, local contamination can occur in weakly permeable aquifers, where groundwater in small fracture zones can be contaminated by relatively rapid infiltration from the surface. Lilly *et al*, (2001) indicated that only their moderately high, high and very high classes of nitrate leaching were likely to give rise to sufficient concentrations of nitrate for significant groundwater contamination. This was verified using the available nitrate data (see Figure 4.3). Therefore only these categories were used in the analysis. Five different classes of coincident zones were identified.

Area A	Highly vulnerable aquifers	+	High and very high nitrate leaching potential.
Area B	Highly vulnerable aquifers	+	Moderately high nitrate leaching potential.
Area C	Moderately vulnerable aquifers	+	High and very high nitrate leaching potential.
Area D	Low vulnerability aquifers	+	High and very high nitrate leaching potential.
Area E	Moderately vulnerable aquifers	+	Moderately high nitrate leaching potential.

Most significant groundwater contamination will occur where high vulnerable aquifers are coincident with moderately high, high or very high nitrate leaching potential – Areas A & B.

3.4 SURFACE WATER CATCHMENTS

Surface water catchments have been calculated for Areas A &B (see Figure 3.4). According to the directive, all waters (surface water and groundwater) flowing across an aquifer at risk must be considered. Small local catchments have the most effect on nitrate concentration in vulnerable aquifers since runoff and small streams from these catchments can recharge major aquifers; shallow groundwater flow over small distances can also be important. This is of particular significance if crops with high nitrate leaching are grown in these areas. However, there is a difference between these small local catchments and upland catchments associated with the main stem of the river. For these upland catchments two approaches can be taken.

1. The entire surface water catchment for each risk area can be included as part of the nitrate vulnerable zone. The rationale for this is that any water flowing into an aquifer can contribute to, or help to dilute, nitrate concentrations.
2. Upland catchments can be excluded from the NVZ because in Scotland, rainfall is generally high and therefore main rivers do not lose water to aquifers, but gain in volume through groundwater discharges, or baseflow, along their length. On the occasions when main rivers and tributaries do recharge groundwater, for example during floods, this can have a beneficial effect on groundwater nitrate concentrations through dilution if the nitrate concentrations of the river water are low.

To help identify the most appropriate approach for Scotland different classes of catchment have been generated (Figure 3.4).

Class 1	Local catchments associated with Area A (See Section 3.3).
Class 2	Local surface water catchments additional to Class 1 when including Area B.
Class 3	The upland portion of Class 1 and 2 catchments. These have been generated from a point on the main river just upstream of the last combined Area A & B.
Class 4	Catchments where there is significant evidence of nitrate contamination occurring as exceptions to the risk analysis methodology. (See Section 4).

During periods of flood, river water can recharge flood gravels, but only as temporary storage and within months the water generally returns to the rivers. Surface water quality data from SEPA (see data on accompanying GIS) are a further aid to assessing upland catchments. Much of the available surface water data show low nitrate concentrations in Class 3 catchments (< 10 mg/l nitrate and often < 5 mg/l nitrate). Assuming upland river water did recharge groundwater for some part of the year it would *reduce* nitrate concentrations in the aquifers. The available evidence therefore suggests that upland catchments (Class 3) should be excluded from NVZs.

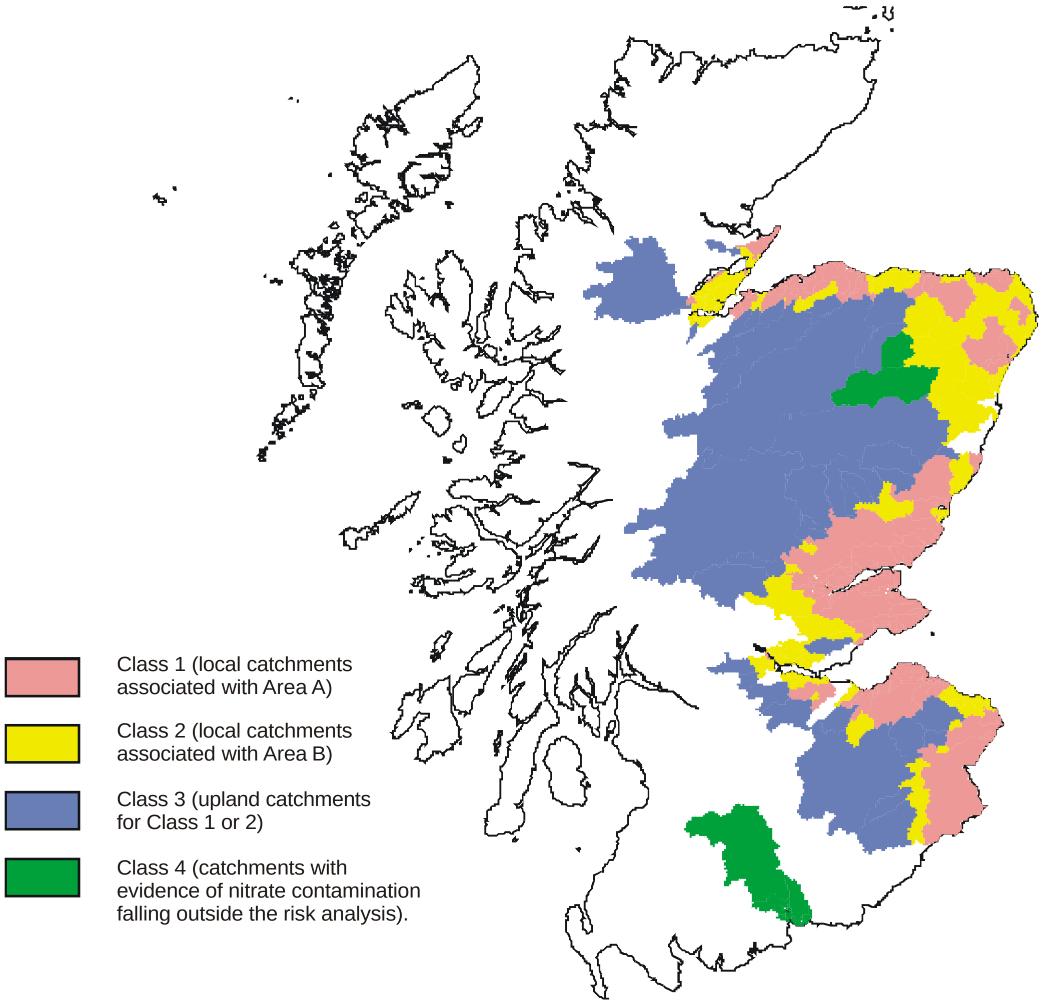

Figure 3.4 Surface water catchments generated for combined high risk and vulnerable aquifers (none in Shetland or Orkney).

The process of generating the catchments led to the omission of small catchments around the coast. This is a technical issue rather than a methodological one and was overcome manually. The omitted catchments were designated the same as the surrounding ones where land use and geology were similar.

Less than 1% of the moderately high, high and very high nitrate leaching areas are outwith the Class 1 and 2 catchments. This reinforces that the local catchments are those that are likely to be producing significant concentrations of nitrate, and that protecting upland catchments (Class 3) will have little benefit in reducing nitrate in groundwater.

4 Available nitrate data

4.1 DATA SOURCES

Nitrate data are necessary to help validate the risk methodology set out in section 3. Although not absolutely necessary under the nitrate directive for designating NVZs, they help to validate the risk methodology and assess baselines against which any improvements can be measured. Scotland does not have good historical data on nitrate concentrations in groundwater. There are four main sources of nitrate data.

SEPA monitoring network. This has been operational since 2000. 150 sites are monitored quarterly although Foot and Mouth disease restrictions affected data collection during 2001. The monitoring network is based on biophysical land use classes (Lilly *et al,* 1999). The network needs to be reviewed in the light of operational experience. Sources vulnerable to local surface contamination need to be identified and reconsidered.

Water Authorities data. Boreholes for public supply are routinely monitored for nitrate. These boreholes are constructed to a high standard and are located in the most productive aquifers in Scotland. However, the dataset is limited with few sources in the areas of interest.

Private Water Supplies Database. There are more than 30 000 private water supplies in Scotland. Information on these sources is kept by Local Authority Environmental Health Offices. In an attempt to make these data readily available, two contracts were issued to digitise the data (contractors: Envirocentre and MLURI). The result is two databases that cover the whole of Scotland, although there is some overlap. Only a few thousand entries include both nitrate data and georeferences. For the current GIS the two datasets were combined. Most of the duplicate entries have been eliminated. Private water supplies are often shallow, unprotected springs in fields around farms, and are, therefore, not ideal monitoring points for regional groundwater chemistry. However when used at a broad scale the data are informative.

Miscellaneous datasets. BGS has data from individual projects assessing groundwater quality throughout Scotland. This small dataset is derived mainly from boreholes; some of the samples are historic (1985), but they have been taken from sources that are representative of their respective aquifers.

The different datasets are compared in Figure 4.1. The private water supply sources (median 50.1 mg/l, 25^{th} percentile 30 mg/l, 75^{th} percentile 61.6 mg/l) have higher nitrate concentrations than the other data sources (median 33 mg/l, 25^{th} percentile 15 mg/l, 75^{th} percentile 46 mg/l). The difference is due to the different nature of the datasets. The water authority, BGS and SEPA monitoring networks are mainly boreholes, while the private water supply data come mainly from shallow springs and wells. E-coli is present in many of the latter indicating a high degree of vulnerability, the presence of rapid recharge and local contamination (Ball *et al*, 1997).

4.2 NITRATE DISTRIBUTION

All available nitrate data for groundwater in Scotland are plotted on Figure 4.2 (available on the accompanying GIS). Although an attempt has been made to clean up the dataset to delete the most obvious duplicates, the data remain of poor quality. The quality of the data mean that individual datapoints cannot stand up to scrutiny, nevertheless the general pattern of nitrate distribution remains valid. Using this approach the following observations can be made.

- Highest nitrate concentrations are generally found in the east of Scotland and associated with the combined risk zones.

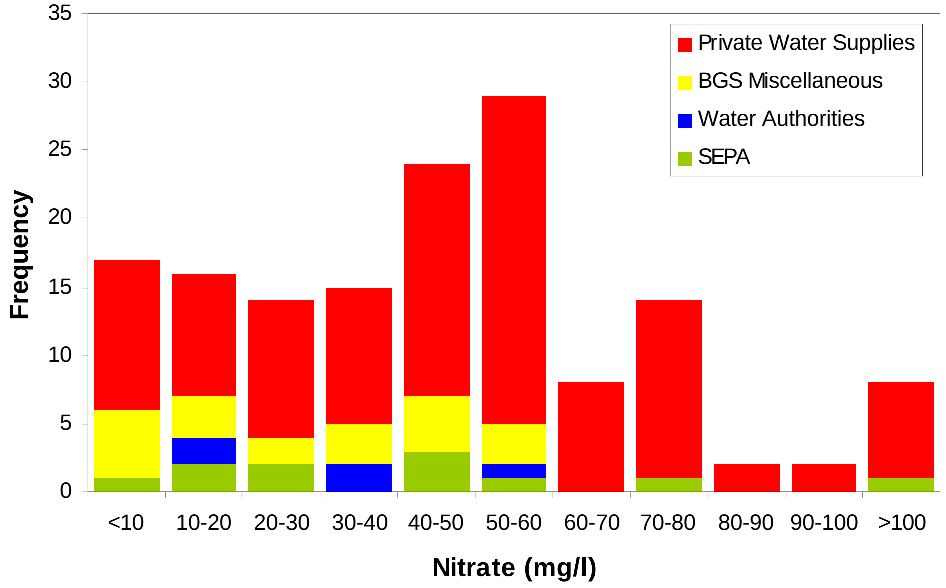

Figure 4.1 Comparing nitrate concentrations from different data sources from the combined risk areas A & B. Private water supplies tend to give higher nitrate concentrations.

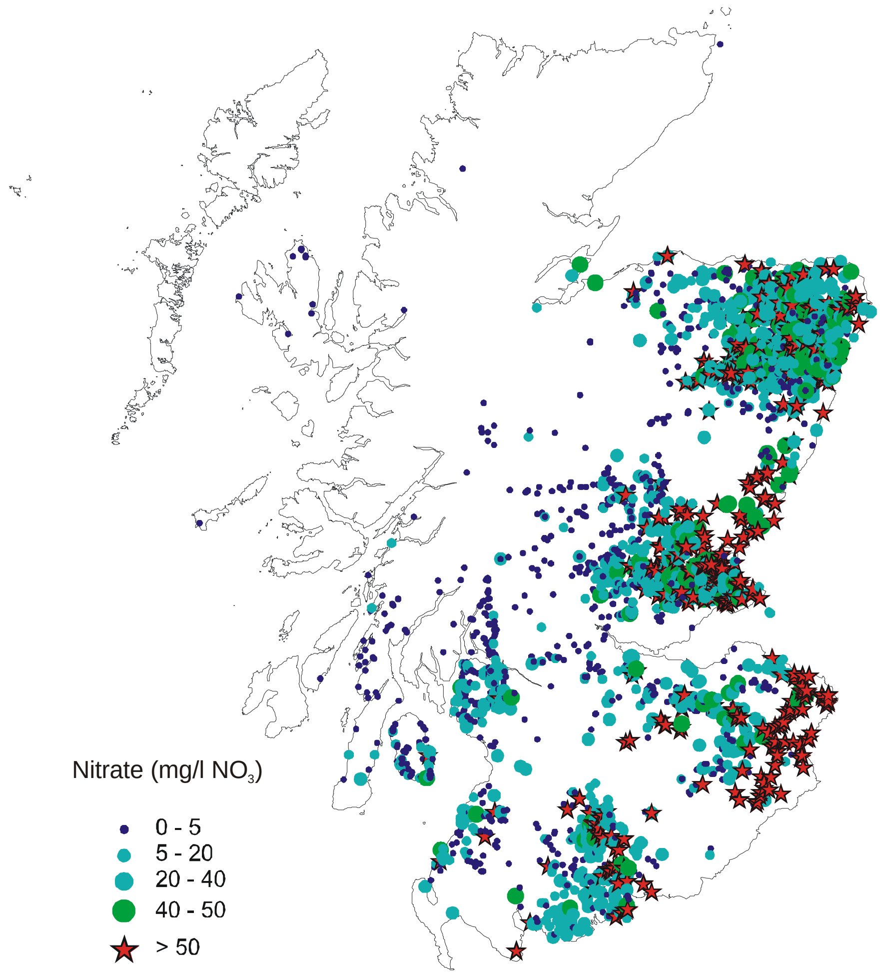

Figure 4.2 All available nitrate data for Scottish groundwaters. Note that much of the data are of poor quality and unverified.

- Nitrate concentrations in upland areas and the west of Scotland are generally small, although the density of data is low. This is confirmed by surface water nitrate data.
- High nitrate concentrations may be observed in areas of low permeability away from highly vulnerability aquifers. This denotes local contamination of groundwater.

There are two areas where high nitrate concentrations are observed on a significant scale away from the nitrate leaching risk areas: Dumfries and the upper Don catchment. The number of datapoints exceeding 50 mg/l in these areas requires attention. They have been designated as Class 4 catchments (see Figure 3.4). The source of high nitrate in these areas is presently unclear, but likely to be due to intensive livestock and permeable soils. Further studies of the effect of livestock on groundwater in Scotland are required.

The distribution of nitrate in groundwater within highly vulnerable aquifers is shown in Figure 4.3; summary statistics are given in Table 4.1. The analysis is restricted to aquifers in Class 1, 2 and 3 catchments (see page 6) to exclude the anomalies from Dumfries and the Upper Don. Two conclusions can be drawn from the data.

1. Nitrate data from highly vulnerable aquifers in high/very high nitrate leaching (Area A) and moderately high nitrate leaching areas (Area B) are similar (statistically equivalent). The data indicate severe contamination (median 46 mg/l).
2. Nitrate data from highly vulnerable aquifers in moderate or low nitrate leaching areas is generally low, median 10 mg/l (excluding Dumfries and the Upper Don).

The data indicate that much of the nitrate in Scotland's highly vulnerable aquifers is a result of agricultural leaching. The available data suggest that the moderately high, high and very high nitrate leaching areas should be considered as one group.

Table 4.1 Summary statistics for nitrate data from highly vulnerable aquifers in Eastern Scotland (Catchment classes 1, 2 and 3).

Nitrate Leaching	*No of datapoints*	*Nitrate (mg/l)*		
		25 percentile	*Median*	*75 percentile*
High or very High	54	29	46.5	59.5
Moderately High	94	26	46	58.5
Moderate or Low	558	3	10	33
All	706	3.2	15.6	44

4.3 NITRATE TRENDS

There are few historical records of nitrate for the groundwaters of Scotland. It was to address this issue that the SEPA groundwater monitoring network was established. However, the network is in its infancy and has only one years worth of data. The best long-term data are from the Water Authorities. As discussed previously, these tend to be the most suitable for information about regional groundwater chemistry in major aquifers. Figure 4.4 shows data for two of the longest standing monitoring boreholes, Balmalcolm in Fife and Manse Road in Dumfries.

The Balmalcom borehole shows a striking upward trend since the early 1970s. Other boreholes in Fife show a similar upward trend during this period (Ó Dochartaigh *et al* 1999). In Dumfries the increase is not so great but is steadily upward (increasing by 4 mg/l over 10 years). Research in Dumfries indicates that young groundwater is recharging with a nitrate concentration of 40-50 mg/l. Water pumped from boreholes has a lower concentration since it mixes with older (pre 1950's) groundwater (MacDonald *et al.* 2000).

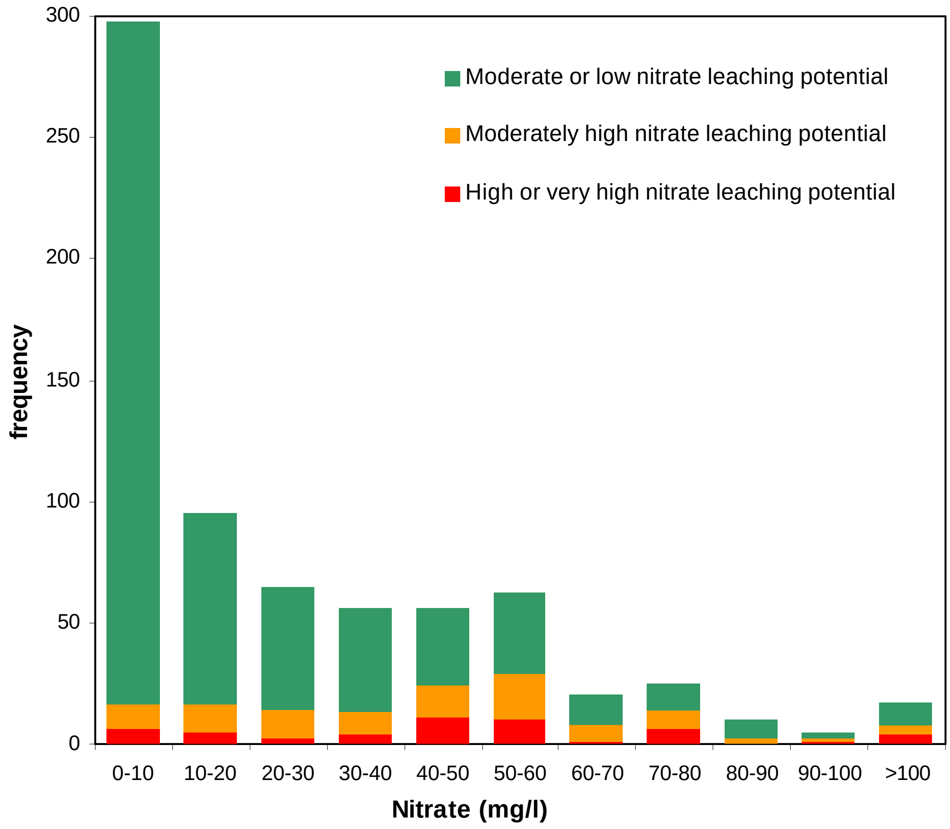

Figure 4.3 Nitrate data for highly vulnerable aquifers in Eastern Scotland.

Note that nitrate concentrations in moderately high, high/very high nitrate leaching classes (Areas A & B) are similar. Nitrate concentrations in highly vulnerable aquifers away from these areas are considerably lower (green shading).

