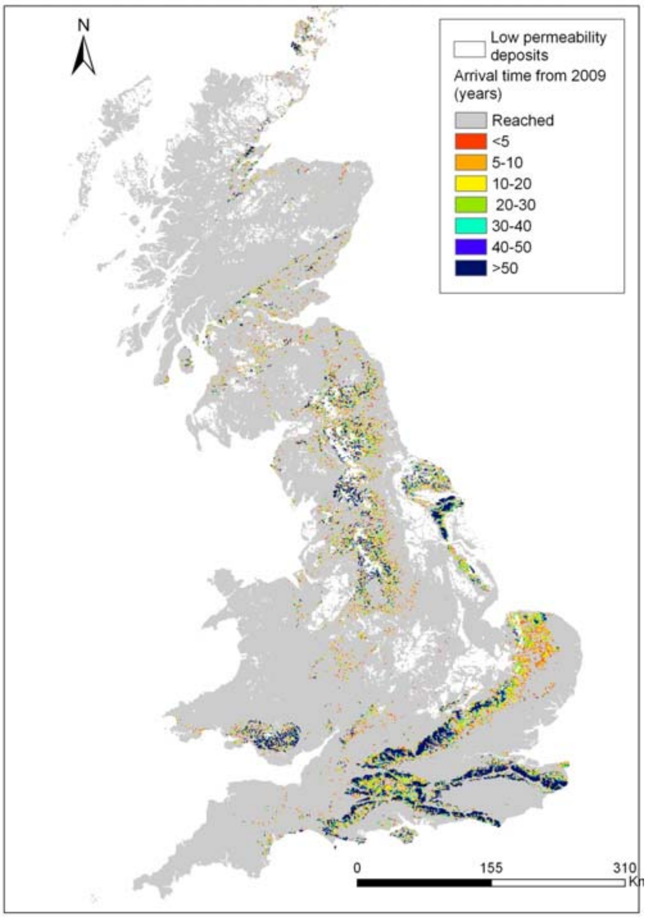
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Regulatory practice and transport modelling for nitrate pollution in groundwater

Groundwater Science Programme

Open Report OR/16/033



BRITISH GEOLOGICAL SURVEY

GROUNDWATER SCIENCE PROGRAMME
OPEN REPORT OR/16/033

Regulatory practice and transport modelling for nitrate pollution in groundwater

M E Stuart, R S Ward, M Ascott, A J Hart[1]

[1] Environment Agency

Keywords

Nitrate Vulnerable Zones; groundwater; unsaturated zone.

Front cover

Modelled nitrate arrival time at the water table

Bibliographical reference

STUART, M E, WARD, R S, ASCOTT, M, HART A J. 2016. Regulatory practice and transport modelling for nitrate pollution in groundwater. *British Geological Survey Open Report*, OR/16/033. 74pp.

Keyworth, Nottingham British Geological Survey 2016

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk
Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG
Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Lyell Centre, Research Avenue South, Edinburgh EH14 4AP
Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD
Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE
Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB
Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB
Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU
Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report forms the first deliverable of a project jointly funded by the British Geological Survey (BGS) and the Environment Agency to inform our understanding of the transport of nitrate in the subsurface and the implications of unsaturated zone travel time in regulation including for he nitrate vulnerable zones (NVZs) designation process. NVZs are delineated by the Environment Agency in compliance with the European Nitrates Directive (91/676/EEC).

Acknowledgements

The report authors are grateful to the staff of the Environment Agency who contributed data, advice and comments during the production of this report. These include Alwyn Hart, Tim Besien, Sarah Scott, Polly Wallace and Lucy Roberts. The project was managed for the Environment Agency by Andrew Onobrakpeya

Contents

FIGURES

TABLES

Summary

This report forms the first deliverable of a project jointly funded by BGS and the Environment Agency to consider the potential for incorporating the outputs from the BGS unsaturated zone travel time work in assessing the risks to water from nitrate. This is to help to inform the nitrate vulnerable zones (NVZs) designation process.

In England, the Environment Agency advises Defra on identifying areas for designation as NVZs. Over time, the designation process has developed and become more complex since the first round of designations in 1996. The designation process for groundwater initially used only public supply monitoring data and the associated source catchment area.

In December 2000, the European Court of Justice held that the UK had failed to designate sufficient NVZs for the protection of all waters, not just for drinking water sources. This resulted in the development of revised methodologies for the designation of NVZs which separately address surface waters, groundwater and waters at risk of eutrophication. This was implemented in 2002. Further reviews have been carried out in 2008 and 2012 and as a result, modifications and improvements to methods have been made at each designation round.

For groundwater the Environment Agency developed a numerical risk assessment procedure that uses a range of risk factors including both nitrate concentration data and nitrate-loading data to assess the risk of nitrate pollution. The loading data is based on farm census returns made to Defra and combined using the NEAP-N methodology developed by ADAS (Lord and Anthony, 2000). The overall risk assessment considers both current observed concentrations and predicted future concentrations as well as current loadings.

However, this approach has a number of disadvantages including a lack of a specific term for the time of travel to the water table and emergence of pollutant both into groundwater and to groundwater discharge points that support surface water features. Instead, these issues are considered at the conceptual level in workshops with local EA hydrogeologists.

A key question for Defra and the Agency is how long it will take for nitrate concentrations to peak and then stabilise at an acceptable, lower level, in response to existing and future land management control measures. This is most important for soils, for aquifers, for lakes and for groundwater-fed wetland systems that respond less quickly to changes in loading. Groundwater and lake catchment numerical models can provide first-order estimates of likely response times, but can be difficult and costly to set-up for many different situations and are difficult to apply consistently at the national scale.

A previous review of nitrate vulnerable zones suggests a range of further needs:

- to understand the recent developments in nitrate pollution simulation and particularly the potential to understand/characterise past nitrate loading from changing land management practices and correlate these with observed nitrate concentrations over time;
- to evaluate the retention of nitrate in catchments, particularly in the unsaturated zone of soils and aquifers;
- to simulate the recent and future anticipated decreases in nitrate loading by sectors within the UK;
- to understand the likely time taken for nitrate concentrations to peak and then stabilise at an acceptable, lower level, in response to existing and future control measures. Without evidence of how long it may take systems to recover it is difficult to evaluate the effectiveness of existing measures or decide whether additional measures are necessary.

The aim of this project is to investigate the use of new models to inform decision-making on nitrate pollution in groundwater and the potential for incorporating unsaturated zone processes in future NVZ designations.

The work described here forms the first task of this project and aims to review NVZ methodology and recent designation experience. As part of this we will:

- collate information from the Agency on the recent application of the methodology;
- provide case study examples of designation in different time-lag settings and/or where these are not corroborated by water quality.

1 Introduction

1.1 BACKGROUND

The increase of nitrate in groundwater was first identified as a local issue for the Chalk of the Eastbourne area in the 1970s (Greene and Walker, 1970). Awareness of the extent of high and rising nitrate in groundwater gradually increased, and it became clear that concentrations in public supply sources often exceeded the WHO values used at the time (Foster and Young, 1980). By the late 1970s the importance of storage of nitrate in unsaturated zone porewater was becoming recognised (Foster and Crease, 1974; Foster and Young, 1980; Oakes et al., 1981; Young et al., 1976b). Pioneering work in understanding nitrate leaching to groundwater was carried out by drilling cored boreholes through the Chalk unsaturated zone to obtain profiles of porewater nitrate concentration as a function of depth (Foster et al., 1982; Young et al., 1976b) . At sites with good cropping records a relationship between historical land use and porewater nitrate concentration could be determined. This showed that retention in the unsaturated zone can retard the migration of nitrate for years or decades.

Similar concerns about nitrate in water were raised across Europe and the Nitrates Directive (91/676/EEC) was ratified which sets out a series of requirements on Member States to assess and control the potential for pollution of waters with nitrogenous compounds generated from agricultural sources. In England, the Environment Agency has been asked to advise Defra on this matter and propose areas subject to pollution or at risk of pollution for designation as nitrate vulnerable zones (NVZs) in compliance with the relevant regulations.

For groundwater NVZs the Environment Agency have developed and published a numerical risk model which uses a range of risk factors including both nitrate concentration data and nitrate-loading data to assess the risk of nitrate pollution. The loading data are based on the NEAP-N algorithms developed by ADAS (Lord and Anthony, 2000). The risk model considers both current and predicted future concentrations as well as current loadings.

However, this approach has a number of disadvantages including a lack of a specific term for the time of travel to the water table and emergence of pollutant both into groundwater and to groundwater discharge points that support surface water features. Instead, these issues are considered at the conceptual level in workshops with local EA hydrogeologists.

A key question for Defra and the Agency is how long it will take for nitrate concentrations to peak and then stabilise at an acceptable, lower level, in response to existing and future land management control measures. This is most important for soils, aquifers, lakes and groundwater-fed wetland systems that respond less quickly to changes in loading. Groundwater and lake catchment numerical models can provide first-order estimates of likely response times, but can be difficult and costly to set up for many different situations and are difficult to apply consistently at the national scale.

A previous review of nitrate vulnerable zones (ENTEC, 2009) suggests a range of further needs:

- to understand the recent developments in nitrate pollution simulation and particularly the potential to understand/characterise past nitrate loading from changing land management practices and correlate these with observed nitrate concentrations over time;
- to evaluate the retention of nitrate in catchments, particularly in unsaturated zone of soils and aquifers;
- to examine the recent and future anticipated decreases in nitrate loading by sectors within the UK;
- to understand the likely time taken for nitrate concentrations to peak and then stabilise at an acceptable, lower level, in response to existing and future control measures. Without

evidence of how long it may take systems to recover, it is difficult to evaluate the effectiveness of existing measures or decide whether additional measures are necessary.

1.2 PROJECT OBJECTIVES

The aim of the project is to investigate the potential use of new numerical models to inform decision-making on nitrate pollution in groundwater and the potential for giving consideration to incorporating such models of unsaturated zone processes in the NVZ process. The work described here forms the first task of this project and aims to review NVZ methodology and recent designation experience. As part of this we will:

- collate information from the Agency on the recent application of the methodology;
- provide case study examples of designation in different time-lag settings and/or where these are not corroborated by water quality.

2 The UK groundwater nitrate legacy

Nitrate units of measurement

Nitrate concentrations can either be quoted as nitrate or NO_3 (mg NO_3 l^{-1}) or as the equivalent amount of N (mg NO_3-N l^{-1}). These units are converted using the factor molecular weight NO_3/molecular weight N = 62/14 =4.43. For example the drinking water limit for nitrate is 50 mg NO_3 l^{-1} or 11.3 mg NO_3-N l^{-1}. In this review mg NO_3-N l^{-1} is used except where graphical material uses NO_3.

2.1 BACKGROUND

The increase of nitrate in groundwater was first discussed by Greene and Walker (1970) who showed nitrate concentrations rising at the Friston and Cornish supply sources in the Chalk close to Eastbourne from 4 to 6 mg NO_3-N l^{-1} and 5 to 8 mg NO_3-N l^{-1} respectively between 1954 and 1966. Through the 1970s, awareness of the extent of high and rising nitrate in groundwater gradually increased, and it became clear that concentrations in public supply sources often exceeded the World Health Organization (WHO) drinking water guideline values used at this time in the absence of UK or EU drinking water standards. In 1973 the Water Act led to a reorganisation of the water industry and this resulted in:

a) the establishment of regional water authorities which raised awareness of nitrate by bringing disparate groundwater quality data together. For the first time, the scale of the problem became apparent. The outcrop areas of all of the principal aquifers in the UK were affected, and a diffuse rather than point source nitrate contamination was implicated;
b) the establishment of the Water Research Centre (WRc) and initiation of work on nitrate pollution of groundwater.

By the late 1970s the importance of storage of nitrate in unsaturated zone porewater was becoming recognised (Foster and Crease, 1974; Foster and Young, 1980; Oakes et al., 1981; Young et al., 1976b). Initially this was recognised in shallow pits in chalk (Foster and Crease, 1974) (Figure 2.1).

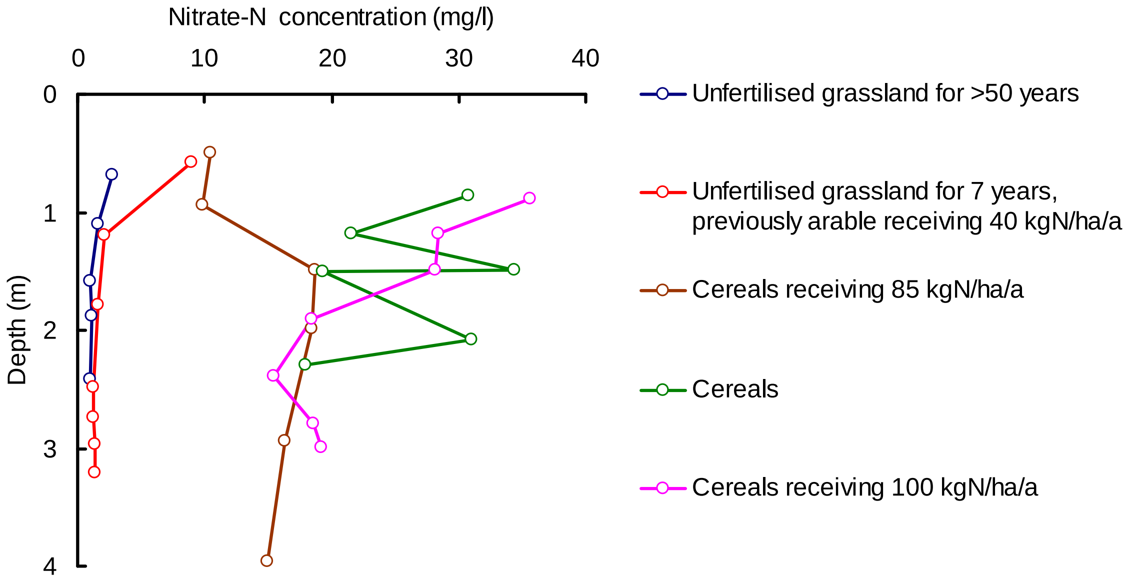


Figure 2.1 Nitrate profiles from shallow pits on the Yorkshire Chalk (from Foster and Crease, 1974)

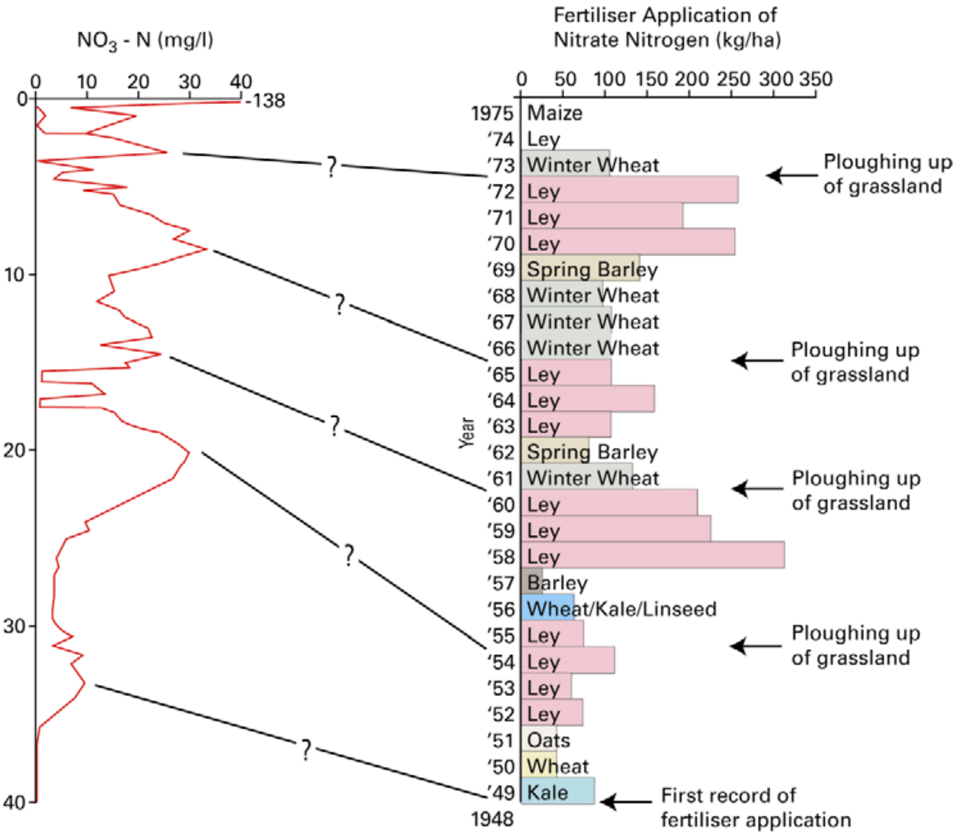


Figure 2.2 Correlating nitrate peaks and cropping records (after Young et al., 1976a)

Pioneering work in understanding nitrate leaching to groundwater was carried out by drilling cored boreholes through the Chalk unsaturated zone to obtain profiles of the porewater nitrate concentration as a function of depth (Foster et al., 1982; Young et al., 1976a). At sites with good cropping records a relationship between historical land use and porewater nitrate concentration could be determined (Figure 2.2) (Young et al., 1976a).

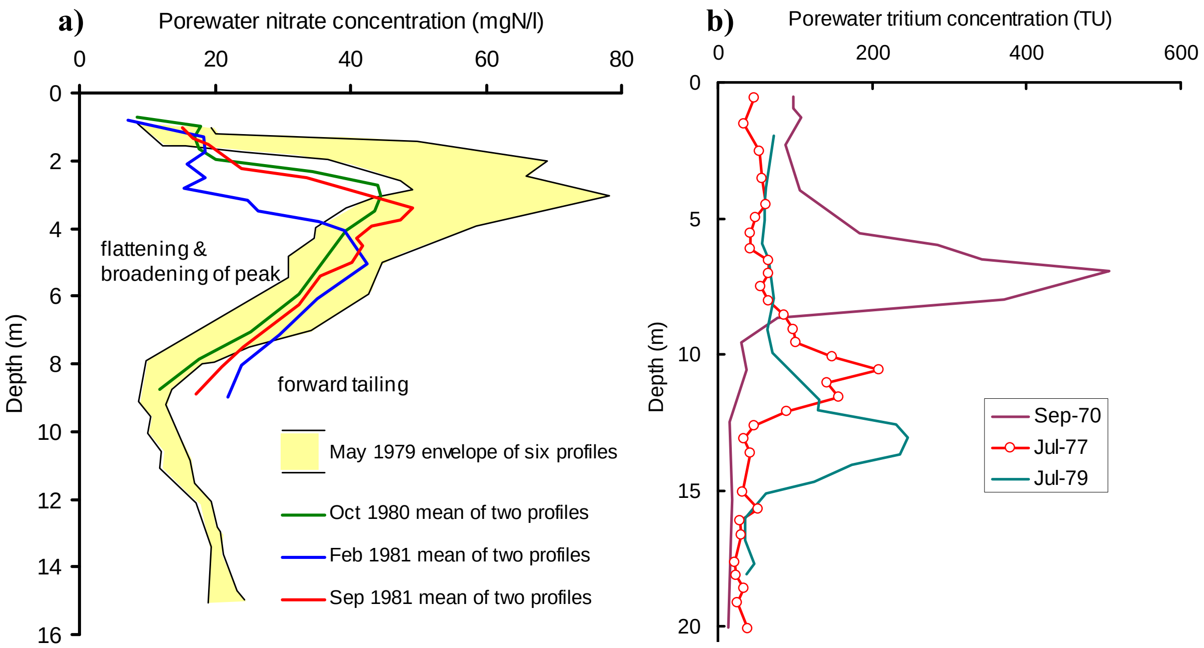


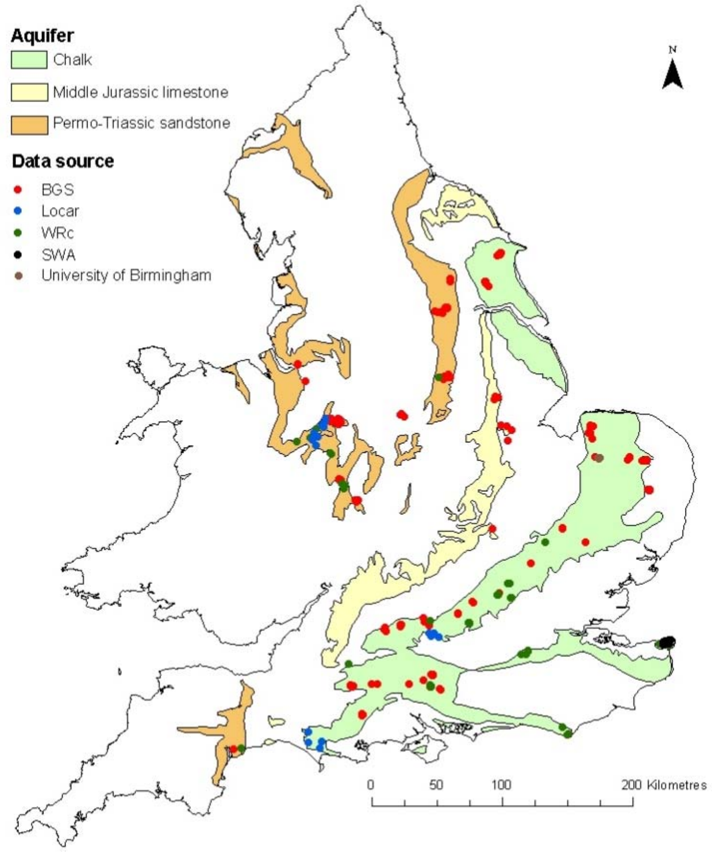
Figure 2.3 a) Typical early nitrate profiles and subsequent sequential reprofiling (from Foster et al., 1986) and b) Sequential porewater profiles for tritium (from Geake and Foster, 1989)

Table 2.1 Rates of unsaturated water movement for selected major aquifers (measured ranges from Chilton and Foster (1991), mean porosity values from Bloomfield et al. (1995) and Allen et al. (1997), mean velocity values calculated

	Porosity (%)		Effective rainfall (mm year^{-1})		Unsaturated zone velocity (m year^{-1})	
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**
White Chalk Subgroup	25-45	33.1	150-350	250	0.3-1.4	0.76
Grey Chalk Subgroup		27.9		250		0.90
Lincolnshire Limestone Formation	10-25	18	150-250	200	0.6-2.5	1.11
Sherwood Sandstone Group	15-35	26	200-350	275	0.6-2.3	1.06

Unsaturated zone travel time was studied using tritium as a conservative tracer (Geake and Foster, 1989; Young et al., 1976b). It was also estimated by a programme of redrilling and obtaining porewater profiles at sites where a well-defined peak could be identified (Figure 2.3). In this figure the main peak can be shown to have migrated from about 3 m depth to about 5 m over 2.5 years, a rate of downwards movement of about 0.8 m per year.

The rates of travel have been established for the three main aquifers, the Chalk, Sherwood Sandstone and the Lincolnshire Limestone (Table 2.1). These values suggest that intergranular velocity can be reasonably estimated from porosity and effective rainfall. Subsequently a large number of porewater profiles collected for the major aquifers of the United Kingdom have been collated by Stuart (2005) (Figure 2.4). This body of work showed how the loading of nitrate in the unsaturated zone had significantly increased due to post-1945 agricultural intensification.



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and geological linework ©Copyright NERC 2016

Figure 2.4 Porewater profiles in the important aquifers in England and Wales collected by BGS, NERC Lowland catchments research project (LOCAR), WRc, Southern Water Authority (SWA) and the University of Birmingham (Stuart, 2005)

Groundwater nitrate concentrations have continued to increase in many areas. Stuart et al. (2007) analysed UK groundwater nitrate using robust linear regression to define past trends and estimate future concentrations. Of the series analysed, 21% showed a significant improvement in the overall fit when a break was included. Half of these indicated an increase in trend with time. Significant seasonality was found in about one-third of the series, with the highest nitrate concentrations usually found during winter months. Inclusion of nearby water-level data as an additional explanatory variable successfully accounted for much of this seasonality. Based on 309 datasets from 191 distinct sites, nitrate concentrations were found to be rising at an average of 0.077 mg NO_3 -N l^{-1} year^{-1}. In 2000, 34% of the sites analysed exceeded the EU drinking water standard. If the trends at that time continued, the authors predicted that 41% could exceed the standard by 2015. Rivett et al. (2007) concluded similarly that 60% of groundwater bodies may fail to reach good status by this time.

Statistical examination of over 8000 nitrate measurements in the Dorset and Hampshire Basin Chalk aquifers indicates that nitrate varies significantly with time, borehole depth and groundwater level, and between Chalk stratigraphic unit, land-use and groundwater body. Arable and urban land-uses are significantly more likely to be associated with higher groundwater nitrate concentrations than managed grassland (Roy et al., 2007).

Much effort has been focussed on understanding the processes associated with nitrate transport and degradation (Geake and Foster, 1989; Lawrence and Foster, 1986; Mathias et al., 2007; Rivett et al., 2007; Wellings and Bell, 1980), on mapping the spatial extent of nitrate contamination of groundwater (Rivett et al., 2007) and aquifer vulnerability to nitrate contamination (Foster, 1993; Lake et al., 2003).

Rivett et al. (2008) conclude that denitrification is the dominant nitrate attenuation process in groundwater. The critical limiting factors are oxygen concentration (denitrification is in the main microbially mediated and the enzyme systems responsible are inhibited by oxygen so anaerobic conditions are required for denitrification to proceed) and electron donor availability. Kinniburgh et al. (1999) concluded that denitrification beneath the soil zone in the unsaturated zone of UK aquifers was probably insignificant relative to the nitrate flux. Other available field studies suggest that denitrification in unconfined aquifers is relatively limited and have demonstrated only minor decreases in nitrate concentrations, estimated at just 1–2% of the nitrate load within infiltrating water in principal aquifers. Such decreases are unlikely to significantly influence regional groundwater quality. Within the saturated zones of the Chalk, Sherwood Sandstone and Jurassic Limestone aquifers, denitrification was only significant once these aquifers became confined and dissolved oxygen had depleted. However, evidence for denitrification is typically weak at the regional aquifer scale and low nitrate concentrations may sometimes be simply ascribed to dilution, lack of pollution or to slow transport of plumes.

Process-based models, typically at the source to catchment scale, have been used to provide estimates of future trends (Whitehead et al., 1998) but as a range of factors affect nitrate fate and transport these models tend to be specific to the study area (Smith et al., 2010). Consequently, it is difficult to generalise observations from these process-based predictive models and they do not enable systematic assessments of future trends in average nitrate concentration. Until recently the application of complex GIS models has only been practical at the catchment scale (Wang and Yang, 2008) and not at regional or national scales.

2.2 BGS NITRATE LEGACY MODEL (NTB)

A simple GIS model for Great Britain was developed on a 1km × 1km grid within BGS to predict nitrate arrival time at the water table (Wang et al., 2012). In this model the distribution of nitrate arriving at the water table depended on only three functions: the nitrate input at the land surface (the temporally varying but spatially uniform leaching of nitrate from the base of the soil); the rate of travel of nitrate through the unsaturated zone (spatially dependent on variations in hydrolithological characteristics); and the thickness of the unsaturated zone (Figure 2.5).

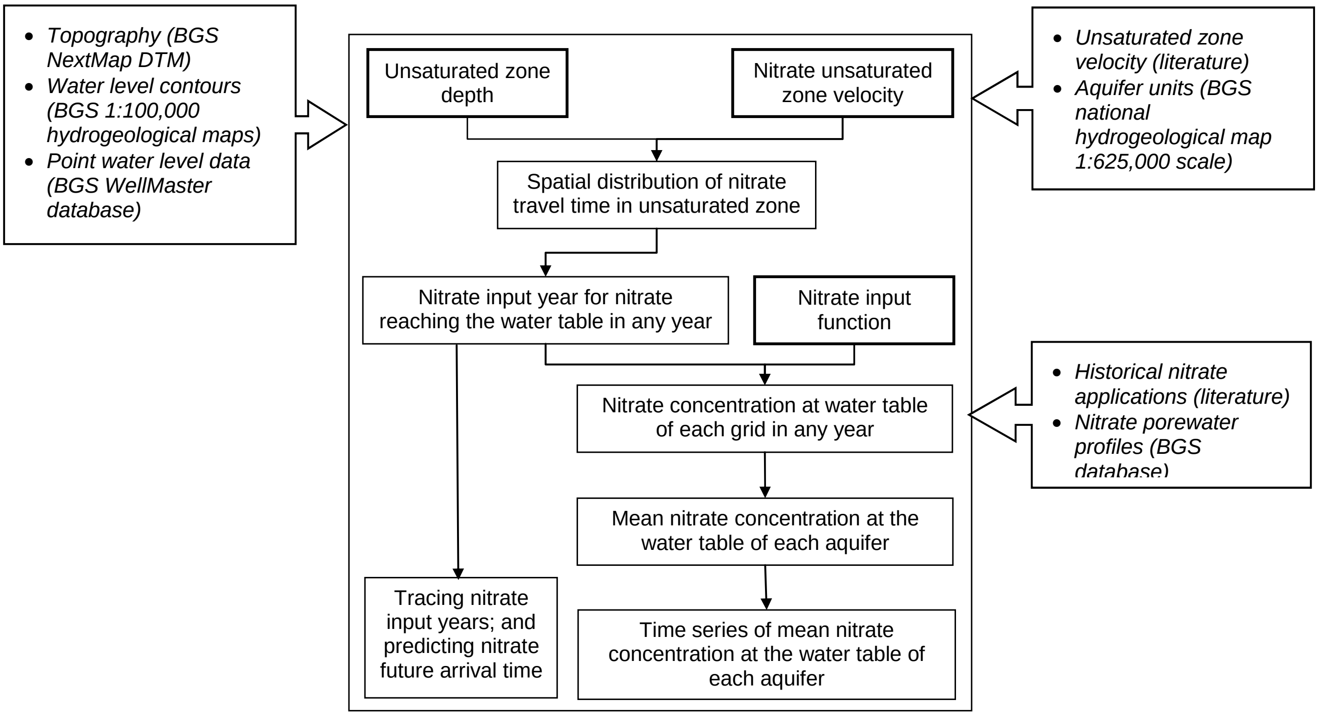


Figure 2.5 Flow chart of the spatial-temporal GIS model and main data sources

The unsaturated zone thickness and nitrate velocity are combined to estimate the spatial distribution of nitrate travel time in the unsaturated zone and from this the input year for nitrate reaching the water table at any defined time. A nitrate input function over time can then be used to estimate the concentration reaching the water table at any point and defined time, assuming that nitrate is conservative.

