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Assessing land-use scenarios to improve groundwater quality: a Slea catchment study

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Steve Killeen

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Head of Science

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March 2006

Executive summary

The way in which land is used can have a profound effect on surface and ground water quality, particularly if the land is intensively farmed. Many European countries encourage land-use practices which incorporate a degree of water quality management, but this approach is rare in the UK, where currently more emphasis is placed on end-of-pipe treatment. This strategy, however, appears increasingly expensive and unsustainable.

As part of the Water4all project (www.water4all.com), funded by the Interreg IIIB North Sea Region Programme, the Environment Agency decided to explore ways in which land use could be adapted to manage and improve water quality in the UK. A pilot study was set up to investigate the effectiveness of land-use measures in reducing nitrate levels in a catchment area. The River Slea in Lincolnshire was chosen for its relatively high surface and groundwater nitrate levels, availability of monitoring data, and its suitability for investigating land-use issues typical of lowland UK. Boreholes into the Lincolnshire Limestone aquifer are an important source of public and private water supply in the area and the River Slea itself is fed predominantly by major springs issuing from the groundwater resource.

Initially, a series of interviews were undertaken and focus groups conducted with local stakeholders (farmers, civic groups, planners, NGOs) to gather opinions on current issues and possible future land-use scenarios (see Table A). A combined export coefficient and numerical groundwater modelling approach was then used to simulate the effects of these scenarios on groundwater nitrate concentrations in the River Slea catchment. The six scenarios and their variants formed the basis for a GIS database of land cover type, cropping patterns and livestock and human population numbers. Export (or release) coefficients for each land use type were compiled following an extensive literature search; the coefficients were then applied to nitrogen application or loading rates for each land use under each scenario. A spreadsheet-based export coefficient model generated estimates of the annual mass of nitrogen leached from each 2-km grid cell in the study area; these were then converted to nitrate concentration values by considering the volume of effective precipitation in each cell.

Table A Future land use scenarios

Scenario	Description
Recent past (RP)	A continuation of existing measures (such as Nitrate Vulnerable Zones).
Impact of current policy reforms (CP)	Incorporate likely land use changes arising from CAP reforms, new agri-environment schemes and other initiatives
Nitrate best practice (BP)	Extend the CP scenarios with agricultural best practice measures (such as use of cover crops or avoidance of the 'leakiest' crops) that would reduce nitrate leaching. Intermediate and protective variants were defined.
Regional Nitrate Sensitive Area (NSA)	Use agricultural practices adopted under the 1990s Nitrate Sensitive Areas scheme across the limestone outcrop.
Land use protection zones (PZ)	Introduce land use protection zones (such as low input grassland and/or woodland) in targeted areas (for example, around well capture zones and the upper River Slea).
Whole catchment change (WC)	Convert 40 per cent of the arable area in the Slea catchment to low input grassland or woodland and reduce livestock numbers by 40 per cent.

Nitrate concentration values calculated with the export coefficient model were entered into a solute transport model to simulate groundwater nitrate concentrations at key spring and water supply borehole sites. The transport model, constructed using MT3DMS, was developed from a groundwater flow model based on the Visual MODFLOW code in which the regional geology was simplified to two model layers: a lower layer equivalent to the Lincolnshire Limestone aquifer and an upper layer representing the overlying confining strata. The flow and transport models were calibrated against observed groundwater heads, flows and nitrate concentrations for the period 1988-2000. This process revealed the importance of the dual-porosity behaviour of the limestone and denitrification in the confined layer in controlling groundwater nitrate concentrations.

Predictions of trends in groundwater nitrate concentrations under average recharge conditions from 2001-2030 were generated using the transport model, with scenarios simulated to start in 2006. Nitrate concentrations fell by up to 30 per cent (compared with projections of recent past land use) for scenarios with significant land conversion from arable to woodland or grassland above the unconfined aquifer west of Sleaford (see Table B). These trends further confirm the effects of denitrification and mass transfer between the fissure and matrix components of the limestone, which result in a gradual shift to new equilibrium groundwater nitrate concentrations in response to land use change. The results demonstrate the need for long-term land management measures to achieve stable and lower nitrate concentrations in groundwater.