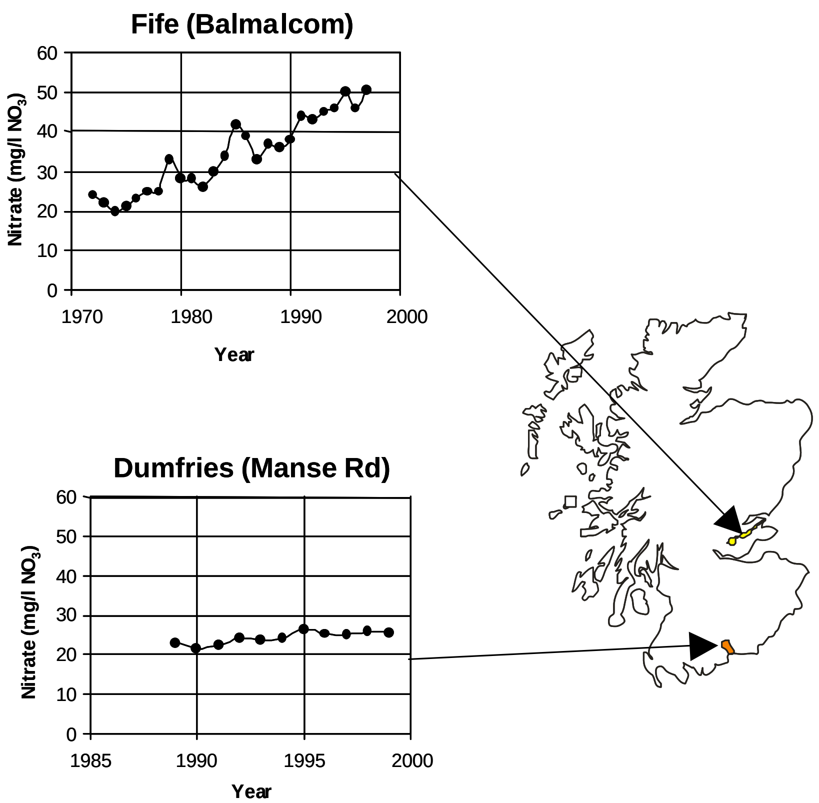

Figure 4.4 Nitrate data from Water Authority boreholes in the two most productive Scottish aquifers, the Devonian aquifer in Fife and Permian aquifer in Dumfries.

5 Area Descriptions

Figure 5.1 shows the areas as described in this section. The boundaries between areas were selected primarily because of the distribution of aquifers. Fine-tuning of the boundaries was then made by linking them to the nearest major surface water catchment.

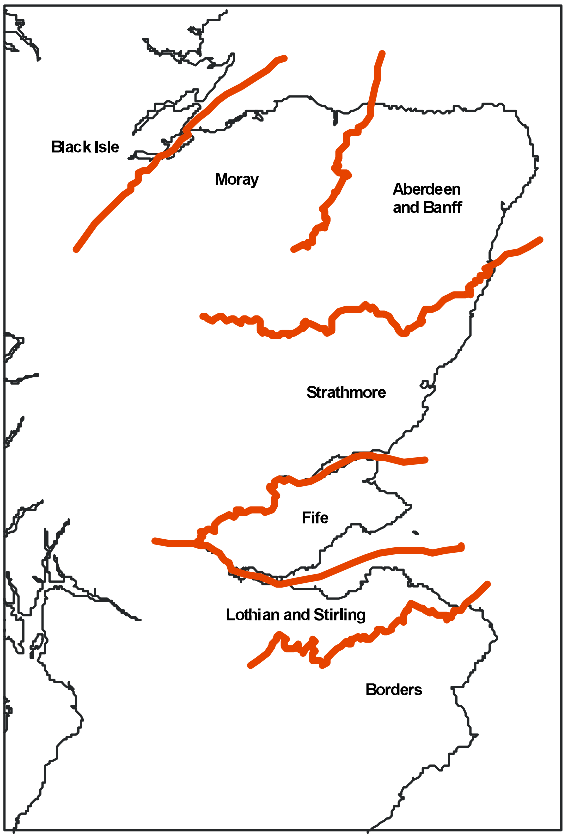

Figure 5.1 The different areas described in Section 5.

5.1 THE BORDERS

5.1.1 Introduction

The eastern Borders cover the area south of Dunbar and east of Galashiels and Hawick (Figure 5.2). The main topographic feature of this region is the large basin-like structure of the lower Tweed valley, centred on Coldstream and Berwick and termed the Merse. Surrounding it to the north, east and south are the hills of the Lammermuirs and the Cheviot. There are no major centres of population, the largest towns within the Class 1 and 2 catchments being Berwick, Eyemouth and Jedburgh.

The main (Devonian) aquifer has never been exploited to any great extent because of the presence of nearby higher ground where surface water resources can be readily exploited. High rainfall avoids the need for irrigation systems in normal conditions. Groundwater usage is confined mainly to private water supplies and irrigation. However, there is a steadily increasing trend in borehole construction for private use. Insufficient yield from traditional wells and springs is often the reason for converting to a deeper source of supply.

The valley gravels are exploited for public supply use in the west of the area, at Selkirk and Innerleithen. No major development has occurred in these superficial aquifers further east amongst the MLURI high risk zones.

5.1.2 Geology and hydrogeology

The most productive superficial aquifers in the region are the valley gravels of the River Tweed and its tributaries. These have been exploited at Selkirk and Innerleithen for public supply.

The principal bedrock aquifer in the area is the Upper Devonian sandstone that occurs from Greenlaw to Jedburgh and covers an area of almost 800 km^2. The aquifer (Figure 5.2) is a red, partly weathered rock with well-developed fracture systems. It is thought to have excellent potential for large-scale regional development, although few data are available on aquifer characteristics. Its vulnerability to pollution is partly tempered by a widespread covering of clayey superficial deposits (Figure 5.1). However, highly permeable alluvial gravels including those in the Rivers Tweed and Teviot valleys cut across it.

The moderately permeable aquifers close to the border with England, around Coldstream (Figure 5.2) comprise a large area of Carboniferous sediments. These are characterised by a cyclical sequence of sandstone and siltstone with some limestone. Northern spurs to the Devonian sandstone aquifer comprise conglomerate rocks that are less permeable than the former.

Outwith of the main aquifers, the surrounding higher ground is composed of Lower Palaeozoic greywacke and igneous rocks. These all have a generally low permeability and, therefore, cannot support large groundwater abstractions, unlike the younger, softer, sandstones. Groundwater is present only within steeply-dipping fractures through which water flow is restricted. However, there are many private supply boreholes constructed in these rock types, as groundwater yields from typical 30 m-deep boreholes are usually sufficient for 1 or 2 houses.

The general direction of groundwater flow within bedrock aquifers in the River Tweed drainage basin is thought to be to the east with groundwater baseflow discharge to the river occurring throughout its length along the lower reaches. However, data to substantiate this are generally lacking.

5.1.3 Land use/aquifer relationships

Figure 5.3 shows the coincidence of aquifer permeability with MLURI risk zones. The coincidence of High and Very High MLURI zones (V+VH) with highly permeable aquifers (HPA) is limited to small areas near Jedburgh and west of Eyemouth. Large tracts of arable land of moderately high risk (MH) coincide with the main Devonian sandstone aquifer because of the influence of the geology on topography and soils. It is clear from a comparison with the aquifer zones on Figure 5.1 that there is a strong relationship between land use and the highly permeable Devonian sandstone aquifer around Jedburgh. Over 80% of the coincident zones represent this sandstone aquifer. Alluvial and glacial sands and gravels overly both the Devonian sandstone and Carboniferous aquifers and dual aquifer systems are found over approximately 6% of the coincident zones.

5.1.4 Catchments and nitrate data

In general terms, there is a strong correlation between surface and groundwater nitrate occurrence and the risk areas. Low nitrate waters flowing off the Southern Uplands and Lammermuir Hills quickly gain in nitrate where drainage from fields enters the main rivers and streams. The same is broadly true for groundwater (Figure 5.4). Almost all the >50 mg/l groundwater nitrate sources are within the moderate, high and very high coincident zones. There are very few data points that are less than 50 mg/l within the high risk catchments. At present, little is known about the nature of the private supplies and it is not known whether shallow or deeper groundwater are being measured.

When the private supply data are compared with Class 1 and 2 catchments and highly vulnerable aquifers, a strong correlation is seen (Figures 5.2 and 5.3, Table 5.1). Unfortunately, there is a lack of data points over the moderately vulnerable Carboniferous aquifers in the Merse area around Kelso. There is also a shortage of nitrate data in the central part of the Devonian sandstone aquifer around Jedburgh. However, the northern part of the aquifer is well represented by private supplies data, although little is known about them. 15 sources record >50 mg/l nitrate within the highly permeable aquifer area, and associated catchment. There is an absence of any data points to the north of the high and moderate risk catchments in the northern part of the Borders area. Data are more plentiful to the west, amongst the higher ground, and show <20 mg/l nitrate in far-western aquifers, with a trend towards 20-40 mg/l nearer the margins of the risk catchments.

Out of a total of 81 sources that lie within Class 1 and 2 catchments, 54, or 67% are in excess of 50 mg/l nitrate. It is unclear why such a high percentage of the sites fall in this area compared to the remainder of eastern Scotland. Further validation of these monitoring sites is required with additional sources selected within the areas with no current data points. Away from the Class 1 and 2 catchments, a further 117 sources are found in mainly higher ground to the west. Only approximately 16 % of these sources are >50 mg/l nitrate. Overall, these data reinforce the high risk classification methodology applied in the Borders area.

Table 5.1 Nitrate data statistics for the Borders.

Database	**Class 1 and 2 catchments**				**Elsewhere**			
	Number samples	**Number failing**		**Median (mg/l)**	**Number samples**	**Number failing**		**Median (mg/l)**
Private Water Supplies	64	52	(81%)	62	97	18	(19%)	15
SEPA Monitoring	8	1	(13%)	15	6	0	(0%)	15
Water Authorities	3	0	(0%)	23	12	0	(0%)	6.1
BGS Miscellaneous	6	1	(17%)	5	2	1	(50%)	NA
Total	**81**	**54**	**(67%)**	**51.7***	**117**	**19**	**(16%)**	**13.8***

* Weighted average of medians

5.1.5 Summary

- The main Devonian sandstone aquifer covers 800 km^2.
- Highly permeable valley gravels are important groundwater sources.
- Groundwater use is confined mainly to irrigation and private supplies.
- There is a strong relationship between land use and aquifer occurrence.
- 67% of sources in Class 1 and 2 catchments are >50 mg/l nitrate. 16% of sources outwith these are >50 mg/l nitrate.

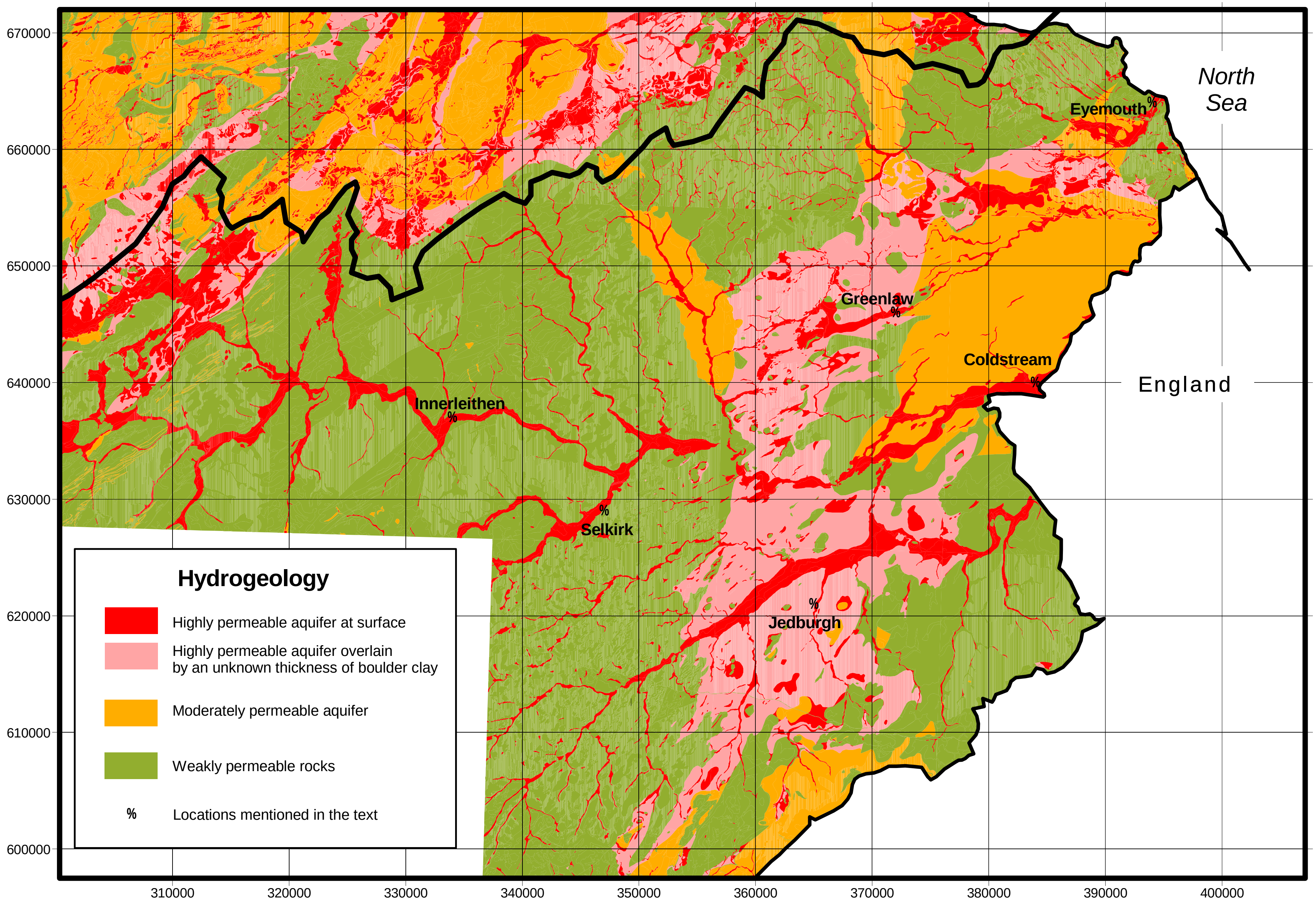

Figure 5.2 Vulnerability of groundwater to nitrate contamination in the Borders.

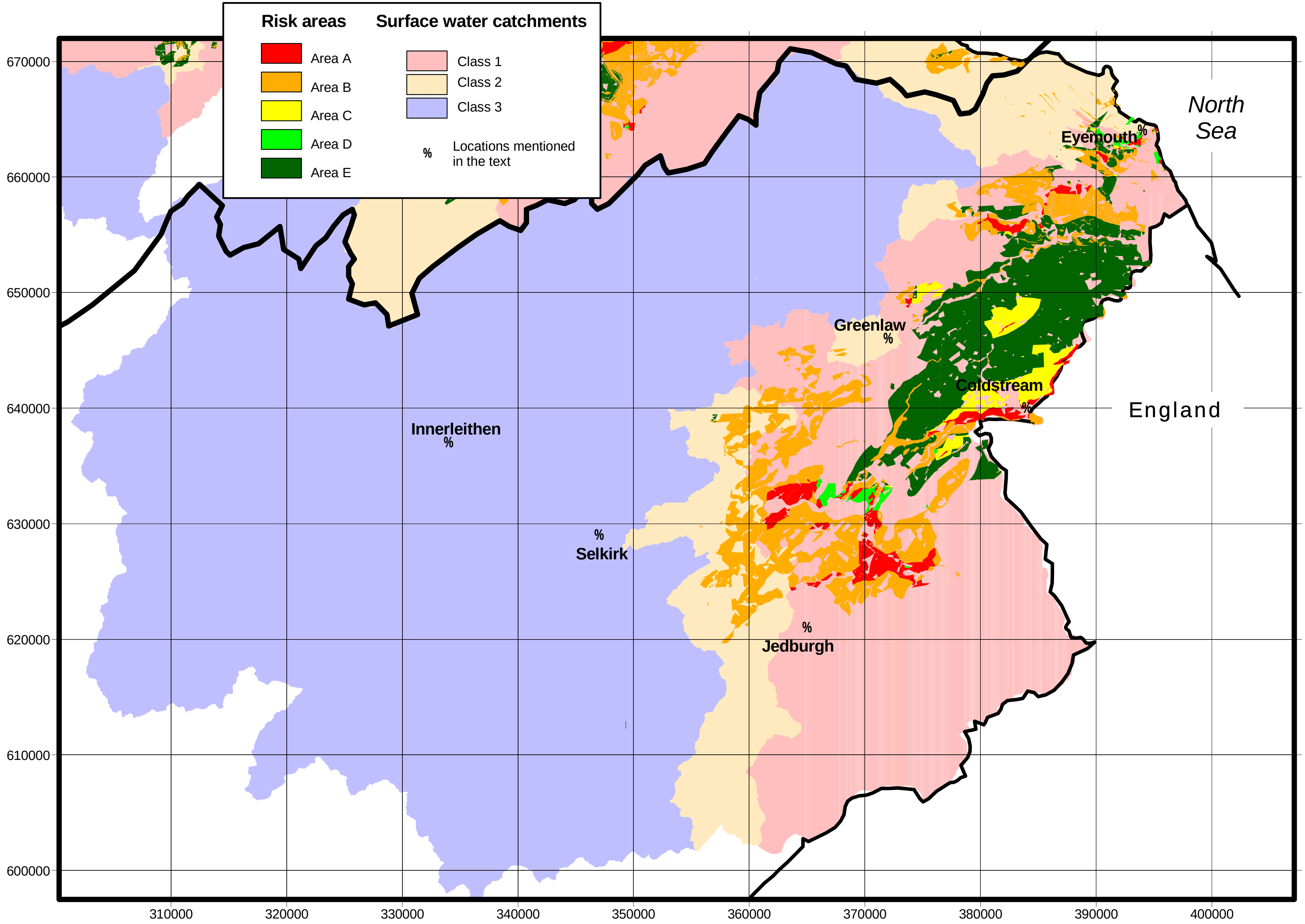

Figure 5.3 Combined risk and vulnerability zones and associated catchments for the Borders.

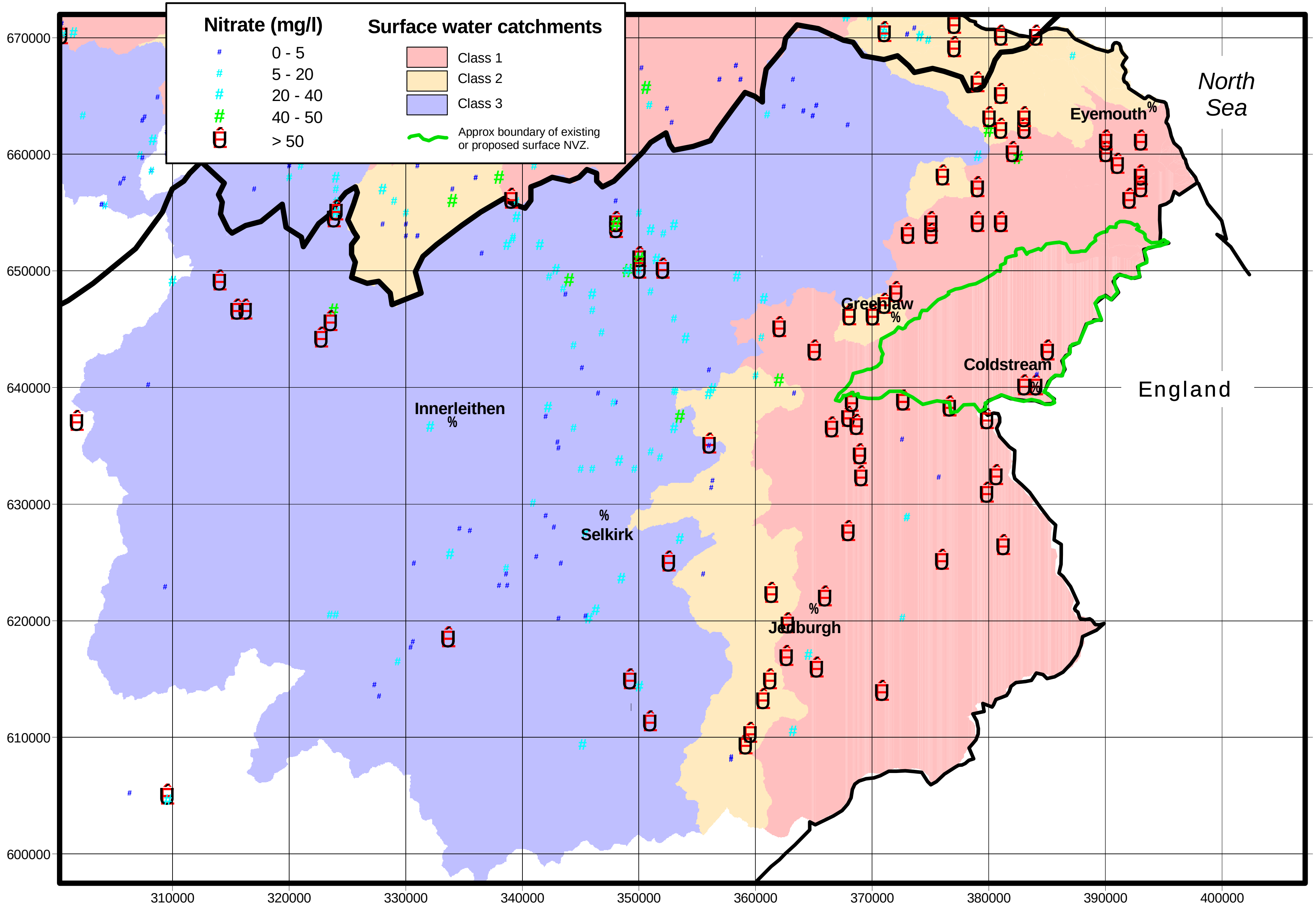

Figure 5.4 Nitrate data and catchments for the Borders.