The presence of thick, low-permeability, superficial deposits limits the amount of nitrate which is able to enter the aquifer and this was accounted for by switching off the input function where such deposits are present. Spatio-temporal variations in recharge rate, nitrate degradation, and diffusive and dispersive processes in the soil and unsaturated zones will all influence the loading of nitrate at the water table, but here these factors are considered to be secondary and were not considered. Factors such as average saturated groundwater flow and groundwater discharge rates which will affect trends in nitrate concentration in the aquifer as a whole were also excluded.

The model is based on the following assumptions:

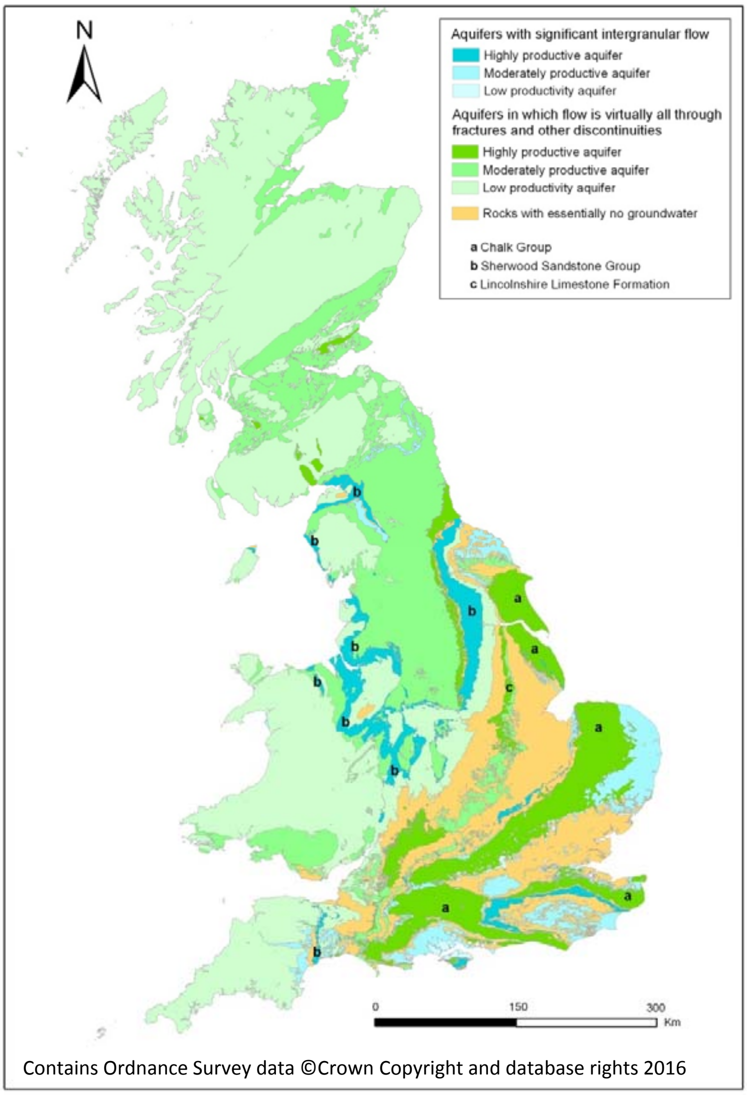
- nitrate input/loading is from the base of the soil;
- movement is through the matrix only in dual-porosity strata;
- the mass of nitrate in the unsaturated zone is preserved except where the bedrock is overlain by low-permeability superficial deposits;
- nitrate moves vertically from the land surface to the water table;
- nitrate moves at a constant velocity through the unsaturated zone; and
- there is no hydrodynamic dispersion of nitrate in the unsaturated zone.

Of these model functions, the unsaturated zone velocity and the depth to water are assumed to be constant over the modelled period and can be relatively well characterised from current hydrogeological data, whereas nitrate leaching will have changed over time and is based on a series of assumptions.

2.2.1 Unsaturated zone velocities

The model requires an effective vertical velocity of nitrate in the unsaturated zone for each 1 km by 1 km cell. The digital 1:625,000 hydrogeological mapping of Great Britain (BGS, 2010) was used as the basis for assigning the spatially dependent nitrate velocities. This was divided into three main classes of aquifer units: i) aquifers with significant intergranular flow, ii) aquifers in which flow is virtually all through fractures and other discontinuities and iii) rocks with essentially no groundwater (Figure 2.6). Within the first two classes aquifers were assessed as high, moderate or low productivity. Using a combination of these classes and other factors such as grain-size and age (as a surrogate for induration) each of the bedrock formations was attributed with a water movement rate.

Smith et al. (1970) used tritium profiles to measure rates of water movement through low permeability strata and obtained a value of 0.09 m year^{-1} for the Oxford Clay Formation. The latter value relates to autumn recharge through cracks (fractures) produced by a summer soil moisture deficit. A value of 0.1 m year^{-1} was therefore used for this and similar clay strata. For all other formations, the values were attributed heuristically using the criteria in Table 2.2. Where formations formed multi-layered aquifers and intergranular flow was significant in the permeable horizons, the prevalence of clay layers, as well as the predominant grain-size of the permeable horizons, was taken into account, to obtain the value.



Contains Ordnance Survey data ©Crown Copyright and database rights 2016

Figure 2.6 Simplified 1:625,000 scale hydrogeological map showing locations of major aquifers with unsaturated zone travel times attributed from measured values in Table 2.1

Table 2.2 Attributed rates of unsaturated movement for rocks not included in Table 2.1

	Type	**Examples**	**Unsaturated zone flow rate (m year^{-1})**
Aquifers with significant intergranular flow	Predominantly sands	Crag Group, Bracklesham and Barton Groups, Upper Greensand Formation, Lower Greensand Group, Bridport Sand Formation	3
	Predominantly silts	Solent Group, Lambeth Group, Thanet Sand Formation	0.3
Fractured aquifers	Karstic	Zechstein Group dolomite, Dinantian limestone, Durness Group	10
	Multi-layered Mesozoic aquifers	Corallian Group, Mercia Mudstone Group	1
	All Palaeozoic (except Zechstein Group dolomites and Permian mudstones), igneous and metamorphic rocks	Old Red Sandstone Supergroup, Coal Measures Group, Millstone Grit Group, granite, Lewisian complex	1
Aquitards	Clays (Jurassic and younger)	Thames Group, Kimmeridge Clay Formation, Oxford Clay Formation, Lias Group	0.1
	Permian mudstones		0.1

The model does not take account of the wide variation in precipitation across Great Britain with over 2000 mm/year in upland areas of the north and west and less than 600 mm in parts of East Anglia. However, most of the important aquifers are located away from the north and west and it has been assumed that unsaturated zone annual travel time within aquifers is uniform at the national scale.

2.2.2 Depth to groundwater at the national scale

A representative depth to groundwater was estimated for each 1 km × 1 km cell across Great Britain based on:

- groundwater levels inferred from estimated river base levels (RBL);
- groundwater levels taken from contours on published hydrogeological maps (generally at 1:100,000 scale) and from other digitised contours;
- point measurements from national networks of observation wells and from well inventories.

Areas of low-permeability rocks are difficult to deal with by this approach so to avoid unrealistic estimations of groundwater levels in low permeability areas with pronounced topography the dataset was filtered so that the maximum thickness of the unsaturated zone was constrained to no more than 10 metres in areas underlain by low permeability rocks.

The RBL surface is an interpolated surface that assumes that rivers are hydraulically connected to aquifers, and approximate to the level of the water table in the aquifer (Figure 2.7). The river network used is derived from the NextMap Digital Surface Model (DSM), with drainage densities appropriate to different hydrolithological units. The depth to groundwater was obtained by subtracting the mean groundwater levels from the NextMap DSM mean topographic elevations for each 1 km by 1 km grid square.

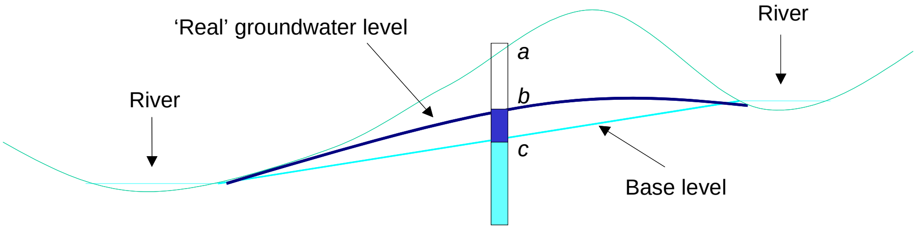


Figure 2.7 Interpolation of groundwater levels from topography and surface water information. In this cross section the base level has been interpolated between two rivers. A borehole has terrain surface a, a 'real' groundwater level at b and a calculated base level at c.

The resulting dataset was compared to field measurements from 30 index boreholes in the National Ground Water Level network. The modelled water levels are within the observed ranges, where observation boreholes were unconfined. Where discrepancies were noted these were generally a result of observations being made close to valley floors, and hence where water tables are shallower than the average over a one kilometre square, which is the value used in the model. The model gives a realistic water table in permeable unconfined aquifers, and close to surface drainage.

2.2.3 Nitrate input function

The nitrate input function used, shown as a red line in Figure 2.8, was based on estimates of the time-varying nitrate content found in the unsaturated zone immediately beneath the soil layer. The curve was divided into six time slices or spans as follows:

Span 1, pre-1940, is a constant input of 25 kg N ha^{-1} year^{-1} reflecting the pre-war level of nitrate input to groundwater (Addiscott, 2005; Foster et al., 1982)

Span 2, from 1940 to 1955, consists of a 1 kg N ha^{-1} year^{-1} rise in input from 25 kg N ha^{-1} in 1940 to 40 kg N ha^{-1} in 1955. This rise is the result of the gradual intensification of agriculture during and just after WWII (based on Foster et al., 1982).

Span 3, from 1955 to 1975, shows a more rapid rise of 1.5 kg N ha^{-1} year^{-1} from 40 kg N ha^{-1} in 1955 to 70 kg N ha^{-1} in 1975. This steeper rise is due to increases in the use of chemical based fertilisers (Addiscott et al., 1991; Foster et al., 1982)

Span 4, from 1975 to 1990, is a constant peak nitrate input value based on the average value obtained by Lord et al. (1999) beneath a range of land-uses

Span 5, from 1991 to 2020, has a gradual decline of 1 kg N ha^{-1} year $^{-1}$ from 70 kg N ha^{-1} in 1991 to 40 kg N ha^{-1} in 2020 due to restrictions on fertiliser application as a result of the implementation of nitrate sensitive areas and vulnerable zones (Lord et al., 1999) and also due to a general decrease in nitrate application of about 30% in fertiliser use between 1990 and 2000 (ADAS, 2003).

Span 6, from 2020 to 2050 (the end of the modelled input), is a constant 40 kg N ha^{-1} assuming a return to nitrate input levels similar to those associated with early intensified farming in the mid-1950s.

The nitrate input function was compared with nitrate concentration data from the porewaters of almost 300 cored boreholes from major aquifers (Stuart, 2005). The function was converted from kg N ha^{-1} to mg NO_3-N l^{-1} by assuming a constant effective rainfall of 250 mm year^{-1}. The porewater data were used to back estimate the nitrate in infiltration entering the unsaturated zone during the past 100 years, using the date at which the samples were taken, their depth below ground surface and an estimate of velocity in the unsaturated zone derived from tritium profiles (Table 2.1). Annual averages show an excellent agreement with the overall modelled input function. The apparent large applications between 1995 and 2000 may be an artefact of both the relatively small number of recent data points and a bias imposed by the focus of recent studies on areas with a nitrate problem.

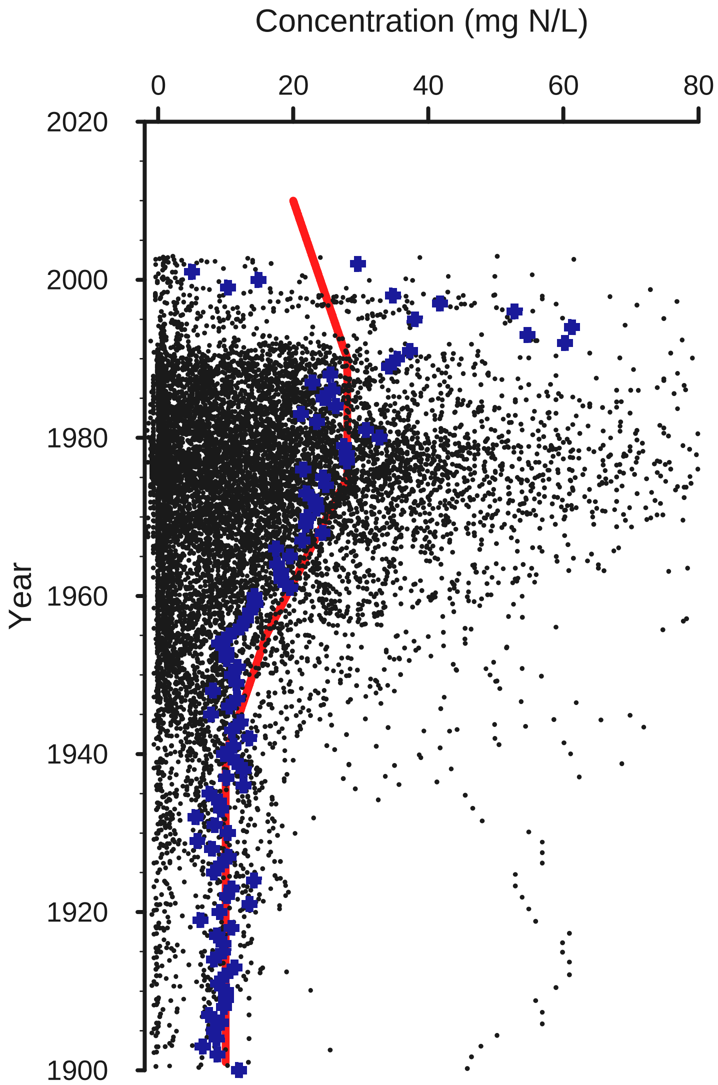


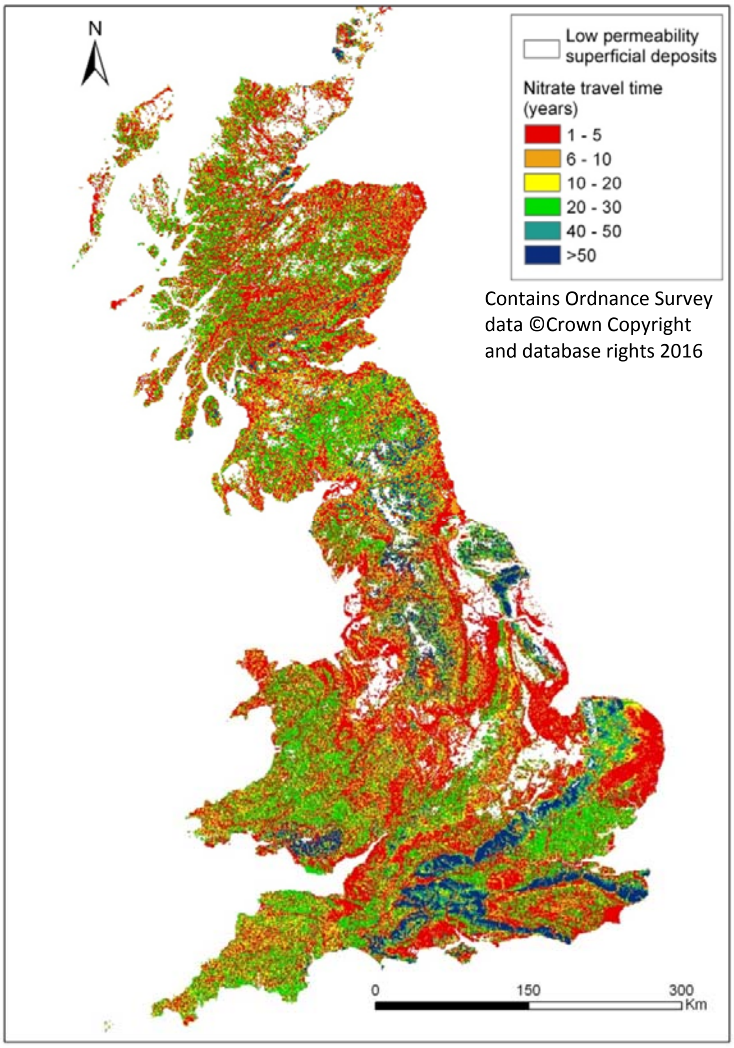
Figure 2.8 Nitrate input function. Solid line shows spans derived from literature data. Black dots show individual porewater nitrate concentrations from ~300 cored boreholes in the BGS database which have been back plotted to give base of the soil zone concentrations at their year of recharge calculated using depth in the profile and estimated unsaturated zone travel time. Blue crosses show mean nitrate concentration for a given year calculated from the porewater data.

2.2.4 Results

The distribution of travel times for the unsaturated zone from the surface to the water table for nitrate, and indeed for any conservative tracer, is presented in Figure 2.9. The calculated nitrate travel time ranges between 1 and over 400 years. On the basis of the model, nitrate is projected to reach the water table of 88.1% of the areas of Great Britain within 20 years of input. It is predicted to take 1 year for nitrate to reach the water table in roughly 27% of areas.

The results can be summarised as:

- the NTB model gave the first modelled national assessment of legacy nitrate in the unsaturated zone;
- this showed that the 1980-90 peak nitrate applications are still in the unsaturated zone in aquifers with thick unsaturated zones, generally due to relief;



Contains Ordnance Survey data ©Crown Copyright and database rights 2016

Figure 2.9 The distribution of predicted nitrate travel time in the bedrock unsaturated zone of Great Britain. Low permeability superficial deposits not coloured

- this was based on measured values for travel time in the major aquifers, but used heuristic values for the others;
- it was based on hydrogeological mapping at the 652k scale;
- it used a literature-based nitrate input function applied uniformly to the whole land area;
- water levels were predominantly derived from hydrological maps and represented autumn minimum levels.

2.2.5 Integrating with the saturated zone at the catchment scale

Wang et al. (2013) developed an integrated modelling method to simulate the nitrate transport in both the unsaturated and the saturated zones at the catchment scale. Three BGS numerical models, the NTB model - described above, GISGroundwater - a groundwater flow model (Wang et al., 2010) and N-FM a nitrate transport model for the saturated zone developed for this work, were integrated to verify and support each other to provide information on nitrate lag time in the groundwater system at a catchment scale. The Eden Valley, which has thick Permo-Triassic Sandstone unsaturated zones and a nitrate groundwater pollution problem, was selected as a case study area.

MODELLING WATER LEVELS

The unsaturated zone (USZ) thicknesses used in the NTB model are too coarse for a catchment scale study. Therefore, a simple and easy-to-use groundwater flow model, GISGroundwater, was used to simulate the long-term average steady-state groundwater levels (GWLs) for the area to derive high spatial resolution of the thicknesses of the Permo-Triassic sandstone USZs in the Eden Valley. GISGroundwater is a seamless GIS 2-dimensional numerical finite difference groundwater flow model (Wang et al., 2010).

The Penrith and St Bees Sandstone formations were simplified as a single layer aquifer with a distribution of hydraulic conductivity values. The modelling extent was defined by a (100m × 100m) GIS layer. A GIS layer containing distributed K values was entered into the model; river nodes and river stages entered were derived from a Centre for Ecology and Hydrology (CEH) river system dataset and a digital elevation model) dataset from CEH; groundwater abstraction data were also entered into the model using a GIS layer.

An average groundwater recharge of 1 mm day^{-1} was used in the groundwater flow model which was calibrated by comparing the simulated long-term average GWLs with observed ones in 39 boreholes. Figure 2.10 shows that the modelled and observed GWLs correlate indicating that the steady-state groundwater flow model for the study area was well calibrated. The K values for modelling the groundwater flow in the Penrith and St Bees Sandstones were 3.5m day^{-1} and 0.6m day^{-1} respectively. The distributed Permo-Triassic Sandstone USZ thickness map for the area was then derived by subtracting the modelled long-term average GWLs from the DSM dataset.

In the study area, the modelled thickness of the Permo-Triassic sandstone USZs is greatest, 183 m in the northwest of the Eden Valley, and reduces to 0 m (i.e. GWLs are the same elevation as the river stages) along the River Eden and its tributaries. Notably SPZs generally have a thicker USZ than other parts of the study area. The nitrate travel time in the Permo-Triassic sandstone USZs correlating with the USZ thickness, ranges from 0 to 61 years with a mean value of 12 years; strip areas along streams have short travel times (0-1 year) due to thin USZs, whilst mountainous areas in the east and west of the Eden Valley have longer nitrate travel times.

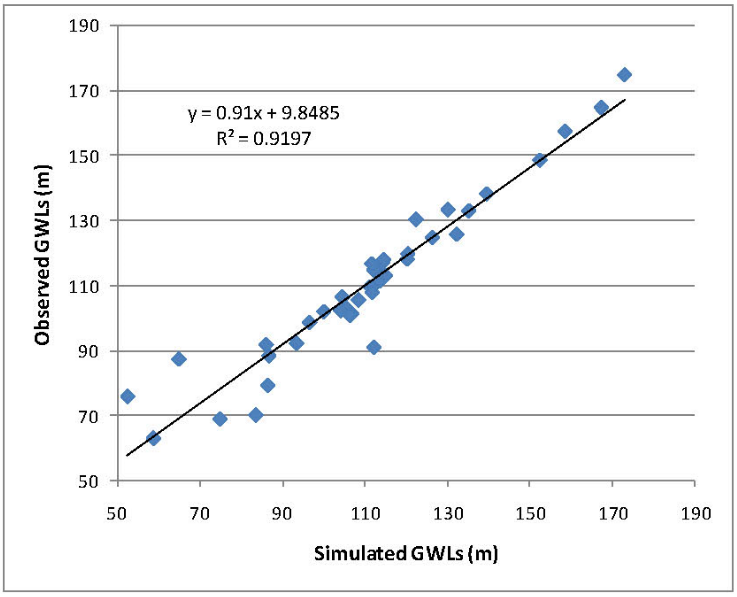


Figure 2.10 **Comparison of observed and simulated water levels**

MODELLING NITRATE DILUTION IN THE SATURATED ZONE

N-FM – a GIS nitrate transport model for the saturated zone was developed to simulate yearly nitrate concentration at a borehole by considering the process of nitrate leaching from the bottom of the soil zone, the nitrate movement in the USZ and dilution in the saturated zone. The simulated pumped nitrate concentration in boreholes was compared with observed values to validate the numerical modelling parameters, such as the nitrate transport velocity in the USZ, the thickness of the USZ, and the aquifer hydraulic conductivity values used for deriving the thickness of the USZ.

Figure 2.11 shows the conceptual model of N-FM. The dilution process was simplified by assuming that nitrate arriving at a borehole dilutes in water pumped out of the borehole, and the groundwater flow within a groundwater Source Protection Zone (SPZ), reaches a steady-state, i.e., the long-term recharge volume within a SPZ equals water pumped out of the borehole in the SPZ. Not all leached nitrate reaches the abstraction borehole due to attenuation in the USZ and the saturated zone. Nitrate concentration may be lowered due to denitrification and absorption in USZs; nitrate in the saturated zones will be absorbed by small pores or transported outside of SPZ due to the diffusion and dispersion processes. Therefore a nitrate attenuation coefficient (*NAC*) was introduced into this model. With this conceptual model, the depth of the saturated zone, and the thickness of active groundwater zone can be ignored, and the nitrate dispersion and diffusion processes can be simplified in simulating yearly nitrate concentration at a borehole in the SPZ.

The modelling showed that the peak nitrate loading around 1983 has affected most of the study area (Figure 2.12). For areas around the SPZs of Bowscar, Beacon Edge, Low Plains, Nord Vue, Dale Springs, Gamblesby, Bankwood Springs, and Cliburn, the peak nitrate loading will arrive at the water table in the next 34 years (Figure 2.12). Statistical analysis shows that 8.7% of the Penrith Sandstone and 7.3% of the St Bees Sandstone have not been affected by peak nitrate.

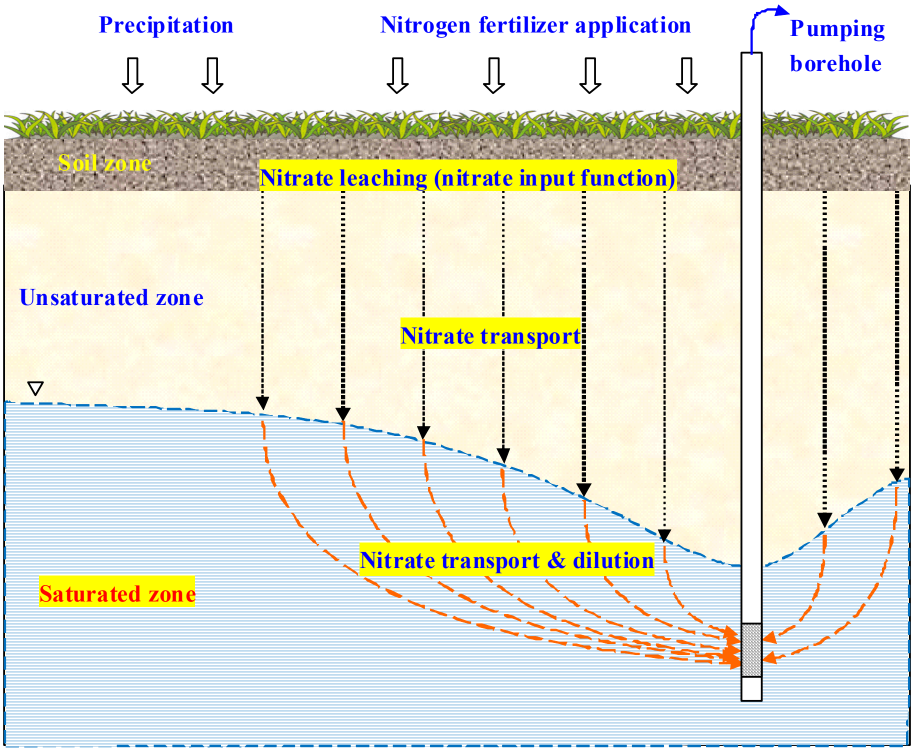


Figure 2.11 Conceptual cross-section for simulating nitrate transport and dilution in groundwater in the N-FM model

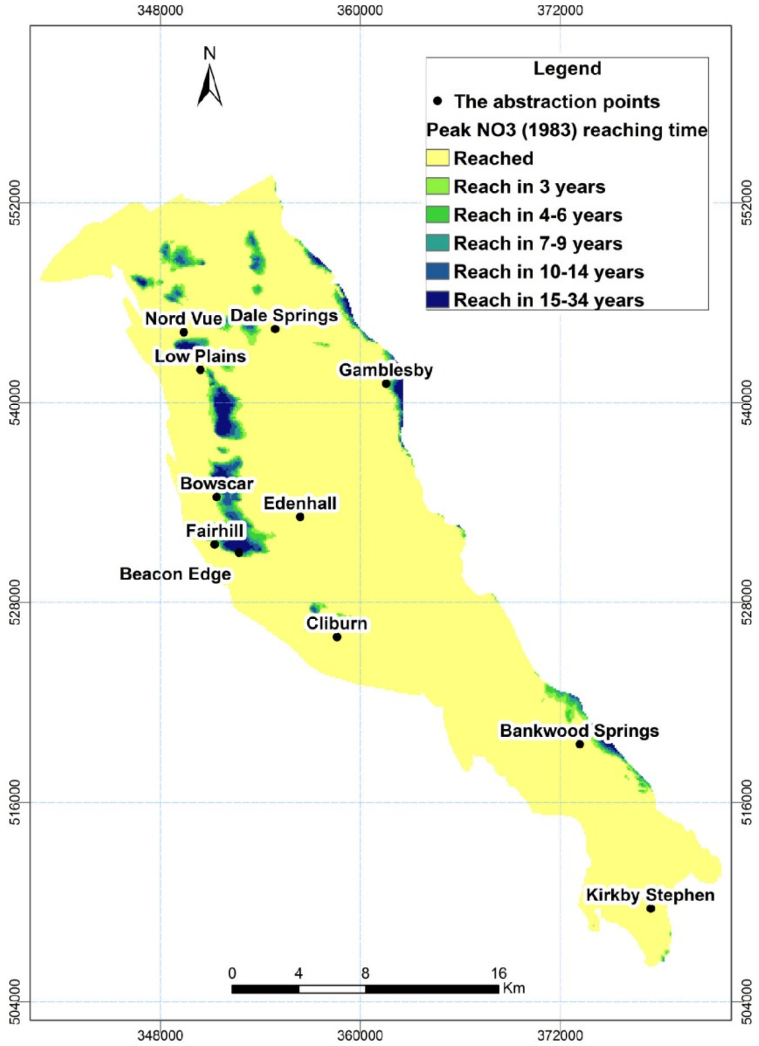


Figure 2.12 Map of Eden valley catchment showing travel time of the 1983 peak nitrate concentration to abstraction points

Distributed maps were produced for nitrate concentration at the water table for each year between 1925 and 2040. The results show that the average nitrate concentration at the water table across the study area has reached its peak and will decrease over the next 30 years (Figure 2.13). Some unaffected areas with thicker USZs around Beacon Edge, Fairhills, Bowscar, Nord Vue, Low Plains, Gamblesby, and Bankwood Springs, will be affected by peak nitrate loadings between 2020 and 2030, and then retain a high nitrate concentration (172 mg NO_3 l^{-1}) (before any groundwater dilution) around 2040.