Table B Summary of scenario modelling results

	Slea Catchment	**Clay Hill Borehole**
Scenario	**Average Soil Nitrate Level (mg/l)**	**2015 Groundwater Nitrate Level (mg/l)**
Recent Past	127	56
Current Policy a	122	55
Current Policy b	118	53
Best Practice 1a	102	49
Best Practice 1b	99	48
Best Practice 2a	82	44
Best Practice 2b	80	44
NSA a	104	44
NSA b	101	43
Protection Zones a	107	42
Protection Zones b	104	42
Whole Catchment a	71	40
Whole Catchment b	69	40

Economic assessments suggest that it would cost at least an additional £1.33 million per year to compensate farmers for the income lost by changing land management practices to reduce groundwater nitrate concentrations sufficiently below the 50 mg/l NO_3 standard to eliminate the need for water treatment. Equivalent current treatment costs for nitrate are approximately £230,000 per year. However, changes in land use may bring additional benefits (such as reductions in other diffuse pollutants, enhancements to biodiversity or recreation opportunities), and treatment costs may well increase. Participation in land management schemes may become increasingly attractive to farmers if levels of return from crops and livestock continue to fall. Land use protection zones were the most positively received scenario when the study's findings were discussed with stakeholders in autumn 2005.

Overall, the study found that considerable changes in land use - beyond those likely from current policy reforms - would be necessary to enable groundwater nitrate concentrations to meet EU targets and remove or minimise the need for water treatment. However, these land-use changes could produce substantial reductions in nitrate levels on a timescale of 10 to 20 years. A key recommendation of this report is to identify mechanisms and funding sources which would allow some pilot measures to be put in place.

Contents

1 Introduction

1.1 Project aims

Meeting the requirements of the Water Framework Directive 2000/60/EC (WFD) poses many challenges for water and land use management in EU countries. The requirement to achieve 'good ecological and chemical status' in surface waters and groundwaters by 2015 is particularly difficult for intensively-farmed areas which often suffer diffuse pollution from fertilisers, pesticides or livestock sources (Environment Agency 2004a). Changes in land use and farming practices can reduce these problems, but place further demands on many farm enterprises already facing an uncertain future from Common Agricultural Policy (CAP) reforms (Department for Environment, Food and Rural Affairs (Defra) and HM Treasury 2004; Countryside Agency 2004)

Water4all was a three-year project (2003-2005) funded by the Interreg IIIB North Sea Region Programme to investigate how groundwater quality protection and land use planning could be better integrated to help meet the objectives of the WFD. The project, involving partners in four countries (Denmark, Germany, the Netherlands and the UK), hosted international meetings to swap experiences, created a website (http://www.water4all.com) and developed a handbook for land managers and planners (Water4all Project 2005). Specific activities were also carried out in the partner countries.

Denmark, Germany and the Netherlands already have many examples of land-use measures for water quality management, such as the Drastrup project near Aalborg (see http://www.aalborg.dk/drastrup). These measures are less common in the UK, where more emphasis is placed on end-of-pipe treatment (Brouwer et al. 2003). However, this approach appears increasingly expensive and unsustainable (Knapp 2005; Shepherd 2005). Thus, the UK partner - the Environment Agency - decided to evaluate the effectiveness of a number of land-use changes in a pilot catchment study. The research focused on nitrate pollution - identified as a major reason why UK groundwater resources may fail to meet WFD objectives (Environment Agency 2004a) - and was based on a case study of the River Slea in Lincolnshire.

Figure 1.1 shows the location and main topographical features of a 40 km by 30 km study area around the Slea catchment. This catchment (approximately 166 km^2 in surface extent) was chosen for its relatively high ground and surface water nitrate levels, availability of monitoring data and its suitability for investigating land-use issues typical of lowland UK. The River Slea itself is fed predominantly by major springs issuing from the Lincolnshire Limestone aquifer; thus, there is a strong interaction between ground and surface water resources relevant to the emphasis on integration in the WFD. Boreholes in the limestone aquifer are an important source of public and private water supply and there have been local concerns regarding pressures on water resources arising from population expansion (especially in the town of Sleaford) and agricultural demands (Gostick undated; Environment Agency 2004b).