5.2 EDINBURGH AND EAST LOTHIAN

5.2.1 Introduction

There is a distinct contrast between the east and west of this area. To the west, the large urban sprawls of Edinburgh and West Lothian restrict arable farming to relatively small areas. In contrast, much of Midlothian and East Lothian is intensively farmed, particularly the latter.

Owing to well-developed surface water mains systems, private groundwater usage is limited. In the southern part of Midlothian, springs are common from the Pentland Hills volcanic rocks and many of these are used for drinking supplies. Elsewhere, (Figure 5.5) only the southern fringes of the area support private supplies from mainly shallow sources. The lack of any large, high-yielding aquifers in the region has restricted deep groundwater exploitation. However, over 20 irrigation boreholes have been constructed in recent years in East Lothian. In particular, the area between Aberlady and Dunbar has been exploited for groundwater from volcanic and sandstone aquifers. These aquifers are not highly productive, but single borehole yields of around 10 l/s are obtainable.

5.2.2 Geology and hydrogeology

High permeability glacial sand and gravel deposits occur along the southern margins of the area. Much of it overlies high permeability bedrock and forms a dual-aquifer system. Along the coast, blown sand and raised beach material form shallow aquifers that are commonly no more than 5 m in thickness. In the upper reaches of the River Forth, near Stirling, thick beds of marine and estuarine clay overlie parts of the Passage Formation, forming an effective seal to surface pollutants.

Bedrock aquifers are, in general, moderately or weakly permeable (Figure 5.5) with highly permeable sandstone units restricted to the area south of Aberlady. These comprise Lower Carboniferous sandstones in East Lothian which, in part, are overlain by volcanic lavas. Towards Falkirk, Passage Formation sandstone forms a ring-shaped outcrop. Many of the Carboniferous sandstone aquifers are restricted in thickness compared to the older Devonian formations. Several are confined between lower permeability mudstone beds and are generally less productive than the latter. Farther west, into Midlothian, older Devonian sandstones are present fringing the Pentland Hills.

5.2.3 Land use/aquifer relationships

Large parts of East and Midlothian are covered by high risk areas (Figure 5.6). Approximately 25% of these are coincident with highly permeable aquifers. Within the high coincident areas inland, Lower Carboniferous aquifers are most affected. Glacial and raised beach units form the greater part of the coincident zones along the coast.

5.2.4 Catchments and nitrate data

Catchments with high coincidence (shaded red on Figure 5.5) cover all of East Lothian and much of the eastern part of Midlothian. Nitrate data points are available only for the southern margins of the catchments and none of these exceed 50 mg/l (Figure 5.7). The only >50 mg/l data point is at Aberlady Mains Farm, near the coast. This is representative of the local Carboniferous aquifer.

West of Edinburgh, a similar story to that in the east is found. Only a small area in the western sector of the high risk catchments have any data points and none are found within the high coincident zones to the south of the Forth Bridges. The small coincident areas near Airth towards Stirling are mostly underlain by thick clays. These help to protect the underlying

Passage Formation aquifer and consideration could be given to excluding much of this area from NVZ designation. As with other parts of this region, there are few nitrate data points available.

Table 5.2 shows nitrate data statistics for the area. A lack of monitoring points within the lower coastal area means that only 12% of the total for the Class 1 and 2 catchments exceeded 50 mg/l nitrate. The few sources in this area are located mostly on the fringes of the higher ground of the Lammermuir and Moorfoot Hills in the south. As these are outwith high risk coincident zones, but within the associated catchments, they may be providing a misleading picture of true distribution of nitrate in groundwater. Additional monitoring sources are currently under investigation in the Aberlady – Dunbar area.

Sources amongst the hills of the southern and western parts of the area show a clear contrast with those on lower ground. Out of 47 sites, there are none that exceed 50 mg/l nitrate.

Table 5.2 Nitrate data statistics for Edinburgh and East Lothian sources.

Database	Class 1 and 2 catchments				Elsewhere			
	Number samples	Number failing		Median (mg/l)	Number samples	Number failing		Median (mg/l)
Private Water Supplies	88	10	(11%)	16	41	0	(0%)	3
SEPA Monitoring	3	1	(33%)	40	1	0	(0%)	NA
Water Authorities	1	0	(0%)	1.3	1	0	(0%)	NA
BGS Miscellaneous	11	1	(9%)	7	4	0	(0%)	15
Total	**103**	**12**	**(12%)**	**15.6***	**47**	**0**	**(0%)**	**3.9***

* Weighted average of medians

5.2.5 Summary

- Bedrock aquifers are manly moderately and weakly permeable.
- Superficial aquifers are not well developed.
- Groundwater use is confined mainly to irrigation and private supplies.
- 25% of the high risk areas are coincident with highly permeable aquifers.
- There is a serious lack of nitrate monitoring points across much of the area.

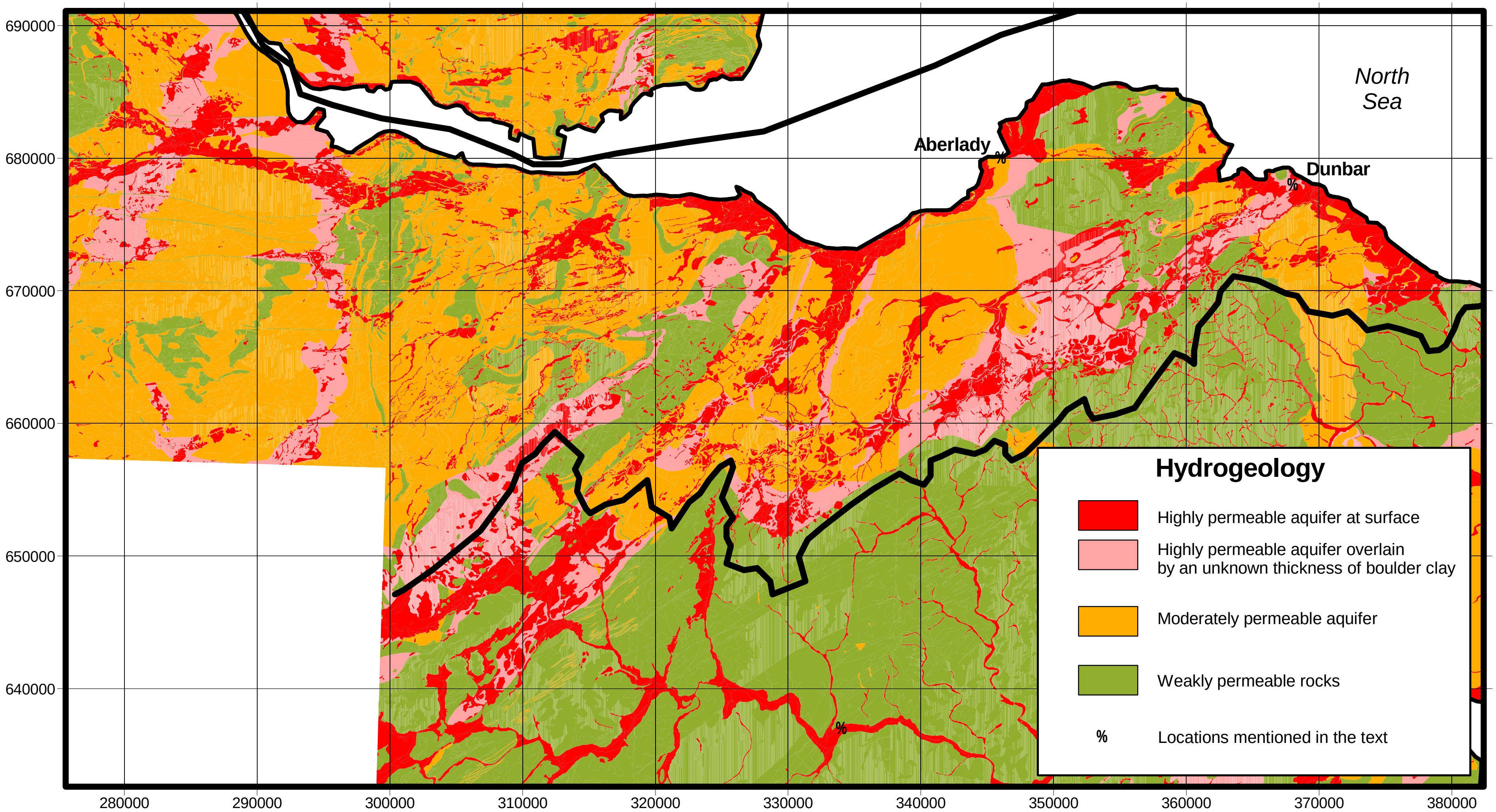

Figure 5.5 Vulnerability of groundwater to nitrate contamination for the Lothian and Stirling area.

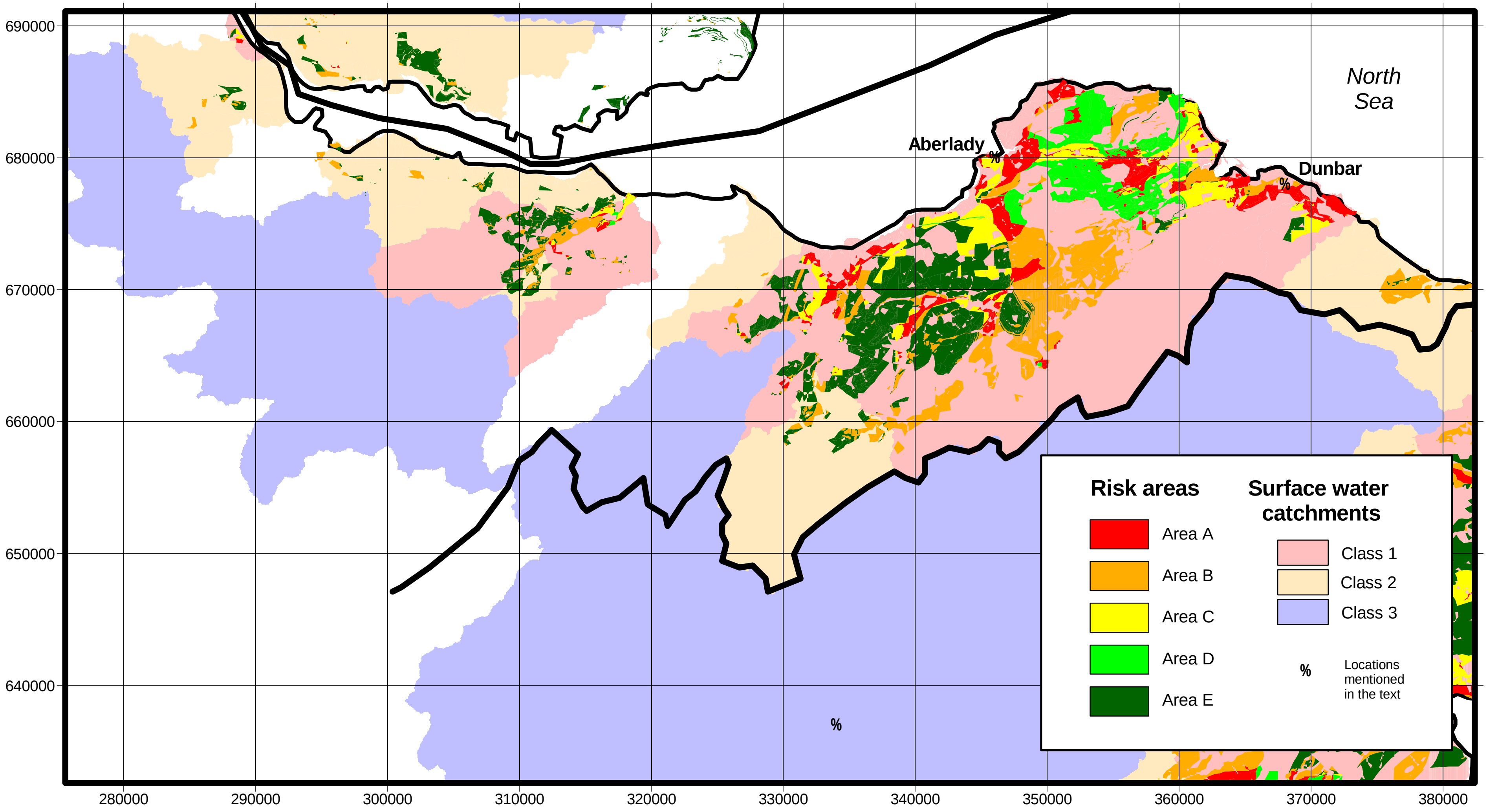

Figure 5.6 Combined risk/vulnerability areas and surface catchments for the Lothian and Stirling areas.

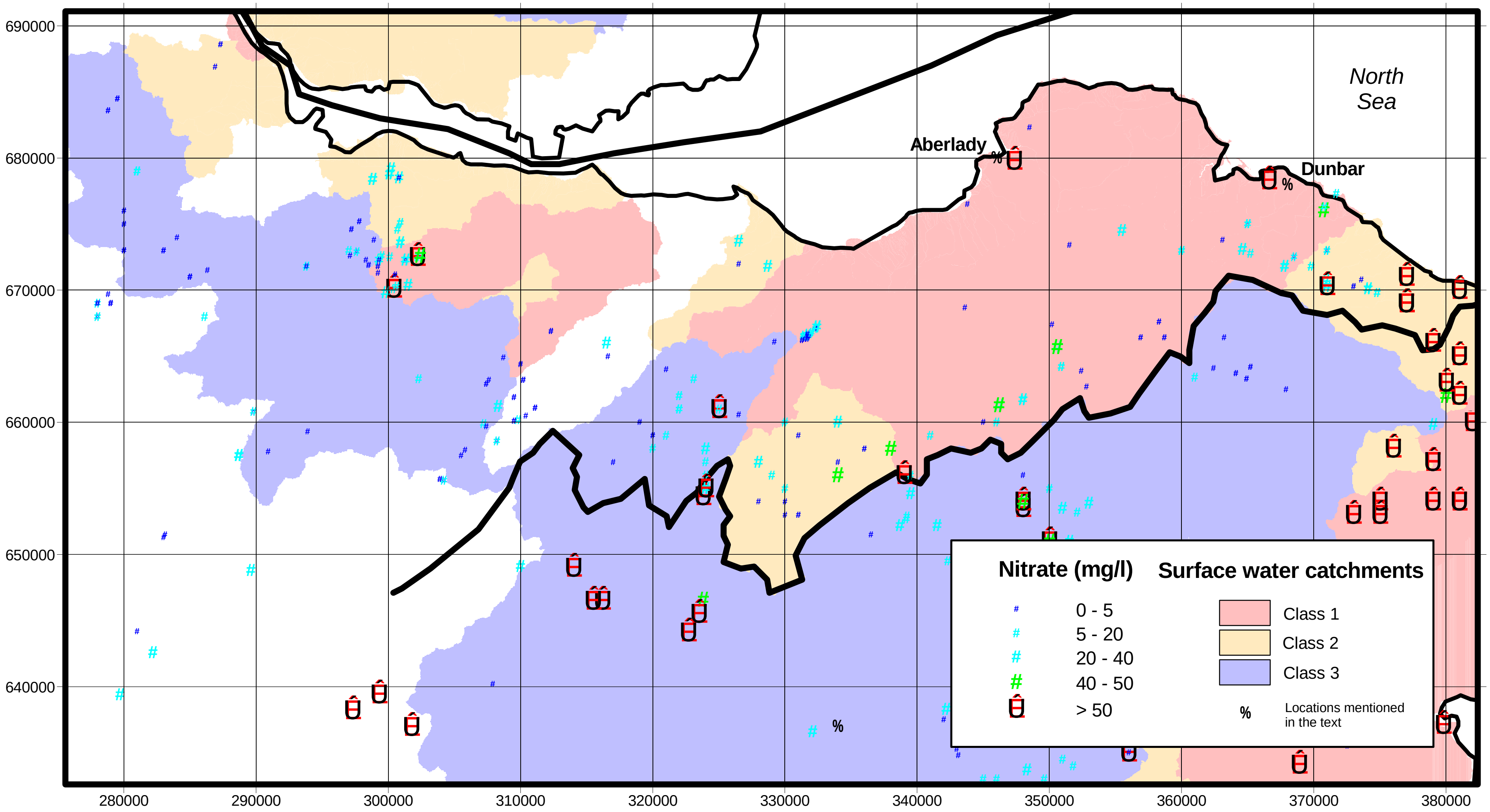

Figure 5.7 Nitrate data and surface catchments for the Lothian and Stirling areas.

5.3 FIFE

5.3.1 Introduction

Fife may be one of the smaller areas in the report, but it contains one of the most highly productive bedrock aquifers in Scotland (Figure 5.8). The Devonian sandstone aquifer has been exploited for many years, particularly over the past 30 years, and provides over 80% of the estimated 25 Mld total groundwater abstraction in Fife. The main centres of population are all along the southern coast where Carboniferous strata have been exploited for coal. The main arable farming areas are therefore in the centre and east of the region.

Continued development of bedrock aquifers over the past 30 years has resulted in localised pockets of intense groundwater abstraction in the Devonian aquifer of central Fife. In particular, water from the area of aquifer between Loch Leven and Ladybank is used all year for public supply abstraction and vegetable processing, but with an added load in the summer months when a dozen or so irrigation boreholes are switched on. Those farms that have no access to the River Eden have no alternative but to construct irrigation boreholes, as surface watercourse are generally too small to support abstraction. It is possible that further borehole construction will occur in the future as the groundwater resource, even in the main Devonian aquifer, is not fully developed.

In addition to Water Authority boreholes, there are many private supplies present, particularly on the high ground in the north-east and central Fife. These are mainly shallow wells, but springs are found within the volcanic hills of the northern part of the area.

5.3.2 Geology and hydrogeology

Highly permeable superficial aquifers comprise mainly superficial raised beach along the southern coast of Fife. Inland, spreads of glacial sand and gravel occur as separate aquifer units and as dual systems with underlying Devonian sandstone.

The main aquifer in the region, the Upper Devonian sandstone, is present from just west of Loch Leven to the coast north of St. Andrews (Figure 5.9). This narrow band of highly permeable sandstone is sandwiched between high ground comprising Devonian volcanic hills to the north and Carboniferous sedimentary and igneous rocks to the south. This important aquifer is most permeable in its upper 50 m where a strong hydraulic connection is present with overlying superficial aquifers. It is this link that has allowed nitrate to infiltrate the bedrock aquifer. This has been well documented for the past 30 years through monitoring of the public supply boreholes at Kinnesswood and around Kingskettle. Other, more comprehensive, investigations (Ó Dochartaigh et al, 1999) show a slight tendency for nitrate to increase steadily.