The results show that:

- The model provides predictions of nitrate concentrations at public supply boreholes;
- catchment scale groundwater modelling simulated water levels and derived unsaturated zone thickness;
- the NTB nitrate application function and unsaturated zone velocities were applicable;
- measured water levels are needed to calibrate the flow model;
- SPZs are needed to calculate nitrate dilution in the saturated zone.

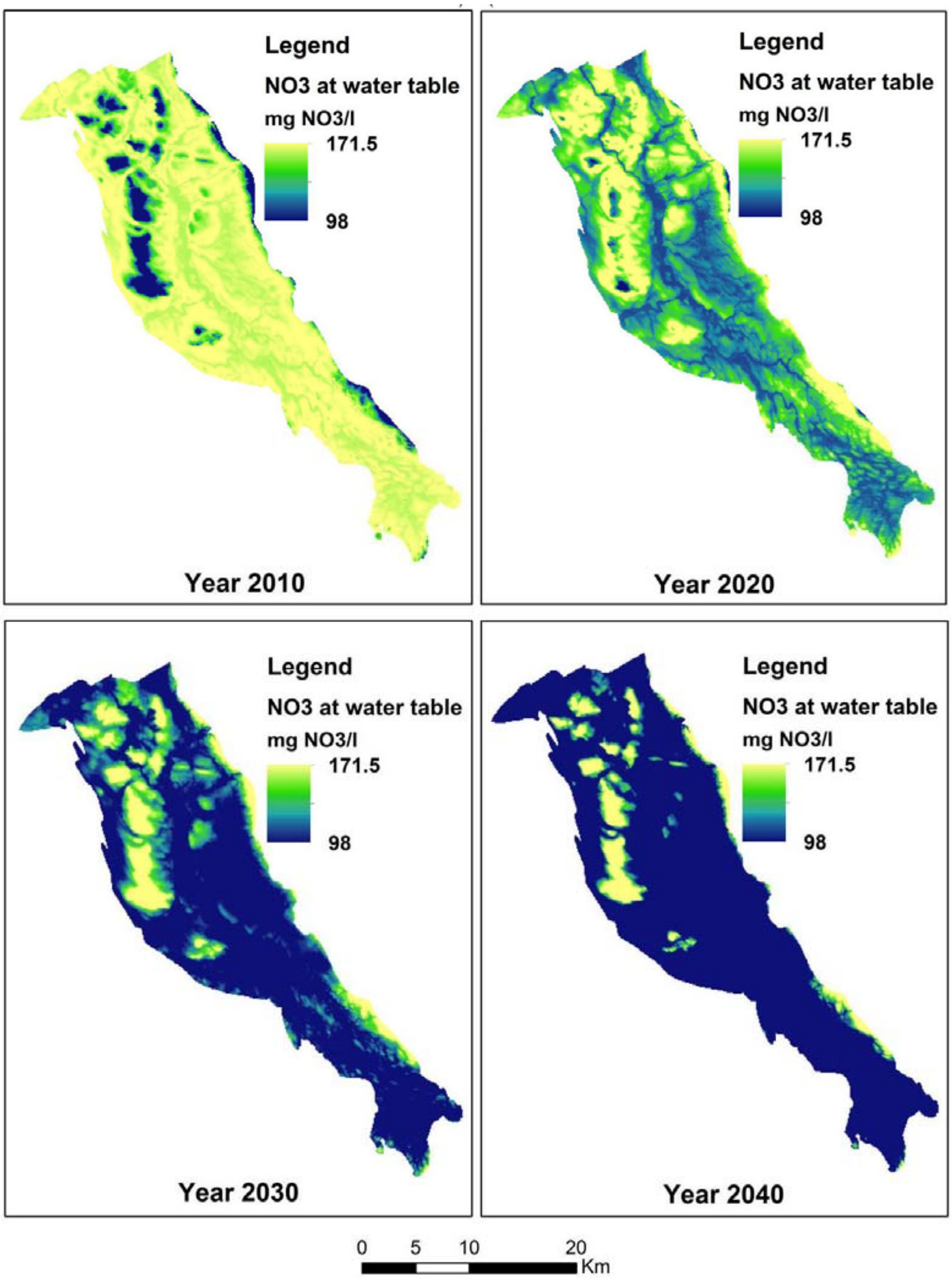


Figure 2.13 **Predicted decrease of nitrate loadings at the water table from 2010 to 2040**

3 NVZ designations under the Nitrates Directive

The first designations were made in 1996. A major review of the designation process was carried out in 2002 with further reviews in 2008 and 2012. The following sections discuss the methods used and results in each of the designation rounds.

3.1 1996

3.1.1 Methodology

Under the Nitrates Directive, Member States were required to identify "polluted water" or water at risk of pollution if no controls were applied. The land draining into these areas and contributing to pollution was then designated as nitrate vulnerable zone. The Directive's criteria were as follows:

- whether surface freshwaters, in particular those used or intended for the abstraction of drinking water, contain or could contain more than 50 mg NO_3 l^{-1} (on the basis that 95% of samples should comply with this limit) if protective action were not taken;
- whether groundwaters contain, or should contain more than 50 mg NO_3 l^{-1} if protective action were not taken;
- whether freshwaters, estuaries coastal and marine waters are eutrophic or may become so if protective action were not taken.

The following considerations were to be taken into account when supplying these criteria:

- the physical and chemical characteristics of the waters and land;
- the current understanding of the behaviour of nitrogen compounds in the environment (water and soil);
- the current understanding of the impact of the remedial action.

The quality of the water was to be established by regular monitoring and there were different provisions for surface and groundwaters. The original designation process is described in MAFF et al. (1994) and an outline is shown in Figure 3.1.

SURFACE FRESH WATER

The Directive required that the monitoring of the nitrate concentration should take place at least monthly over a 12-month period. For this assessment the National Rivers Authority (NRA) used monitoring data for the calendar year 1992 for sampling points used for the Surface Water Abstraction Directive.

The lower extremity of a polluted water was determined by an abstraction point which exceeded the 50 mg NO_3 l^{-1} limit. The upper point was either the first upstream sampling point which complied with the 50 mg NO_3 l^{-1} on a 95 percentile approach using five years' data or the source of the headwaters, if all sampling points failed. The vulnerable land was the land draining into this polluted water. The land was defined by delineating the boundary of the natural catchment, upstream of the abstraction, and reducing this catchment as appropriate to exclude land draining to the first upstream passing point. Defining the natural catchment in this way assumed the drainage follows the lie of the land. Where man-made drainage arrangements rendered this approach invalid (particularly in low-lying areas) these were taken into account in defining the land draining to the abstraction point.

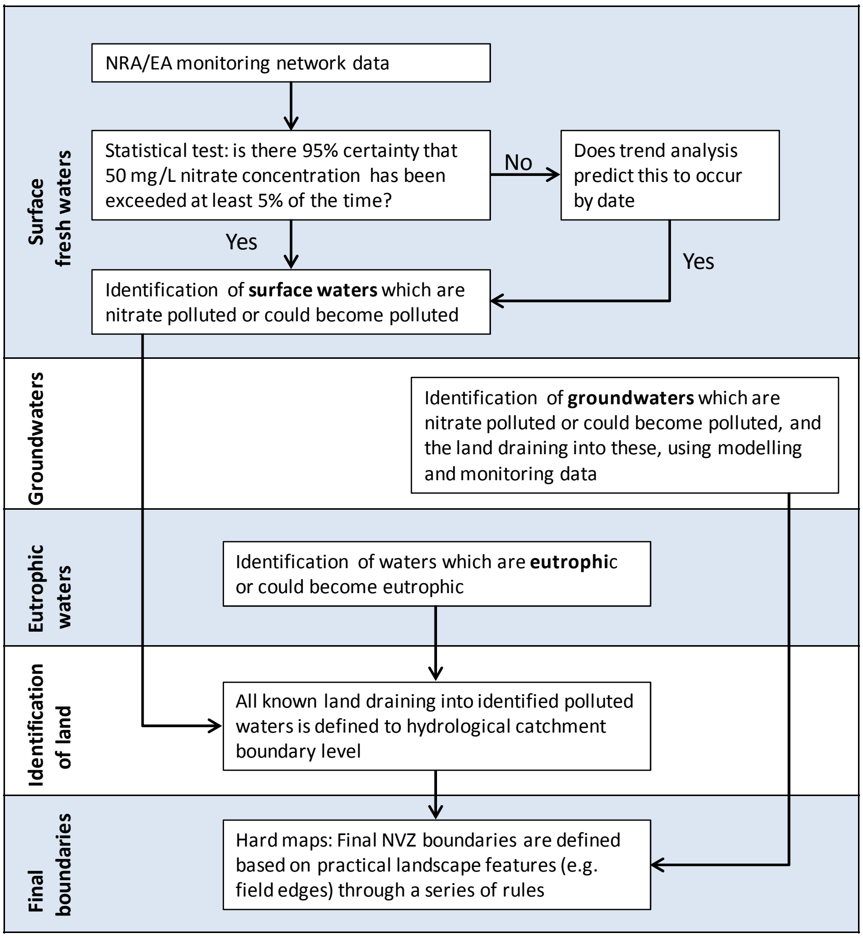


Figure 3.1 Designation process steps (after MAFF et al., 1994)

GROUNDWATER

All groundwater boreholes, wells and springs used for public water supply in England and Wales were examined by the then NRA to see if there was evidence that nitrate levels already exceeded the 50 mg l^{-1} limit or were on a trend to exceed it by the year 2010. Data over recent years were examined and assessed relative to the likely position by the year 2010.

For each well or spring system, which had exceeded or was expected to exceed the 50 mg l^{-1} limit, the groundwater source catchment was identified. This was based on the area within which all water would flow to the abstraction. The source catchment was defined both by modelling and by the study of relevant hydrogeological factors. An area became a potential groundwater zone where the location of the majority of the land draining into the abstraction was known and where agriculture was the principal factor in determining nitrate levels in the water.

Sources were grouped into common vulnerable zones in a number of cases. The most straightforward cases were those where separate catchments adjoined each other and it was possible to extend the boundary to cover more than one catchment. In a number of other cases where catchments lay close together, the amount of the groundwater resource used for public supply was not sufficient to provide definitive guidance for a clear division of land into catchment and non-catchment. In such cases geological features provided the basis for much of the vulnerable zone boundary. The groups of sources were placed in common vulnerable zones only where the amount of land forming catchments to polluted waters constituted a high proportion of the area of land which can be defined by reference to geological features.

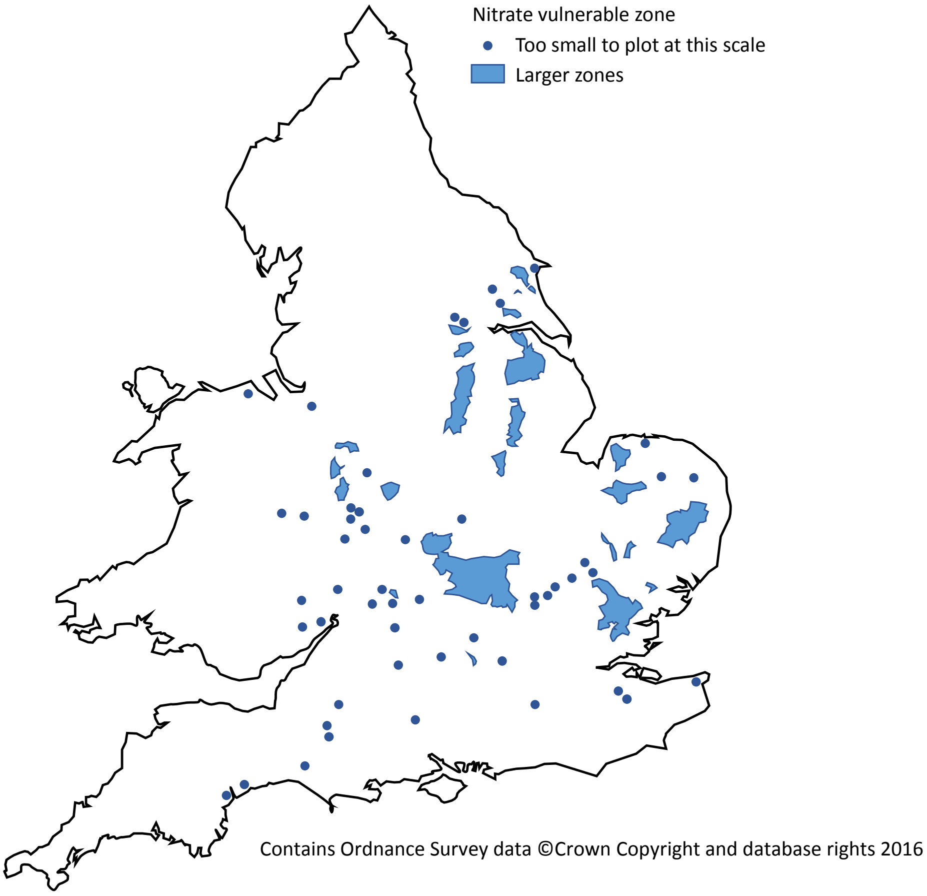


Figure 3.2 Zones in original designation (derived from MAFF et al., 1994)

EUTROPHIC WATERS

Eutrophication is defined in the Directive as the enrichment of water by nitrogen compounds. It causes an accelerated growth of algae and higher forms of plant life to produce and undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned. There were no designations under this heading.

BOUNDARIES

The proposed boundaries of vulnerable zones were based on "hard features" such as roads and field boundaries. The following criteria were accepted:

- where a proposed zone is large enough – so that minor erosion of the boundary does not affect its environmental impact – the hard boundary lies inside the hydrological boundary;
- in groundwater zones the proposed designation corresponds to a reasonable proportion of the theoretical catchment required to recharge the water abstracted.

DESIGNATED NVZ AREAS

Land draining into 11 river systems and land being identified as the catchment of 141 groundwater abstraction zones were put forward as candidate vulnerable zones, giving 72 NVZs in total. An outline of these zones is shown in Figure 3.2. Four of these were surface water catchments, some were joint, but the majority were groundwater catchments. The total area of the proposed NVZs was about 6,500 km^2. Action plans related to these designations came into effect in 1998.

3.1.2 Appeals to independent review panel

Appeals against designation were heard by an independent review panel appointed by the Secretary of State and their report is published in MAFF (1995). This report reviewed the number, range and nature of the submissions. Objections were received to 29 of the proposed 72 NVZs. These covered a wide variety of themes, including boundary location, sampling point location and possible effects of non-agricultural sources. Others raised issues of principle. These included:

- arbitrariness of the limit;
- frequency of testing;
- trend estimation in groundwater;
- non-agricultural sources;
- marginal failures;
- boundary definitions;
- grouped sources;
- absence of compensation;
- non-representative monitoring data.

Of the 29 NVZs which were contested, the panel's conclusions were that:

- 1 was considered to be too small;
- 1 had inadequate monitoring data;
- 1 needed better boundary definition;
- 1 was not significantly shown to be due to agriculture;
- 1 surface water not accepted but an associated groundwater NVZ was;
- 2 were deferred

The others were all considered to be valid under the specified procedure. The final agreed changes are set out in MAFF et al. (1995).

3.2 2002 REVIEW

In December 2000, the European Court of Justice held that the UK had failed to designate sufficient NVZs for the protection of all waters, not just for drinking water sources. On 27 June 2002, the Government announced the intention to designate additional NVZs in England. Except for the purposes of identifying waters that are eutrophic or are likely to become eutrophic, new criteria replaced the methodology for designating NVZs in Department of the Environment et al. (1993) and were set out in Defra (2002).

3.2.1 Revised methodology

SURFACE WATER

Surface waters with nitrate concentrations exceeding 50 mg NO_3 l^{-1}, or which could exceed 50 mg NO_3 l^{-1}, were identified through the following steps:

a) sampling nitrate concentrations between 1996 and 2000 at water quality monitoring points representative of all major surface waters in England. This dataset contained about 60 samples for each of 7000 sites. This was a major change as previously only public supply sources had been used;
b) analysing the monitoring data over the 1996 to 2000 period to identify those points where there was 95% statistical certainty that the level of 50 mg l^{-1} of nitrate had been exceeded at least 5% of the time. This was done by calculating a 95 percentile from the dataset and constructing a 90% confidence interval around this. If the lower confidence interval on the calculated the 95 percentile exceeded the 50 mg NO_3 l^{-1} level, then the sample point was judged, with 95% certainty, to be affected by nitrate pollution;

c) trend analysis to identify any additional points which could exceed 50 mg NO_3 l^{-1} in the future if action is not taken. This work used a ten-year dataset from 1991 to 2000 to extrapolate future trends. Points predicted with 95% confidence to exceed the level of 50 mg/L at least 5% of the time by 2004, which was the year of the next monitoring review required under the Nitrate Directive, were judged to be waters that could be affected by pollution if no action is taken;

d) identification of all known areas of land draining into all the tributaries of the river network upstream from each polluted monitoring point. Although nitrate concentrations in some of these upstream tributaries may have fallen below 50 mg NO_3 l^{-1}, land draining into these waters still needed to be included because nitrate loss throughout the catchment will be contributing to the downstream pollution.

GROUNDWATER

Geostatistical analysis was used to interpolate nitrate concentration data between monitoring sites in England. Future nitrate concentrations were predicted by extrapolating from the actual nitrate monitoring data. These, together with modelling of nitrate leaching vulnerability, were used to identify land draining into groundwaters which exceeded 50 mg NO_3 l^{-1}, or were expected to exceed this if no action was taken.

Identification of groundwaters which were nitrate polluted or which could become polluted used the following steps:

a) gathering historic nitrate concentration data from groundwater monitoring sites (boreholes, wells and springs) in England between 1990 and 2000. This included all available data for 3714 monitoring sites in England and Wales from both the Environment Agency and Water Companies;

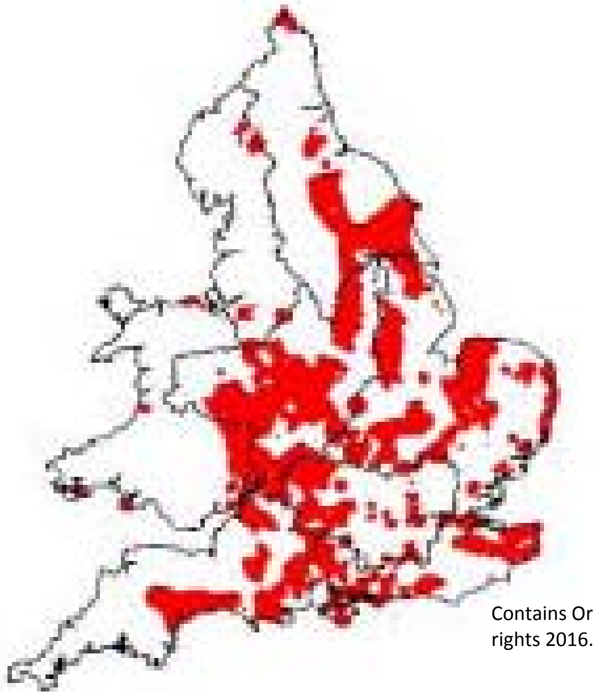
b) subjecting actual groundwater data to predictive computer analysis to produce a map estimating the probability of any location exceeding 50 mg NO_3 l^{-1} by 2017. This was 25 years from 1992, the first full year in which the Nitrates Directive was in force. Groundwater residence times are longer than surface waters and therefore responses to changes in nitrate losses from agricultural land will take longer. This involved the collation of trend values and disjunctive kriging to provide local estimates and also probabilities.

The final areas are shown in Figure 3.3.

Identification of all known areas of land which drained into these groundwaters involved the following steps:

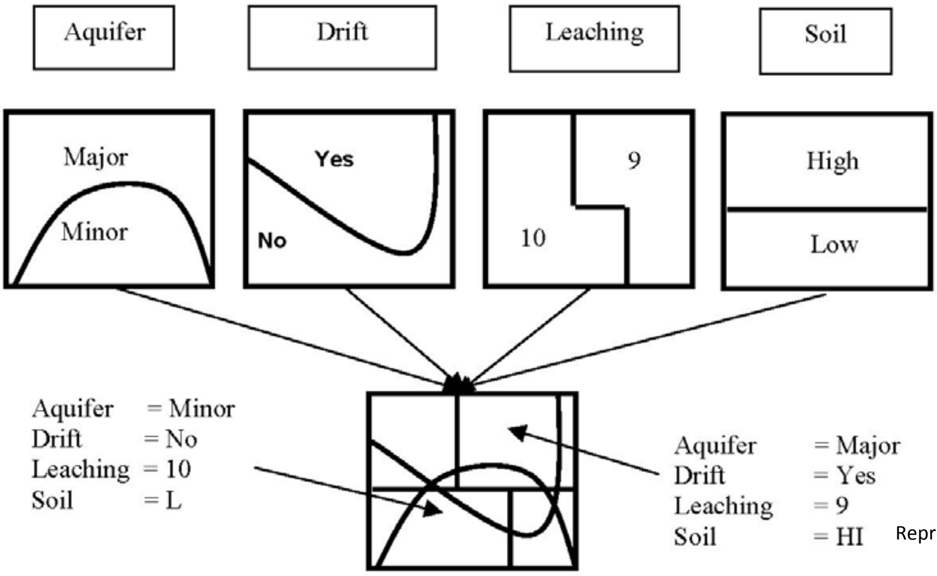
a) modelling the nitrate leaching vulnerability using a GIS model which took account of climate, nitrate loading, soil characteristics, and superficial and bedrock geology. Nitrate leaching vulnerability was estimated using the ADAS MAGPIE model (Lord and Anthony, 2000; Lord et al., 1999) and the Environment Agency's published vulnerability maps. The model structure is shown in Figure 3.4;

b) combining the map of the predicted future nitrate levels with the calibrated model of groundwater vulnerability and applying a buffer. The overall effect was to identify areas of land draining into groundwaters which could exceed the 50 mg/L nitrate concentration limit by 2017 and where it was possible that the groundwaters are vulnerable to nitrate leaching from agricultural land. These areas of land were therefore those which drained into groundwaters that are affected by pollution, or could be affected by pollution if no action were taken. The threshold vulnerability was set using the cumulative percentage of high nitrate boreholes.



Contains Ordnance Survey data ©Crown Copyright and database rights 2016. Reproduced courtesy of Defra

Figure 3.3 Areas with probability of exceeding 50 mg l^{-1} nitrate in groundwater ≥0.2 in 2002 assessment (from Defra, 2002)

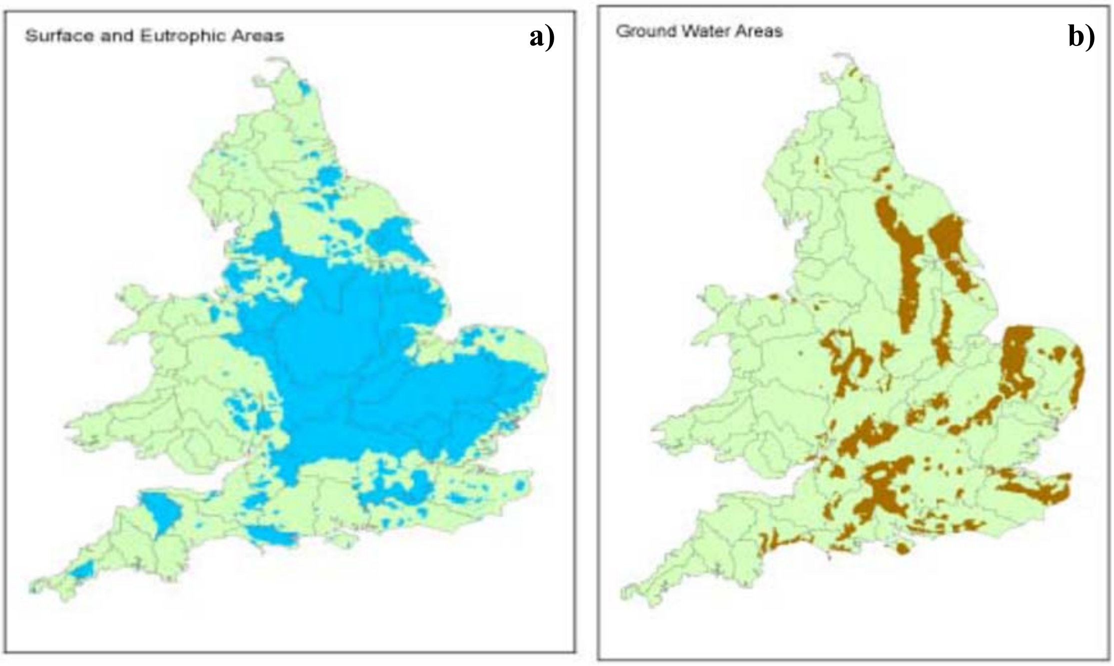


Reproduced courtesy of Defra

Figure 3.4 Combination of data layers within GIS to derive nitrate leaching vulnerability in 2002 (from Defra, 2002)

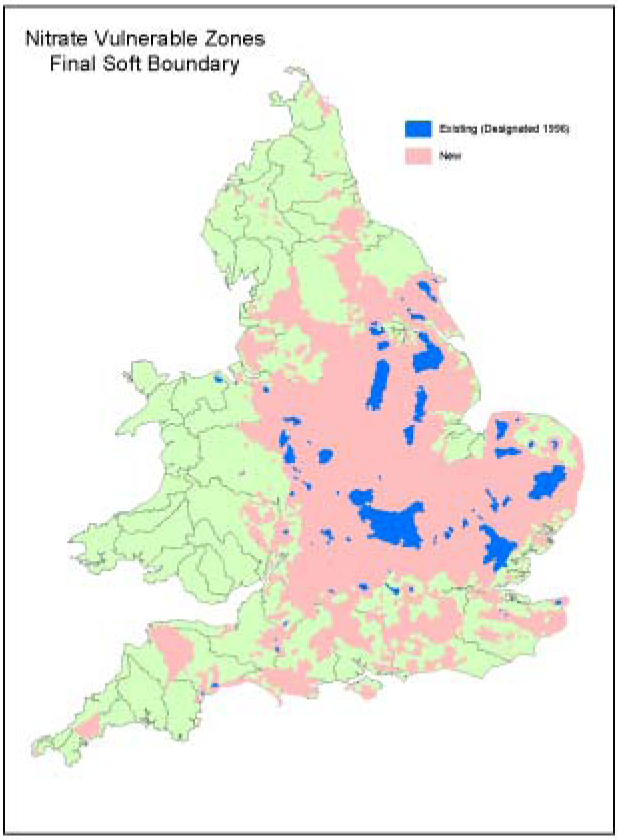
3.2.2 Designated areas

The areas derived from the 2002 assessment are shown in Figures 3.5 and 3.6.



Contains Ordnance Survey data ©Crown Copyright and database rights 2016. Reproduced courtesy of Defra

Figure 3.5 NVZs identified in 2002 for: a) surface water and b) groundwater (from Defra, 2002)



Contains Ordnance Survey data ©Crown Copyright and database rights 2016. Reproduced courtesy of Defra

Figure 3.6 Final and new zones in 2002 (from Defra, 2002)

3.3 2008 REVIEW

3.3.1 Methodology

Changes in methodology for application in this round are set out in Environment Agency (2007) and the finalised methodology is set out in Defra (2008). A new surface water method was developed, and the monitoring network also developed, mainly in line with the requirements of the Water Framework Directive. The minimum dates for collection of monitoring data were 1999-2004, with samples dating to 1980 used where these were available to determine concentration in mid-2005. The date for the statistical modelling of trends which would fail the 50 mg NO_3 l^{-1} value became 2021.

Most of the already existing NVZs drained to waters that the 2008 method also showed to be polluted waters. However some were not, for two reasons:

- there were areas where the water quality had apparently improved and did not meet the designation criteria;
- there were existing groundwater NVZs which would not be designated due to the improvements in the method or the form of monitoring.

The Nitrate Directive has no specific provision within it to allow de-designation of NVZs. Moreover, short-term improvements in quality may have been only temporary, resulting from climate variations or temporary agricultural changes (such as de-stocking after the foot and mouth disease outbreak). Hence, although the 2008 groundwater method contained options for identifying land for removal from designation, no such case was assessed as sufficiently strong, and so all the pre-existing (i.e. 1996 and 2002) NVZs remained designated.

SURFACE WATER

The catchments used are defined in the Water Framework Directive as surface water body catchments. There were two types of surface water catchment:

Type 1. Those catchments that had monitoring data, trend data and model data (predictions of 95 percentile nitrate concentration based on land-use and other sources of nitrate). For Type 1 catchments monitoring and trend data were used to define whether a surface water meets the Directive's criteria for identification as a polluted water. If a main river in any surface water catchment failed, the entire upstream catchment was designated as a nitrate vulnerable zone i.e. all land draining to the failing water was designated;

Type 2. Those catchments that only had model data (predictions of 95 percentile nitrate concentration). For Type 2 catchments, modelled data was used to indicate whether the surface water met the Directive's criteria for identification as polluted water. If a surface water catchment was identified, the upstream catchment was designated at least as far as the first monitoring point. From the first monitoring point upstream the Type 1 rules applied.