In 2003, the Environment Agency commissioned the School of Environmental Sciences at the University of East Anglia to undertake the Slea catchment case study. The project's aims were to:

- improve the understanding of pedological (soil-water interactions), hydrogeological (underground water) and hydrological (surface water) systems within the catchment and the links between them and existing land use;

- work with local stakeholders to develop several future scenarios regarding land use and management practices in the area;
- evaluate the types of changes (radical or slight) needed to achieve a sustainable system in which nitrate concentrations would remain within acceptable limits;
- discuss with local stakeholders how acceptable these changes would be, examine how they might be achieved and evaluate their effect on the socio-economic structure of the local community.

The project therefore required both research into nitrate levels in groundwater and the factors influencing them, and discussions with stakeholders on the socio-economic implications of different possible land-use scenarios.

The remainder of Section 1 provides an introduction to the nitrate pollution problem and the study area chosen. Subsequent sections outline the data collected and methods used, the scenarios developed with the stakeholders, the modelling results and the economic assessment of their implications. The final section (Section 6) summarises the study's findings and considers the next possible steps.

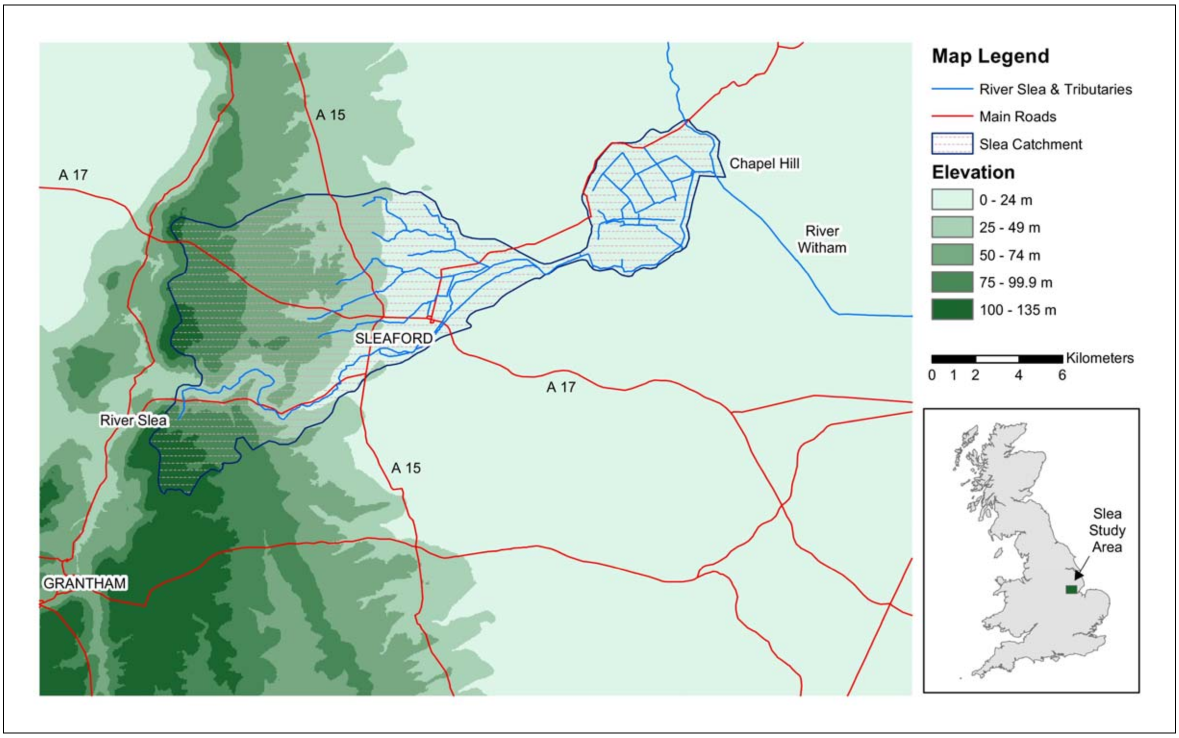


Figure 1.1 Location of the study area

1.2 Nitrate problems and policy responses