The importance of the superficial cover, proximity of nitrate sources and borehole construction are amply illustrated in Fife. For example, the Balmalcolm and Kettlebridge public supply sources, approximately 3 km apart, show average nitrate of almost 50 mg/l in the former and 25 mg/l in the latter. At Balmalcolm, 6.5 m thickness of sand and fine gravel overlies sandstone in the 75 m-deep source. At Kettlebridge, the lower nitrate concentration is probably due to the combined thickness of 1.6 m of clay in the drift sequence allied with a source depth of 123 m. It is thought that the deeper Kettlebridge borehole has access to higher quality groundwater at depth. Farther west at Kinnesswood, two of the three public supply sources present differ by almost 20 mg/l nitrate despite being separated by only 123 m. Of these, the borehole source located almost 50 m downslope from a farm and with only 12 m depth of surface casing yields water of over 40 mg/l nitrate. The other borehole contains 50 m of casing and lies farther from sources of nitrate pollution.

5.3.3 Land use/aquifer relationships

Coincident risk zones form a roughly circular shape in the east of Fife (Figure 5.9). In the valley of the River Eden, most of the flood plain east of Freuchie is covered by high risk zones. Arable land is restricted to the lower ground of the river floodplain and coincides with the main Devonian aquifer. In places, alluvium and raised beach gravels form a dual aquifer system. The north-eastern part of Fife contains several patches of very high risk/high aquifer, but these are mainly glacial sand and gravel deposits.

The coastal fringes of eastern Fife, continuing to Leven in the south form the southern arc of the high risk circle. Here, highly permeable bedrock aquifers are absent, with only thin superficial deposits present, forming shallow aquifer units.

5.3.4 Catchments and nitrate data

The whole of eastern Fife is designated as high risk catchment. Where moderately high risk zones are included, much of the remainder of the region is also captured. Over 60 private and other sources have +50 mg/l nitrate (Figure 5.10). These are almost all located in the east of the region, but less than half coincide with highly permeable aquifers. The high nitrate sources are located within both the main Fife aquifer and the weakly permeable volcanic rocks under the hills to the north. The large number of springs and shallow wells present in the latter area indicate a serious problem with near-surface nitrate contamination. In the Eden valley, there are a sufficient number of sources available to confirm the designation of the main Devonian aquifer.

The drift aquifers along the southern coast contain very few monitoring points at present. However, these shallow aquifers may only be exploited to a very small extent and extending the nitrate monitoring network may be difficult. To the north of Leuchars, sources are also currently few in number, but the presence of thick, patchy gravels and small areas of bedrock aquifer has encouraged the construction of a number of new boreholes.

Table 5.3 along with Figure 5.10 clearly show the contrast in the source populations between Class 1 and Class 2 catchments. Only 3% of the sites lie within Class 2 catchments out of 376 in total. One third of the sources exceeded 50 mg/l nitrate from within combined Class 1 and 2 catchments. There are clusters of >50 mg/l sites within area A zones (see page 6 - H+VH land use zones plus highly permeable aquifers) to the west of Leuchars, but in other areas also. The line of volcanic hills that form the northern boundary of the main Devonian aquifer support many private supplies. The greater proportion of them have >40 mg/l nitrate, including several springs that occur along the foot of the hills adjacent to the river Eden floodplain. Many of the clusters of high nitrate amongst the hills of north-east Fife are located within moderately high land use risk zones coinciding with low permeability volcanic formations. One of the conclusions to be drawn from this is that localised shallow nitrate contamination can occur within shallow groundwater systems across a wide range of permeability classifications. This is particularly the case where arable farming is practised. The small number (38) of sites outwith Class 1 and 2 catchments are mostly less than 40 mg/l nitrate.

Table 5.3 Nitrate data statistics for Fife sources.

Database	Class 1 and 2 catchments				Elsewhere			
	Number samples	Number failing		Median (mg/l)	Number samples	Number failing		Median (mg/l)
Private Water Supplies	350	126	(36%)	36	35	0	(0%)	3
SEPA Monitoring	5	0	(0%)	16	0	0	(0%)	NA
Water Authorities	9	1	(11%)	28.5	1	0	(0%)	NA
BGS Miscellaneous	12	2	(17%)	15	2	0	(0%)	NA
Total	**376**	**129**	**(34%)**	**34.9***	**38**	**0**	**(0%)**	**2.8**

* Weighted average of medians

5.3.5 Summary

- Bedrock aquifers include the highly permeable Fife Devonian aquifer.
- Superficial aquifers are not well developed.
- Groundwater use includes important public supply sources near Falkland as well as irrigation and private supplies.
- Much of eastern Fife is a high risk catchment.
- Over 60 sources are >50 mg/l nitrate. They are located across a wide range of aquifer types.

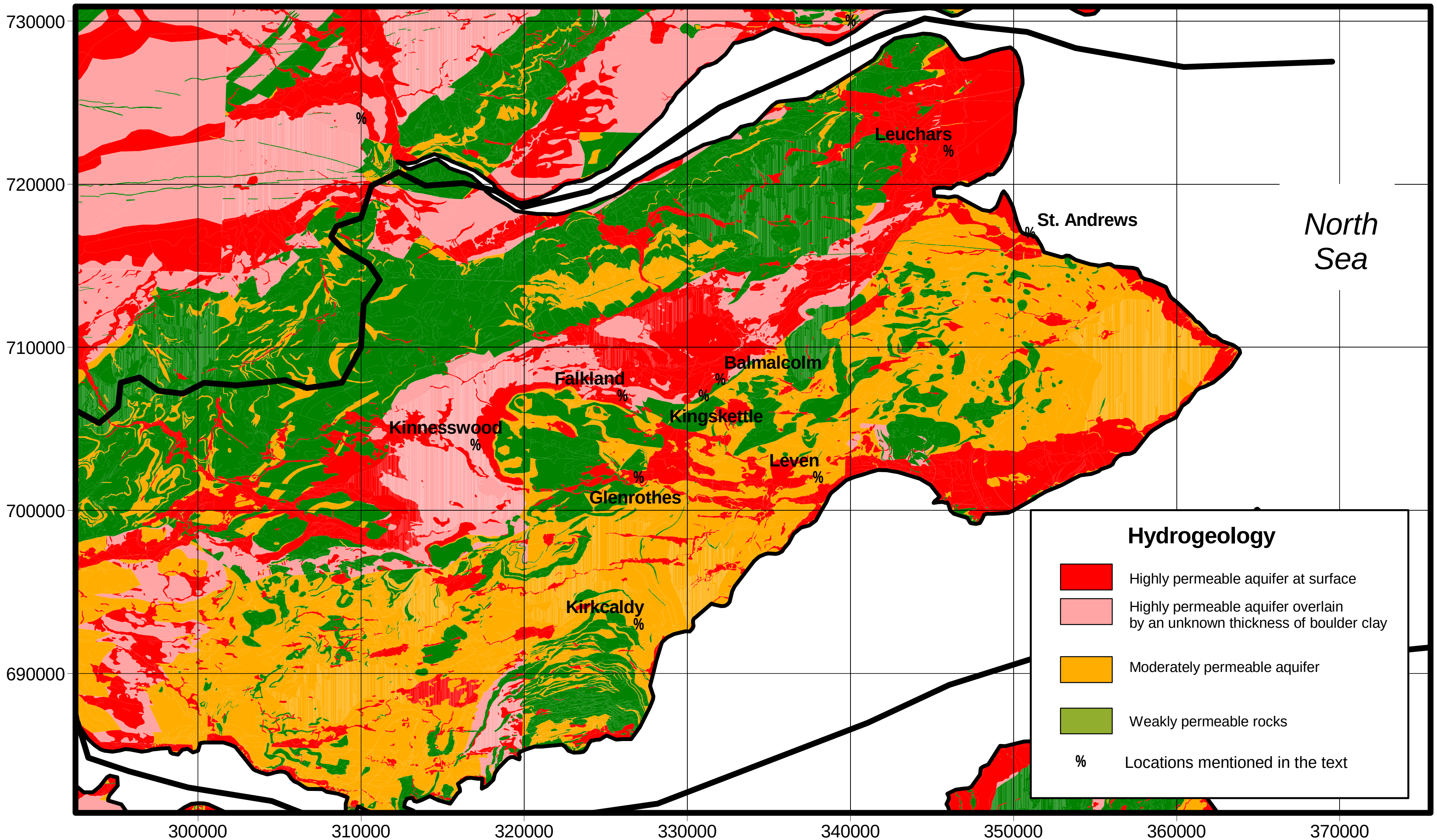

Figure 5.8 Hydrogeology of Fife.

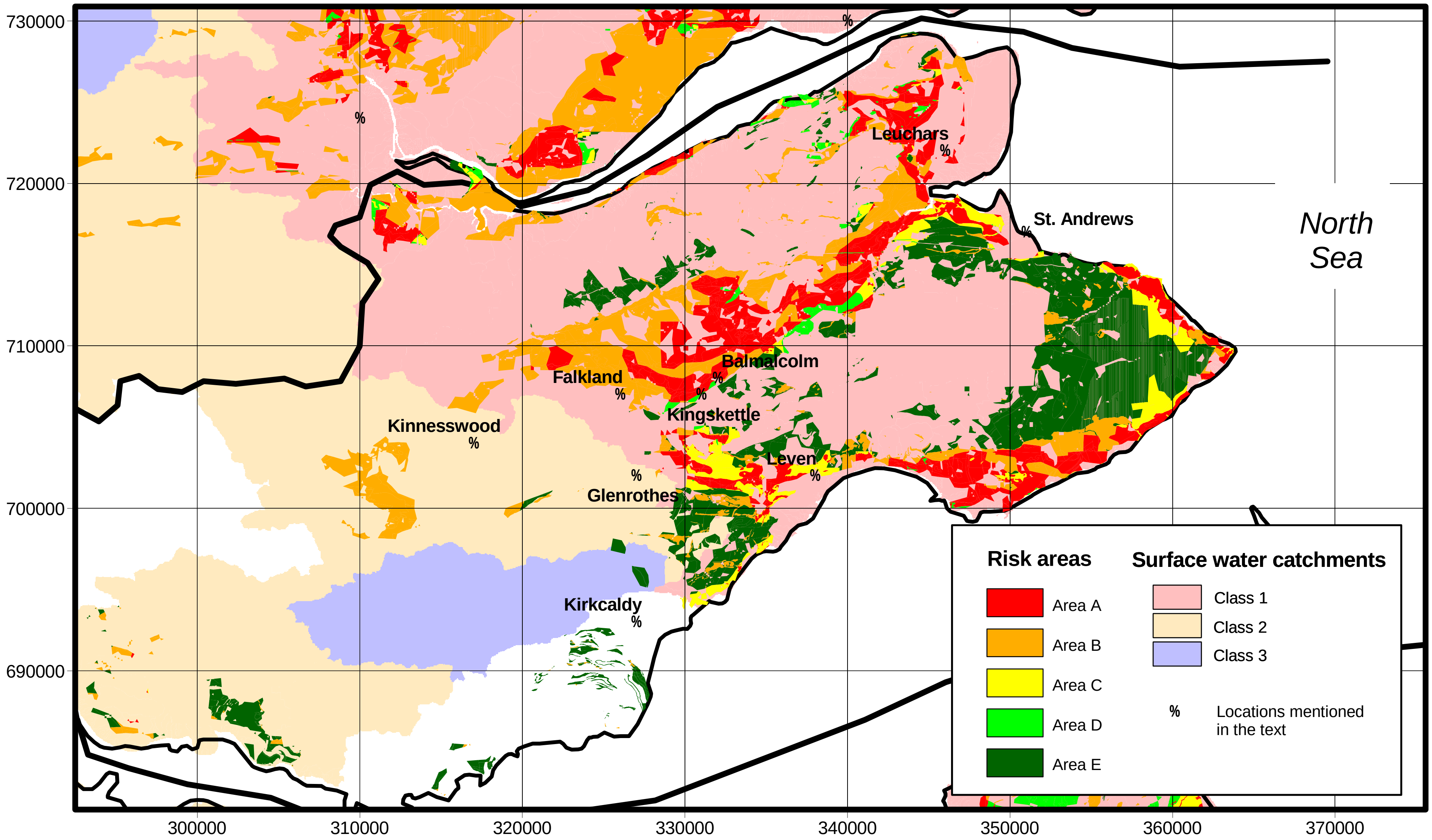

Figure 5.9 Combined risk/vulnerability and surface catchments for Fife.

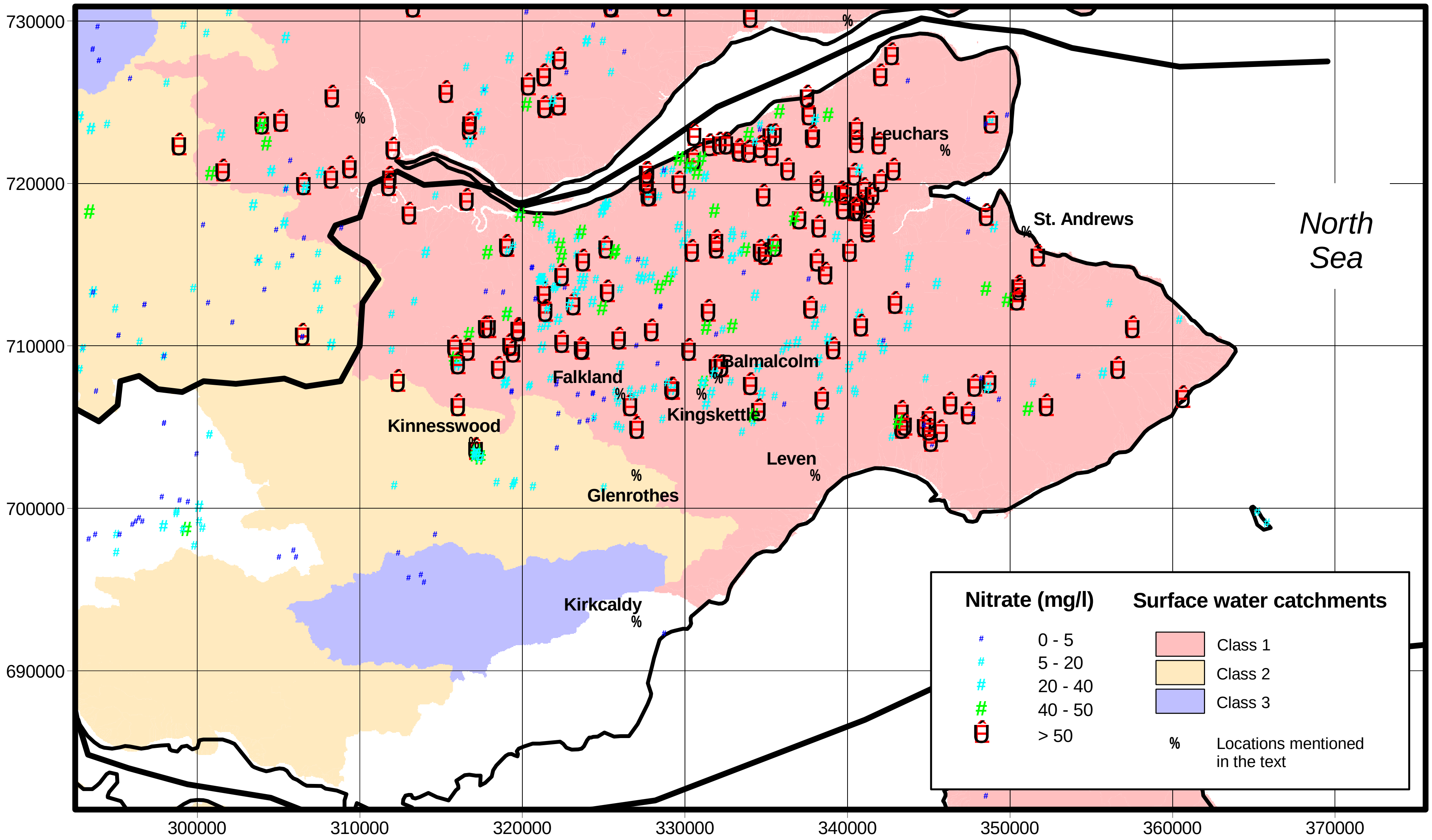

Figure 5.10 Nitrate data and surface catchments for Fife.

5.4 STRATHMORE

5.4.1 Introduction

Strathmore occupies a large tract of land to the south of the Highlands from Stonehaven in the north-east to Crieff in the south-west (Figure 5.11). It is an important agricultural area in which the drier eastern half depends on irrigation for successful crop production. Partly as a consequence of this, there is a distinct pattern of distribution of groundwater source type. The upland areas of the southern Highlands and the volcanic ridges of Strathmore commonly have many wells and springs providing potable supplies. The south-west contrasts with the remainder of the region in having a higher density of private supplies where the Vale narrows. In contrast, the lower ground in the east has many irrigation boreholes from deep aquifer sources in addition to some industrial sources along the Arbroath-Montrose coastal strip.

Attempts to exploit Strathmore aquifers for public supply have met with mixed success. Favourable hydrogeological conditions are present in some areas, such as around Edzell, but the resource has never been developed. As a consequence, only the Borrowfield borehole near Montrose was ever commissioned, but even this is only used as a stand-by source.

5.4.2 Geology and hydrogeology

The distribution of superficial highly permeable aquifers in Strathmore is characterised by well-developed spreads of outwash sand and gravel associated with large meltwater rivers draining the Highlands. In places, significant thicknesses of this material have accumulated. Granular raised beach deposits are not widespread, but in places they are of significant thickness. At Montrose, over 30 m thickness is present under the town. Under the Carse of Gowrie, between Dundee and Perth, thick beds of marine and estuarine clay overlie Devonian sandstone and form an effective barrier between the aquifer and surface activities.

The Vale of Strathmore stretches for over 100 km from Crieff to Stonehaven. Within this area, an extensive regional aquifer is present. The Lower Devonian sandstone aquifer forms part of an elongate structural feature in which the strata have been extensively folded. Interbedded with the sandstones are mudstones and igneous rocks, the latter forming ridges parallel to the north-easterly structural trend (Figure 5.11).

In spite of their generally low permeability, the mudstones have proved to be a useful source of groundwater near Crieff where yields up to 10 l/s are obtainable from deep boreholes. Several dozen boreholes have been drilled in other parts of Strathmore, mainly for irrigation purposes. Data on them are sparse, but they have been drilled into most rock types, including igneous intrusions. Most of the area has good groundwater potential and the eastern sector has the capacity to sustain over 10 l/s from many abstraction boreholes, with over 20 l/s available near Montrose.

5.4.3 Land use/aquifer relationships

Approximately 20% of the high risk areas overlie dual high permeability aquifer systems (Figure 5.12). The latter comprise mainly glacial sand and gravel overlying Lower Devonian sandstone. The remaining 80% overlie till-covered Lower Devonian sandstone.

A large part of the Carse of Gowrie on the north bank of the Firth of Tay is thought to be underlain by thick marine clay. This intensively farmed zone is also almost entirely covered by high and very high risk zones. There is a case here for excluding much of the Carse from NVZ designation because of the protective barrier formed by the clays.

5.4.4 Catchments and nitrate data

The total number of groundwater sources on the current databases is relatively low. Across the whole Vale from Perth to Stonehaven, 77 sources show nitrate > 50 mg/l (Figure 5.13 and Table 5.4). A further 19 are in the range 40-50 mg/l. Out of the 16 SEPA monitoring sites, two exceed 50 mg/l in Class 1 and 2 zones, although one of these (Huntingtower Castle) has now been removed from the list. Approximately one-quarter of all sites within Class 1 and 2 catchments exceed 50 mg/l nitrate. This compares to 2% of the 312 total number of sources within the upland catchments. This clear division reflects land use and aquifer type. However, there is not enough detail in the databases to define the source aquifers of most of the sites. Further work is required to distinguish between shallow wells and the newer, deeper sources, such as Brathinch Farm, a SEPA failing site.

Figure 5.13 shows nitrate data for Strathmore. There is a distinct contrast between overall nitrate concentrations across high ground to the north-west in Class 3 catchments compared to the Class 1 and 2 areas of the lowlands. 27% of the sources in the latter area are >50 mg/l nitrate, but most of these are unverified and it is not known how many of them represent shallow or deep aquifers. There are only 10 sites in Class 1 and 2 catchments in the monitoring network with 6 elsewhere. Large gaps exist in the network, particularly in the central area and new, verified, sites are required. It is important to determine to what extent the results from the Brathinch Farm monitoring borehole are representative of deep groundwater in the area (80 – 100 mg/l nitrate). From Figure 5.13, high nitrate concentrations are clearly a concern in Strathmore and further work is necessary to determine the extent of the problem.