GROUNDWATER

This followed a similar process to that used in the previous round. Following determination of concentration and trends, kriging was used to provide some indication of potential levels across all the land surface.

A risk model for groundwater was used to combine the calculated amount of nitrate released with both the current and predicted future groundwater nitrate concentrations. The output from this risk model represented the risk that the groundwater nitrate concentration exceeded, or was likely to exceed 50 mg NO_3 l^{-1} by 2021, and that the source of nitrate was current agricultural practice.

The risk associated with the monitored data was a combination of the current and the predicted nitrate concentrations. The current concentrations are given the greatest weight, followed by the predicted concentrations. The nitrate released from current agriculture is given the same weight as current monitoring data. The nitrate released from urban loading was given a negative weight. The risk was assessed for every 1km square in England and Wales. Three levels of risk were identified:

- **High.** Both monitoring data and calculated agricultural nitrate releases showed that nitrate concentrations exceed or are likely to exceed 50 mg NO_3 l^{-1};
- **Medium.** Either monitoring or calculated agricultural nitrate releases showed that nitrate concentrations exceed or are likely to exceed 50 mg NO_3 l^{-1}.This risk class highlighted areas where the evidence from monitoring and loading conflicted. It also captured areas where agriculture was not a significant source of nitrate;
- **Low.** Both monitoring and calculated agricultural nitrate releases showed that nitrate concentrations are not likely to exceed 50 mg NO_3 l^{-1}.

The output from the groundwater risk model was reviewed and modified by area experts within the Environment Agency. This was to ensure that the risk model did not contradict local knowledge and represented the Environment Agency's best understanding of the risk posed to groundwater by agricultural nitrate. The following national datasets were used to inform this process; solid geology, drift geology, drift thickness, drift permeability, risk of solution features, depth of unsaturated zone, groundwater head, available water and mean surface water nitrate concentration from the surface water regression model.

Agency area staff applied four modifications which they could make to improve the risk model. These modifications were:

- de-nitrification or mixing. If there were processes which will decrease the nitrate concentration before it reaches the groundwater this modification allows the risk to be downgraded;
- point source pollution. If monitoring was representative of point source pollution this modification allows the risk to be upgraded;
- groundwater monitoring was unrepresentative of diffuse nitrate pollution from agriculture. Groundwater monitoring depends on the depth of water being sampled. Sampling at depth can be representative of very old water. This modification allows the risk to be both increased and decrease;
- surface water monitoring was representative of groundwater quality. Where groundwater monitoring is infrequent surface water data can be used to identify groundwater quality. This modification can be used to upgrade the risk.

Evidence was required before a modification could be made. The level of evidence required for each test was set out initially to ensure that all local modifications were consistent and justified.

The final phase of the work was to put boundaries around the land draining to the high risk areas identified by the risk model using catchment characterisation datasets. The boundaries listed below were used to de-lineate groundwater NVZs in decreasing order of preference.

- solid or drift geology 1:50k;
- risk of solution features 1:50k. Where solution features are present it can be more appropriate to use this layer than solid geology. This is because the solution feature layer includes a three dimensional aspect at the edge of an aquifer. If the rock at the surface is non aquifer but it is prone to solution features then it is important that the NVZ is extended to include this area;
- feature where groundwater flows out into surface water (river, lake, sea). These features often define a groundwater divide (i.e. the line from which groundwater will flow in different directions). Where nitrate risk is high on one side of such a feature they can be used to define catchments;
- urban areas do not represent a hydraulic boundary. However they can be useful as a boundary beyond which there is no agricultural nitrate contributing to the high risk area;

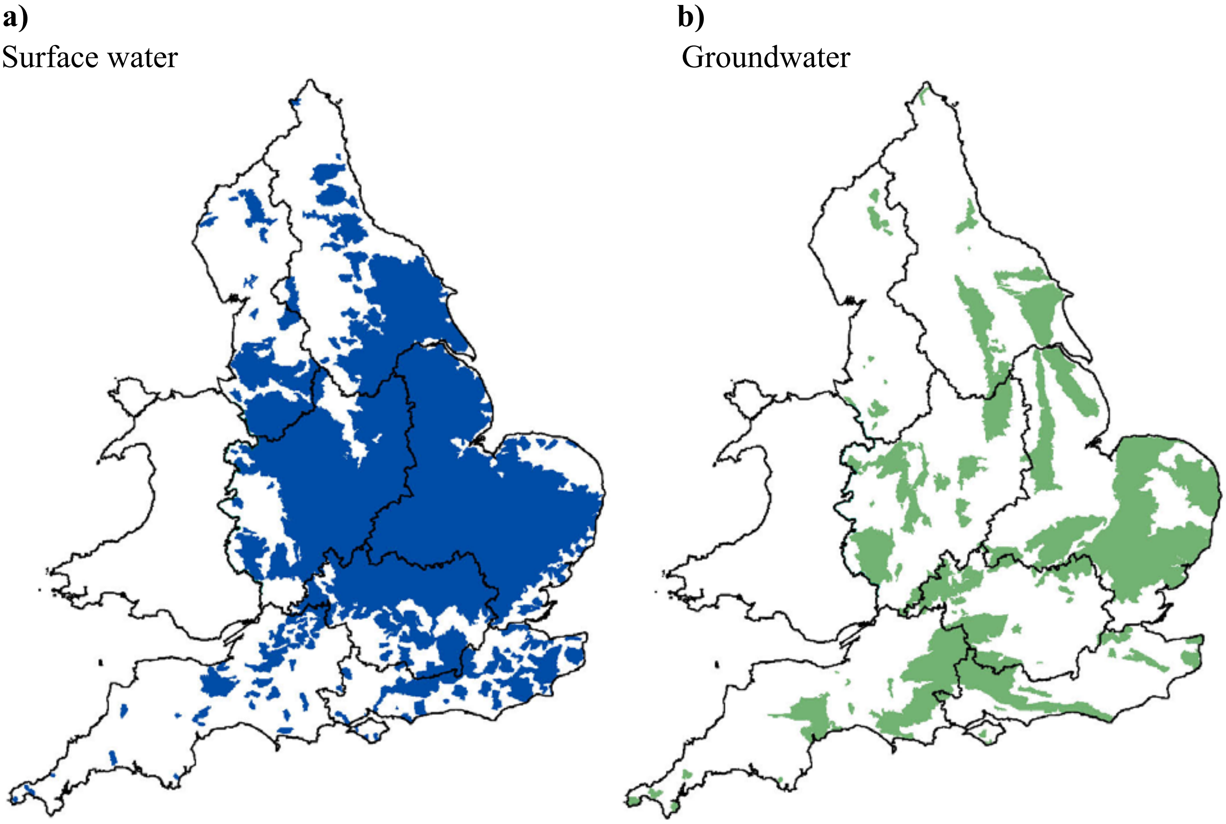
- flow lines can be used to delineate within an aquifer. A flow line represents a line across which groundwater does not flow. Flow lines are drawn perpendicular to contours of the level of groundwater. This type of boundary is subject to professional judgement and has only been used when none of the other boundaries is appropriate.

To ensure the highest level of reliability of the outcome of this method, each proposed NVZ was checked to see if it has more than one monitoring point that was exhibiting high nitrate. If there was only one monitoring point within the NVZ it must have a reasonable record (at least one full season) to enable confidence that the readings were representative.

It is theoretically possible that monitoring points with high current and predicted nitrate could be identified as high risk by the model even though the agricultural loading is low. Each NVZ has been checked to ensure that a significant proportion of the NVZ has an agricultural loading of greater than 30 mg l^{-1}. If an NVZ fails either of these tests it is not proposed as an NVZ at this review.

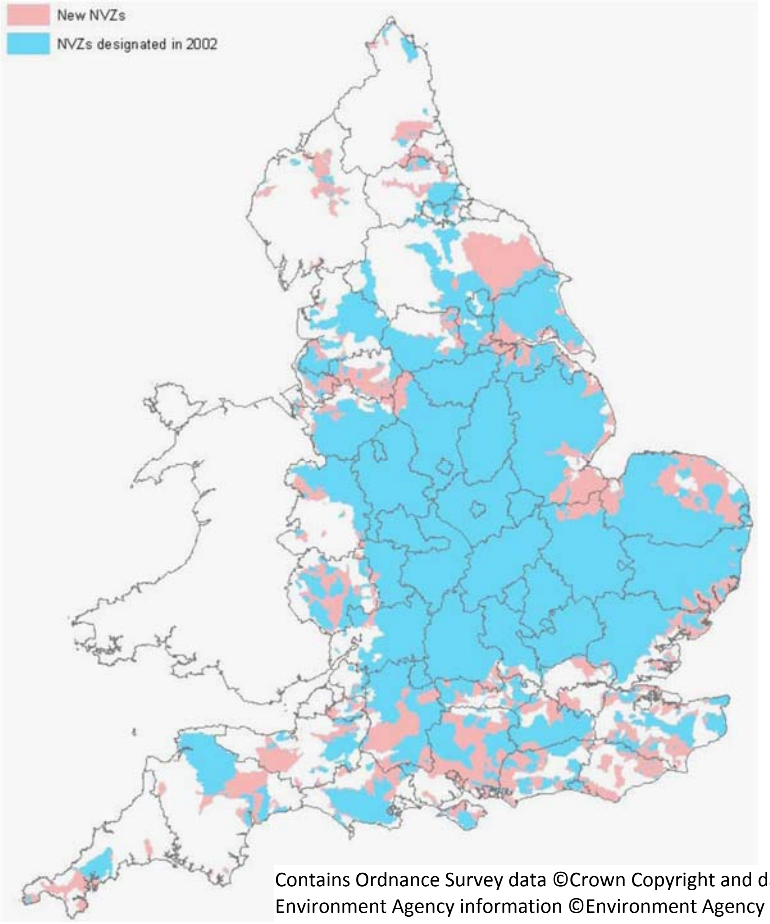
3.3.2 Designated area

A total area of 32,047 km^2 for NVZs was identified in the 2008 review (31,821 km^2 in England and 226 km^2 in Wales) for groundwater (Figures 3.7 and 3.8). The comparable figures were 66,190 km^2 (65,950 km^2 in England and 240 km^2 in Wales) for surface water. NVZs covered 3.4 million hectares arable and 1.8 million hectares managed grassland (ADAS, 2011).



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 3.7 NVZs identified in 2008 for: a) surface water and b) groundwater (from Environment Agency, 2008)



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 3.8 Final and new zones in 2008 (from Environment Agency 2008)

3.3.3 Appeals results

A summary of the NVZ appeals panel at 7th April 2010 (Defra, 2010) showed that of 626 appeals made with complete information provided 47% of appeals were upheld or partly upheld (Table 3.1). The majority (78%) were made on the grounds - (AB) Does not drain to specified water & water not polluted and (B) Water not polluted. The summary is shown in Appendix 1.

Overall the success of surface water appeals was much higher than for groundwater appeals with only 16% of groundwater only appeals being successful.

Table 3.1 NVZ appeal summary 2010 (from Defra, 2010)

Appeal	Class	Number
Type of appeal	Surface water (S)	360
	Groundwater (G)	76
	Surface water & groundwater (SG)	36
	Eutrophic groundwater (GE)	9
	Eutrophic surface water & groundwater (SGE)	2
	Eutrophic (E)	11
	Not specified (NS)	132
Grounds	Does not drain to specified water & water not polluted (AB)	252
	Water not polluted (B)	234
	Does not drain to specified water (A)	133
	Not specified or obscure (N)	7
Decision	Rejected	336
	Upheld	261
	Partially upheld	29

Table 3.2 Appeal success per type (upheld or partly upheld) in 2010 (from Defra, 2010)

		Success rate				
Type		**AB**	**B**	**A**	**N**	**All**
	S	58% (93 / 160)	49% (58 / 118)	71% (58 / 82)	-	58% (209/ 360)
	G	16% (6 / 38)	13% (3 / 23)	20% (3 / 15)	-	16% (12 / 76)
	SG	41% (9 / 22)	17% (1/ 6)	0% (0 / 7)	100% (1 / 1)	31% (11 /36)
	E	33% (1 / 3)	0% (0 / 3)	75% (3 / 4)	0% (0 /1)	36% (4 / 11)
	GE	33% (1 / 3)	0% (0 / 6)	-	-	11% (1 / 9)
	SGE	0% (0 / 1)	0% (0 / 1)	-	-	0% (0/2)
	NS	20% (5 / 25)	53% (41 / 77)	28% (7/ 25)	0% (0 / 5)	40% (53 / 132)
Total		46% (115/ 252)	45%(103/ 234)	54%(71 / 133)	14% (1 / 7)	47% (290 / 626)

4 Assessment of the 2012 designation process for groundwater

4.1 METHODOLOGY

The NVZ assessment methodology used for the 2012 review of groundwater quality in England and Wales adopted a weight of evidence approach (Environment Agency, 2012). It combined observed data from monitoring with data on agricultural land use calculated using a national-scale nitrate leaching model. The methodology was reviewed by an external panel made up of independent technical advisors (including BGS) and representatives from affected bodies including all the farming unions and the Country Land and Business Association (CLA). The method was agreed by the whole panel at the final meeting. The results of the review were used to identify new groundwater NVZs. The methodology comprised six main steps:

Step 1 - Identification of groundwater boreholes for analysis and statistical analysis of groundwater quality monitoring data

MONITORING DATA

The method used both Agency and water company data. The Agency network comprises 15,105 points, including 592 where data were supplied by water companies, plus an additional 1,132 water company monitoring points provided for this exercise. Data from blended and treated sources were excluded. Sampling points included boreholes, springs, wells & adits, pits and landfill sites. Data were cleaned to remove zero values (assumed to be analytical errors), outliers (using a multiple outlier test (Ellis, 1998)) , values > 200 mg l^{-1}, and duplicates within any day. Values below the limit of quantification, "<" values, were treated by dividing the recorded value by 2. Data from samples collected between 1980 and 2009 were included, whereas older data and points with fewer than 6 values were excluded. This left a total of 3839 sites in the final dataset.

STATUS AND TREND

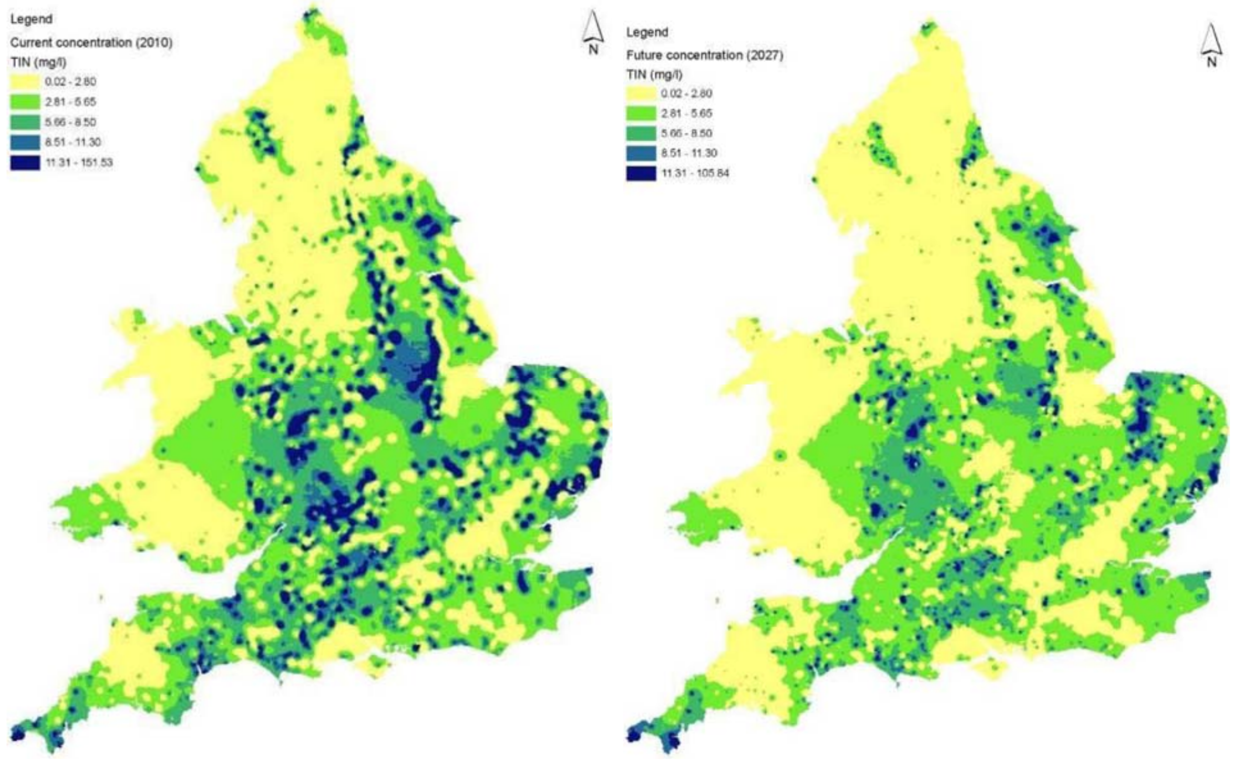
All groundwater monitoring points with sufficient data were analysed to determine whether:

- the 95 percentile of the measured nitrate concentrations exceeded 50 mg NO_3 l^{-1} in 2010; and;
- the 95 percentile of the nitrate concentrations was likely to exceed 50 mg NO_3 l^{-1} in 2027.

If the current or future 95 percentile nitrate concentration exceeded 50 mg NO_3 l^{-1} with at least 95% confidence, it was deemed to have failed the statistical test. In practice, this means testing whether the lower 90% confidence interval on the 95 percentile exceeds 50 mg NO_3 l^{-1}. This approach is precautionary and is required to offer protection against the high uncertainty caused by very limited monitoring data at many groundwater monitoring points.

The year 2027 was chosen as the future time horizon because it (i) is consistent with the approach used in the 2008 review, (ii) allows a sufficient period of time for measures to take effect, and (iii) ties in with the Water Framework Directive river basin planning cycle.

As in the 2008 review, most sites had insufficient data to estimate the 95 percentile concentration. For these sites, the mean concentration was calculated instead and an empirical conversion factor was applied to convert the mean concentration to a 95 percentile concentration. The data were analysed statistically with the method version depending on data availability: Weibull procedure for current status (2010) where there were 24 samples between 2004 and 2009, and AntB or the simpler AntC tools for current status and trends for 2027 for fewer samples. Where there were insufficient data for the Ant tools a 45 mg NO_3 l^{-1} threshold was used instead on the basis that the mean is commonly 5 mg NO_3 l^{-1} lower than the lower 90% confidence on the 95 percentile.



a) Current concentration

b) Future concentration

Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 4.1 Mean predicted groundwater total inorganic nitrogen concentrations in: a) 2010 and b) 2027 as interpolated by ordinary kriging (from Environment Agency, 2012)

The variable total inorganic nitrogen (TIN) was calculated for each monitoring point where:

TIN = (total oxidised N (TON) + ammoniacal N) or (nitrate-N + nitrite-N + ammoniacal N)

Step 2 - Identifying pollution in areas between boreholes

Step 1 only enables the assessment of groundwater nitrate concentrations at specific points within aquifers (the exact area of land represented by a monitoring point will depend on the volume and depth of the abstraction and geology). In order to estimate nitrate concentrations across the country and use the methodology at a 1 km^2 resolution, a statistical interpolation technique (kriging) was used to understand spatial patterns in the groundwater dataset and, hence, estimate nitrate concentrations at unmonitored locations. Kriging was used to assess current and future predicted (to 2027) nitrate concentrations for all areas of groundwater by quantifying the spatial correlation between pairs of measurements over the whole dataset and characterising the relationship between pairs of measurements with different degrees of separation. This relationship is then applied to estimate the measured variable at unmonitored locations from the values observed at surrounding locations (Figure 4.1).

The kriging results were used to inform the designation process in a number of ways:

- to estimate the probability that nitrate concentrations exceed the set threshold; this assessment of confidence in the data mirrors that used for surface waters;
- to help delimit the extent of the contamination in aquifers;
- to identify monitoring points with anomalously high or low nitrate concentrations; these may then be screened out if they are deemed to be unrepresentative of the water bodies (e.g. if they are influenced by a local point source discharge).

Kriging has limitations and the method used here took no account of geological formations or changes in geology. The results were reviewed in consultation with local staff e.g. in Step 5.

Step 3 - Modelling assessment of nitrate leaching to groundwater

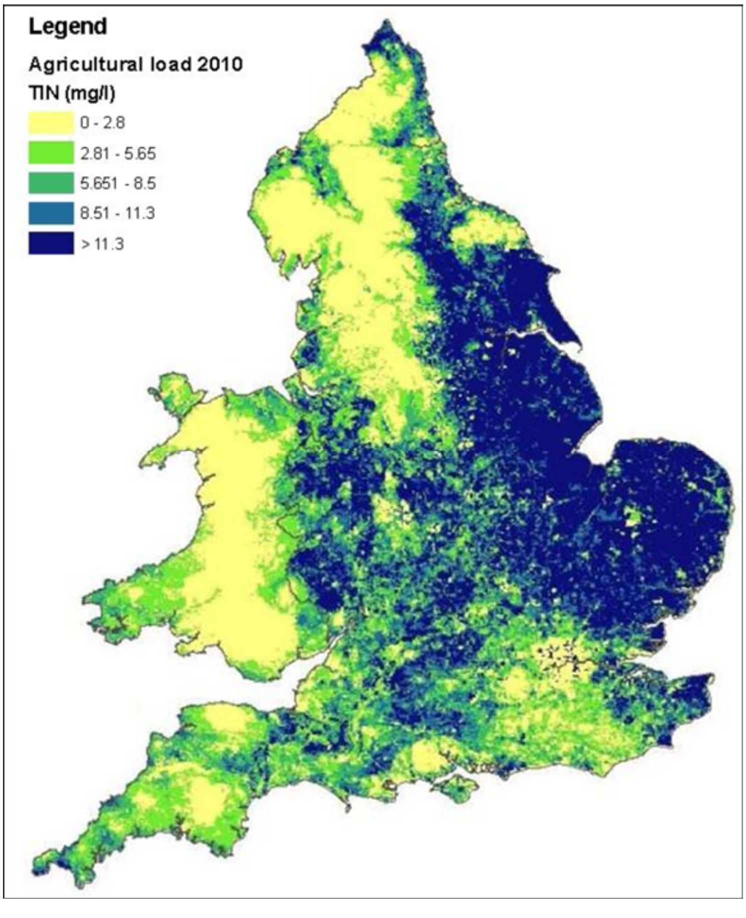
AGRICULTURE

In addition to the analysis of monitored water quality data, nitrate leaching from agricultural land was calculated from farm census returns to Defra. The data were processed by ADAS using the NEAP-N national-scale nitrate leaching algorithms. This approach considers a single maximum potential nitrogen loss coefficient for individual crop and livestock types, modified by spatially distributed information on soil type and hydrologically effective rainfall (HER). It contains data related to average annual soil drainage, nitrate flux and concentrations from diffuse sources at a 1 km^2 resolution. It uses average climate conditions (1971-2000) and data on agricultural land use based on the 2010 Defra Agricultural Census. The model does not include any point source contributions.

Nitrate losses for crops and animals were then aggregated to provide estimates of leaching for three land use classes: managed arable crops, managed grassland and rough grazing. Total values for agricultural nitrate were calculated by combining losses for the three categories on a 1 km^2 scale. To convert the load figures into concentrations, losses were standardised by dividing by HER for the 1 km^2 cell. Due to the uncertainty in the data coverage, each 1 km^2 cell was averaged with its direct neighbouring cells, where available. The resulting agricultural nitrate concentration leaching to groundwater is shown in Figure 4.2.

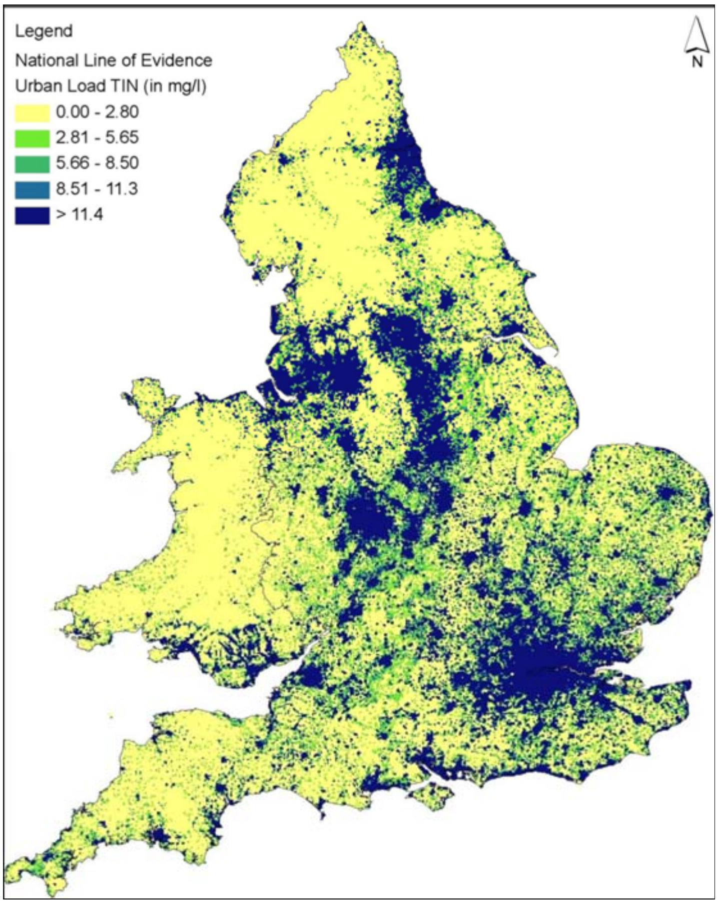
The principal purposes of using the land use data were to:

- identify the significance of the agricultural contribution to any nitrate pollution identified;
- provide further confidence in the conclusions of the statistical analysis of monitoring data;
- minimise the possibility that the borehole fails due to historic landuse because of long travel times for nitrate at the surface to reach deep groundwater.



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 4.2 Agricultural N loading for 2010 as TIN estimated using the ADAS NEAP-N model (from Environment Agency, 2012)



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 4.3 Estimated urban N leaching as TIN using model of Lerner 2000 (from Environment Agency, 2012)

URBAN LEACHING

Nitrate leaching from urban land areas was calculated according to the component model of Lerner (2000), whereby nitrate losses to groundwater are expressed as export coefficients per hectare of each urban land cover type. The model was integrated with land cover data from the CORINE 2000 and the ADAS National Land Use databases. The model identifies 14 components of runoff, although only parks and gardens, recreational grassland, construction activities, and industrial and commercial units were estimated from CORINE, and leaking sewers and water mains from population density. These data were then combined to give a total nitrate load per 1 km^2 from urban sources and divided by the HER for that grid square to give a measure of concentration (Figure 4.3).

ATMOSPHERIC DEPOSITION

Data on nitrate loads from atmospheric deposition were also needed to estimate nitrate leaching to groundwaters, but are not normally included within losses from agriculture in the NEAP-N leaching model. The dataset is based on spatial interpolation of monitoring data then input to the MAGPIE soil leaching model. These data were then input into the NEAP-N model. The methodology used for calculating nitrate from atmospheric deposition was the same as that used in the 2008 review.

Step 4 - Combining the evidence from monitoring and modelling

A GIS-based risk model with a weighted scoring system was used to determine potential groundwater NVZs in 2012 by overlaying the results from Step 2) with those from Step 3). For every 1 km square, the risk model assesses the confidence with which it could be determined that the nitrate concentration in the groundwater exceeded, or is likely to exceed, 50 mg/l and that the source of nitrate includes agriculture. This largely reproduced the results from the model used in the 2008 review. The risk model combines lines of evidence data plus local evidence from Environment Agency specialists. Areas of high risk are shown as a potential groundwater NVZ.

The risk model consists of eight components (Table 4.1). Three components describe pressures and are mainly derived from modelled inputs of nitrate data where the higher the pressure, the greater the risk that groundwater nitrate concentrations will exceed 50 mg NO_3 l^{-1}. The other five components describe the observed nitrate and draw upon a combination of water quality monitoring data and local Environment Agency evidence.

Four of the components were derived using national datasets; nitrate monitoring data were interpolated to produce national maps of current (2010) and future (2027) groundwater nitrate concentration and agricultural and urban nitrate leaching were estimated from land use. The other four components were derived using the professional judgement of local area Agency staff.

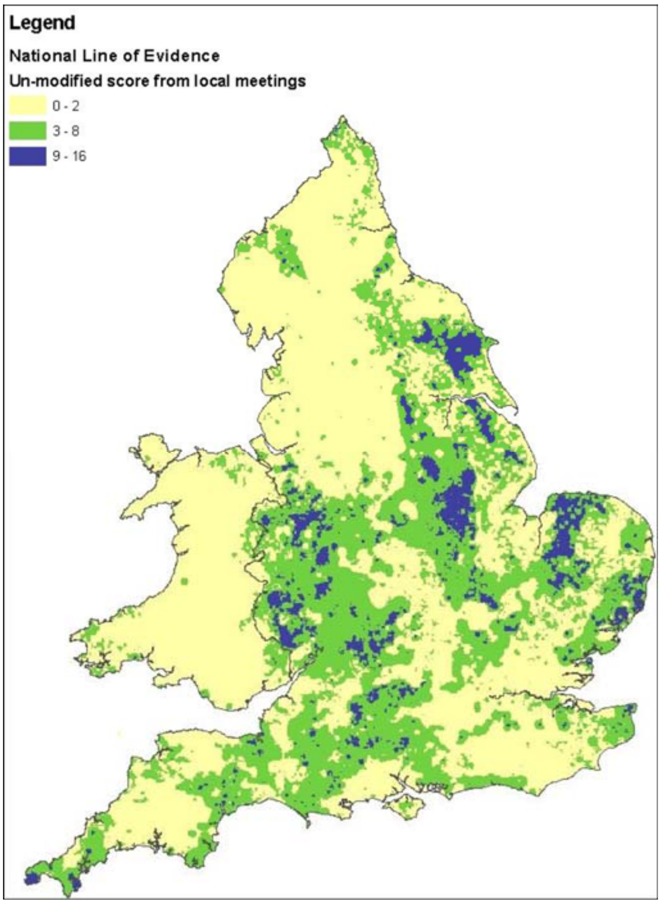
Weightings were designed to give the greatest importance to groundwater monitoring data and secondary importance to agricultural nitrate loss data derived from the NEAP-N model. The model had the flexibility built-in to incorporate the understanding of local Environment Agency hydrogeologists but scores were set using national lines of evidence. Each component was given a score (positive scores increase the overall risk and negative scores decrease the overall risk) and weightings were applied to these scores. The weighted scores were then combined to yield an overall risk score indicating the strength of evidence that the groundwater was polluted by nitrate from agricultural sources.

For a situation where observed nitrate is unrealistically low and <50 mg NO_3 l^{-1} (observed risk 4, Table 4.1) there are three possible reasons:

- nitrate pollution has not passed through the unsaturated zone; it is on its way but has not yet been detected by monitoring;
- deep abstractions sample older, cleaner water that is not representative of current nitrate pressure; due to the depth of monitoring the data are unrepresentative;
- uncertainty in predicted nitrate values caused either by short duration of monitoring or a significant variation in the dataset.

Table 4.1 Components of the GIS risk model (from Environment Agency, 2012)

Risk	**Factors**
Pressure	1. Agricultural nitrate leaching from the NEAP-N model (National) Score: <25= 0, 25-50 = 1, >50 = 2, Weighting = 3
	2. Urban nitrate leaching from the Lerner model (National) Score: <25= 0, 25-50 = 1, >50 = 2, Weighting = -2
	3. Denitrification or mixing lower the nitrate input from agriculture to groundwater (Area) Score: good evidence = 2, some evidence = 1, no evidence = 0, Weighting = -1
Observed	1. Kriged current groundwater nitrate concentration (National) Score: <25= 0, 25-50 = 1, >50 = 2, Weighting = 3
	2. Kriged future (2027) groundwater nitrate concentration (National) Score: <25= 0, 25-50 = 1, >50 = 2, Weighting = 2
	3. Monitored nitrate is representative of point source pollution (Area) Score: good evidence = 2, some evidence = 1, no evidence = 0, Weighting = -5
	4. Monitored nitrate is unrepresentative of real groundwater nitrate concentrations (Area) Score: yes good evidence = 2, yes some evidence = 1, no evidence = 0, no some evidence = -1, no good evidence = -2, Weighting = 3
	5. Surface water – groundwater interactions identify that surface water quality is a reasonable indicator of groundwater quality (Area) Score: good evidence = 2, some evidence = 1, no evidence = 0, Weighting = 1



Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 4.4 **Risk score map showing national lines of evidence prior to local Environment Agency workshops (from Environment Agency, 2012)**

The evidence can include:

- a nearby water company source has been abandoned due to high nitrate;
- an unsaturated zone of >30 m thickness is delaying nitrate measurement;
- an aquifer that is layered is layered or sampling is at depth.

The scores for the pressure risk components are summed to provide an intermediate positive pressure risk score. Since the urban loading score is associated with a negative weight (-2), where urban loading outweighs the agricultural load, the intermediate pressure score could be negative. The methodology indicates that the pressure risk score has to be set to zero as a minimum and therefore pressure risk scores have been set to zero if negative pressures were found. The scores for observed risk components are also summed to provide an intermediate positive observed risk score.

If the risk that groundwater nitrate concentration is exceeding 50 mg NO_3 l^{-1} and agriculture is the source, the score will be higher than 8. This will lead to potential groundwater NVZ designations. A medium score ranges from 8 to 3 and shows that either the monitoring or modelling assessments exceeded or were likely to exceed 50 mg NO_3 l^{-1}. These areas are likely to be included in potential designation areas around high risk areas dependent on the hydrogeological setting. A low score is lower than 3 where both the monitoring and modelling assessments show that nitrate concentrations were not likely to exceed 50 mg NO_3 l^{-1}. These are generally not considered for designation and any low risk areas that are repeatedly shown to be so may be considered for removal from designation.

All areas scoring higher than 8 and currently not in NVZ areas have been highlighted and presented at the workshops to understand local factors that could affect the final score for these areas. The final risk score map for England and Wales is presented in Figure 4.4.

Step 5 – Ground-truthing the draft designations

Regional workshops were held to allow local EA staff to comment on the preliminary results of the review. The workshops focussed on where there was less certainty in the results and were attended by observers from external stakeholder groups.

Step 6 - Identifying land draining to polluted waters

Land that is directly above a polluted groundwater does not necessarily drain into it. With professional judgement, the following physical and hydrogeological boundaries that allow major aquifers to be split into groundwater bodies and delineate the catchments of the polluted groundwaters have been used including:

- solid or drift geology (1:50,000): geological boundaries such as faults and geological contacts; high permeability drift outcrops; low permeability drift outcrops;
- risk of solution features (1:50,000);
- surface water outflow features; surface water catchment boundaries; rivers, acting as groundwater catchment divides; lakes; coastlines;
- groundwater level contours and flow lines;
- urban areas.

Before making a final determination of the land draining to a polluted groundwater, further checks were undertaken for those waters which had been identified by limited monitoring data to confirm that:

- the monitoring point data that were exhibiting high nitrate concentrations were robust (data period and representativeness);
- the land draining to monitoring points had an agricultural loading.

These checks were made to prevent any unsupportable designations being made as a result of the greater weight given by the risk model to monitoring data. If the land failed either of these checks it was not considered further for designation as an NVZ during this cycle.

Workshops were held across England and Wales with Environment Agency groundwater specialists to understand factors that could affect the final risk scores. All potentially new NVZ areas were reviewed. The following questions were raised during the meetings to help understand if any local conditions might impact on the final scores.

- Is the monitoring point location correctly recorded? Is it representing the correct groundwater body? Is the monitoring point representative of water quality?
- Are there any issues with the land use characterisation?
- Has the weighting methodology been modified from the initial assessment
- Yes, which lines of evidence have been modified?
- Are there any issues caused by the underlying geology or drift geology?
- Has the recharge area been correctly delineated? Will these changes result in a change in designation? Will this be an increase or decrease in the size of the area to be designated?
- Is there any significant point source influence?
- Is there any evidence of denitrification?
- Is there any inconsistency between the kriging results and the loading from land use? Is there any inconsistency between the kriging results and the overall score?
- Has the recharge area been correctly delineated?
- Will these changes result in a change in designation? If the monitoring point cannot be used to represent groundwater quality, can surface water be used as an alternative?

4.2 DESIGNATED NVZ AREAS

The total area identified as draining to polluted groundwater was approximately is 32,858 km^2 (32,599 km^2 in England and 259 km^2 in Wales) compared to 32047 km^2 identified in the 2008 review (31821 km^2 in England and 226 km^2 in Wales). The new area that could be designated for groundwater is 810.4 km^2 (777.7 for England and 32.7 km^2 for Wales). The total new area identified for designation was is 2,150 km2 (2,110 km^2 in England and 40 km^2 in Wales). This represented a 1.6% increase in the area designated in England and a 0.2% increase in the area designated in Wales.

There were also some areas of existing NVZ that previously met the criteria for a polluted water but passed the 2012 review criteria. The total area concerned was approximately 18,402 km^2. A total area of approximately 5550 km2 (all in England) was removed from designation based on improved evidence, showing good and sustained water quality and a low risk of future deterioration. A map of the proposed groundwater NVZs is shown in Figure 4.5.

4.3 APPEALS PROCESS

The First-tier Tribunal (Environment) was set up in 2010 but only in 2013 has it handled a significant work-load. Previously appeals were heard by panels appointed by the Secretary of State. Appeals were heard during 2013, and according to the Tribunal, there were 455 appeals in all, with 38% (172) allowed, and 13% (57) part-allowed. A small number (11) were dealt with by a Consent Order. 31% (142) appeals were dismissed, and the remainder were either struck out or withdrawn. A number of different appeals may relate to the same NVZ. The change to the appeals process from panels to tribunals resulted in a larger percentage being successful. This was due to a greater emphasis on proving that water in a particular location was polluted. For groundwater this was primarily due to the distribution of monitoring points in areas of complex geology.

Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 4.5 2008 and new proposed groundwater NVZ areas for 2012 (from Environment Agency, 2012)

5 The Water Framework Directive

5.1 INTRODUCTION

The European Water Framework Directive (WFD) (2000/60/EC) which came in to force in 2000 provides a framework for the protection of the water environment including groundwater. It sets out a series of environmental objectives that must be achieved by implementing programmes of measures. The achievement of the objectives for groundwater means that groundwater bodies should have achieved good status by the end of 2015. It is recognised that there are diverse hydrogeological conditions which will require different specific solutions and that this diversity needs to be taken into account when planning and executing the programmes of measures. Additionally time extensions, beyond the 2015 deadline, are possible, up to 2027, provided that a justification can be provided. This includes where natural conditions, such as an unsaturated zone lag time, do not allow the deadline to be met.

The WFD sets out a stepwise process which must be followed and which comprises:

- delineation of groundwater bodies and groups of groundwater bodies (management units);
- characterisation of groundwater bodies including the hydro(geo)logical and baseline conditions, the (abstraction and pollutant) pressures, evidence of impact etc.;
- an evaluation of the risk of failing to meet the relevant environmental objectives for each groundwater body;
- establishment of groundwater monitoring programmes;
- determination of groundwater body status (chemical and quantitative) and pollutant trends;
- identification of programmes of measures to restore groundwater bodies to good status, reverse upward trends in pollutant concentrations and prevent deterioration of bodies currently at good status;
- publication of river basin management plans every six years that set out the strategy/ies for implementing programmes of measures and achieving environmental measures in accordance with the WFD.

The WFD and its daughter directive the Groundwater Directive (GWD) (2006/118/EC) recognises that nitrate is one of the most widespread groundwater pollutants and so requires an assessment of the risks and impact of nitrate pollution to be made and appropriate measures implemented. Whereas the Nitrates Directive focuses on delivering measures to address agricultural sources of nitrate the WFD requires measures for <u>all</u> sources of nitrate. There are other differences between the directives, e.g., dates for achieving objectives, different standards/thresholds and different reporting cycles. However the measures implemented under the Nitrates Directive, e.g. NVZs will contribute significantly to achieving WFD objectives.

To protect groundwater, the WFD, through the GWD, establishes a default groundwater quality standard for nitrate of 50 mg NO_3 l^{-1}. However the WFD is a risk–based directive and where it is considered that this value would not adequately protect groundwater and/or associated receptors, a lower value (threshold value) must be set. This is the case for protection of drinking water (37.5 mg/l) and groundwater-dependent terrestrial ecosystems (range: 4 – 26 mg/l depending on ecosystem/wetland type).

5.2 ENVIRONMENTAL OBJECTIVES

The WFD contains a number of specific environmental objectives for groundwater. These are to:

- prevent or limit inputs of pollutants to groundwater;
- prevent deterioration in chemical and/or quantitative status;
- restore bodies to good chemical status (from poor status);

- reverse environmentally significant and sustained upward trends in pollutant concentrations;
- achieve Protected Area objectives. These are the specific objectives for; 1) Drinking Water Protected Areas (DrWPA) and; 2) Nitrate Vulnerable Zones (NVZs).

5.3 2009 WFD NITRATE RESULTS

An assessment of groundwater is made at least once every six years for the WFD. Groundwater monitoring data are used to assess groundwater body status and identify pollutant trends. For status assessment the data for the previous six years are used and for trends the previous ten years.

Chemical status assessment comprises the consideration of five tests which each consider one or more of the criteria which all must be met to achieve good status. The criteria are:

1. The chemical composition of the groundwater body is such that concentrations of pollutants: a). do not exhibit the effects of saline or other intrusions; b) do not exceed relevant quality standards; c) are not such as would result in failure to achieve the environmental (and status) objectives for associated surface waters; d) do not cause significant damage to terrestrial ecosystems which depend directly on the groundwater body;
2. Changes in specific electrical conductivity are not indicative of saline or other intrusion into the groundwater body.

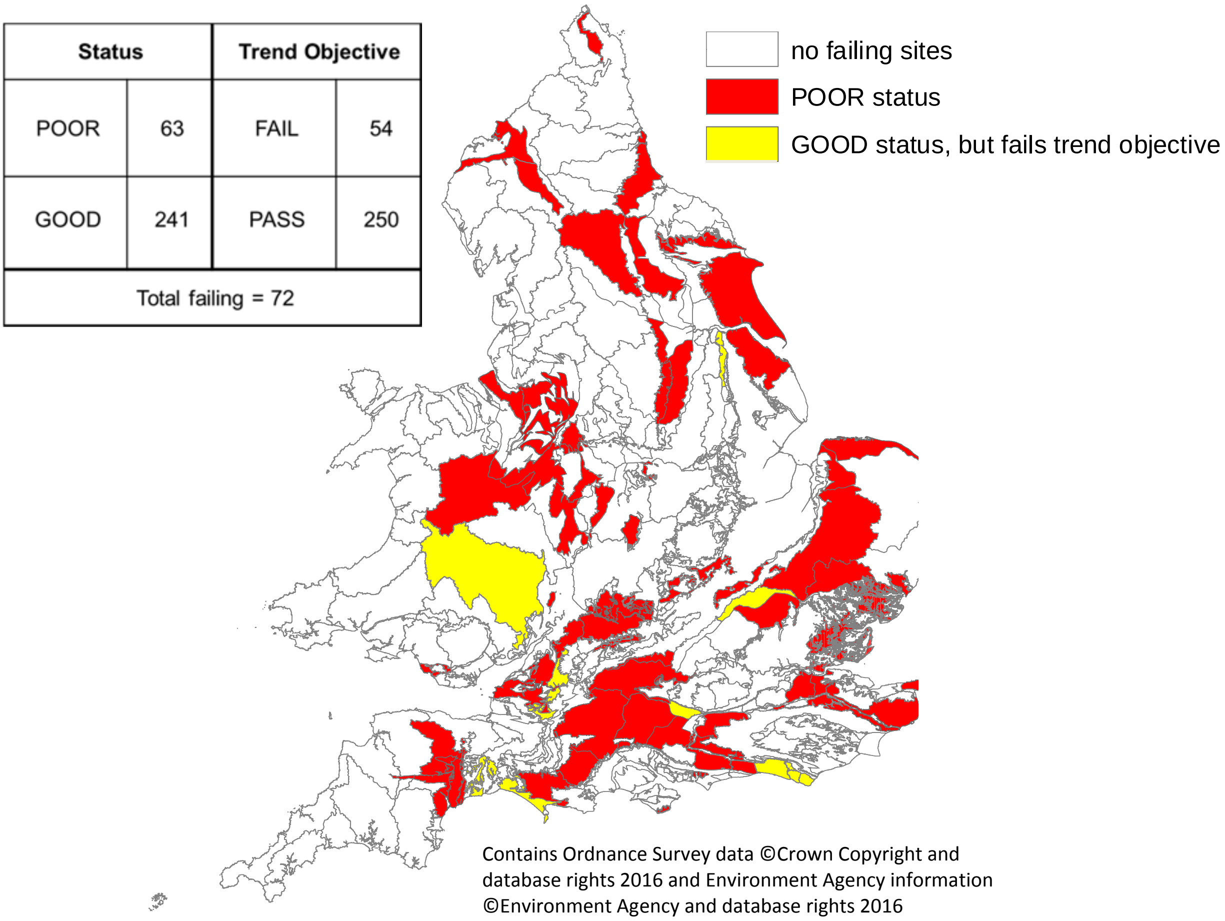
Trend assessment comprises, in the first instance, the identification of any significant and sustained upward trend in concentrations of pollutants, groups of pollutants or indicators of pollution in groundwater bodies. Where an ‘environmentally significant’ upward trend is identified, i.e. one that would lead to a future failure of one or more of the criteria for good status, then this must be reversed through the programmes of measures. Subsequent trend assessment (in future river basin planning cycles) should then seek to demonstrate trend reversal.

The first evaluation of status and trends was carried out in 2009 and reported in the River Basin Management Plans. The next evaluation was in 2015. A map showing the groundwater bodies that were at poor status as a result of nitrate pollution and those with upward trends is presented in in Figure 5.1.

In total 63 (21%) of the 304 groundwater bodies across England and Wales were at poor (chemical) status due to nitrate pollution, principally derived from agricultural sources. A total of 54 bodies (18%) failed the trend objective.

A review of the area of land designated as NVZ in 2006 and the groundwater bodies that have failed their good status and trend objectives due to nitrate (ENTEC, 2009) indicated that there was good correlation between the two. Spatial analysis of the differences, where they occurred, showed that these could be accounted for by: a) the NVZ methodology considering all areas, whereas status assessment excluded unproductive strata as these were not designated as groundwater bodies; b) NVZs being based on groundwater data for exceeding the 10 years used for the WFD and; c) difference in delineation method – NVZs were based on field bodies whereas groundwater bodies are based on catchment/hydrogeological boundaries.

A site by site comparison between the WFD and NVZ assessments showed that the WFD dataset identified more exceedances of the relevant threshold value (standard) due to a lower value used in the WFD, 42 mg/l compared to 50 mg NO_3 l^{-1} for NVZ delineation.



Status		Trend Objective	
POOR	63	FAIL	54
GOOD	241	PASS	250
Total failing = 72			

Contains Ordnance Survey data ©Crown Copyright and database rights 2016 and Environment Agency information ©Environment Agency and database rights 2016

Figure 5.1 Groundwater bodies at poor status and/or with upward trends in nitrate concentrations

6 Other nitrate legacy modelling

6.1 NITRATE CONCENTRATIONS IN THE THAMES BASIN

Howden et al. (2010; 2011) related the historical measured nitrate concentrations in the Thames to nitrate inputs in the catchment.

6.1.1 Thames time series

Figure 6.1 shows the continuous monthly record of average nitrate concentrations for the Thames at Hampton for 140 years starting in 1868. Nitrate concentrations rose during World War II (WWII) and then stabilized at almost double their previous level (~2 mg NO_3 l^{-1} 1868–1940, ~4 mg NO_3 l^{-1} 1945–1970). There was a further step change in the early 1970s, when the average concentrations jumped from around 4 mg NO_3 l^{-1} to almost 8 mg NO_3 l^{-1} and, in common with the WWII increase, these concentrations have remained stubbornly high despite continent-wide interventions to decrease catchment nitrogen inputs since the early 1980s (EU Nitrates Directive 91/676).

Such shifts in concentration may be driven by changes in the climate, flow regime, land use or population. However they are not explained by changes in monthly precipitation, average temperature or abrupt changes in population in the Thames basin.

6.1.2 Nitrate input

Howden (2010) considered that land use change is the only basin-wide driver that can account for the shifts in concentration shown in Figure 6.1. Figure 6.2 shows their estimates of the fraction of the Thames Basin under arable crops and the total modelled nitrate input to the catchment system. By far the most sudden changes were during WWII and in the mid-1960s; these are reflected in the nitrate record shortly after.

Differences in the relative magnitudes of the two step changes were explained as follows. The extensive ploughing of permanent grassland in WWII was achieved through mechanization, but there is no evidence of increased fertilizer application). In contrast in the 1960s, a smaller area of grassland was converted to arable but this was accompanied by increases in the grant-aided land drainage (Green, 1979) and considerable intensification, especially a substantial increase in fertilizer application: annual fertilizer use in the UK was 485 kt N in 1960, increasing to 921 kt N by 1970 and peaking at 1588 kt N in 1984 (Green, 1979).

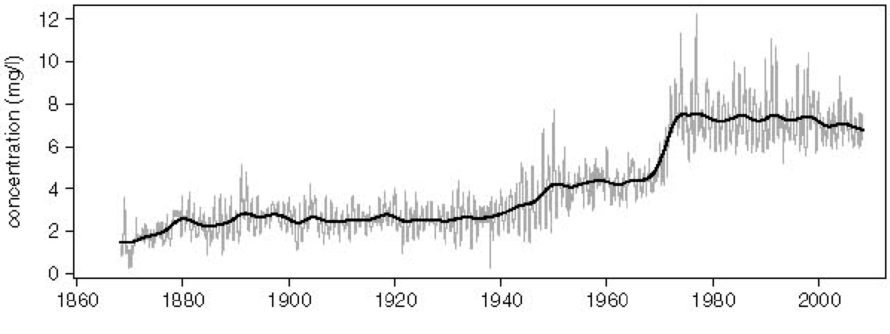


Figure 6.1 Time series plot of nitrate concentrations in the River Thames at Hampton (from Howden et al., 2010)

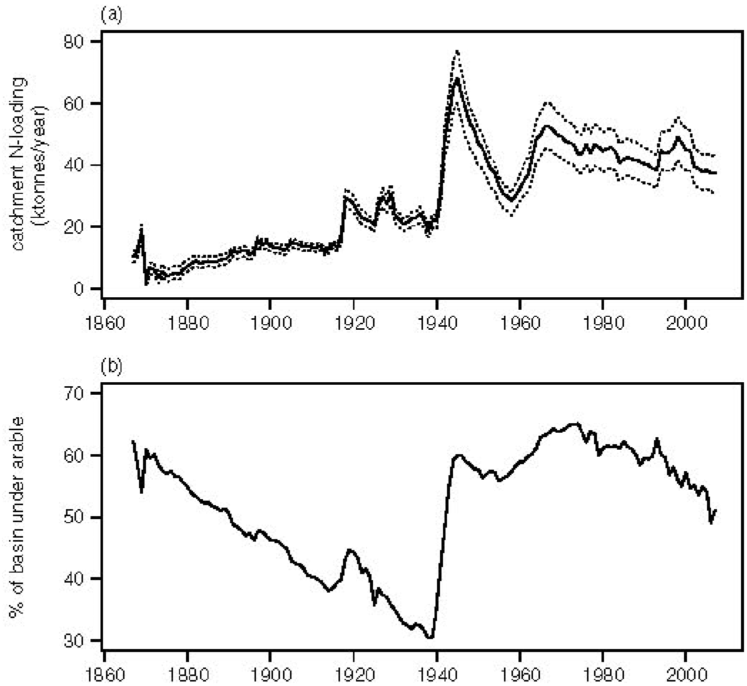


Figure 6.2 Land use and nitrate loading in the Thames Basin 1868–2008: a) estimated nitrate loading using the structured model approach (Worrall and Burt, 1999). Mean loading estimate shown as solid line enclosed between dotted lines representing the 5th and 95th estimate percentiles; b) percentage of the Thames Basin under arable land use 1868–2008 (from Howden et al., 2010)

The 1960s shift in concentration was more rapid because increased drainage reduced catchment residence time and increased quantities of inorganic fertilizers were immediately available for leaching. Reversions from arable to grassland are not reflected in the nitrate record and concentrations remain obstinately high after each increase. Since the early 1980s, attempts to manage high nitrate concentrations have focused on control of nitrogen fertilizer inputs. While fertilizer input is certainly a contributing factor to rising nitrate concentrations, the stepped increases are driven by longer-term processes following land use change: release of soil N and groundwater transport both operate on at least decadal timescales.

Howden et al. (2011) collected data for calendar years from 1868 onward from the following sources:

- landuse from parish records and interpolated from national data from 1988 onwards;
- N loading data from the UK literature;
- N loading from sewage from population data from census returns;
- riverflow mean daily flows from Kingston.

Landuse combined with N loading were combined to provide the elements of the loading shown in Figure 6.3.

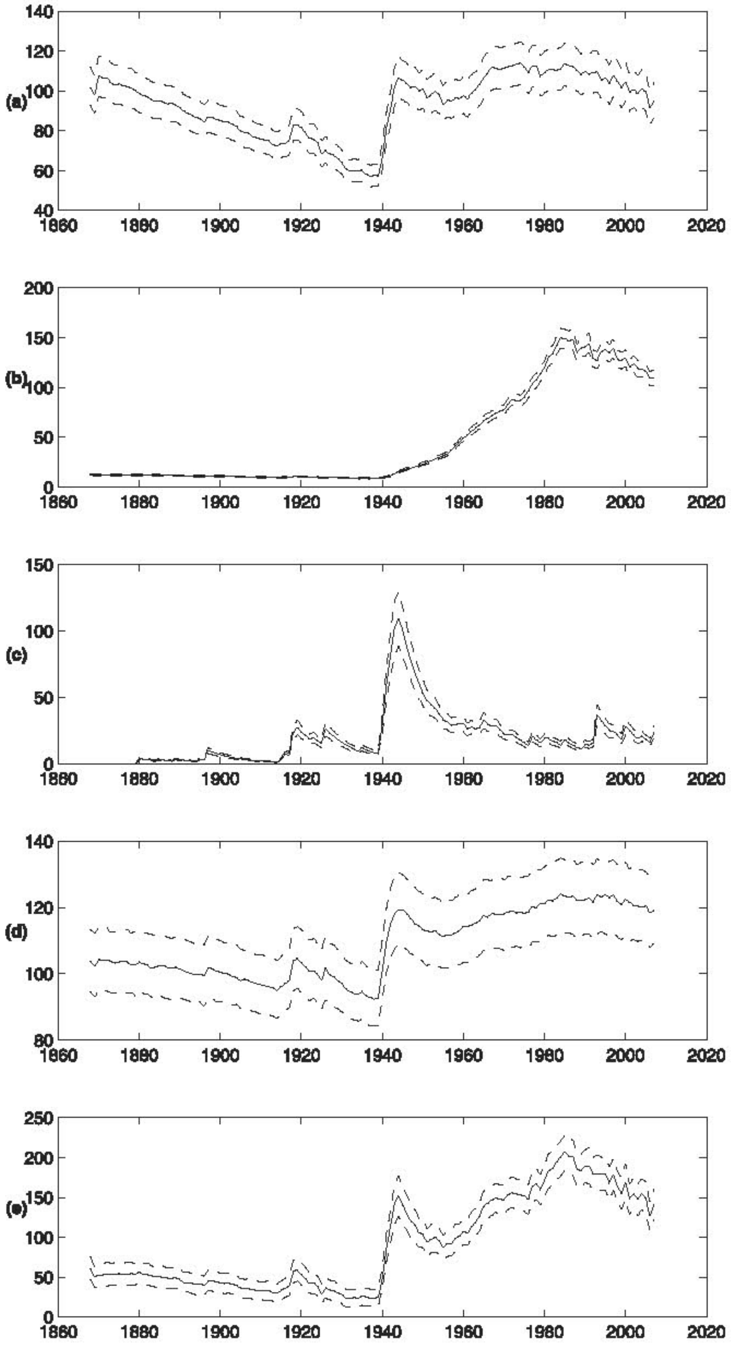


Figure 6.3 Estimated loading components: a) animal inputs; b) fertilizer inputs; c) inputs from enhanced mineralization because of ploughing of permanent grassland; d) losses from uptake from crops and grasslands; and e) estimated nitrogen available for leaching. Dashed lines 5th and 95th percentiles (from Howden et al., 2011)

6.1.3 Transport model

Howden et al. (2010) used a simple two reservoir transfer function to route the loading through a rapid runoff and a slow groundwater pathway. All processes were lumped together over the whole catchment to the lack of spatial information to define inputs at a sub-basin scale over such a long period. The split between runoff and groundwater was assumed to be similar to the baseflow index of the Thames at Kingston (BFI = 0.65) but this was adjusted during model calibration to approximately 0.55. A 1-D advection dispersion equation was used to attenuate nitrate loading for both the fast and slow pathways.

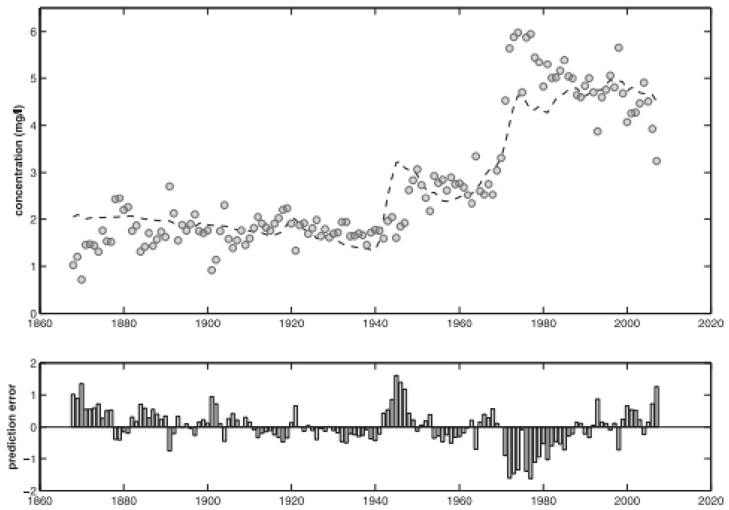


Figure 6.4 Median predictions from the 12,000 top-performing parameter sets predicting nitrate concentrations in the Thames, from 1868 to 2008 (Howden et al., 2011).