The picture for surface waters is similar. As in other parts of eastern Scotland, surface water draining high ground where the use of fertilisers is limited is low in nitrate. Where they meet lower, more intensively farmed ground, field drainage rich in nitrate is added to the flow, resulting in concentrations of between 10 and 50 mg/l.

Table 5.4 Nitrate data statistics for the Strathmore sources.

Database	**Class 1 and 2 catchments**				**Elsewhere**			
	Number samples	**Number failing**		**Median (mg/l)**	**Number samples**	**Number failing**		**Median (mg/l)**
Private Water Supplies	238	66	(28%)	21	299	7	(2%)	2
SEPA Monitoring	10	2	(20%)	20	6	0	(0%)	21
Water Authorities	0	0	(0%)	NA	3	0	(0%)	1.1
BGS Miscellaneous	34	9	(26%)	39	4	0	(0%)	8
Total	**282**	**77**	**(27%)**	**23.1***	**312**	**7**	**(2%)**	**2.4**

* Weighted average of medians

5.4.5 Summary

- Strathmore includes an extensive, regional aquifer comprising Devonian sandstone.
- Many private supply sources and irrigation boreholes are in use.
- 27% of the sources are >50 mg/l nitrate, although most of these require verification.
- Most of Strathmore is included in Class 1 and 2 catchments.

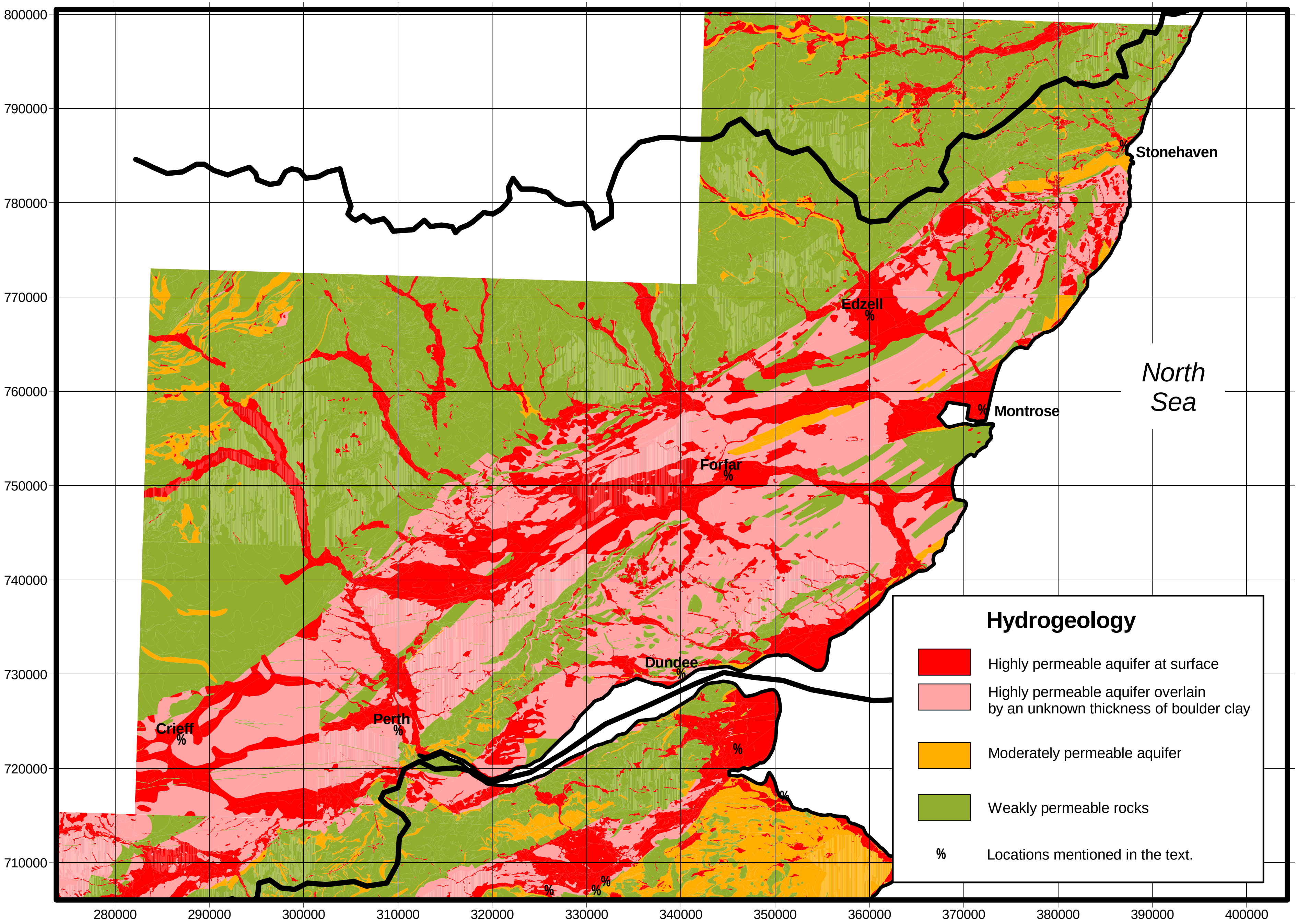

Figure 5.11 The hydrogeology of Strathmore.

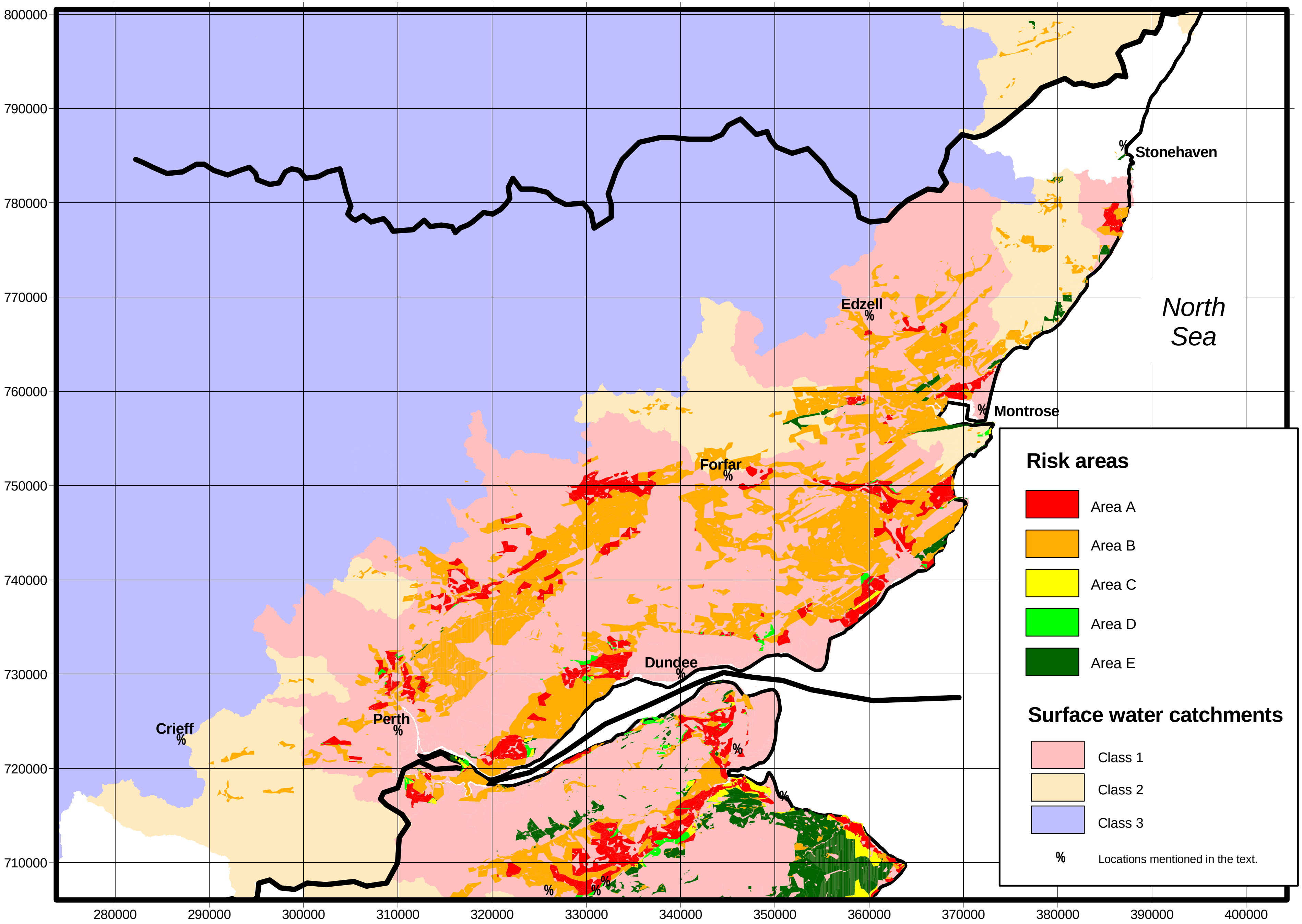

Figure 5.12 Combined risk/vulnerability areas and surface catchments for Strathmore.

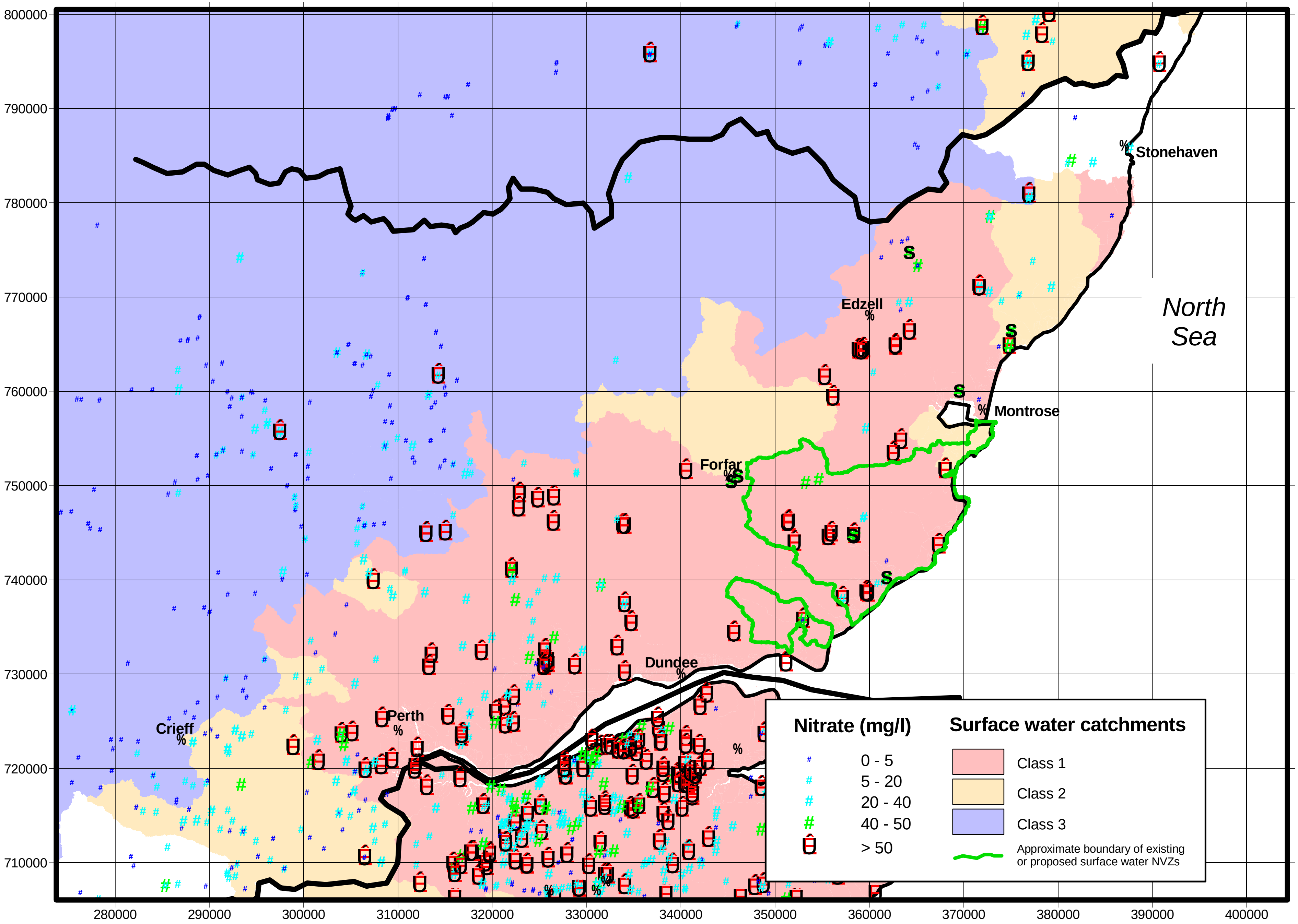

Figure 5.13 Nitrate data and surface catchments for Strathmore.

5.5 ABERDEENSHIRE WITH BANFF AND BUCHAN

5.5.1 Introduction

In the hinterland to the City of Aberdeen and the coastal towns of the north-east, population density is low. The absence of any highly productive regional bedrock aquifers has resulted in only limited groundwater development for public supply and industry. However, the gently undulating arable farmland that covers much of the area has led to a reasonably even spread in population density, with only a small amount of unproductive upland. As a consequence, a large number of private groundwater supplies exist. Most of these are old, shallow wells or springs, but the recent past has seen many new boreholes, typically drilled to depths of 30 m. There has been a trend over the past 20 years for existing wells and springs to be replaced by boreholes. This has been due to the lack of supply capacity in many of the traditional sources and also to an increased awareness of contamination issues.

5.5.2 Geology and hydrogeology

Highly permeable superficial aquifers are restricted to the main valleys where glacial sand and gravel flanks the valley sides, and alluvium is present under the floodplains. The latter deposits are often very favourable for exploitation, as the water table is shallow and the aquifers located within discharge areas. Boulder clay, or till, is normally considered a non-aquifer, but large areas of the region contain many wells that abstract water only from this deposit. Water-bearing tills occur where there are gravelly beds included within the deposit. Inflow rates of groundwater to domestic wells are normally low, but the large storage factor of a dug well allows constant seepage to occur, so that periods of high demand during the day can be met. Therefore, the till, normally regarded as a barrier to water infiltration, is an aquifer in its own right over much of the area.

Aberdeenshire with Banff and Buchan have almost no highly permeable aquifers (Figure 5.14). Moderately permeable formations are also limited, with only the Middle Devonian Turriff basin of any size. 75% of the region is underlain by weakly permeable PreCambrian Dalradian rocks. These are metamorphosed fine-grained sedimentary, volcanic and intrusive rocks that have no intergranular porosity available for the storage and transmission of groundwater. In general, the most permeable part of the Dalradian is the upper weathered zone. This is found at rockhead, immediately below the superficial cover and formed through the effects of water action and ice during the last glaciation. It is this zone that is often exploited for groundwater by the construction of shallow wells. Many springs in the area are also fed by shallow groundwater moving through this zone and appearing on hillsides or near valley floors.

Groundwater is present within fractures and fissures in the rock and can be found at depths greater than 100 m where associated with structural features such as faults. Boreholes drilled to depths of between 30 m and 50 m into the Dalradian are becoming common. In spite of the low permeability of the aquifer, boreholes can normally sustain sufficient flow to supply 1 or 2 houses.

Large granitic and other igneous intrusions are present over parts of southern Aberdeenshire. These rock types are also weakly permeable, generally more so than the Dalradian. However, they can often yield enough water for small domestic supplies. The absence of any highly productive bedrock aquifers across the region has not, therefore, prevented the exploitation of groundwater. Demand for private supplies which can be met even by rock formations that at first sight appear completely unfavourable for groundwater.

5.5.3 Land use/aquifer relationships

Figure 5.15 shows the coincident areas of high risk land use and highly permeable aquifers. In this region, less than 100 km^2 are covered by these categories, owing to the lack of any highly permeable bedrock aquifers. Where coincident zones for high and very high risk occur, they are underlain by shallow superficial aquifers. Of these, glacial sand and gravel aquifers form over 80% of the zones, the remainder being valley alluvium.

Moderate MLURI risk zones occupy over 90% of the high risk category in the region. Over 90% of the moderate risk area overlies weakly permeable bedrock aquifers. The risk of nitrate contamination of bedrock aquifers is, therefore, low. Gravelly tills and the bedrock weathered zone, however, form a shallow groundwater system which is much more vulnerable. Owing to the lack of data on the nature and location of the more permeable tills and weathered rock, it is not possible to produce a more detailed vulnerability map of the shallow aquifers.

5.5.4 Catchments and nitrate data

Figure 5.16 shows point source nitrate data with zoned surface water catchments. Overall, there is no obvious correlation between nitrate concentrations in groundwater across the region. Particularly in the Upper Don catchment, but elsewhere, many private supplies record +50 mg/l nitrate where there is an absence of MLURI risk zones. Both the Class 1 and 2 catchments and the Upper Don contain private sources where one-fifth exceed 50 mg/l nitrate. Outwith these catchments, only 1% of 143 sites are +50 mg/l nitrate. Owing to a lack of detail in the private supplies dataset, no trends between shallow and deep groundwater can be recognised. It would appear that shallow nitrate contamination is common over the whole area. In addition, the SEPA monitoring sites at Backhill Farm and Upperheads of Skelmuir indicate that deeper groundwater is also being contaminated. Further monitoring sites need to be established in Aberdeenshire to build up a larger dataset for the area.

Table 5.5 Nitrate data statistics for sources in the Aberdeen, Banff and Buchan areas.

Database	Class 1 and 2 catchments				Elsewhere (excluding 1, 2 and 4)			
	Number samples	Number failing		Median (mg/l)	Number samples	Number failing		Median (mg/l)
Private Water Supplies	777	161	(21%)	27	128	1	(1%)	3
SEPA Monitoring	23	3	(13%)	26	10	0	(0%)	8.1
Water Authorities	9	2	(0%)	30.8	5	1	(20%)	24.4
BGS Miscellaneous	0	0	(0%)	NA	0	0	(0%)	NA
Total	**809**	**166**	**(21%)**	**27.0***	**143**	**2**	**(1%)**	**4.1***

* Weighted average of medians

Table 5.6 Nitrate statistics for sources in the Class 4 catchments of Aberdeen, Banff and Buchan.

Database	Class 4 catchments			
	Number samples	Number failing		Median (mg/l)
Private Water Supplies	273	62	(23%)	24
SEPA Monitoring	1	0	(0%)	NA
Water Authorities	5	0	(0%)	11.9
BGS Miscellaneous	0	0	(0%)	NA
Total	**279**	**62**	**(22%)**	**23.7***

* Weighted average of medians

5.5.5 Summary

- Bedrock aquifers are almost entirely weakly permeable Precambrian rocks.
- Superficial aquifers are restricted mainly to the river valleys.
- Private groundwater supplies total 777 of which 21% are >50 mg/l nitrate.
- Sources exceeding 50 mg/l nitrate are scattered across the area, with no clear link to the geology or risk zones.
- High nitrate concentrations are found in the Upper Don away from high nitrate leaching zones identified by MLURI .