6.1.4 Results

Figure 6.4 shows observed and modelled nitrate concentrations in the Thames at Hampton. The model appears to replicate the observed increases in concentrations reasonably well. A 30 year lag in the groundwater component of the model was required in the calibration of the model. Consequently it is argued that the step increases in nitrate concentrations in the Thames in the 1950s and 1970s are the result of intensification of agriculture during the 1920s and 1940s (the “Dig for Victory” campaign). Using a number of input function scenarios, it is shown that changes in basin-wide land use would take decades to be effective. Howden et al. (2011) also argue that an accurate input function is more important than a complex flow model, as demonstrated in the case of the Thames.

6.2 OTHER APPROACHES TO PREDICTING NITRATE CONCENTRATIONS IN GROUNDWATER

In addition to the work discussed above, numerous other approaches to numerical modelling of legacy nitrate have been adopted in the UK and internationally. Examples from both the peer-reviewed and grey literature are discussed herein. Table 6.1 summarises this work.

6.2.1 Chesapeake Bay, United States

Sanford and Pope (2013) undertook a study attempting to quantify the role of groundwater in delays in improvements in nitrate concentrations in Chesapeake Bay, United States. A 3D steady state groundwater flow model was developed in MODFLOW and MODPATH was used to calculate the travel time for groundwater recharge in each cell to reach the river or coast. An input function was derived for each model cell using fertilizer and manure histories for the catchment. This input function was dissolved in an amount of recharge calculated using a water-balance regression approach, and then transferred to the river based on the travel time. Riparian and groundwater denitrification were included as zero-order model terms, but in the final model calibration groundwater denitrification was very small. The model was able to simulate observed trends in groundwater and stream nitrate concentrations, and forward predictions were made using a number of nitrate loading scenarios.

6.2.2 Upper Dyle Basin, Belgium

César et al. (2014) undertook simulations on nitrate concentrations at a regional scale in the Upper Dyle basin, Belgium. A similar water balance model was used to derive spatially distributed steady-state recharge values for the aquifer. This was linked to a steady-state numerical groundwater flow model and transient transport model with no dispersion. Simplified nitrate input functions are used based on cultivation and land use patterns. Very limited data were available for calibration so it is difficult to assess the success of the modelling effort. It is clear, however, that the input function dominates the modelled trends.

6.2.3 UK Water Industry Approaches

In addition to the approaches reported in the peer-reviewed literature, a substantial body of work on modelling of nitrate in groundwater has been undertaken by the UK Water Industry. Whilst peer-reviewed studies generally consider catchment-scale impacts of nitrate loadings on rivers, water industry studies focus on impacts on specific public water supply boreholes. Continued rises in groundwater nitrate concentrations to over the drinking water standard have resulted in significant regulatory pressure to develop long term sustainable solutions to this problem. The high costs of nitrate treatment and blending have resulted in a focus on catchment management as a possible approach. In order to provide evidence that catchment management could improve source water quality, water companies have undertaken nitrate modelling studies to assess the potential impact of catchment mitigation options on groundwater nitrate concentrations. These studies are briefly reviewed below.

Nitrate concentrations at 8 Wessex Water chalk boreholes in the Frome, Piddle and Wey catchments were modelled by Rukin et al. (2008). Historic fertiliser inputs and observation borehole nitrate data were used to derive a nitrate input function for 1990 to 2007. Unsaturated zone travel time was derived from the infiltration rate (derived from the South Wessex Recharge Model), matrix porosity and depth to water. Using the travel time and estimates of borehole catchment areas, nitrate concentrations at abstraction points have been estimated. Seasonal variations and spikes in nitrate were modelled empirically based on observed seasonal water level changes and bypass recharge from the South Wessex recharge model respectively. Current nitrate trends are the result of leaching from the soil zone 10 – 60 years ago. Forward predictions of nitrate concentrations at public water supply abstractions have been made based on a number of different soil leaching scenarios.

A total of 44 Severn Trent Water and United Utilities public water supply borehole catchments in the Permo-Triassic Sandstone aquifer were investigated by Buss (2013). A source term of nitrate leaching into the unsaturated zone was derived from NEAP-N data interpolated with national fertilizer use data and county-scale livestock numbers in conjunction with annual recharge estimates. A lag function is then applied to the input to fit the timings of the observed borehole nitrate concentrations. In-borehole dilution and mixing from other sources of water are represented as simple percentage dilutions to match the observed concentration magnitudes. The modelling showed that typical transport times were 15 – 35 years, with the peak in nitrate inputs in the 1980s having passed, or will imminently pass through the aquifer. Predictions of future nitrate concentrations at each of the sources were used to assess the feasibility of catchment management options.

Anglian Water's North Pickenham boreholes penetrate the Chalk and have shown increases in nitrate concentrations from the start of monitoring in the 1980s to present. Concentrations now consistently exceed the drinking water standard. Price et al. (2011) linked an Environment Agency regional groundwater model with MT3D and the WAVE (Water and Agrochemicals in the soil, crop and Vadose Environment) model to estimate unsaturated zone transport and saturated zone nitrate transport to abstraction boreholes. The model was calibrated using historic nitrate concentrations at the abstraction point and land use change scenarios were undertaken to estimate potential future nitrate concentrations. This approach was extended to other supply boreholes (Price and Andersson, 2014). This included an unsaturated zone travel time based on the approach of Wang et al. (2012) where the long-term average recharge is divided by the porosity.

Table 6.1 Summary of nitrate modelling approaches

Authors	Title	Study Area	Input Function	Unsaturated Zone Transport	Saturated Zone Transport	Borehole Processes	Notes
Wang et al., 2012	Prediction of the arrival of peak nitrate concentrations at the water table at the regional scale in Great Britain	Great Britain	Simple time-variant input function based on porewater nitrate concentrations	Travel time based on river bed level model and national groundwater level contours and best estimates of unsaturated zone velocities	Nitrate loading to water table diluted based on total saturated thickness and effective porosity. Routed to rivers based on permeability and distance to river	n/a	Saturated zone processes used in WQ0223version of the model for DEFRA project
Wang et al., 2013	The nitrate time bomb: a numerical way to investigate nitrate storage and lag time in the unsaturated zone	Eden Valley, England	Simple time-variant input function based on porewater nitrate concentrations	Travel time based on catchment-scale steady state modelled groundwater levels	n/a	Uses source protection zones to dilute nitrate loading to derive nitrate concentrations at the borehole	
Howden et al., 2011	Nitrate pollution in intensively farmed regions: What are the prospects for sustaining high-quality groundwater?	Thames Basin, England	Bottom-up input function derived for the whole catchment from landuse change data, fertilizer history, census returns and literature values	Simple 2 pathway reservoir model considering fast runoff (45% of loading, no lag) and slow groundwater components (55% of loading, 30 year lag), calibrated to observed nitrate concentrations in the Thames at Hampton		n/a	
Sanford and Pope, 2013	Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality	Delmarva Peninsula, United States	Fertilizer and manure history for the catchment	Travel time based on recharge rate and effective porosity. Reasonably low due to thin unsaturated zones	Steady-state MODFLOW model used with MODPATH to derive saturated zone travel times for each grid cell. Travel times used to transfer nitrate loading the river. Denitrification in soils included	n/a	Only study to include denitrification
Cesar et al., 2014	Simulation of spatial and temporal trends in nitrate concentrations at the regional scale in the Upper Dyle basin, Belgium	Upper Dyle Basin, Belgium	Simple nitrate inputs based on cultivation and land use patterns	Travel time based on recharge rate and effective porosity	Steady-state groundwater flow model linked to transient transport model with no dispersion.	n/a	Very limited calibration data

Authors	Title	Study Area	Input Function	Unsaturated Zone Transport	Saturated Zone Transport	Borehole Processes	Notes
Rukin et al., 2008	Modelling Nitrate Concentrations with Variations in Time	Frome, Piddle and Wey catchments, Dorset and Hampshire	Historic fertilizer inputs and observed groundwater nitrate concentrations	Travel time based on recharge rate (EA recharge model) and effective porosity	Linked fertilizer inputs with borehole catchment areas to derive borehole concentrations. Seasonal variations and spikes in concentration represented empirically with water level variations and bypass recharge respectively	n/a	
Buss, 2013	Is catchment management feasible for improving quality of public groundwater supplies?	Permo-Triassic sandstone catchments in northwest England and the West Midlands	NEAP-N data interpolated with national fertilizer use data and county livestock numbers	Input function diluted in average annual recharge		Nitrate inputs lagged to match observed borehole nitrate timings. Dilution and mixing from other sources of water represented as simple percentage dilutions	
Price et al., 2011	Nitrate pollution in groundwater: a modelled approach to catchment management	North Pickenham, Norfolk	Historic fertilizer inputs and observed groundwater nitrate concentrations	WAVE model	EA regional groundwater model linked to MT3D	n/a	

7 Application of the BGS unsaturated zone model to inform NVZ designation

7.1 APPROACH

A key question in the mitigation of groundwater nitrate pollution is the time taken for N concentrations to peak and then stabilise at an acceptable, lower level, in response to existing and future control measures. Without evidence of how quickly systems may recover, it is difficult to evaluate the effectiveness of existing measures or decide whether additional measures are necessary. These questions are most important for soils, for aquifers and for lakes, systems that respond less quickly to changes in loading. Groundwater and lake catchment models can provide first-order estimates of likely response times, but can be difficult and costly to set up for many different situations. It is also necessary for these concepts to be communicated in a convincing way to affected groups.

The approach in the 2012 NVZ review incorporates some consideration of the issues of time of travel of nitrate through the unsaturated subsurface. Some allowance for a thick unsaturated zone or aquifer layering is made in the risk components set out in Table 4.1 and the text describing “observed risk 4”. However this does not fully account for the estimated wide range of time of travel and there is no numerical evidence to quantify travel to the water table and emergence of pollutant both into the groundwater and if it finally discharges from groundwater for example as baseflow into a supported surface water feature.

The method also lacks a numerical estimation of the attenuation of nitrate due to denitrification within the unsaturated or saturated zones or for future decreases in nitrate loading due to control measures. Again, this aspect relies on the expert knowledge and input of local Agency staff. They will have local knowledge but there is no formal guidance on this aspect.

The overall relationship between observed concentrations and modelled risks is summarised in Table 7.1. This highlights situations where the low modelled risk cannot account for high nitrate concentrations in water and conversely where the risk is high but the observed concentrations are low. These areas are shaded in the table.

There are a number of possible scenarios which could explain these discrepancies:

- current or recent applied nitrate is high but has not yet reached the water table due to a thick unsaturated zone;
- current or recent applied nitrate is low but nitrate arriving at the water table reflects earlier practices due to a thick unsaturated zone;
- the risk model does not adequately allow for impermeable layering in the unsaturated zone;
- the risk model does not adequately allow for denitrification in the unsaturated zone.

In recent years a number of alternative models have been published in the open literature that attempt to improve understanding of the historic burden of nitrate from the land and the discharge of that nitrate to surface water features where this occurs and to do this at catchment or river basin scales or greater.

Table 7.1 Risk assessment matrix

		Modelled risk		
		High	Medium	Low
Observed concentrations	High	Designate	▨	▨
	Medium	▨	▨	▨
	Low	▨	▨	No action

7.2 PROPOSED PHASE 2 PROJECT ACTIVITIES

7.2.1 Unsaturated zone travel time

The BGS NTB model could be used to identify areas where unsaturated zone retention of nitrate is likely to be significant and to provide an estimate of the delays. There are a number of enhancements which could be made to the model to improve this process:

1. Building a process-based model to improve travel time estimation. In the NTB model only the Chalk, Permo-Triassic Sandstones, the Lincolnshire Limestone and the Oxford Clay have measured unsaturated travel times; other values were attributed using professional judgement. A process-based model may provide better values, but this will require sufficient parameters for model calibration. A suitable national-scale recharge model has recently been developed.
2. Attribution of the BGS 250k scale geological mapping, instead of the 625k scale, with travel times and aquifer properties. This should improve estimations, particularly for layered aquifers, such as the Jurassic limestones and the Coal Measures which are mapped as one unit at 625k. Aquifer properties would be required for a process-based model.

7.2.2 Nitrate loading

In the 2012 review, the loading data used were for the most recent agricultural practice for which data were available (based on the returns of the agricultural census for 2010). This approach is therefore unable to take account of past (or indeed future predicted) changes in farming practice and hence N-leaching.

There have been a number of methods used to estimate nitrate loading at the base of the soil:

- modelled concentrations extrapolated from returns from the agricultural census. The NEAP-N model provides estimates of N leaching from 1980 onwards;
- estimated concentrations from arable land from the literature. This approach was used in the BGS NTB model and estimated leaching from 1925 onwards;
- using returns from the agricultural census on a catchment scale. This was used by Howden et al. (2011) for the Thames basin.

7.2.3 Nitrate attenuation

Denitrification remains difficult to quantify in UK aquifers in general (Lawrence and Foster, 1986; Rivett et al., 2007) and estimates during recharge through the unsaturated zone vary from negligible to perhaps 50% (Cannavo et al., 2004; Deurer et al., 2008; Kinniburgh et al., 1999). The BGS NTB model has an attenuation factor but this is not used in the current version for nitrate. The impact of nitrate attenuation could be investigated by running a series of simulations using a range of possible values.

7.2.4 Catchment scale comparisons

The NTB model can be used in conjunction with simple saturated flow models and estimates of rapid surface runoff. This could generate results which can be used to compare with other approaches to modelling nitrate inputs to surface water from groundwater, e.g. the Howden work on the Thames.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

ADAS. 2003. Production and use of nitrogen fertilisers. *ADAS UK Ltd Report for Defra Project NT2601* http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=11771#RelatedDocuments.

ADAS. 2011. Economics report for NIT18 NVZ action programme impact assessment. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82410/20111220nitrates-directive-consult-evid3.pdf.

Addiscott, T M. 2005. *Nitrate, agriculture and the environment*. (Wallingford: CAB International.)

Addiscott, T M, Whitmore, A P, and Powlson, D S. 1991. *Farming, fertilizers and the nitrate problem*. (Wallingford: CAB International.)

Allen, D J, Brewerton, L J, Coleby, L M, Gibbs, B R, Lewis, M A, MacDonald, A M, Wagstaff, S J, and Williams, A T. 1997. The physical properties of major aquifers in England and Wales. *British Geological Survey Technical Report WD/97/34, Environment Agency R&D Publication 8. British Geological Survey Technical Report WD/97/34, Environment Agency R&D Publication 8.*

Bloomfield, J, Brewerton, L, and Allen, D. 1995. Regional trends in matrix porosity and dry density of the Chalk of England. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 28, S131-S142.

Buss, S R. 2013. Is catchment management feasible for improving quality of public groundwater supplies? . *33rd Annual Groundwater Conference, IAH (Irish Group)*, Tullamore, Ireland, International Association of Hydrogeologists.

Cannavo, P, Richaume, A, and Lafolie, F. 2004. Fate of nitrogen and carbon in the vadose zone: in situ and laboratory measurements of seasonal variations in aerobic respiratory and denitrifying activities. *Soil Biology and Biochemistry*, Vol. 36, 463-478.

César, E, Wildemeersch, S, Orban, P, Carrière, S, Brouyère, S, and Dassargues, A. 2014. Simulation of spatial and temporal trends in nitrate concentrations at the regional scale in the Upper Dyle basin, Belgium. *Hydrogeology Journal*, Vol. 22, 1087-1100.

Defra. 2002. Description of the methodology applied by the Secretary of State in identifying additional Nitrate Vulnerable Zones in England (2002).

Defra. 2008. Description of the methodology applied in identifying waters and designating Nitrates Vulnerable Zones in England (2008) http://webarchive.nationalarchives.gov.uk/20090306103114/defra.gov.uk/environment/water/quality/nitrate/.

Defra. 2010. Summary of the decisions made by the NVZ Appeals Panel (as at 7th April 2010). http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/documents/appeals-table.pdf.

Department of the Environment, MAFF, and Welsh Office. 1993. Methodology for identifying sensitive areas (Urban Wastewater Treatment Directive) and methodology for designating vulnerable zones (Nitrate Directive) in England and Wales. *Consultation paper*.

Deurer, M, Von Der Heide, C, Böttcher, J, Duijnisveld, W, Weymann, D, and Well, R. 2008. The dynamics of N 2 O near the groundwater table and the transfer of N 2 O into the unsaturated zone: A case study from a sandy aquifer in Germany. *Catena*, Vol. 72, 362-373.

Ellis, J C. 1998. Test Data Facility User Guide Version 3.1. *WRc plc*.

ENTEC. 2009. Groundwater Quality Nitrate Assessment - review of NVZ and WFD assessment of nitrate in groundwater. *Report prepared for the Environment Agency (unpublished)*.

Environment Agency. 2007. Summary of methodology for identifying Nitrate Vulnerable Zones 2006. Nitrates Consultation Supporting Paper G1 – Summary of NVZ method *Report to Defra*.

Environment Agency. 2012. Method statement for nitrate vulnerable zone review - Groundwaters *Environment Agency report to Defra and Welsh Government – supporting paper for the Implementation of the Nitrates Directive 2013 – 2016*.

Foster, S S D. 1993. The Chalk aquifer - its vulnerability to pollution. 1-13 in *The Hydrogeology of the Chalk of North-West Europe*. Downing, R, Price, M, and Jones, G (editors). (Oxford: Clarendon Press.) ISBN 0198542852

Foster, S S D, Bridge, L R, Geake, A K, Lawrence, A R, and Parker, J M. 1986. The groundwater nitrate problem: a summary of research on the impact of agricultural land-use practices on groundwater quality between 1976 and 1985. *British Geological Survey Research Report*, 86/2.

Foster, S S D, and Crease, R I. 1974. Nitrate pollution of chalk ground water in east Yorkshire- a hydrogeological appraisal. *Journal of the Institute of Water Engineers*, Vol. 28, 178-194.

Foster, S S D, Cripps, A C, and Smith-Carington, A K. 1982. Nitrate leaching to groundwater. *Journal of Hydrology*, Vol. 46, 343-364.

Foster, S S D, and Young, C P. 1980. Groundwater contamination due to agricultural land-use practices in the United Kingdom. 262-282 in *Aquifer Contamination & Protection*. *Studies and Reports in Hydrogeology Series*, 30. (UNESCO-IHP.)

Geake, A K, and Foster, S S D. 1989. Sequential isotope and solute profiling in the unsaturated zone of British Chalk. *Hydrological Sciences Journal*, Vol. 34, 79-95.

Green, F H W. 1979. Field under-drainage and the hydrological cycle. 9-17 in *Man's Impact on the Hydrological Cycle in the United Kingdom*. GE, H (editor). (Norwich: GeoBooks.)

Greene, L A, and Walker, P. 1970. Nitrate pollution of Chalk waters. *Water Treatment and Examination*, Vol. 19, 169-182.

Howden, N J K, Burt, T P, Worrall, F, Mathias, S, and Whelan, M J. 2011. Nitrate pollution in intensively farmed regions: What are the prospects for sustaining high-quality groundwater? *Water Resources Research*, Vol. 47, W00L02.

Howden, N J K, Burt, T P, Worrall, F, Whelan, M J, and Bieroza, M. 2010. Nitrate concentrations and fluxes in the River Thames over 140 years (1868–2008): are increases irreversible? *Hydrological Processes*, Vol. 24, 2657-2662.

KINNIBURGH, D G, GALE, I N, GOODDY, D C, DARLING, W G, MARKS, R J, GIBBS, B R, COLEBY, L M, BIRD, M J, and WEST, J M. 1999. Denitrification in the unsaturated zones of the British Chalk and Sherwood Sandstone aquifers. *British Geological Survey Technical Report* WD/99/2.

LAKE, I R, LOVETT, A A, HISCOCK, K M, BETSON, M, FOLEY, A, SÜNNENBERG, G, EVERS, S, and FLETCHER, S. 2003. Evaluating factors influencing groundwater vulnerability to nitrate pollution: developing the potential of GIS. *Journal of Environmental Management*, Vol. 68, 315-328.

LAWRENCE, A R, and FOSTER, S S D. 1986. Denitrification in a limestone aquifer in relation to the security of low-nitrate groundwater supplies. *Journal of the Institution of Water Engineers and Scientists*, Vol. 40.

LERNER, D N. 2000. Guidelines for estimating urban loads of nitrogen to groundwater. *Defra Project Report NT 1845*.

LORD, E I, and ANTHONY, S. 2000. MAGPIE: A modelling framework for evaluating nitrate losses at national and catchment scales. *Soil Use and Management*, Vol. 16, 167-174.

LORD, E I, JOHNSON, P A, and ARCHER, J R. 1999. Nitrate sensitive areas: a study in large scale control of nitrate loss in England. *Soil Use and Management*, Vol. 15, 1-27.

MAFF. 1995. Report of the independent review panel on nitrate vulnerable zones 1995. PB 2419.

MAFF, DEPARTMENT OF THE ENVIRONMENT, and WELSH OFFICE. 1994. Designation of vulnerable zones in England and Wales under the EC Nitrate Directive (91/676). *Consulation document*, PB 1715.

MAFF, DEPARTMENT OF THE ENVIRONMENT, and WELSH OFFICE. 1995. Government response to the consultation on the designation of nitrate vulnerable zones in England and Wales. PB 2215.

MATHIAS, S A, BUTLER, A P, IRESON, A M, JACKSON, B M, MCINTYRE, N, and WHEATER, H S. 2007. Recent advances in modelling nitrate transport in the Chalk unsaturated zone. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 40, 353-359.

OAKES, D B, YOUNG, C P, and FOSTER, S S D. 1981. The effects of farming practices on groundwater quality in the United Kingdom. *Science of the Total Environment*, Vol. 21, 17-30.

PRICE, V, ANDERSSON, M, VAN WONDEREN, J, and SANDBERG, J. 2011. Nitrate pollution in groundwater: a modelled approach to catchment management. *Impacts of Land Use and Catchment Management on Groundwater*, London, International Association of Hydrogeologists.

PRICE, V M, and ANDERSSON, M A. 2014. Numerical modelling of catchment management options to manage nitrate concentrations in water abstracted from the Chalk aquifer, Cambridgeshire, UK. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. Early view.

RIVETT, M O, BUSS, S R, MORGAN, P, SMITH, J W, and BEMMENT, C D. 2008. Nitrate attenuation in groundwater: a review of biogeochemical controlling processes. *Water Research*, Vol. 42, 4215-4232.

RIVETT, M O, SMITH, J W N, BUSS, S R, and MORGAN, P. 2007. Nitrate occurrence and attenuation in the major aquifers of England and Wales. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 40, 335-352.

ROY, S, SPEED, C, BENNIE, J, SWIFT, R, and WALLACE, P. 2007. Identifying the significant factors that influence temporal and spatial trends in nitrate concentrations in the Dorset and Hampshire Basin Chalk aquifer of Southern England. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 40, 377-392.

RUKIN, N, ROY, S, and DAVISON, P. 2008. Modelling Nitrate Concentrations with Variations in Time. *UK Water Industry Research Limited* (London).

SANFORD, W E, and POPE, J P. 2013. Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality. *Environmental Science & Technology*, Vol. 47, 13330-13338.

SMITH, D B, WEARN, P L, HICHARDS, H J, and ROWE, P C. 1970. Water movement in the unsaturated zone of high and low permeability strata by measuring natural tritium. *IAEA Symposium on Isotope Hydrology*, Vienna, 73-87.

SMITH, J T, CLARKE, R T, and BOWES, M J. 2010. Are groundwater nitrate concentrations reaching a turning point in some chalk aquifers? *Science of the Total Environment*, Vol. 408, 4722-4732.

STUART, M E. 2005. Development of nitrate profiles database. *British Geological Survey Internal Report*, IR/05/058.

STUART, M E, CHILTON, P J, KINNIBURGH, D G, and COOPER, D M. 2007. Screening for long-term trends in groundwater nitrate monitoring data. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 40, 361-376.

WANG, J L, and YANG, Y S. 2008. An approach to catchment-scale groundwater nitrate risk assessment from diffuse agricultural sources: a case study in the Upper Bann, Northern Ireland. *Hydrological Processes*, Vol. 22, 4274-4286.

WANG, L, BUTCHER, A S, STUART, M E, GOODDY, D C, and BLOOMFIELD, J P. 2013. The nitrate time bomb: a numerical way to investigate nitrate storage and lag time in the unsaturated zone. *Environmental Geochemistry and Health*, Vol. 35, 667-681.

WANG, L, MANSOUR, M, and A., H. 2010. Description of the GIS based regional groundwater flow model. *British Geological Survey Internal Report*, IR/10/070.

WANG, L, STUART, M E, BLOOMFIELD, J P, BUTCHER, A S, GOODDY, D C, MCKENZIE, A A, LEWIS, M A, and WILLIAMS, A T. 2012. Prediction of the arrival of peak nitrate concentrations at the water table at the regional scale in Great Britain. *Hydrological Processes*, Vol. 26, 226-239.

WELLINGS, S R, and BELL, J P. 1980. Movement of water and nitrate in the unsaturated zone of Upper Chalk near Winchester, Hants., England. *Journal of Hydrology*, Vol. 48, 119-136.

WHITEHEAD, P G, WILSON, E J, and BUTTERFIELD, D. 1998. A semi-distributed Integrated nitrogen model for multiple source assessment in catchments (INCA): Part I—model structure and process equations. *Science of the Total Environment*, Vol. 210, 547-558.

WORRALL, F, and BURT, T P. 1999. The impact of land-use change on water quality at the catchment scale: the use of export coefficient and structural models. *Journal of Hydrology*, Vol. 221, 75-90.

YOUNG, C P, HALL, E S, and OAKES, D B. 1976a. Nitrate in groundwater - studies on the Chalk near Winchester, Hampshire. *WRc Technical Report* TR 31 (Medmenham).

YOUNG, C P, OAKES, D B, and WILKINSON, W B. 1976b. Prediction of future nitrate concentrations in groundwater. *Ground Water*, Vol. 14, 426-438.