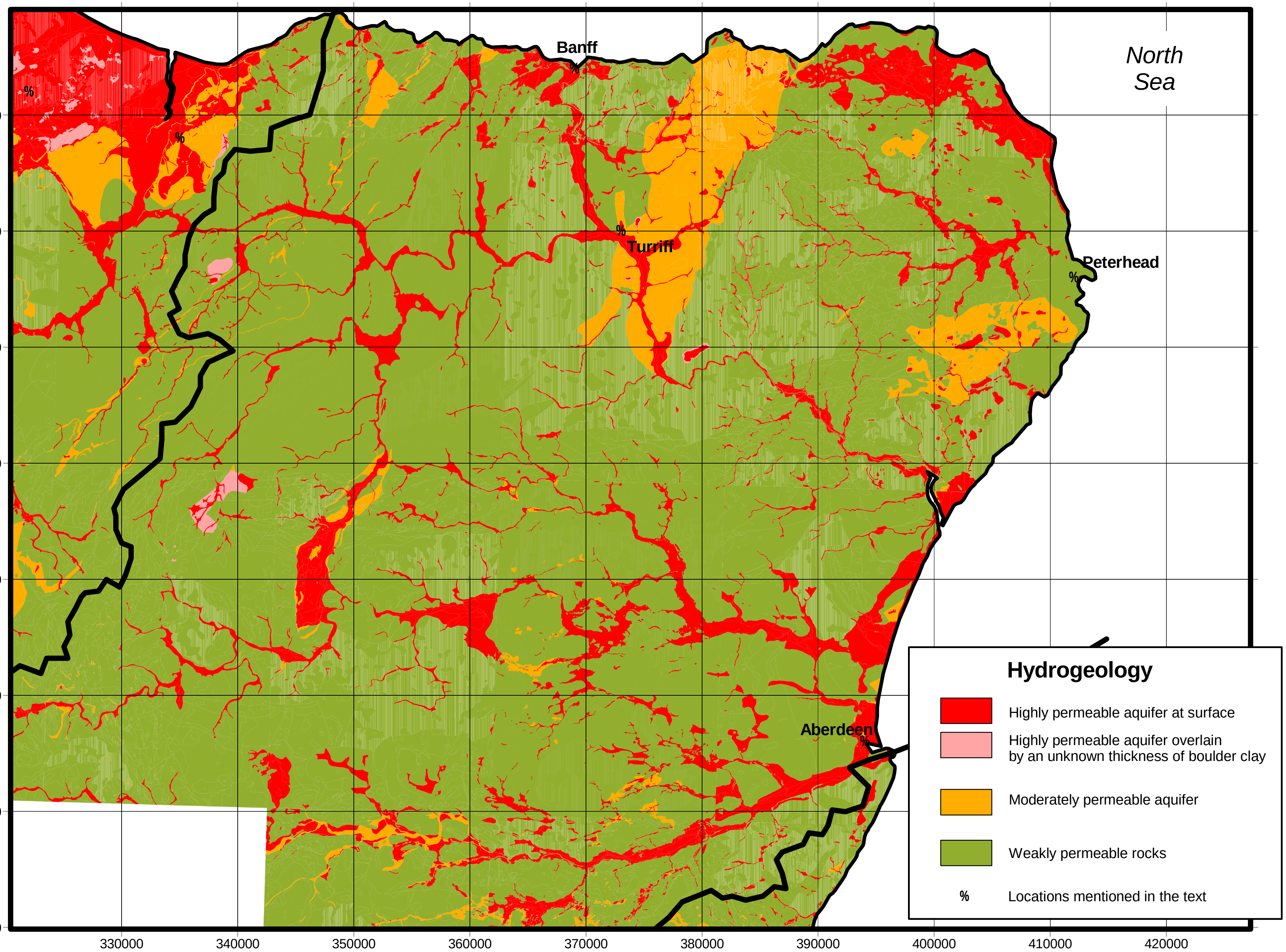

Figure 5.14 The hydrogeology of Banff and Aberdeenshire.

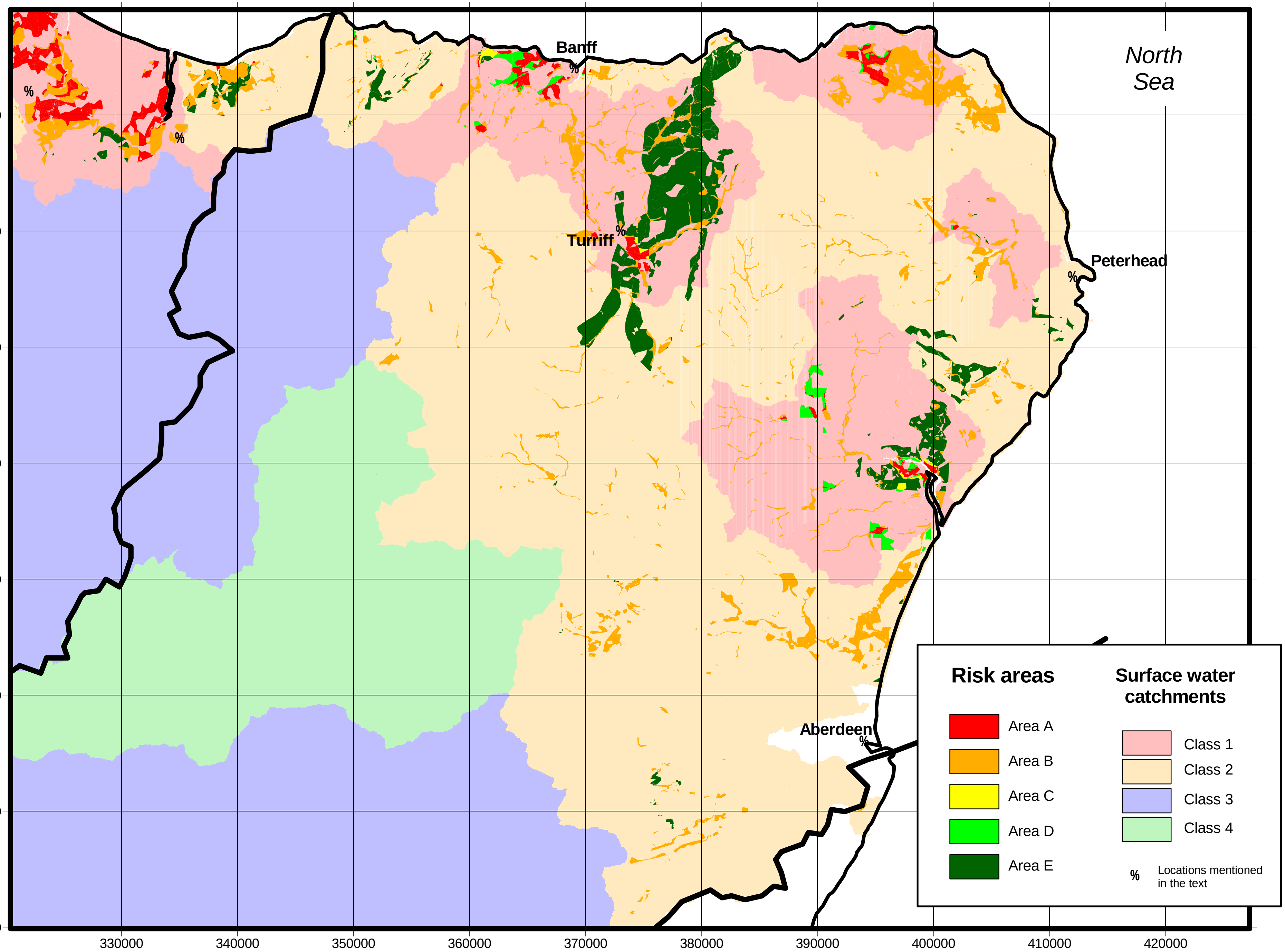

Figure 5.15 Combined risk/vulnerability areas and surface catchments for Banff and Aberdeenshire.

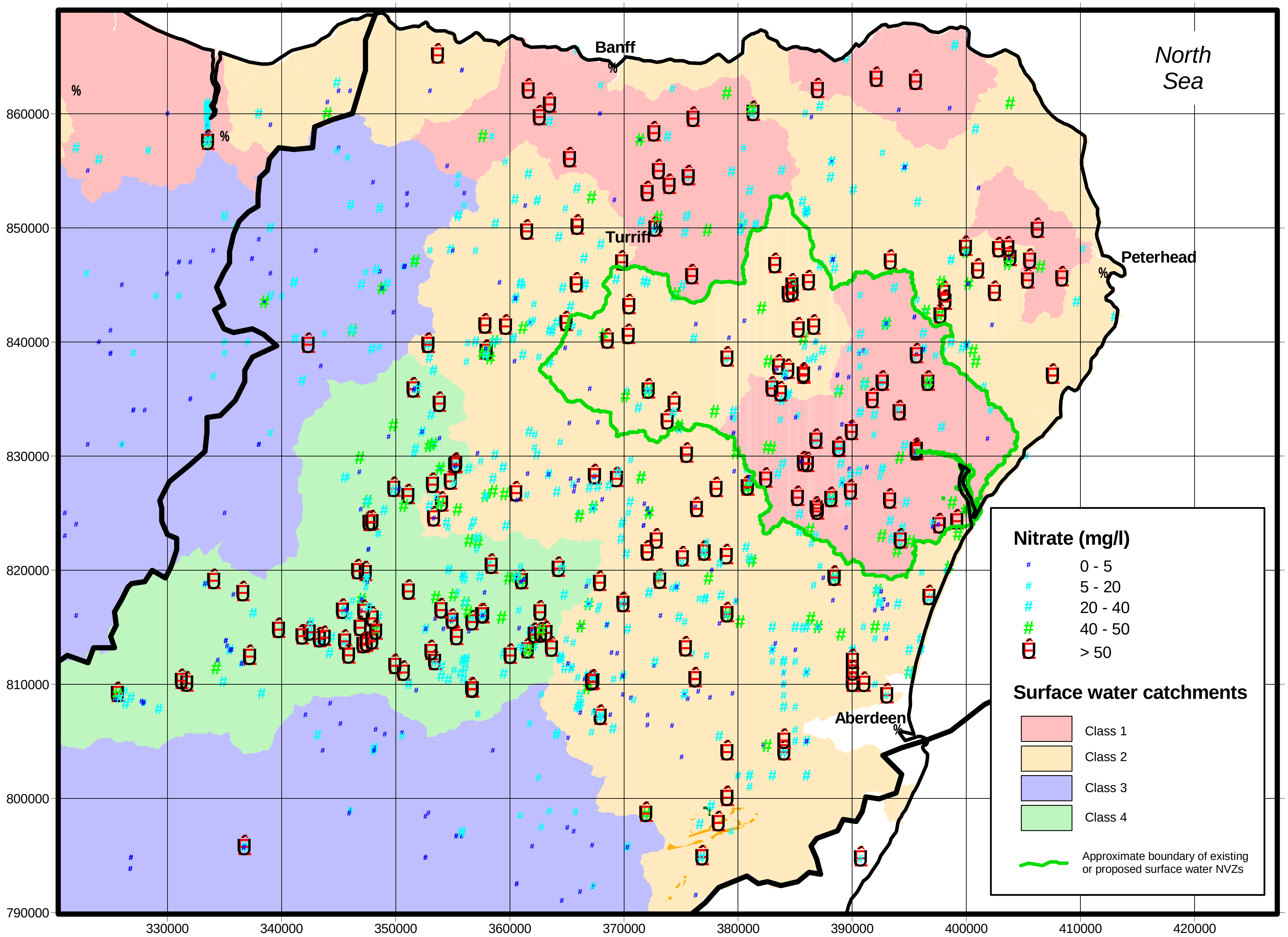

Figure 5.16 Nitrate data and surface catchments for Banff and Aberdeenshire.

5.6 MORAY AND INVERNESS

5.6.1 Introduction

The Morayshire-Inverness area (Figure 5.17) is characterised by high ground and deep valleys in the southern part that contrast with the low coastal plain from Fochabers to Inverness. The underlying bedrock geology is responsible for this, with Precambrian metamorphic rocks forming the southerly hills and softer sandstones nearer the coast. The highest population density is on the coastal belt which is where most of the arable farming is carried out.

Groundwater remains an undeveloped resource across the whole area. There is a public supply borehole at Burghead and a well field on the flood plain of the River Spey near Fochabers, which has the capacity to abstract 27 Mld, but few other sources. These cover a wide range of uses, including maltings, distilleries and private supplies. Favourable geological conditions along the coastal belt mean that groundwater supplies from sources up to 10 l/s are thought to be available across a wide area from the Devonian sandstone aquifers.

5.6.2 Geology and hydrogeology

The coastal lowland plain is masked by extensive deposits of glacial sand and gravel with raised beach deposits along parts of the coast. Parts of the lower ground adjacent to the coast, such as around Inverness airport, include patchy estuarine and marine clays. To the south, the sands and gravels transgress partly on to higher ground underlain by Highland rocks and igneous intrusions.

The Upper Devonian sandstone aquifer between Elgin and Nairn along with smaller sandstone formations in the Burghead to Lossiemouth area (Figure 5.17 are all classed mainly as highly permeable. They form a belt approximately 15 km in width from the coast. The aquifers are not as highly productive as those in Fife, for example, but, nevertheless, have considerable potential for development.

To the west as far as Inverness, Middle Devonian sandstone is moderately permeable owing to the finer-grained nature of the rock compared to the Upper Devonian farther east. Almost the whole of the Devonian is covered by glacial sand and gravel with basal clays, leading to confined groundwater conditions in much of the aquifer.

5.6.3 Land use/aquifer relationships

MLURI risk zones are scattered along the length of the coastal plain between Fochabers and Inverness (Figure 5.18). Over 95% of these zones are coincident with highly permeable aquifers. The extensive spread of glacial sand and gravel on the coastal plain means that dual aquifer systems are widespread. Almost the whole of the high risk zones are underlain by the dual system. In many places, the superficial aquifers are significant in thickness and are potentially important aquifers in their own right.

The southern part of the area comprises high ground that is, for the most part, devoid of both land use high risk zones and highly or moderately permeable aquifers.

5.6.4 Catchments and nitrate data

The Moray area has very few SEPA monitoring sites and, as a consequence, no trends in nitrate distribution can be identified (Figure 5.19). Of these, the high nitrate springs at Blervie House have been recommended for rejection from the network. Only one other source near the coast has recorded a sample of >50 mg/l nitrate, but little is known of the quality of this site. At least 5 sites are required along the coastal plain in order to adequately monitor the aquifer system.

Table 5.7 shows the statistics for the Moray area. These data are striongly influenced by the North of Scotland Water Authority well field on the banks of the River Spey at Fochabers. Over 40 sources are represented, all of which are less than 50 mg/l nitrate. This leads to only 4% of the total number of sources exceeding the nitrate limit. Clearly, the identification of new data points is necessary along the Moray coast.

Table 5.7 Nitrate data statistics for Moray sources.

Database	Class 1 and 2 catchments				Elsewhere			
	Number samples	Number failing		Median (mg/l)	Number samples	Number failing		Median (mg/l)
Private Water Supplies	52	1	(2%)	7	62	1	(2%)	5
SEPA Monitoring	5	1	(20%)	10	8	0	(0%)	2.5
Water Authorities	3	1	(0%)	9.9	4	0	(0%)	0.7
BGS Miscellaneous	7	0	(0%)	2	0	0	(0%)	NA
Total	**67**	**3**	**(4%)**	**6.8***	**74**	**1**	**(1%)**	**4.5***

* Weighted average of medians

5.6.5 Summary

- Bedrock aquifers comprise mainly Devonian sandstones that occur along a broad coastal strip.
- Superficial aquifers form widespread deposits over much of the Devonian rocks.
- Groundwater is not used on a large scale except for the Spey gravel public supply scheme.
- Private groundwater supplies total 52 of which only one is >50 mg/l nitrate.
- An increase in the number of monitoring points is required.

5.7 THE BLACK ISLE – TAIN AREA

5.7.1 Introduction

The area termed the Black Isle - Tain covers the ground north from Inverness to Tain. It is divided in two by the Cromarty Firth with the more northerly Invergordon-Tain area having the majority of the arable farming land. This is due to the more favourable topography of the area compared to the ground inland from Fortrose which rises to over 200 m elevation. Data on groundwater are sparse for the Black Isle, although information gathering is currently underway. There appears no reason why bedrock aquifers should not be developed. The geology is favourable and, where coincident with broad areas of low-lying ground, should offer good potential for the construction of abstraction sources.

5.7.2 Geology and hydrogeology

Highly permeable raised beach deposits with some elongate areas of glacial sand and gravel form shallow vulnerable aquifers over low-lying ground near Tain. Clayey layers are likely to be common within large sections of the deposits.

Most of the area is underlain by Middle Devonian sandstone which is classed as being moderately permeable (Figure 5.17). Exposures of bedrock along the Moray Firth coast reveal a large number of igneous intrusions within the sandstone that are associated with the Great Glen Fault, but are hidden by the cover of drift. The intrusions are likely to be acting as barriers to groundwater flow and, therefore, dividing the aquifer up into cells. The effect of this may be to restrict regional groundwater flow and limit nitrate contamination to localised areas.

5.7.3 Land use/aquifer relationships

Much of the Tain area is covered by high risk MLURI areas, but only approximately 50% of this coincides with highly permeable aquifers, at the head of Nigg Bay (Figure 5.18). In this area, there are no highly permeable bedrock aquifers present as the whole of the Middle Devonian sandstone succession is classed as moderately permeable. Raised beach sands and gravels cover large areas of low-lying ground and are associated with all of the high risk coincident areas (Figure 5.17). Within them, the water table is generally shallow. This renders much of the deposit highly susceptible to nitrate contamination.

There are no highly permeable bedrock aquifers within the Black Isle as it is mostly underlain by moderately permeable Devonian sandstone. Only along the southern shores of the Cromarty Firth and near Conon Bridge are highly permeable aquifers found. The former comprises superficial raised beaches and the latter a spread of outwash glacial sand and gravel.

5.7.4 Catchments and nitrate data

The southern shores of the Cromarty Firth as well as near the town of Cromarty both contain small high risk catchments associated with superficial raised beach aquifers (Figure 5.19). The western boundary of the Black Isle includes a small area of glacial sand and gravel coincident with high and very high leaching zones.

Most of the Tain area is included in high risk catchments, including all of the low-lying ground. Data points to confirm the high risk catchments are absent across the whole Black Isle–Tain area. Investigations are currently underway to increase the coverage of the nitrate monitoring network in this area.

Table 5.8 shows the need for more monitoring sites in the Black Isle. To date, no sites have been found that exceed 50 mg/l nitrate, but a total of only 4 sites have been recorded so far.

Table 5.8 Nitrate data statistics for Tain and Black Isle sources.

Database	Class 1 and 2 catchments				Elsewhere			
	Number samples	Number failing		Median (mg/l)	Number samples	Number failing		Median (mg/l)
Private Water Supplies	0	0	(0%)	NA	0	0	(0%)	NA
SEPA Monitoring	0	0	(0%)	NA	2	0	(0%)	NA
Water Authorities	2	0	(0%)	NA	0	0	(0%)	NA
BGS Miscellaneous	0	0	(0%)	NA	0	0	(0%)	NA
Total	**2**	**0**	**(0%)**	**NA**	**2**	**0**	**(0%)**	**NA**

5.7.5 Summary

- Much of the area is underlain by Devonian sandstone.
- Superficial aquifers are mainly raised beach deposits.
- There are no private groundwater sources data for the area.
- Monitoring sites for the area are required particularly as a large part of the Tain area is designated as a Class 1 catchment.

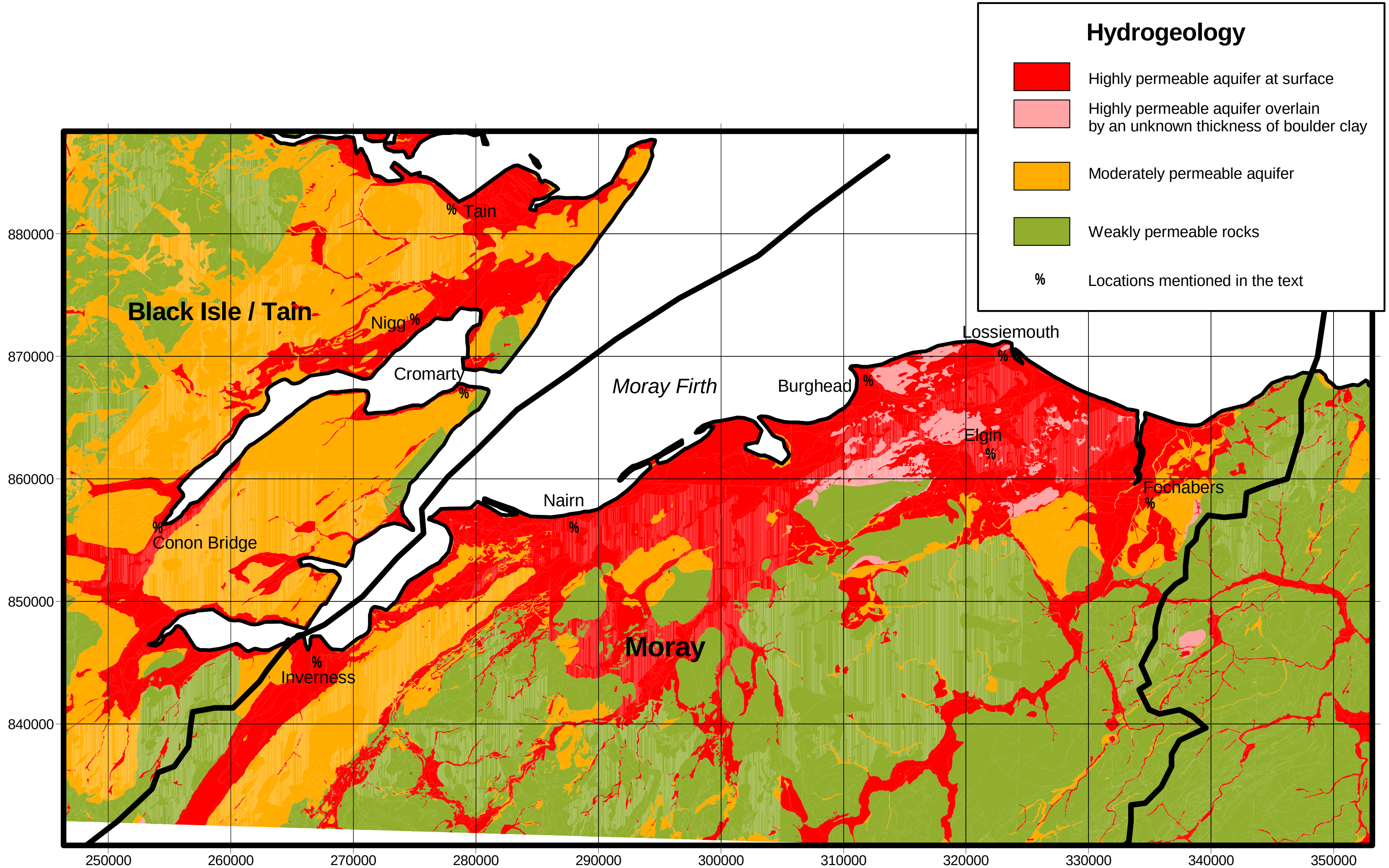

Figure 5.17 The hydrogeology of Moray and the Black Isle.