Appendix 1 Summary of the decisions made by the NVZ Appeals Panel (as at 7th April 2010)

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
1	Shropshire	SY7 8HN	35/041/0003	B	S	08/11/2009	Upheld
2	Herts	AL3 6RG	TL 097 080	AB	S	30/11/2009	Rejected
3	Herts	AL3 6RG	TL 008 047	AB	S	30/11/2009	Rejected
4	Herts	AL3 6RG	TL 088 096	AB	S	30/11/2009	Rejected
5	Herts	AL3 6RG	TL 132 108	AB	S	30/11/2009	Rejected
6	Herts	AL3 6RG	TL 096 056	AB	S	30/11/2009	Rejected
7	Herts	AL3 6RG	TL 105 097	AB	S	30/11/2009	Rejected
8	Dorset	DT11 0QG	384653, 107236	AB	G	20/10/2009	Rejected
9	Somerset	BS40 8BB	353724, 162702, ST 537-627	B	NS	05/03/2009	Rejected
10	Norwich	NR12 9JT	TG3526	B	E	10/12/2009	Rejected
11	St Helens	WA11 7JG	SJ4697 NG9373, SJ4797 NG2683, SJ4797 NG5080, SJ4797 NG5080, SJ4797 NG6329, SJ4797 NG8820	AB	NS	24/09/2009	Rejected
12	Essex	SS4 3RN	588118	AB	NS	30/11/2009	Rejected
13	Wilts	SP3 2ND	SU2318	B	NS	28/09/2009	Rejected
14	Bath	BA5 3EZ	ST591 491	B	S	30/09/2009	Upheld
15 -18	Cornwall	PL26 7ST	SW9653, SW9352	B	S	29/10/2009	Rejected
19	Cornwall	TR19 6NA		A	G	13/12/2009	Rejected
20	Cornwall	TR19 6NA		A	G	13/12/2009	Rejected
23 - 25	Cornwall		SW5235	A	S	29/10/2009	Rejected
26 - 27	Cornwall	TR27 5JX	SW5736	AB	SG	24/11/2009	Rejected
28	Hampshire	SO23 8SS		B	S	10/10/2009	Upheld
29	Hampshire	RG25 2HE	SU624433	B	S	30/09/2009	Rejected
30 - 49	Cumbria	CA1 2RS	NZ244 382	B	S	16/10/2009	Upheld
50	N. Lincolnshire	DN20 0NU	TA 1003 7874	B	S	05/12/2009	Rejected
51	Devon	EX20 3QE	SS4423	A	S	11/12/2009	Upheld
52	Ipswich	IP9 1LW	TM215 339	AB	G	11/12/2009	Rejected
53	Dorset	DT6 3TR	SY5395	A	G	11/12/2009	Upheld
54	Dorset	DT6 3TR	SY5395	A	G	11/12/2009	Upheld
55	Cumbria	LA11 7LX	SD3975	A	S	11/12/2009	Upheld
56	Wiltshire	SP4 8JX	SU 155 470	A	G	11/12/2009	Rejected
57	Cornwall	TR12 6RF	SW 7319 7395	A	G	11/12/2009	Rejected
58	Helston	TR12 6RG	AB		NS	18/11/2009	Rejected
59 - 65	Cumbria	CA7 2NG	NY1040 7560, 8967, 8443, 0204, NY 1140 0050NY 0940 9622NY 0939 9295	A	S	11/12/2009	Upheld
66	Shropshire	SY7 8AQ	SO 372870	B	S	17/11/2009	Upheld
67	Helston	TR13 0BH	SW 6318 030 93	AB	GE	11/12/2009	Rejected
68	Lincolnshire	PE12 6HW	TF 474 269	AB	S	14/12/2009	Rejected
69	Lincolnshire	PE12 6HW	TF 3330	AB	S	14/12/2009	Rejected
70	Lincolnshire	PE12 6HW	TF 416 246	AB	S	14/12/2009	Rejected
71	Lincolnshire	PE12 8EW	TF 3833	AB	S	14/12/2009	Upheld
72	Lincolnshire	PE12 8EW	TF 4231	AB	S	14/12/2009	Upheld
73	Lincolnshire	PE12 8EW	TF 3831	AB	S	14/12/2009	Upheld
74	Lincolnshire	PE128EW	TF3829	AB	S	14/12/2009	Upheld
75	Lincolnshire	PE12 8EW	TF 3629	AB	S	14/12/2009	Upheld
76	Doncaster	DN9 1EA	TF 432 301	AB	S	14/12/2009	Upheld
77	Lincolnshire	PE12 7PP	TF 3328 – TF 3429	AB	S	14/12/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
78	Lincolnshire	PE12 7PP	TF 3426 – TF 3824	AB	S	14/12/2009	Rejected
79	Lincolnshire	PE12 6HW	TF 3231 – TF 3230	AB	S	14/12/2009	Rejected
80	Lincolnshire	PE12 6HW	TF 3832 – TF 3932	AB	S	14/12/2009	Upheld
81	Lincolnshire	PE12 9PB	TF 442 295	AB	S	14/12/2009	Partially Upheld
82	North Lincolnshire	DN20 0NU	TF 4330, TF 4132	AB	S	14/12/2009	Upheld
83	Lincolnshire	PE12 8LR	TF 404 285	AB	S	14/12/2009	Partially Upheld
84	Lincolnshire	PE12 8HB	TF 361 331	AB	S	15/12/2009	Partially Upheld
85	Lincolnshire	PE12 0AT	TF 4226TF 4227TF 4328	AB	S	14/12/2009	Rejected
86	Lincolnshire	PE12 0AT	TF 4226TF 4227TF 4328	AB	S	14/12/2009	Partially Upheld
87	Lincolnshire	PE12 6LT	TF 3237 – TF 3229	AB	S	14/12/2009	Rejected
88	Lincolnshire	PE12 6LT	TF 3332	AB	S	14/12/2009	Rejected
89	Lincolnshire	PE12 8EF	TF 391 316	AB	S	14/12/2009	Upheld
90	Lincolnshire	PE12 8LR	TF 370 320	AB	S	14/12/2009	Upheld
91	Lincolnshire	PE12 8LR	TF 3729	AB	S	14/12/2009	Upheld
92	Lincolnshire	PE12 0AJ	TF 41 26	AB	S	15/12/2009	Partially Upheld
93	Lincolnshire	PE12 8JJ	TF 3827 – TF 3828	AB	S	15/12/2009	Partially Upheld
94	Lincolnshire	PE12 8JJ	TF 4526	AB	S	15/12/2009	Upheld
95	Lincolnshire	PE12 8JJ	TF 4426	AB	S	14/12/2009	Rejected
96	Somerset	BA10 0ND		B	G	11/12/2009	Rejected
97	Dorset	DT9 4SW	ST610466	AB	S	07/11/2009	Rejected
98	Berkshire	RG19 8BQ	SU46/56444656	AB	G	22/12/2009	Rejected
99	Wiltshire	SP3 5PJ	ST 9726	B	G	15/10/2009	Rejected
100	Somerset	TA21 9QN	ST1019, ST0819; ST0820; ST 0919	A	SG	11/12/2009	Rejected
101	Notts	VG22 0PF	SK7169 8999	AB	NS	28/09/2009	Rejected
102	Devon	EX13 7DG		AB	SG	30/11/2009	Rejected
103	Cheshire	SK11 0PL	SJ 9667 SJ 9470	B	S	23/12/2009	Partially Upheld
104	Newcastle Upon Tyne	NE18 0BA	NZ104 710	B	S	16/10/2009	Rejected
105	Lincolnshire	PE12 7JP	TF4228 -1833	AB	S	15/02/2009	Rejected
106	Dorset	DH20 5AD	SY923865	AB	S	19/11/2009	Rejected
107	Cumbria	CA8 9LGC		AB	NS	24/2009009	Rejected
108	Norwich	NR14 6DQ	TG3530 0320	AB	NS	28/09/2009	Rejected
109	Gloucester	GL19 4JA	382163, 220310	A	NS	24/09/2009	Rejected
110	North Yorks	YO13 9JZ	SE 979 855	AB	SG	23/12/2009	Rejected
111	North Yorks	YO13 9LR	SE978844	AB	SG	23/12/2009	Rejected
112	North Yorks	YO13 9LR	SE 98 84	AB	SG	23/12/2009	Rejected
113	Dorset	DT11 9AZ		AB	NS	24/11/2009	Rejected
114	E Yorks	HU12 0QN	TA 283 209	AB	NS	11/12/2009	Rejected
115	Surrey	RH7 6OE	540239, 154243	AB	S	07/11/2009	Rejected
116	Essex	CM9 8RP	TL932117	A	S	07/11/2009	Upheld
117	N. Yorkshire	BD24 0HX	SD 782750	AB	S	27/11/2009	Rejected
118	Cumbria	CA1 2RS	NY6333 7372	B	NS	30/11/2009	Rejected
119	Penrith	CA10 3DU	NY 5621	A	S	13/12/2009	Upheld
120	Kent	DA2 8DZ	TQ57 555800,170100	AB	G	30/09/2009	Rejected
122	Lincs	TF 3813 3863		B	NS	30/11/2009	Rejected
123	Somerset	BA10 0LW	ST6531	B	G	11/12/2009	Rejected
124	Somerset	BA16 0NY	ST 494 375	A	S	21/12/2009	Upheld
125	Cornwall	TR11 5RP	SW 732 342	A	E	24/09/2009	Upheld
126	Carlisle	CA1 2RW		AB	SG	15/10/2009	Partially Upheld
127	Carlisle	CA1 2RW		A	S	15/10/2009	Rejected
128	Carlisle	CA1 2RW		AB	SG	15/10/2009	Partially Upheld
129	Carlisle	CA1 2RW		SG	NS	30/11/2009	Rejected
130	Merseyside	L34 4AG	SJ 465960	AB	S	07/11/2009	Rejected
131	Somerset	BA10 0LW	ST6531	B	G	11/12/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
132	Lancashire	BB7 4LH	SD 802637	AB	S	27/11/2009	Upheld
133	Lancashire	BB7 4LH	SD 854638	AB	S	27/11/2009	Upheld
134	Lancashire	BB7 4LH	SD 801476	AB	S	27/11/2009	Rejected
135	Kent	TN29 0DT	TR048311	A	NS	28/09/2009	Rejected
136	Kent	TN29 0DT	TR049242	A	NS	28/09/2009	Rejected
137	Cumbria	LA11 7PJ	SD3975, SD3976	A	NS	05/10/2009	Rejected
138	Cambridge	CB2 9LD	525848 326434 524510 328846 527474 333855 531300 329500 528000 325000 526000 320000 529000 324000 532000 316000	AB	NS	10/12/2009	Upheld
139	Cambridge	CB2 9LD	530010 321592 531978 319719 535365 321899 536053 323714 534561 316883 537947 318777 535227 325572 537069 325402 531492 325730	AB	S	10/12/2009	Upheld
140	Cambridge	CB2 9LD	TF3323	AB	S	10/12/2009	Upheld
141	Cambridge	CB2 9LD	370550	AB	S	10/12/2009	Upheld
142	Cambridge	CB2 9LD	380927	AB	S	10/12/2009	Upheld
143	Cambridge	CB2 9LD	375375	AB	NS	10/12/2009	Upheld
144	Shropshire	SY7 0JF	SO334819	B	S	17/11/2009	Upheld
145	Wells	BA5 2PJ	ST620543	AB	G	20/10/2009	Rejected
146	Isle of Wight	PO34 4JY	442193, 88507	AB	E	20/10/2009	Rejected
147	Isle of Wight	PO30 4NA	443219 089603	AB	E	08/11/2009	Rejected
148	East Sussex	BN27 1RG	563806, 112059	B	NS	24/11/2009	Rejected
149	Lancashire	BB7 3LX	SD6542; SD6642; SD6641	B	S	05/03/2009	Upheld
150	Surrey	KT9 2NH	TQ 168576	AB	S	27/11/2009	Rejected
151	Devon	EX17 5AH		AB	S	20/10/2009	Rejected
152	Dorset	DT8 3SF	ST4902	A	G	11/12/2009	Upheld
153	Cornwall	TR19 7BE	SW3627/3727	AB	G	28/09/2009	Rejected
154	Cornwall	TR19 7BE	SW3626 366.269	AB	G	28/09/2009	Rejected
155	Cornwall	TR19 7BE	SW 3829 3929	AB	G	28/09/2009	Rejected
156	Cornwall	TR19 7BE	SW 3682 3728	AB	G	28/09/2009	Rejected
157	West Yorks	HD4 7BX	SE116133	B	G	15/12/2009	Rejected
158	N. Lincolnshire	DN20 0NU	SE 8112 6181	B	S	10/12/2009	Rejected
159	N. Lincolnshire	DN40 3JQ	TA11216148	B	S	05/12/2009	Upheld
160	N. Lincolnshire	DN40 3JQ	TA10166909	B	SG	15/12/2009	Rejected
161	Devon	EX39 5LZ		A	E	20/10/2009	Upheld
162	N. Lincolnshire	DN20 0NU	TF 0991 6283	B	S	10/12/2009	Rejected
163	Kent	TN29 0JR	602285	AB	S	30/11/2009	Rejected
164	Kent	TN29 0JR	610672, 131149	AB	S	30/11/2009	Upheld
165	Kent	TN29 0JR	611348 133505	AB	S	30/11/2009	Upheld
166	Kent	TN29 0JR	600967 125585	AB	S	05/12/2009	Rejected
167	Kent	TN29 0JR	599836 123521	AB	S	30/11/2009	Upheld
168	Filey	YO14 9QE	TA1081 7182	A	S	11/12/2009	Upheld
169	Filey	YO14 9QE	TA1081 7182	A	S	11/12/2009	Upheld
170	Lancashire	BB7 4BX		B	S	30/10/2009	Upheld
171	Lancashire	BB7 4QH	SD7346	B	S	30/10/2009	Upheld
172	Lancashire	BB7 4QH	SD 7444/45	B	S	30/10/2009	Upheld
173	Lancashire	PR3 3BL	SD 5934-5	A	S	13/12/2009	Partially Upheld
174	Shropshire	SY7 0HN	SO 378 854	B	S	17/11/2009	Upheld
175	Shropshire	SY9 5LA	SO 314 848	B	S	17/11/2009	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
176	Cheshire	SK7 6NN	SJ 944868	AB	S	13/12/2009	Upheld
177	Shrewsbury	SY5 0HZ	SJ 415 146	B	S	30/11/2009	Upheld
178	Cumbria	LA11 6SQ	SD 44180344	A	S	11/12/2009	Upheld
179	Cumbria	LA11 7LZ	SD 773393	A	S	11/12/2009	Upheld
180	Lancaster	LA2 0EY	SS454515	AB	S	11/12/2009	Rejected
181	Hull	HU120SD	TA306207	AB	S	11/12/2009	Rejected
182	Taunton	TA1 3RQ	ST224216	B	S	11/12/2009	Rejected
183	Cornwall	TR27 6JP	SW5435 0115	A	SG	11/12/2009	Rejected
184	Sidmouth	EX10 0QG	SW1595 1462	B	G	11/12/2009	Rejected
185	Cornwall	PL14 3PW	SX2758 8655	A	S	12/12/2009	Upheld
186	Gloucestershire	GL20 8LX	SO 941 331	AB	NS	12/12/2009	Rejected
187	Oxford	OX7 3LX	SP 335 219	AB	S	11/12/2009	Rejected
188	N Yorks	YO7 3PG	SE 3875	AB	G	11/12/2009	Rejected
189	N Yorks	YO7 3PG	SE 3875	AB	G	11/12/2009	Rejected
190	Wiltshire	BA12 OJN	ST 9546 4207	B	G	10/12/2009	Rejected
191	Cumbria	LA7 7AG		B	S	10/12/2009	Upheld
192	Radstock	BA3 4LU	359521	A	S	10/12/2009	Rejected
193	Cumbria	CA10 3DF		A	NS	10/12/2009	Rejected
194	Lancashire	BB7 4EE	SD 8246	B	SG	10/12/2009	Upheld
195	Surrey	KT9 2NH	TQ 185 559	AB	NS	10/12/2009	Rejected
196	Carlisle	CA1 2RW		B	G	23/12/2009	Rejected
197	Carlisle	CA1 2RW	NY5152 2558	AB	S	23/12/2009	Upheld
198	Wiltshire	SN14 7AF	ST 7875	AB	SGE	10/12/2009	Rejected
199	Castleford	WF10 2AB	443 429	A	S	23/12/2009	Rejected
200-201	Cornwall	TR20 8RN	SW 4229 2256, SW 4229 3855, SW 4229 3346 (Application Ref. 200). SW 4129 0136, SW 4129 1645 (Application Ref. 201)	A	G	10/12/2009	Rejected
202	Hereford	HR2 8DP	SO605276	AB	NS	24/09/2009	Rejected
203	Lancs	BB7 1PT	SD 7640 1919	B	S	30/11/2009	Upheld
204	Norfolk	PE30 1PH		B	S	24/09/2009	Rejected
205	Herts	AL5 3NS	18/046/0014	A	S	30/09/2009	Rejected
206	Herts	AL5 3NS	18/046/0090	B	S	30/09/2009	Rejected
207	Herts	AL5 3NS	18/108/0086	B	S	30/09/2009	Rejected
208	Essex	SS6 9QG	TQ 867946	AB	S	30/11/2009	Upheld
209	Essex	SS6 9QG	TQ890948	AB	S	30/11/2009	Upheld
210	Lancs	BB9 6PB	SD84410269	B	SG	14/12/2009	Rejected
211	Cumbria	CA10 1RN	NY6433	B	S	30/11/2009	Rejected
212	Wiltshire	SP1 2PU	SU155470	B	S	30/11/2009	Rejected
213	Ipswich	IP9 1NS	TM 236350	AB	NS	24/09/2009	Rejected
214	Norfolk	IP20 9AU	600272, 287386	B	NS	24/09/2009	Rejected
215	Cornwall	TR12 6JN	SW7625	B	G	10/12/2009	Upheld
216	Cheshire	SK11 0RP	942 614	B	NS	22/12/2009	Rejected
217	Cheshire	SK11 0RP	938 617	B	NS	22/12/2009	Rejected
218	Cheshire	SK11 0RP		B	NS	22/12/2009	Rejected
219	Derbyhire	DE62HS	SK1348	A	S	22/12/2009	Rejected
220	Bristol	BS40 8YH	ST 540 602	B	S	17/11/2009	Rejected
221		PL26 7ST	SW 965 531		E	17/11/2009	Rejected
222	Cheshire	WA14 5RG	SJ 541 773	B	S	28/09/2009	Rejected
223	Kent	TN29 0DB	607675	A	NS	30/11/2009	Upheld
224	Suffolk	IP9 1EQ		B	NS	24/09/2009	Rejected
225 - 226	Durham	DL13 4PH	NZ 0838 9509, 0937 0295, 0938 0808	A	S	16/10/2009	Rejected
227	Devon	EX16 7PE	ST0116 4905 5237	B	S	16/10/2009	Rejected
228	Cambridgeshire	PE13 5PH	TF 4515, TF 4516, TF 4517, TF 4617	A	S	16/10/2009	Rejected
229	Herts	AL3 6RG	TL 097 080	AB	S	03/12/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
230	Suffolk	IP9 1EW		AB	NS	24/11/2009	Upheld
232	Dorset	DT6 4PN	SY 527 913	B	NS	10/12/2009	Rejected
233	Dorset	DT3 4JE	SY 611851	AB	E	03/12/2009	Upheld
234	Devon	EX16 7EZ	ST 0288 1255	A	NS	12/12/2009	Rejected
235	Devon	EX16 7HB		B	NS	10/09/2009	Rejected
236	Derbyshire	DE6 5NS	SK1237SK1236SK1133	AB	NS	24/09/2009	Rejected
237	Cornwall	TR20 8RD			NS	24/11/2009	Rejected
238	E	ST10 1SH	SK018425	B	S	30/09/2009	Rejected
239	Cumbria	LA7 7LR	SD505 831	A	S	05/10/2009	Upheld
240	Durham	DL17 0PG	NZ 2831 8432; NZ 2930 0399; NZ 2931 1643, 4410, 4462, 4642,6126,6905,7063, 7174, 7642, 9715, 9737	A	S	16/10/2009	Rejected
241	Taunton	TA1 3RQ	ST 229 229	B	S	21/12/2009	Upheld
242	Lincolnshire	DN21 4QR	SE8212	B	S	08/11/2009	Rejected
243	Cumbria	LA7 7DN	SD496835	A	NS	05/10/2009	Rejected
244	Cumbria	LA7 7DN	SD505826	A	NS	02/10/2009	Upheld
245	Cornwall	TR12 6DG		A	NS	24/09/2009	Rejected
246	Cornwall	TR19 6NN	SW4427	B	S	17/02/2009	Rejected
247	Cornwall	TR19 6AH	SW 357 245	AB	S	27/11/2009	Rejected
248	Cornwall	TR19 6AL	SW 443 281	AB	S	27/11/2009	Rejected
249	Cornwall	TR2 4SN		A	S	16/10/2009	Rejected
250	Helston	TR13 0BJ		A	S	16/10/2009	Rejected
251	Cornwall	TR12 6HZ		A	NS	10/12/2009	Rejected
252	Cheshire	SK7 6NN	SJ 9486, SJ 9386	B	S	18/10/2009	Upheld
253	Dorset	SP7 0EE		B	NS	10/12/2009	Rejected
254	Shropshire	SY7 0HJ	SO 361809	B	S	17/11/2009	Upheld
255	Shropshire	SY7 8BB	SO 337 845	B	S	17/11/2009	Upheld
256	N. Yorkshire	BD24 0DW	SD 806 622	B	S	10/12/2009	Upheld
257	Yorkshire	BD240DW	SD806622	B	S	10/12/2009	Upheld
258	N. Yorkshire	BD24 0DW	SD 806 622	B	S	10/12/2009	Upheld
259	York	YO62 7LB	SE 673 969	B	S	23/12/2009	Upheld
260	Essex	CM9 8AG	594090	AB	S	10/12/2009	Upheld
261	Shrewsbury	SY5 9NE	SJ 394 151	B	SG	15/12/2009	Rejected
262	Shrewsbury	SY5 0HZ	SJ 4015	AB	S	30/11/2009	Upheld
263	Shrewsbury	SY5 0HZ	SJ 4016	AB	S	30/11/2009	Upheld
264	Shrewsbury	SY5 0HZ	SJ 4017	AB	S	30/11/2009	Upheld
265	Shrewsbury	SY5 0HZ	SJ 4115	AB	S	30/11/2009	Upheld
266	Shrewsbury	SY5 0HZ	SJ 4116	AB	S	30/11/2009	Upheld
267	Shrewsbury	SY5 0HZ	SJ 4117	AB	S	30/11/2009	Upheld
268	Shrewsbury	SY5 0HZ	SJ 416 170SJ 459 168	AB	SG	15/12/2009	Partially Upheld
269	Shrewsbury	SY5 0HZ	SJ 333 137	AB	S	30/11/2009	Upheld
270	Shrewsbury	SY5 0HZ	SJ 342 127	AB	S	30/11/2009	Upheld
271	Shrewsbury	SY5 0HZ	SJ 325 133	AB	S	30/11/2009	Upheld
272	Shrewsbury	SY5 0HZ	SJ 393 175SJ 358 185SJ 373 157	AB	SG	15/12/2009	Partially Upheld
273	Shrewsbury	SY5 0HZ	SJ 367 207	AB	SG	15/12/2009	Partially Upheld
274	Shrewsbury	SY5 0HZ	SJ427123	SB	SG	17/02/2010	Partially Upheld
275	Shropshire	SY11 4HR	SJ3828	B	S	07/09/2009	Rejected
276	Shropshire	SY11 4HR	SJ3728	B	S	07/09/2009	Rejected
277	Shropshire	SY11 4HR	SJ3729	B	S	07/09/2009	Rejected
278	Lincs	PE12 0LW	TF 3111 8399	B	S	14/12/2009	Upheld
279	Lincs	PE12 0LW	TF 3715 6146	B	S	14/12/2009	Upheld
280	Lincs	PE12 0LW	TF 3309 3839	B	S	14/12/2009	Upheld
281 - 291	Lincs	PE12 0LW	TF 3715 3178, TF 3422, TF 3522, TF 4212 1158, TF 4115	B	S	14/12/2009	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
			4393, TF 4015 9987, TF 3720, TF 3820, TF 3919, 7507, TF 3820, TF 4215 2857, TF 3312 5840, TF 4216 3641				
292	Norfolk	NR12 8XX	TG3417	AB	G	30/11/2009	Rejected
293	Norfolk	NR29 5NU	TG3715, TG3716, TG3717, TG3815, TG3816, TG3817, TG3818, TG3819, TG3915, TG3916	AB	G	22/02/2009	Partially Upheld
294	Lancaster	LA1 3JQ	SD440504	AB	S	14/12/2009	Upheld
295	Norfolk	NR12 8JG	TG356221	B	SGE	29/10/2009	Rejected
296	Essex	SS4 2BF	589837	AB	S	30/11/2009	Upheld
298	Chichester	PO18 9JL	SU 808116	B	GE	10/10/2009	Rejected
299	Norfolk	PE33 9AH	5540 3195	B	S	20/12/2009	Partially Upheld
300	Ipswich	IP9 1AJ	TM 2638	AB	SG	20/12/2009	Rejected
301	Ipswich	IP9 1AJ	TM 1738, TM 1938	AB	SG	20/12/2009	Rejected
302	Ipswich	IP9 1AJ	TM 2439	AB	SG	20/12/2009	Rejected
303	Ipswich	IP9 1AJ	TM 2838	AB	G	20/12/2009	Rejected
304	Ipswich	IP9 1AJ	TM 2135	AB	G	20/12/2009	Rejected
305	Ipswich	IP9 1AJ	TM 1835	AB	G	20/12/2009	Rejected
306	Kendal	LA9 4JH	SD5153 -1115	AB	S	30/11/2009	Upheld
307	Kendal	LA9 4JH	SD 4952 - 9412	AB	S	30/11/2009	Upheld
308	Kendal	LA9 4JH	SD 4952-7756	AB	S	30/11/2009	Upheld
309	Kendal	LA9 4JH	SD4851 -3083	AB	S	30/11/2009	Upheld
310	Kendal	LA9 4JH	SD 4951-6077	AB	S	30/11/2009	Upheld
311	Kendal	LA9 4JH	SD 4952-5236	AB	S	30/11/2009	Upheld
312	Kendal	LA9 4JH	SD 5052-1260	AB	S	30/11/2009	Upheld
313	Kendal	LA9 4JH	SD 5052-1260	AB	S	30/11/2009	Upheld
314	Kendal	LA9 4JH	SD 4952-4592	AB	S	30/11/2009	Upheld
315	Kendal	LA9 4JH	SD 4953-8237	AB	S	30/11/2009	Upheld
316	Somerset	BA10 0ND	36/395/0020	B	S	07/11/2009	Rejected
317 - 318	Somerset	BA6 8RH	36/324/0007	B	S	22/10/2009	Upheld
319	Cumbria	LA11 7JU	SD394764	A	S	05/10/2009	Upheld
320	Cumbria	LA11 6RA	SD428795	A	S	05/10/2009	Upheld
321	Nottingham	NG12 2GT	TG120187	B	G	10/12/2009	Rejected
323 -329	E Yorks	HU15 1DR	SE9128	B	S	10/12/2009	Upheld
330	Cumbria	LA7 7NB	SD507840	A	S	05/10/2009	Upheld
331	Nottingham	NG5 8PQ	SK 583 504	AB	G	10/12/2009	Rejected
332	Cumbria	LA11 6QX	SD425792	A	S	05/10/2009	Upheld
333	Cumbria	LA11 6QX	SD425792	A	S	05/10/2009	Upheld
334	Cumbria	LA11 6QX	SD425792	A	S	05/10/2009	Upheld
335	Cumbria	LA11 6QX	SD425792	A	S	05/10/2009	Upheld
336	Cumbria	LA11 7QA	SD394776	A	S	05/10/2009	Upheld
337 - 338	N. Devon	EX31 4SH	SS569408 & SS577440	B	S	10/10/2009	Rejected
339	Cumbria	LA11 6RJ	SD4480, SD4580	A	S	05/10/2009	Upheld
340	Cumbria	LA11 6RJ	SD4479	B	S	05/10/2009	Upheld
341	Chichester	PO20 2DX	SU8501	B	S	07/09/2009	Rejected
342	Chichester	PO18 9HU	SU834144	AB	S	07/09/2009	Rejected
343 - 346	Cornwall	TR12 6ET	SW 760 222, SW 760 222, SW 783 229, SW 786 232	B	G	10/12/2009	Rejected
347	Cornwall	TR12 6ET	SW 787 244	B	G	10/12/2009	Upheld
348	Somerset	BA10 0ND	36/395/0020	B	S	07/11/2009	Rejected
349	Shrewsbury	SY5 0HZ	SJ375179, SJ343257, SJ275245, SJ371209, SJ365245, SJ283259,	AB	S	08/03/2010	Partially Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
			SJ310250, SJ315215, SJ340250				
350	Shrewsbury	SY5 0HZ	SJ389137	AB	G	23/03/2010	Partially Upheld
351	Shrewsbury	SY5 0HZ	SJ297261, SJ303264, SJ303257, SJ307258, SJ312255, SJ311249, SJ308321, SJ341258	AB	S	25/02/2010	Partially Upheld
352	Shrewsbury	SY5 0HZ	SJ 334 142	AB	SG	15/12/2009	Upheld
353	Shrewsbury	SY5 0HZ	SJ297261, SJ303264, SJ303257, SJ307258, SJ312255, SJ311249, SJ308321, SJ341258	AB	S	25/02/2010	Partially Upheld
354	Shrewsbury	SY5 0HZ	SJ393176, SJ388169	AB	SG	08/03/2010	Partially Upheld
355	Shrewsbury	SY5 0HZ	SJ 354 127	AB	S	30/11/2009	Upheld
356	Shrewsbury	SY5 0HZ	SJ 402 132SJ 465 141SJ 451 128SJ 452 142	AB	S	20/12/2009	Upheld
357	Cornwall	TR20 8RH		A	G	23/12/2009	Rejected
358	Cornwall	TR20 8RH		A	G	23/12/2009	Rejected
359	Cornwall	TR20 8RH		A	G	23/12/2009	Rejected
360	Cornwall	TR20 8RH		A	G	23/12/2009	Rejected
361	Cornwall	TR20 8RH		A	G	23/12/2009	Rejected
362 - 364	High Wycombe	HP15 6UZ	SU8999 5428, SU8899 8315, SU9097 0262	AB	G	30/11/2009	Rejected
365	Cornwall	TR19 6EZ	SW 428 266	AB	G	27/11/2009	Rejected
366 - 367	Cornwall	TR19 6NN	SW 460 250	B	G	27/11/2009	Rejected
368	Cornwall	TR12 6NY	SW 796 202	B	G	10/12/2009	Rejected
369	Cornwall	TR12 6NT	SW 784 206	B	G	10/12/2009	Rejected
370	Devon	EX39 5EE	SS432247	B	S	20/10/2009	Rejected
371	Ipswich	IP9 1BX	TM193340	AB	NS	05/03/2010	Rejected
372	Ipswich	IP5 1DA	TM1837	AB	NS	28/09/2009	Rejected
373	Cornwall	TR12 6QL	SW 800 220	B	G	10/12/2009	Rejected
374	North Yorkshire	DL8 2LA	SE 3084/7025	A	S	15/10/2009	Rejected
375	Shropshire	SY7 OJQ	839 329	B	S	01/12/2009	Upheld
376	Lancashire	BB7 4LX	SD804505	AB	S	27/11/2009	Upheld
377	Devon	EX22 6SF		B	NS	05/10/2009	Upheld
378	Devon	EX22 6SF	SX313994	B	S	05/10/2009	Upheld
379	Devon	EX22 6NB		B	S	05/10/2009	Upheld
380	Devon	EX22 6QA	10/184/0013	B	S	17/10/2009	Upheld
381	Devon	EX22 6SF	SS 324 011	B	NS	05/10/2009	Upheld
382	Devon	EX22 7BJ	SS 3361 0756	B	NS	05/10/2009	Upheld
383	Devon	EX22 6RJ	SX3198 6437, SX3198 6415, SX3197 8195, SX3197 9894, SX3197 7482, SX3197 8773, SX3297 0348, SX3297 0474, SX3197 8773, SX3197 8362, SX3197 9356, SX3197 8745, SX3197 6255, SS3200 6535, SS3200 7548, SS3200 9057, SS3200 9548, SS3200 7548, SS3200 9038	B	NS	05/10/2009	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
384	Devon	EX22 7BJ	SS 333 057, SS 334 057, SS 336 057	B	NS	05/10/2009	Upheld
385	Devon	EX22 6LJ	SS3203 7314, SS3202 8394, SS3202 6896, SS3202 7582, SS3202 8570, SS3202 9456	B	NS	05/10/2009	Upheld
386	Devon	EX22 6NE	SS335016	B	NS	05/10/2009	Upheld
387	Devon	SS 359 077		B	NS	05/10/2009	Upheld
388	Devon	EX22 6NY	SS 369 048	B	NS	05/10/2009	Rejected
389	Devon	EX22 6NE		B	NS	05/10/2009	Upheld
390	Devon	EX22 6JY	10/194/0072	B	NS	05/10/2009	Upheld
391	Devon	EX22 6JY	10/194/0010	B	NS	05/10/2009	Upheld
392	Devon	EX22 6NE	10/194/00098	B	NS	05/10/2009	Upheld
393	Devon	EX22 6SP	10 194 0004	B	NS	05/10/2009	Upheld
394	Devon	EX22 6SH	10 194 0043	B	NS	05/10/2009	Upheld
395	Devon	EX22 7SH	SS 328 074	B	NS	05/10/2009	Upheld
396	Devon	EX22 6NH	10/455/0080	B	NS	05/10/2009	Rejected
397	Devon	EX22 6NH	10 455 0103	B	NS	05/10/2009	Rejected
398	Devon	EX22 6NH	10/189/0096	B	NS	05/10/2009	Rejected
399	Devon	EX22 6PT	SX336993	B	NS	05/10/2009	Upheld
400	Lancashire	BB7 4NZ	7850 7529	B	S	30/11/2009	Upheld
401	Hull	HU12 0DZ	TA 2618-2718	A	NS	10/12/2009	Rejected
402	Cornwall	TR4 9DZ	SW 8147	AB	S	10/12/2009	Rejected
403	Cumbria	CA1 2RS	NY5515 4021	B	S	30/11/2009	Rejected
404	Cumbria	CA1 2RS	NY5515 4205	B	S	30/11/2009	Rejected
405	Cumbria	CA1 2RS	NY5515 2454	B	S	30/11/2009	Rejected
406	Cumbria	CA12RS	NY5515 0166	B	S	30/11/2009	Rejected
407	Cumbria	CA1 2RS	NY5515 1482	B	S	30/11/2009	Rejected
408	Cumbria	CA1 2RS	NY5415 8193	B	S	30/11/2009	Rejected
409	Cumbria	CA1 2RS	NY5515 0601	B	S	30/11/2009	Rejected
410	Cumbria	CA1 2RS	NY5416 8818	B	S	30/11/2009	Rejected
411	Cumbria	CA1 2RS	NY5515 3483	B	S	30/11/2009	Rejected
412	Cumbria	CA1 2RS	NY5516 1709	B	S	30/11/2009	Rejected
413	Cumbria	CA1 2RS	NY5516 0637	B	S	30/11/2009	Rejected
414	Cumbria	CA1 2RS	NY5516 3320	B	S	30/11/2009	Rejected
415	Cumbria	CA1 2RS	NY5515 4887	B	S	30/11/2009	Rejected
416	Cumbria	CA1 2RS	NY5516 5807	B	S	30/11/2009	Rejected
417	Cumbria	CA1 2RS	NY5515 5458	B	S	30/11/2009	Rejected
418	Cumbria	CA1 2RS	NY5515 7559	B	S	30/11/2009	Rejected
419	Cumbria	CA10 3NB	NY5515 8868	B	S	20/03/2010	Rejected
420	Carlisle	CA5 6QL	NY29502497	A	S	05/12/2009	Upheld
421	Carlisle	CA5 6QL	NY3151 2909	A	S	05/12/2009	Upheld
422 - 426	Buxton	SK17 9UK	SK147708		NS	19/11/2009	Rejected
427	Cumbria	LA7 7LP	SD502823, SD492817	A	S	05/10/2009	Upheld
428	Cumbria	LA7 7LP	SD502823, SD492817	A	S	05/10/2009	Upheld
429	Somerset	TA2 8LR	ST 256 298	A	S	11/12/2009	Rejected
430	Hampshire	RG25 2HX	SU623 467	AB	S	08/11/2009	Rejected
431	Cumbria	CA10 1QB	NY633 352	AB	NS	28/09/2009	Rejected
432	Dorset	DT11 0NA	ST 8204	AB	G	11/12/2009	Rejected
433	Cumbria	LA7 7FH	SD4883, SD5083	A	S	25/10/2009	Rejected
434	Exeter	EX5 2JN	SY 035 910	AB	SG	11/12/2009	Rejected
435	Dorset	DT11 0EE	ST 820 077	B	G	11/12/2009	Rejected
436	Norfolk	NR12 9ES	TG389 245	AB	GE	23/11/2009	Partially Upheld
437	Norwich	NR12 9ES	TG389 245, TG365 263	B	GE	29/10/2009	Rejected
438	Dorset	DT11 0EB		AB	G	23/12/2009	Rejected
439	Hull	HU12 0QL	TA 2131	B	S	11/12/2009	Rejected
440	Kent	TN29 0DB	607892	A	NS	30/11/2009	Upheld
441	Kent	TN29 0DB	604994	A	NS	30/11/2009	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
442	Lancashire	BB7 1PP	SD 7439	B	S	30/11/2009	Upheld
443 - 444	Ripon	HG4 3AR	SE 2867	A	NS	11/12/2009	Rejected
445	Kent	TN29 0DB	599661 130857	A	S	30/11/2009	Rejected
446	Kent	TN29 0DB	6004241 128306	A	S	30/11/2009	Upheld
447	Kent	TN29 0DB	600619 128244	A	S	30/11/2009	Rejected
448	Kent	TN29 0DB	599477 124612	AB	S	30/11/2009	Upheld
449	York	YO1 6LF	TA266233	AB	S	05/12/2009	Upheld
450	York	YO1 6LF	TA264224	AB	S	05/12/2009	Upheld
451	York	YO1 6LF	TA224215	AB	S	05/12/2009	Rejected
452	York	YO1 6LF	TA266210	AB	S	05/12/2009	Upheld
453	York	YO1 6LF	TA278206	AB	S	05/12/2009	Upheld
454	York	YO1 6LF	TA282209	AB	S	05/12/2009	Rejected
455	York	YO1 6LF	TA303199	AB	S	05/12/2009	Upheld
456	York	YO1 6LF	TA 339213	AB	S	05/12/2009	Rejected
457	York	YO1 6LF	TA257195	AB	S	05/12/2009	Upheld
458	York	YO1 6LF	TA245189	AB	S	05/12/2009	Upheld
459	York	YO1 6LF	TA276186	AB	S	05/12/2009	Upheld
460	York	YO1 6LF	TA266193	AB	S	05/12/2009	Upheld
461	York	YO1 6LF	TA232204	AB	S	05/12/2009	Rejected
462	York	YO1 6LF	TA312195	AB	S	05/12/2009	Rejected
463	York	YO1 6LF	TA266182	AB	S	05/12/2009	Upheld
464	York	YO1 6LF	TA293192	AB	S	05/12/2009	Upheld
465	York	YO1 6LF	TA 306207	AB	S	05/12/2009	Rejected
466	York	YO1 6LF	TA 346219	AB	S	05/12/2009	Rejected
467	Shewsbury	SY2 6LG	SJ 4410 1090	AB	S	30/11/2009	Upheld
468	Shrewsbury	SY2 6LG	SJ333 250	AB	SG	25/02/2010	Rejected
469	Shewsbury	SY2 6LG	SJ 4260 1170	AB	S	30/11/2009	Upheld
470	Shewsbury	SY2 6LG	SJ 3517 1147	AB	S	30/11/2009	Upheld
471	Shewsbury	SY2 6LG	SJ 4589 1119	AB	S	30/11/2009	Upheld
472	Shewsbury	SY2 6LG	SJ 4523 1167	AB	S	30/11/2009	Upheld
473	Shrewsbury	SY2 6LG	SJ408181	AB	SG	25/02/2010	Partially Upheld
474	Norfolk	NR12 9SH	TG355 260	B	GE	29/10/2009	Rejected
475	Isle of Wight	PO30 4BY	SZ 4480 6778	A	S	08/11/2009	Upheld
476	Shropshire	SY7 8BA	SO 326 858	B	S	17/11/2009	Upheld
477	e	AL5 2AY	TL124123	AB	S	16/10/2009	Rejected
478	Norwich	NR12 0TP	TG3432, TG3433, TG3432, TG3432, TG3532, TG3532	B	S	20/11/2009	Rejected
479	Oxon	RG9 5DL	SU 703 849	AB	S	20/12/2009	Upheld
480	Wells	BA2 2PJ	ST527308	AB	G	20/10/2009	Rejected
500	Devon	EX22 6PU	SX 348 994	B	NS	05/10/2009	Upheld
501	Devon	EX22 6PT	10/184/0011	B	NS	05/10/2009	Upheld
502	Devon	EX22 6RJ	10 455 0129	B	NS	05/10/2009	Upheld
503	Cornwall	PL15 9RF	10 193 0096	B	NS	05/10/2009	Upheld
504	Devon	EX22 7EH	SS3204 4147, SS3204 5124	B	NS	05/10/2009	Upheld
505	Devon	EX22 7JA	SS316059	B	NS	05/10/2009	Upheld
506	Devon	EX22 7JF	SS 319 066	B	NS	05/10/2009	Upheld
507	Devon	EX22 7HU		B	NS	05/10/2009	Upheld
508	Devon	EX22 6NY	10 455 0220	B	NS	05/10/2009	Rejected
509	Derbyshire	SK23 7NP	SK 025827	B	S	18/10/2009	Upheld
510	Ipswich	IP9 1JU	TM 2137TM 2237	A	G	15/10/2009	Rejected
511	Herefordshire	HR3 6DX		A	S	12/11/2009	Upheld
512	Lancs	BB7 3LY	SD6541; SD6542; SD6641	B	NS	28/09/2009	Rejected
513	Hull	HU12 0AN	TA 2421	AB	G	11/12/2009	Rejected
514	Kent	TN29 0JJ		AB	NS	28/09/2009	Rejected
515	Southampton	SO32 2AP	15/098/0008	A	E	03/12/2009	Rejected
516	Southampton	SO45 1AB		A	S	08/11/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
517	Wiltshire	SP5 5BE	SU018 211, SU017 233	AB	G	16/12/2009	Rejected
518	Cumbria	CA5 6BQ	NY 2852	A	S	24/09/2009	Rejected
519	Carlisle	CA4 9TH		A	SG	23/11/2009	Rejected
520	Carlisle	CA4 9RN	NY5447	A	SG	24/11/2009	Rejected
521	OXON	RG9 6HG	SU 736 893	AB	S	20/12/2009	Rejected
522	Cambs	PE13 5QT	TF 433 192	B	S	15/12/2009	Upheld
523	Cambs	PE13 5QT	TF 475 192	B	S	15/12/2009	Upheld
524 - 527	N. Lincolnshire	DN19 7EB	TA 112 733	A	S	11/12/2009	Upheld
528	Dorset	DT8 3SH	ST 486 040	AB	NS	11/12/2009	Rejected
529	Cumbria	LA7	SD481846	A	S	05/10/2009	Upheld
530	Cumbria	CA8 9BT	NY5254, NY5354	A	NS	05/03/2009	Rejected
531	Devon	EX11 1PL		B	G	13/12/2009	Partially Upheld
532	Lancashire	BB7 4LY	SD 8051 8151	B	S	30/11/2009	Upheld
533	Norfolk	PE34 4JB	TF5420 6976	A	S	21/03/2010	Upheld
534	Cornwall	TR12 6DU	SW 761 223	B	G	11/12/2009	Rejected
535 - 536	Somerset	BA4 6AX	372394, 138954, 372551, 138855, 372665, 138829	A	S	10/10/2009	Upheld
537	Cumbria	LA11 6SG		A	S	05/10/2009	Upheld
538 - 539	West Sussex	RH16 3BN	TQ 4003, TQ 4105	AB	G	11/12/2009	Rejected
540	Shropshire	SY4 5SA	35/251/0014	AB	S	19/10/2009	Rejected
541	Berkshire	RG19 8BQ	SU46/56444656	AB	G	22/12/2009	Rejected
542	Cheshire	SK11 0RP	SJ 942 614	B	S	21/02/2010	Rejected
543	Cheshire	SK11 0RP	SJ 938 617	B	S	21/02/2010	Rejected
544	Cheshire	SK11 0RP	SJ 938 617	B	S	21/02/2010	Rejected
545	Cheshire	SK11 0RP	SJ 892 617	B	S	21/02/2010	Rejected
546	Wiltshire	SP4 8JX	SU 158 468	B	G	11/12/2009	Rejected
547	Hull	HU19 2BU	TA 2719	AB	S	11/12/2009	Rejected
548	West Sussex	RH16 3BN	SU 9226	AB	S	15/10/2009	Rejected
549	West Sussex	RH16 3BN	SU 9316	AB	S	15/10/2009	Rejected
550	West Sussex	RH16 3BN	SU 9320	AB	SG	15/10/2009	Rejected
551	Essex	CM0 7EH	TQ 965 988	AB	SG	11/12/2009	Partially Upheld
552 - 553	West Sussex	RH16 3BN	TQ 3503, TQ3903	AB	G	11/12/2009	Rejected
554	Bucks	HP10 9QD	SU 853 907	AB	S	20/12/2009	Upheld
555	County Durham	DL14 8AQ	NZ 251 315	A	S	20/11/2009	Rejected
556	Somerset	TA6 6DF	ST 216 286	A	SG	11/12/2009	Rejected
557	E Yorks	HU15 9HE	TA 264224	AB	S	14/12/2009	Rejected
558	E Yorks	HU12 0DY	TA 2621	AB	NS	11/12/2009	Rejected
559	Cumbria	CA7 2LR	NY097 401	A	S	11/12/2009	Upheld
560	York	YO61 2QE	SE 455 727	A	S	11/12/2009	Upheld
561	North Yorks	SE 979 855		B	SG	11/12/2009	Rejected
562	North Yorks	YO62 7UZ	SE 667 949	B	NS	23/12/2009	Upheld
563	North Yorks	YO62 7LB	SE 675 964	B	S	23/12/2009	Upheld
564	North Yorks	SE980 864		B	SG	23/12/2009	Rejected
565 - 567	Devon	EX14 3PW	SY 106 942	B	G	13/12/2009	Rejected
568	Hampshire	SO21 3QD	SU4842 9309, SU4941 2564	AB	GE	08/11/2009	Rejected
569	Cumbria	CA15 6TN	NY 0939 7890NY 0940 8112	A	NS	24/09/2009	Upheld
570	Cumbria	CA15 6TN	NY 093 389NY 094 390	A	NS	24/09/2009	Upheld
571	Cumbria	CA4 0NR	NY427 444	A	NS	30/11/2009	Rejected
572	Cumbria	CA5 7AR	NY404 470	A	NS	10/12/2009	Upheld
573	N. Lincolnshire	DN20 0NU	SE 7915 0329	B	S	15/12/2009	Rejected
574	N. Lincolnshire	DN20 0NU	SE 8307 4374	B	S	15/12/2009	Rejected
575	North Yorks	YO17 9QP	SE 796 680	A	SG	23/12/2009	Rejected
576	Hope Valley	S33 7ZL	SK117 853	B	S	19/11/2009	Upheld
577	Norfolk	NR25 6QL	28/378/0039	A	SG	24/09/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
578	Norfolk	NR12 9EZ	TG369268	B	GE	29/10/2009	Rejected
579	Norwich	NR12 0NW	TG3730, TG3731	A	S	20/10/2009	Upheld
580	Norwich	NR12 0NW	TG3431	B	GE	29/10/2009	Rejected
581	Cumbria	LA7 7LY	SD508832	A	S	05/10/2009	Upheld
582	Cumbria	LA11 6RE	SD470843, SD449807, SD440791, SD427786, SD441791	AB	S	05/10/2009	Upheld
583	Cumbria	LA11 6RE	SD470843, SD449807, SD440791, SD427786, SD441791	AB	S	05/10/2009	Upheld
584	Cumbria	CA8 9DP	NY5453 4657	A	G	17/02/2010	Rejected
585	N. Lincolnshire	DN18 6EN	SE 993 156	AB	S	14/12/2009	Rejected
586	Helston	TR12 6NZ		AB	G	11/12/2009	Rejected
587	Cornwall	TR13 8ER	SW7729	AB	S	16/10/2009	Rejected
588	Helston	TR12 6SF	SW 7618, SW7717, SW7821	AB	G	11/12/2009	Rejected
589	Cornwall	TR13 8ER	SW6635	AB	S	16/10/2009	Rejected
590	Cornwall	TR20 9AQ		AB	G	13/12/2009	Rejected
591	Helston	TR12 6DP	SW7423 5623	AB	G	11/12/2009	Rejected
592	Cornwall	TR138ER	SW7729	AB	S	16/10/2009	Rejected
593	Helston	TR12 6ED	SW7321 4584	AB	G	11/12/2009	Partially Upheld
594	Northumberland	TD15 2PY	NT937372	B	S	18/10/2009	Rejected
595	West Sussex	BN17 5RQ	SU9801 3542	A	S	08/11/2009	Upheld
596	Cumbria	CA1 2RS	NY395 501	A	S	20/12/2009	Upheld
597	Cumbria	CA1 2RS	NY395 501	A	S	10/12/2009	Upheld
598	Cumbria	CA1 2RS	NY388 501	A	S	10/12/2009	Upheld
599	West Sussex	BN18 9LW	TQ 007 131, 500778 113159	AB	G	03/12/2009	Upheld
600 - 601	Dorset	DT1 1UP	SY 942792, SY 915803	A	S	10/10/2009	Upheld
602 - 603	Essex	CM9 8HH	TL 9414 9030, TL 9312 8557	AB	S	10/10/2009	Rejected
604	Derbyshire	DE45 1AH	SK117 853	B	S	19/10/2009	Upheld
605	Devon	EX16 9RH	SS912 158	B	S	16/10/2009	Rejected
606	Gloucester	GL19 4HY	380665, 222529, 381441, 222172	A	S	20/12/2009	Partially Upheld
607	Gloucester	GL19 4HY	381631, 225252,381845, 222569	B	S	20/12/2009	Rejected
608	Shropshire	SY7 0HH		AB	S	02/12/2009	Rejected
609 - 617	Cumbria	CA1 2RS	NY6333 6788	B	S	30/11/2009	Rejected
618 - 639	Penrith	CA10 3DU	NY 562 567	B	S	14/12/2009	Upheld
640	Lincs	PE12 0HE	TF3915 4548; 7502TF4014 7563; 9275; 1169TF3914 7979; 9790	B	NS	15/10/2009	Rejected
641	Lincs	PE12 0HE	TF 3915 9292	B	NS	30/11/2009	Rejected
642	Lincs	PE12 0HE	TF3616 9895	B	NS	30/11/2009	Rejected
643	Cornwall	TR19 6NN	SW4427	B	NS	17/02/2010	Rejected
644	Cambridge	CB2 9LD	525848 326434524510 328846527474 333855531300 329500528000 325000526000 320000529000 324000532000 316000	AB	NS	10/12/2009	Upheld
645	Somerset	BS40 7UZ	ST522 611	B	S	24/11/2009	Rejected
646	Lincs	PE12 0LU	537310	B	NS	15/12/2009	Rejected