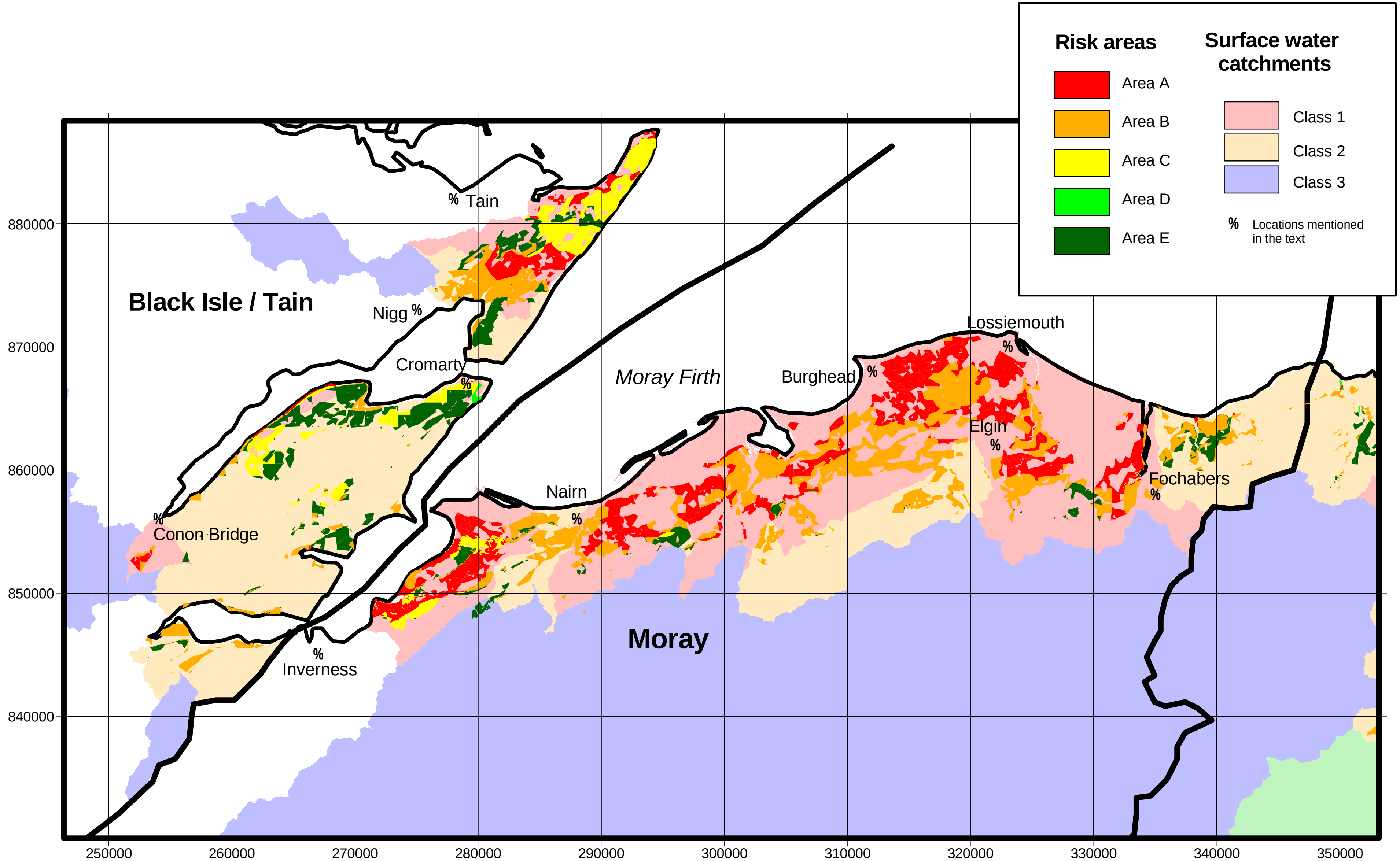

Figure 5.18. Combined risk/vulnerability areas and surface catchments for Moray and the Black Isle.

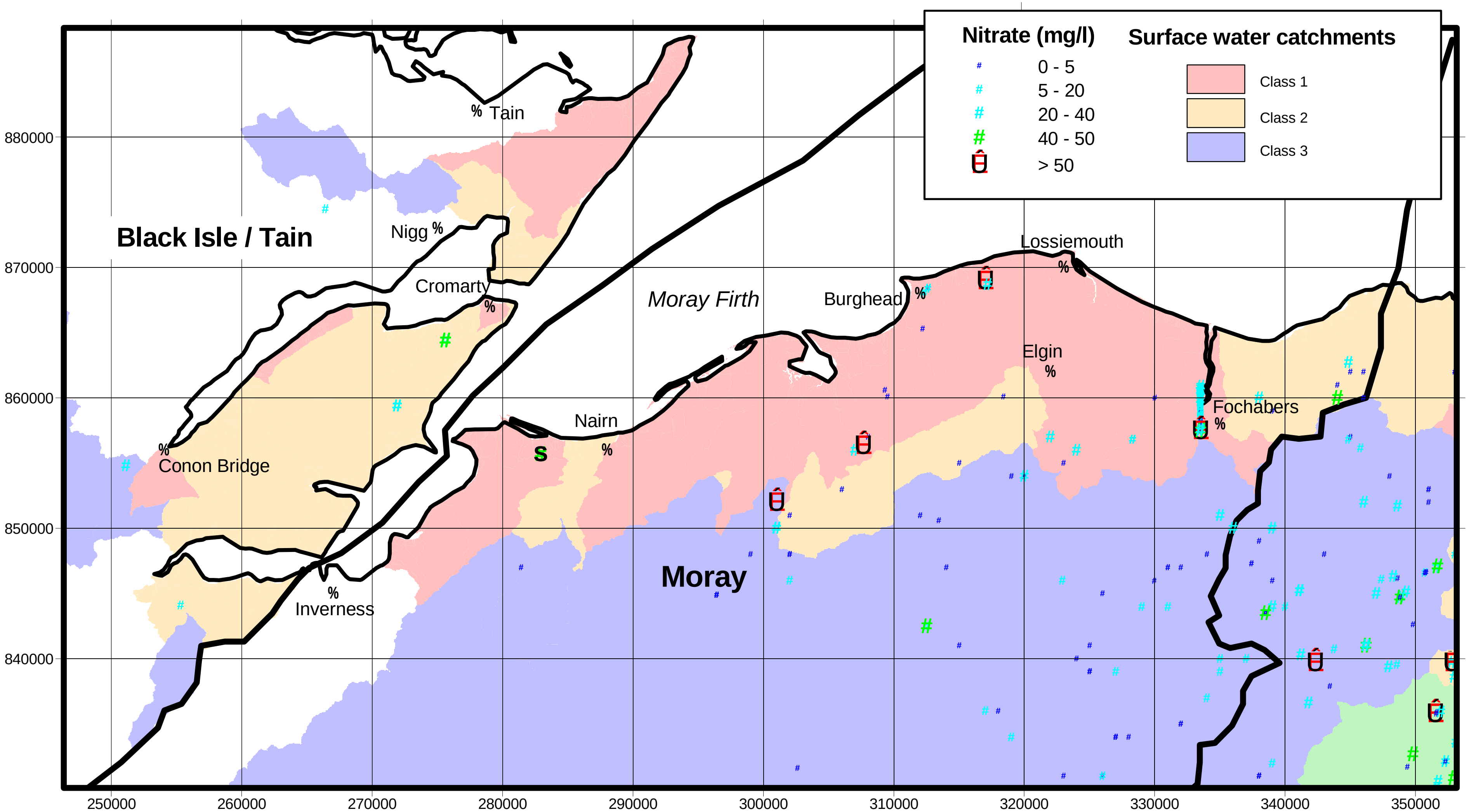

Figure 5.19. Nitrate data and surface catchments for Moray and the Black Isle.

5.8 THE DUMFRIES BASIN

The Permian basin of Dumfries is one of Scotland's most important aquifers. It comprises a semi-elliptical basin 25 km long and 10 km wide infilled with more than 1000 m thickness of sediments (Figure 5.19). Approximately 11 000 Ml are abstracted annually, which accounts for 11% of the total volume of groundwater abstracted in Scotland. Groundwater from the aquifer provides much of the town's domestic and industrial water supply, through both private abstractions and public supply. The aquifer also provides water for two large fish farms, various dairy and arable farms and a mineral water company.

The conceptual model of nitrate leaching developed by MLURI calculates that nitrate leaching is low throughout Dumfries (Lilly *et al.* 2001). However the available nitrate data indicate that nitrate concentrations in groundwater are high (see Section 4 and Table 5.8). The source of the nitrate is unclear, but may be due to a combination of livestock farming and permeable soils.

Recent research by BGS investigated nitrate trends within the Dumfries aquifer (MacDonald *et al.* 2000). The research indicated that the average nitrate concentration of water recharging the aquifer was 40-50 mg/l. The nitrate concentration of waters sampled from individual boreholes depended on the mixing of this young water with older (pre 1950) nitrate free groundwater.

The catchment for the River Nith, as shown on the GIS, includes not only the Dumfries Permian sandstone aquifer, but the smaller and more northerly Thornhill basin also. The geology of the catchment area has yet to be imported to the GIS, but clusters of high nitrate concentrations are seen in the general area of the Permian aquifers as well as associated with adjacent outwash glacial sand and gravel. This needs further investigation.

Table 5.9 shows that the percentage of failures in the Dumfries basin (21%) is approximately the same as in parts of eastern Scotland where high risk catchments have been identified.

Table 5.9 Nitrate data statistics for Dumfries catchment sources.

Database	Class 4 catchments			
	Number samples	Number failing		Median (mg/l)
Private Water Supplies	108	29	(27%)	24
SEPA Monitoring	9	0	(0%)	30
Water Authorities	3	0	(0%)	29.2
BGS Miscellaneous	20	0	(0%)	26
Total	**140**	**29**	**(21%)**	**24.8***

* Weighted average of medians

5.8.1 Summary

- The Dumfries basin includes an important Permian sandstone aquifer used for public supply.
- Average nitrate concentrations in shallow groundwater are in the range 40-50 mg/l.
- Almost one-quarter of the groundwater sources exceed 50 mg/l nitrate, but this total includes many unverified private water supplies.

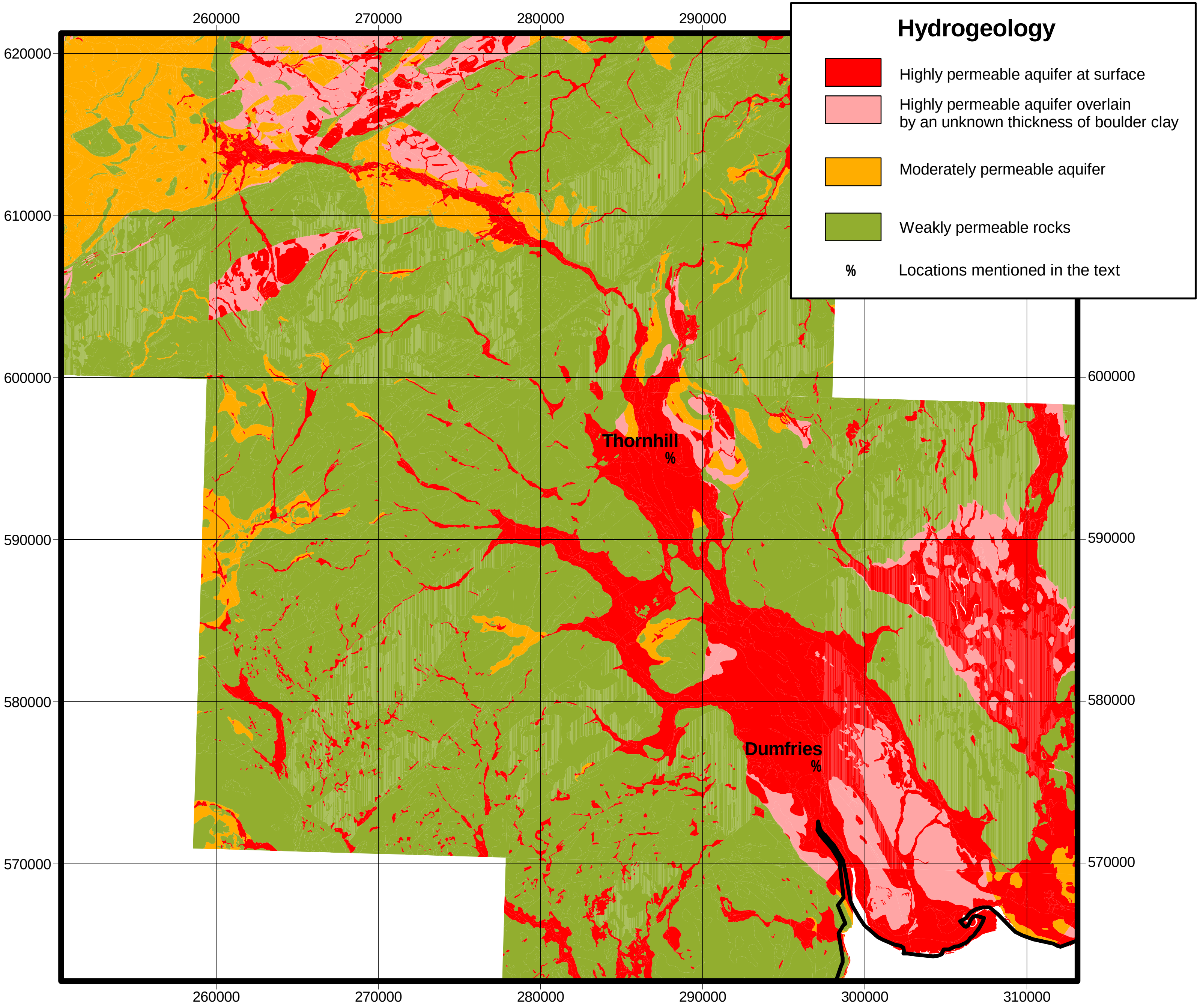

Figure 5.20 The hydrogeology of the Dumfries and Thornhill area.

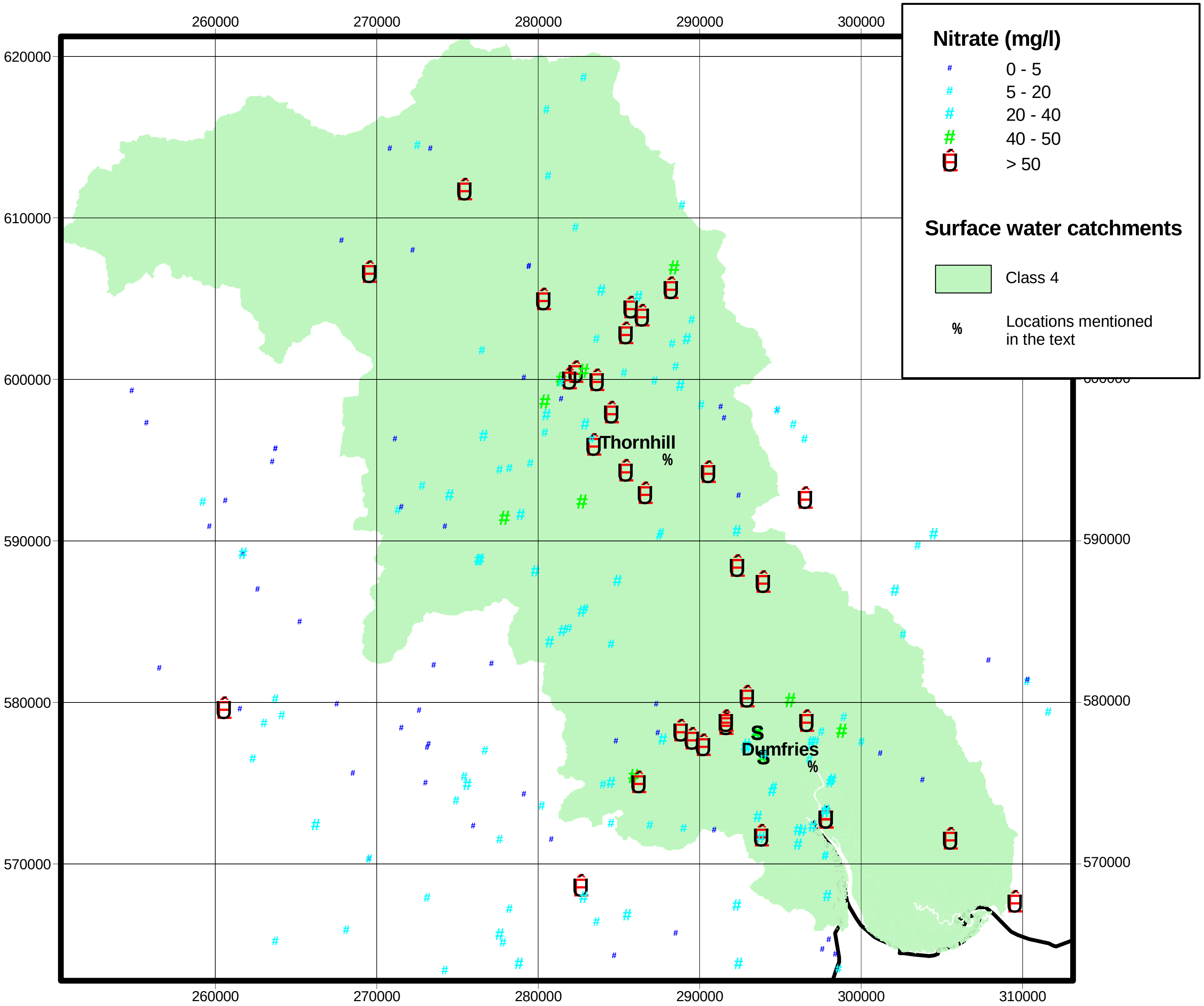

Figure 5.20 Nitrate data and catchment boundary for the Dumfries and Thornhill area.

6 Conclusions

6.1 VULNERABILITY AND RISK METHODOLOGY

The combined vulnerability and risk methodology developed for the designation of nitrate vulnerable zones requires a multi-disciplinary approach and integration of diverse datasets. These include digital geological linework, land use data, river networks, digital terrain models, and groundwater/surface water databases.

The incorporation, interpretation and analysis of all data within a GIS is essential for the production of the NVZs.

The results of the vulnerability/risk analysis are consistent with the available nitrate data for much of Scotland. There are discrepancies in only two catchments, Dumfries and the Upper Don.