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
647	Cheshire	SK11 0QH	SJ959662	AB	NS	17/02/2010	Rejected
648	Cheshire	WA14 5RG	SJ 33 72	B	G	30/11/2009	Rejected
649	Cheshire	WA14 5RG	SJ5276	B	S	16/12/2009	Rejected
650	Cheshire	WA14 5RG	SJ4776	A	S	14/12/2009	Rejected
651	Shropshire	SY12 0NW	SJ4335	A	S	16/12/2009	Upheld
652	Shropshire	SY12 0NW	SJ4335 3262	A	S	16/12/2009	Upheld
653	Derbyshire	DE6 1NL	09/308/007	AB	S	25/11/2009	Rejected
654	E. Yorks	HU12 0AP	TA 2519	A	NS	11/12/2009	Rejected
655	N. Lincolnshire	DN40 3PN	TA1219, TA0918, TA1123, TA0922, TA1015	AB	SG	15/12/2009	Rejected
656	Norwich	NR10 5PJ	TG 376220	B	G	29/10/2009	Rejected
657	Cumbria	CA10 1PT	NY6135 7557	A	NS	10/12/2009	Rejected
658	Cumbria	CA10 1PT	NY6035 6165	A	NS	10/12/2009	Rejected
659	Shropshire	SY7 8AA	842358810 362	AB	S	01/12/2009	Upheld
660	W. Sussex	RH19 3DF	TF 467 248	AB	S	15/12/2009	Rejected
661	York	YO23 2XA	SES4NE-45774454	A	S	05/10/2009	Rejected
662	Wiltshire	SN8 4AN	ST802366	AB	S	12/10/2009	Rejected
663	Wiltshire	SN8 4AN	SU217324	AB	S	12/10/2009	Rejected
664	Wiltshire	SN8 4AN	ST806363	AB	S	12/10/2009	Rejected
665 - 666	Devon	EX17 5AF	SX708759	B	S	16/10/2009	Upheld
667	Herts	AL5 1HH	TL 151129	AB	G	25/01/2009	Rejected
668 - 669	Derbyshire	SK17 0AB	09/086/0049	A	S	25/11/2009	Rejected
670	E. Yorks	HU12 0QN	TA 2619-2819	A	NS	11/12/2009	Rejected
671	N. Lincolnshire	DN20 0NU	672 491	B	S	23/12/2009	Rejected
672	Cumbria	CA8 9BY	NY 5251	AB	S	12/10/2009	Partially Upheld
673	N. Lincolnshire	CB2 9LD	525848	AB	S	30/11/2009	Rejected
674	N. Lincolnshire	DN18 6EN	SE 003 118	AB	S	14/12/2009	Rejected
675	Cumbria	LA8 8ET	SD469819, SD468847	A	S	05/10/2009	Upheld
676	Cumbria	LA8 8ET	SD466835	A	S	05/10/2009	Upheld
677	Norwich	NR12 9HX	TG3531, TG3629, TG3430, TG3429, TG3529, TG3530	B	E	29/10/2009	Rejected
678	Norwich	NR28 9SP	TG3130, TG2932, TG2931, TG3031, TG3132, TG3230	B	E	29/10/2009	Rejected
679	Stafford	ST19 9LQ	SJ887118	AB	S	16/10/2009	Rejected
681 - 682	North Lincs	DN15 0DB	SE9611 NG5525, SE9315 NG 1414	AB	SG	10/10/2009	Rejected
683	North Lincs	DN18 6EN	SE 993 156	AB	S	14/12/2009	Rejected
684	E Yorks	HU15 1RX	SE8829	A	S	14/12/2009	Rejected
685 - 699	E Yorks	HU15 1RX	SE9028	A	S	14/12/2009	Upheld
700	Northumberland	NE70 7DS	NU 175 355	A	E	24/11/2009	Upheld
701	York	YO30 7WZ	SF 350 907	AB	S	16/10/2009	Rejected
702	Devon	EX22 6PX	10/184/0001	B	NS	05/10/2009	Upheld
703	Devon	EX22 7JJ	10/455/0051	B	NS	05/10/2009	Upheld
704	Devon	EX22 7NG	10/195/0015	B	NS	05/10/2009	Upheld
705	Devon	EX22 7NJ	10/455/0029	B	NS	05/10/2009	Upheld
706	Devon	EX22 7QJ	SS334086	B	NS	05/10/2009	Upheld
707	Devon	EX22 7NH	10/455/0068	B	NS	05/10/2009	Upheld
708	Devon	EX22 7NH	10/455/0069	B	NS	05/10/2009	Upheld
709	Devon	EX22 7BJ	10/455/6516	B	NS	05/10/2009	Upheld
710	Devon	EX22 7NQ	10/195/0055	B	NS	05/10/2009	Upheld
711	Devon	EX22 7NJ	10/455/0218	B	NS	05/10/2009	Upheld
712	Devon	EX22 7NJ	10/455/0145	B	NS	05/10/2009	Upheld
713	Devon	EX22 6JS	10/455/0144	B	NS	05/10/2009	Upheld
714	Devon	EX22 7HU	10/194/069	B	NS	05/10/2009	Upheld
715	Devon	EX22 7HZ	SS317 046	B	NS	05/10/2009	Upheld
716	Devon	EX22 6PP	10/184/0072	B	NS	05/10/2009	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
717	Devon	EX22 6NA	10 455 0008	B	NS	05/10/2009	Rejected
718	Devon	EX22 6NA		B	NS	05/10/2009	Upheld
719	Devon	EX22 6NW	SS3704	B	S	17/10/2009	Rejected
720	Devon	EX22 7BP	10 455 0056	B	NS	05/10/2009	Rejected
721	Devon	EX22 7BP	10/193/0027/01	B	NS	05/10/2009	Rejected
722	Devon	EX22 6NZ	10/193/0027/01	B	NS	05/10/2009	Rejected
723	Devon	EX22 7BX		B	NS	05/10/2009	Rejected
724	Devon	EX22 7RN	SS 349 074	A	S	20/11/2009	Rejected
725	Devon	EX22 5JW	SS362 047	B	NS	05/10/2009	Rejected
726	Devon	EX22 6JW	SS357 043	B	NS	05/10/2009	Rejected
727	Devon	EX22 7LN	10/183/0047	B	NS	05/10/2009	Rejected
728	Devon	EX22 6NR	10/455/0031	B	NS	05/10/2009	Rejected
729	Devon	EX2 9RW	10/184/0013	B	S	17/10/2009	Upheld
730	Devon	EX22 7RG	SS3205	B	NS	05/10/2009	Rejected
731	Devon	EX22 6NQ	10/455/0070	B	NS	05/10/2009	Rejected
732	Devon	EX22 7JX	SS325 041	B	NS	05/10/2009	Rejected
733	N. Lincolnshire	DN20 0NU	SE 996 147	AB	NS	11/12/2009	Upheld
734	N. Lincolnshire	DN19 7EL	1019, 1011	AB	G	30/11/2009	Upheld
735	N. Lincolnshire	DN20 0NU	TA2919 3419, TA 2917 3379, TA 2718 6663	AB	S	15/12/2009	Rejected
736	N. Lincolnshire	DN20 0NU	TA 1323 3945	AB	S	14/12/2009	Upheld
737	N. Lincolnshire	DN20 0NU	TF 4330 5384TF 4132 2050	AB	S	10/12/2009	Upheld
738	N. Lincolnshire	DN20 9OL	TA 113 242	AB	S	12/10/2009	Upheld
740	Cumbria	LA7 7LH	SD491834, SD484836, SD484827, SD486823	A	S	05/10/2009	Upheld
800	Gloucester	GL2 9NU	SO 832 225	B	S	23/12/2009	Upheld
801	High Peak	SK22 2JS	SK045856	AB	S	27/11/2009	Upheld
802	High Peak	SK22 2JS	SK 044857	AB	S	27/11/2009	Upheld
803	High Peak	SK22 2JW	SK 042863	AB	S	27/11/2009	Upheld
804	Cumbria	LA7 7EZ	SD476839, SD502827, SD491819	A	S	05/10/2009	Upheld
805	Cumbria	LA7 7EZ	SD476839, SD502827, SD491819	A	S	05/10/2009	Upheld
806	Cumbria	LA7 7EZ	SD476839, SD502827, SD491819	A	S	05/10/2009	Upheld
807	Cumbria	LA7 7EB	SD494826	A	S	05/10/2009	Upheld
808 - 817	Shrewsbury	SY5 0HZ	SJ389137	AB	G	23/03/2010	Partially Upheld
818	Lancs	BB7 4JA	SD8053 & SD8152	B	S	05/12/2009	Upheld
819	Lancs	BB7 4JA	SD8051	B	S	02/12/2009	Upheld
820	Lancs	BB7 4JA	SD8151, SD8251, SD8252	B	S	05/12/2009	Upheld
821	Cumbria	LA8 8EU	SD458836	A	S	05/10/2009	Upheld
822	Cumbria	LA8 8EU	SD465848	A	S	05/10/2009	Upheld
823	Shropshire	SY7 9NN	SO 3684 6595	AB	S	02/12/2009	Upheld
824	Shropshire	SY7 9NN	SO 3684 6595	AB	S	03/12/2009	Upheld
825	Cumbria	LA8 8DU	SD503 837	A	S	05/10/2009	Upheld
826	Cumbria	LA8 8DU	SD472 849	A	S	05/10/2009	Upheld
827	Cumbria	CA11 9TG	NY5422 3599	B	S	30/11/2009	Rejected
828	Dorset	DT8 3SH	ST4804 4606	A	NS	17/02/2010	Rejected
829	Lancashire	BB7 4TL	SD7445	B	S	05/12/2009	Upheld
830	Lancashire	BB7 1HG	SD615226		NS	26/11/2009	Rejected
831	Lancashire	BB7 1HG	SD 643 283	AB	S	11/12/2009	Upheld
832	Herefordshire	HR5 3HA	SO309545	B	S	19/10/2009	Upheld
833	Norwich	NR14 7BE	TG3430 0230	AB	NS	30/11/2009	Rejected
834	Lancashire	BB7 1HG	SD 784 442	B	S	24/11/2009	Upheld
835	Smalborough	NR12 9NB	TG2927 2857	B	GE	20/11/2009	Rejected
836	Lancashire	BB7 1HG		AB	S	17/02/2010	Upheld

Appeal No.	County	Postcode	Grid Reference	Grounds of Appeal	Type of Appeal	Date of Decision	Decision
837	Lancs	BB7 1HG	SD883 542	B	S	14/12/2009	Upheld
838	Shropshire	SY7 9NN	SO 3385 8171	AB	S	02/12/2009	Upheld
839	Cornwall	TR19 7BE	SW 3625	AB	G	10/12/2009	Rejected
Appeal withdrawn		21, 22, 121, 231, 297, 680					
Appeal dismissed		322, 379					
Grounds of Appeal: A = Land does not drain into water identified by the Secretary of State as being polluted							
B = Land drains into water that the Secretary of State should not have identified as being polluted							
Type of Appeal: S = Surface Water; G = Ground Water; E = Eutrophic; NS - Not Specified							