Surface water nitrate data have shown strong agreement with groundwater data in both upland and lowland catchments. Designation of upland catchments (Class 3) as NVZs is unlikely to improve nitrate concentrations in vulnerable aquifers.

Lowland areas contain most high and very high land use risk zones. These often coincide with vulnerable aquifers. Bedrock aquifers generally comprise sandstone formations. Superficial aquifers are mostly river alluvium, glacial sand and gravel or raised beach deposits.

Upland areas have little intensive arable farming and are generally underlain by weakly permeable rocks including igneous and metamorphic rocks.

6.2 DATA

Out of the 12 SEPA monitoring sites that were exceeding 50 mg/l nitrate, 6 have been found to be unsound following inspection. They are recommended to be excluded from the network.

Lowland (Class 1 and 2) catchments have many more sites (approx. 20-30%) exceeding 50 mg/l nitrate than upland areas (Class 3 catchments).

High concentrations of nitrate in groundwater can occur in other parts of Scotland in addition to the east. In Ayrshire as well as Dumfries and Galloway, dairy farming appears to be a threat to local groundwater quality. The daily production of quantities of cattle waste combined with permeable superficial deposits may be the cause of contamination.

6.3 RECOMMENDATIONS FOR FUTURE WORK

The work has shown a need for better quality databases for private groundwater sources. Information on the soundness of each source, its depth and the aquifer unit from which water is abstracted are the most crucial data required.

A greater number of data points than available in the SEPA monitoring network are needed in order to adequately monitor nitrate in groundwater across all the designated catchments.

The existing nitrate monitoring network requires expanding in all areas of Scotland. The current study has shown there to be a serious lack of data points particularly in parts of Strathmore, Morayshire and the Black Isle.

A total of 6 of the 12 SEPA monitoring sites inspected proved unsuitable for further monitoring. It may be necessary to carry out further reviews of the remaining sites to check their suitability for use.

Further work is required to assess the effects of farming practices in west and south-west Scotland allied to the concnentrations of nitrate in groundwater.

Appendix 1 Aquifer classification

SOLID AQUIFERS

Highly permeable	Moderately permeable	Weakly permeable
Permo Triassic sediments - sandstones Upper Devonian sandstones & conglomerates Lower Devonian sandstones and marls Lower Carboniferous Strathclyde and Inverclyde Groups – sandstones/mudstones Upper Carboniferous sandstones Passage Formation - sandstone	Carboniferous sediments except Lower Carb in East Lothian and Passage Formation, but including Lower Limestone Formation, Limestone Coal Formation, Upper Limestone Coal Measures and Upper Carboniferous sandstones & limestones Ballagan Formation; Great Conglomerate Lower Devonian conglomerates Lower and Middle Devonian sandstones (& sandstones with mst & sltst) except Lower Devonian sandstones and conglomerates in Strathmore Devonian pisolitic silcrete on sheet 65E Ordovician limestones and metalimestones Dalradian limestones, metacarbonates, metalimestones, calcsilicates, limestones and calcareous schists, dolomites	Permo-Carboniferous quartz dolerite Lower Devonian shales/mudstones and extrusives All pre-Devonian rocks except Great Conglomerate, including: Silurian tuffs, shales and nodular limestones Ordovician and Silurian psammites, congolmerates, cherts, slates, metabasalts, pelites and metamafic rocks Ordovician Highland Border Complex Dalradian phyllites/slates, schists, quartzites, schistose grits/psammites, grits, psammites, gneisses, Green Beds, pelites, semipelites and Boulder Bed (tillite) Moine Supergroup All Intrusive rocks

SUPERFICIAL GEOLOGY

Highly permeable	Moderately permeable	Weakly permeable
Blown sand & beach/marine deposits where dominated by sands & gravels Alluvium where dominated by sand &/or gravel River terrace deposits where dominated by gravels Glaciofluvial sands and gravels Talus	Landslip Scree including debris cones Hummocky glacial deposits Raised marine deposits where silty or clayey Glacial meltwater deposits and morainic gravels Alluvium where dominated by silt or clay but with significant sand &/or gravel	Peat Lacustrine and glacio-lacustrine deposits (dominated by silts & clays) Undefined silts and clays Till/boulder clay Alluvial or undefined silts and clays Head (dominated by clay & silt)

Appendix 2 Files on NVZ GIS

GIS Version 2.0 (21 December 2001)

The accompanying CD contains shapefiles constructed for use with ArcView Version 3.2a. A project (nvz.apr) is included to help interpret and analyse the shapefiles. The following is a description of the various data files include on the GIS.

Gwv_south1	Combined groundwater vulnerability and nitrate leaching risk for north area.
Gwv_north2	Combined groundwater vulnerability and nitrate leaching risk for south area.
catchments4	Generated surface water catchments for groundwater vulnerability high and nitrate leaching risk very high, high and moderate.
Sepa_catchments	Major catchment in Scotland - defined by SEPA.
Rivers42bgs2	River network for Scotland, generated by SEPA.
Sscotland_per_se	Groundwater vulnerability to nitrate contamination for south area. Information on solid and drift permeability is also included.
Nscotland_per_se	Groundwater vulnerability to nitrate contamination for north area. Information on solid and drift permeability is also included.
Dumfries_per_se	Groundwater vulnerability to nitrate contamination for the Dumfries area. Information on solid and drift permeability is also included.
Mluri_rskgwn	Nitrate leaching risk from MLURI.
Scot50k5	Boundaries of Scottish 1:50k geology sheets.
Coastline	Scottish coastline.
All_clay	Areas of thick clay overlying the bedrock aquifers.
Sw__screened_ndata	Surface water nitrate concentrations (in NO3-N) from SEPA for SW Scotland (Appendix 3 is a description of this data set by SEPA).
Se_screened_ndata	Surface water nitrate concentrations (in NO3-N) from SEPA for SE Scotland (Appendix 3 is a description of this data set by SEPA).
Hig_screened_ndata	Surface water nitrate concentrations (in NO3-N) from SEPA for North Scotland (Appendix 3 is a description of this data set by SEPA).
bgs_misc2	Groundwater nitrate (NO3) concentrations from miscellaneous BGS projects.
SEPA_mon	Groundwater nitrate (NO3) concentrations for SEPA monitoring network.
Private_ws	Groundwater nitrate (NO3) concentrations for private water supplies. Data from MLURI and Envirocentre databases.
Private_ws_single	Data from private_ws processed to delete most of the duplicate values to give the maximum nitrate concentration at each site.
Water_authority	Groundwater nitrate concentrations from water authority data.
Wa_single	Water authority data processed to give the maximum annual average of nitrate for each site.

Appendix 3 The use of SEPA data

The Scottish Environment Protection Agency (SEPA) operates dedicated, and representative, networks for measuring nitrate levels in both surface and ground waters. These networks are used to identify areas for detailed assessment for the purposes of compliance with the EC Nitrates Directive (91/676/EEC).

For surface waters, SEPA operates 253 sites and samples these on a monthly basis. For groundwaters, 150 sites are monitored at least four times a year.

As part of the four yearly review of data required under the EC Nitrates Directive, SEPA undertakes a rigorous assessment of the results obtained via its ‘representative’ networks, screening out all artificially ‘high’ and ‘low values, determining longer term trends and producing summary statistics etc. This is to ensure that SEPA’s advice is based on robust and scientifically sound information.

All currently operational surface and groundwater monitoring locations have been rigorously checked for their location, ensuring correct spatial representation of the data. Monitoring sites which are no longer sampled by SEPA have not been rigorously checked in this way, and their precise geographical location, as represented on the CD, cannot therefore be guaranteed.

Furthermore, the data included on this CD have not been screened by SEPA in the same way as it would as part of the four yearly reviews required by the EC Nitrates Directive. Instead, SEPA has provided all of the available data it holds with respect to nitrates so as to assist BGS in making a broad assessment of the level of nitrates in surface waters in areas adjoining proposed groundwater NVZs. Whilst such data can assist in the overall assessment of the water quality in a spatial context, it should not be used in isolation, without further detailed evaluation by SEPA.

In collating the data for this CD SEPA has therefore attempted to ensure that:

1. The nitrates data is recent or current (i.e. the site in question has been sampled since 1992).

2. There have been at least 48 samples taken at the site in question.

3. All sites located to monitor impacts associated with consented sewage discharges (i.e. not agriculturally-derived nitrate) have specifically been excluded. Sites located to monitor trade effluent discharges have also been excluded where locally high nitrate concentrations have been identified.

4. All sites with artificially ‘high’ values (e.g. arising from pollution incidents) have been excluded, to avoid undue emphasis being placed upon potentially misleading summary statistics.

5. Any sites with obvious errors in their geo-referencing have been excluded, to avoid incorrect spatial interpretation.

Appendix 4 SEPA Site Reports Summary

This report is a summary of the findings for each site. The nitrate data for the 12 sites is shown in Table 1.

TABLE 1 SEPA HIGH NITRATE SITES (AFTER SEPA)

Site Name	Date 1	mg/l NO3	Date 2	mg/l NO3	Date 3	mg/l NO3	Date 4	mg/l NO3
Arnhead	22.06.00	49.14	31.07.00	53.57	20.09.00	52.24	2.11.00	48.25
Backhill Farm	21.06.00	37.19	31.07.00	50.47	20.09.00	48.7	02.11.00	68.61
Blervie House	15.06.00	84.95	10.08.00	65.08	21.09.00	62.42	06.11.00	62.86
Upperheads of Skelmuir	16.06.00	50.03	24.07.00	51.35	08.09.00	57.11	1.11.00	51.8
Aberlady Mains	04.12.00	91.18	11.12.00	86.31	18.12.00	106.2	21.12.00	79.23
Huntingtower Castle	30.05.00	53.55	22.06.00	50.46	25.07.00	52.67	19.09.00	53.55
Brathinch Farm	30.05.00	104.9	25.07.00	87.63	18.09.00	102.24	12.12.00	89.85
Cowbog Farm	11.12.00	50.01	18.12.00	71.26	21.12.00	74.36	-	-
The Curragh	27.06.00	29.96	18.08.00	60.15	16.10.00	32.00	19.12.00	52.67
West Lindsaylands Farm	30.06.00	46.74	22.08.00	58.42	19.10.00	39.79	18.12.00	40.19
Whitecrook Farm	28.06.00	91.35	29.08.00	95.60	28.09.00	99.59	07.12.00	91.62
Imperial Hotel	20.06.00	54.97	24.08.00	48.69	30.08.00	55.77	19.10.00	42.98

Backhill Farm (nr. Banff – NJ 6345 6076)

Status of the monitoring site – generally sound. The borehole is 30 m deep but no proper headworks are present. Suggest that the top is properly sealed and a manhole cover fitted.

Sources of nitrate

Point source: pig waste, drainage pipe within 2 m of borehole. However the farm is generally well maintained and none of the point sources appear to be the cause of nitrate.

General: cattle grazing (used to be pigs) fertiliser added and dung spread periodically. Also barley and turnips. The soil is permeable. The catchment for the borehole is entirely farming (either pasture or crops). The most likely source of the high nitrate is from the farming.

This is probably representative of much of the farms in the northeast.

***Recommendation*: Retain in network – but work required at wellhead.**

Blervie House (Nr. Forres NJ 0765 5636)

Status of the monitoring site – unsound. Large tank in field fed by two springs from the middle of a field. The tank is open and cattle walk all over the springs. The source represents field drainage rather than deep groundwater.

Sources of nitrate

Point sources. Cows congregating around spring areas.

Recommendation: **Remove from network**

Imperial Hotel (Castle Douglas NX 7655 6275)

Status of the monitoring site – unsound. Old, low yielding well in urban area. Little protection around the well head.

Sources of nitrate

Point sources. Sewerage pipe within 10 m, old slaughterhouse, old fertiliser store.

Diffuse sources. Leaking sewers old septic tanks.

Recommendation: **Remove from network.**

Whitecrook Farm (nr. Stranraer – NX 1680 5600)

Status of the monitoring site – sound. Shallow groundwater from drift aquifer. Abstraction is constant.

Sources of nitrate.

Point sources. Dairy farm is present 200 m uphill to the north – silage pits, dung heap drainage etc are present.

Diffuse sources. Dairy cattle with dung spreading on very permeable soils above the borehole.

Recommendation: **retain in network. Could be representative of other dairy farms on permeable soils**

The Curragh (nr. Girvan – NS 2003 0146)

Status of the monitoring site – sound. This is a deep borehole within a fenced area. The area around the borehole is poorly protected and should be sealed with cement.

Sources of nitrate

Point source: silage pits, slurry, dung heap.

General. Dairy cows and dung spreading in close fields.

Both the point sources and diffuse sources from cows and spreading could be contributing to the borehole nitrate.

Recommendation: **retain in network, but some work required at the wellhead.**

Huntingtower Castle (nr. Perth – NO 0826 2520)

Status of the monitoring site – unsound. The sample point is a cistern outflow, but the water source is the old castle well, the location of which is unknown, as is the condition of the pipe linking the two.

Sources of nitrate

Diffuse sources: unlikely, as the well is probably within a small grass paddock.

Point sources: septic tank leakage to the pipe may be the source.

Recommendation: **remove from network unless further investigatory work is carried out eg. tracer tests on the septic tank.**

Aberlady Mains Farm (nr. Aberlady – NT 4735 7979)

Status of the monitoring site – basically sound. Some well head protection would be useful. Suggest a borehole cap to prevent fertiliser from entering the borehole directly. A 67 m-deep borehole drilled into a highly permeable aquifer.

Sources of nitrate:

Diffuse sources: fertiliser from arable crops on fields immediately adjacent to the source. Thin sandy drift cover over the aquifer will allow recharge.

Point sources: none.

Probably representative of the aquifer in general.

Recommendation: **Retain in network.**

Brathinch Farm (nr. Brechin – NO 5910 6420)

Status of the monitoring site – sound. This is a fairly recent borehole, 46 m deep, with good well head protection. Drilled into a highly permeable sandstone aquifer.

Sources of nitrate

Diffuse sources: intensive arable farming practised in adjacent fields with up to 140 kg/ha fertiliser applied.

Point sources: nothing obvious, although a cottage septic tank is present 60 m away, slightly downslope.

Probably representative of the aquifer.

Recommendation: **retain in network**

Arnhead (nr. Turriff – NJ 7040 4309)

Status of the monitoring site – basically sound, but the 'well' (in reality a collection sump into which water enters via a horizontal shallow pipe) is only receiving shallow field drainage, not deeper groundwater. A large manure heap is present 25 m away from the well, but is probably not affecting water quality.

Sources of nitrate

Diffuse sources: fertiliser and slurry from the surrounding arable fields.

Point sources: Possibly drainage from the farm area and manure heap.

This site is sampling very shallow water which, although representative of shallow recharge from the fields, is coming from a network of field drains.

***Recommendation*: remove from network.**

Cowbog Farm (9 Km south of Kelso - NT 7594 251)

Status of monitoring site – unsound. The site is a 4 m-deep well located in a farmyard. The well cover allows surface water drainage into the well. Stone lining in the well walls from 1 m below surface allows shallow water to enter. Infiltration from the adjacent lawn can reach the well. A cattle shed is located 25 m from the well.

Sources of nitrate

Diffuse sources: The lawn, where fertiliser is applied.

Point sources: The cattle shed.

The well is almost certainly receiving recharge from the farmyard area. There are sources of nitrate nearby. Therefore, localised nitrate contamination is probable.

***Recommendation*: remove from network.**

Upperheads of Skelmuir (Nr. Mintlaw – NJ 9767 4228)

Status of the monitoring site – sound. A 29 m deep borehole drilled about 9 years ago and located in a private garden, although adjacent to arable fields. The aquifer is a low permeability igneous rock (weathered near the surface).

Sources of nitrate

Diffuse sources: Arable farming in adjacent fields within the borehole catchment.

Point sources: The cottage septic tank is 25 m away along the contour and may possibly be a source of nitrate.

This borehole may be receiving shallow groundwater flow from within the weathered zone of the hard rock aquifer.

***Recommendation:* retain in network**

West Lindsaylands Farm (nr. Biggar – NT 0175 3695)

Status of the monitoring site – unsound. This is a shallow water collection system draining to a sump. The source of the water is probably shallow drainage from the nearby steep hill. The flow was only a slight trickle at the time of the visit.

Sources of nitrate

Diffuse sources: none obvious.

Point sources: cattle in the field where the system of collection sumps has been established can relieve themselves directly over the flat concrete covers which are not watertight. There are possibilities of contamination of the sample water.

Recommendation: **remove from network.**

Glossary

Aquifer - saturated underground rock or sediment formation which is sufficiently permeable to transmit water to wells and springs.

Base flow - groundwater that enters a stream channel, maintaining stream flow at times when it is not raining.

Bedrock - any solid rock exposed at the Earth's surface or overlain by unconsolidated material.

Boulder Clay - see **Till**

Breccia - a clastic rock in which the gravel-sized particles are angular in shape and make up an appreciable volume of the rock.

Confined Aquifer - an aquifer which is overlain by a confining bed of significantly lower hydraulic conductivity which retards the vertical movement of water.

Conglomerate – a clastic sedimentary rock composed of lithified beds of rounded gravel mixed with sand.

Discharge - the release or extraction of water from an aquifer. Typical mechanisms of natural discharge are springs, and drains to surface water bodies. Pumping is a man-caused discharge.

Drainage basin - the area from which a stream and its tributaries receives its water.

Fault - the surface of rock rupture along which there has been differential movement of the rock on either side.

Floodplain - area bordering a stream over which water spreads when the stream tops its channel banks.

Gaining Stream - a body of surface water which is gaining water from the inflow of ground water.

Geology - the science that deals with the study of the planet Earth, the materials of which it is made, the processes that act to change these materials from one form to another, and the history recorded by these materials; the forces acting to deform the outer layers of the Earth and create ocean basins and continents; the processes that modify the Earth's surface; the application of geologic knowledge to the search for useful materials and the understanding of the relationship of geologic processes to people.

Glaciation - the formation, advance and retreat of glaciers and the results of these activities.

Granite - light coloured, coarse grained, intrusive igneous rock characterized by the minerals orthoclase and quartz with lesser amounts of plagioclase feldspar and iron-magnesium minerals. Underlies large sections of the continents.

Hydraulic Conductivity - the capacity of a porous medium to transmit water through a unit cross-sectional area. Hydraulic conductivity is dependent upon the physical properties of the porous medium and the viscosity of the water and is expressed in units of length/time.

Hydraulic Connection - a condition that exists between surface water and ground water when the water table is near or above the bottom of a lake or stream. In this situation, changes in water table change the rate at which a surface water body will gain water from, or lose water to the aquifer.

Igneous rock - a rock that has crystallized from a molten state.

Losing Stream - a surface stream or lake which is losing water by seepage into the ground.

Metamorphic rock - a rock changed from its original form and/or composition by heat, pressure, or chemically active fluids, or some combination of them.

Mudstone - a fine-grained sedimentary rock made up of clay- and silt-sized particles.

Porosity - a measure of the void or pore space within rocks and sediments (the ratio of the volume of void spaces to the total volume).

Recharge - mechanisms of inflow to the aquifer. Typical sources of recharge are precipitation, applied irrigation water, underflow from tributary basins and seepage from surface water bodies.

Runoff - the precipitation that runs directly off the surface to stream or body of standing water.

Sandstone - a clastic sedimentary rock in which the particles are dominantly of sand size, from 0.062 mm to 2 mm in diameter.

Sedimentary rock - rock formed from the accumulation of sediment, which may consist of fragments and mineral grains of varying sizes from pre-existing rocks, remains or products of animals and plants, the products of chemical action, or mixtures of these.

Sorption - assimilation of molecules of one substance by a material in a different phase. Adsorption (sorption on a surface) and absorption (sorption into bulk material) are two types of sorption phenomena.

Till (**unstratified drift**) – glacial superficial deposits composed of rock fragments that range from clay to boulder size and randomly arranged without bedding.

Transmissivity - the rate of flow of water through a vertical strip of aquifer which is one unit wide and which extends the full saturated depth of the aquifer. Transmissivity is measured in metres squared per day.

Unconfined Aquifer - an aquifer that is not under pressure.

Water Table - the elevation of the water in an unconfined aquifer.

Zone of aeration - zone immediately below the ground surface within which pore spaces are partially filled with water and partially filled with air.

Zone of leaching - the upper horizons in a soil, through which gravitational moisture travels, removing soluble decomposition products.

Zone of saturation - the zone below the zone of aeration in which all pore spaces are filled with water.

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