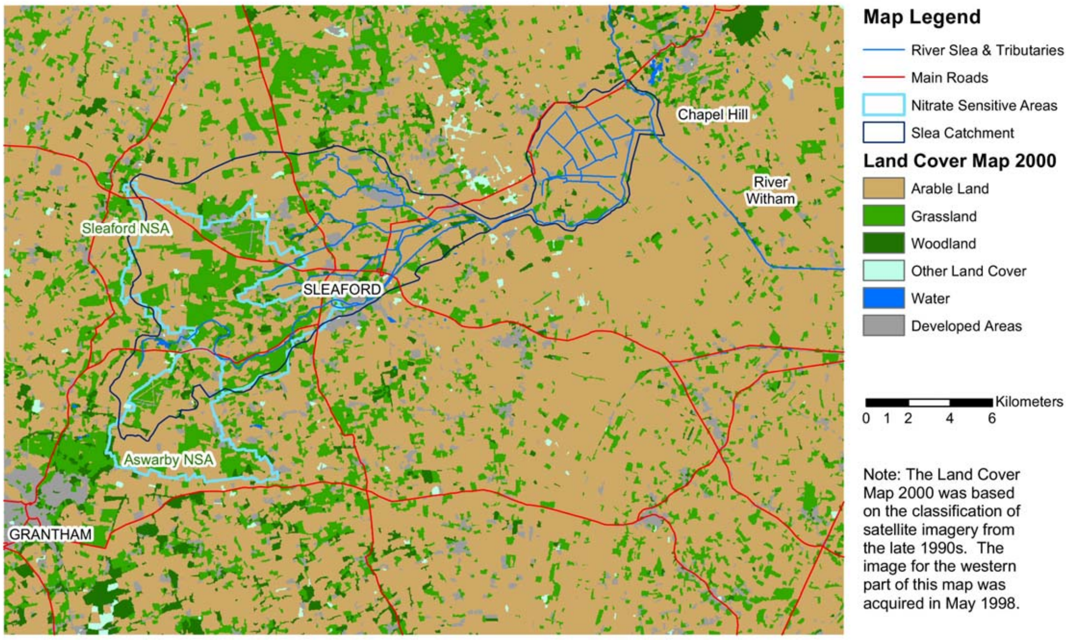
Many surface water catchments, groundwater bodies and estuaries in lowland England are under pressure from nitrogen pollution; because of this, they are classified as currently at risk of failing to meet WFD objectives (Defra 2004; Environment Agency 2004a). Increases in nitrate concentrations have coincided with an intensification of farming, suggesting that diffuse pollution from farming may be the cause. Agricultural sources account for approximately 70 per cent of the nitrogen entering UK waters (Environment Agency 2002). Crops given greater amounts of nitrogen fertiliser return more organic matter to the soil, increasing the soil's organic nitrogen pool which can be rapidly mineralized by soil micro-organisms (Burt and Haycock 1992). Nitrates are both soluble and mobile and are therefore highly susceptible to leaching if there is no actively growing crop (Burt et al. 1993).

Initial concerns over high nitrate levels in drinking water were based on suspected risks of infant methaemoglobinaemia (blue-baby syndrome) and stomach cancer (Levallois and Phaneuf 1994). More recently, the evidence for these health risks has been subject to considerable criticism, though it is still recognised that high nitrate levels can trigger ecological problems such as algal blooms in estuarine waters (Addiscott 2005). In response to the initial health concerns, the EC Drinking Water Directive (80/778/EEC) in 1980 set a 'maximum admissible concentration' of nitrate of 50 mg NO_3/l in water intended for human consumption. There has since been much debate regarding the justification for this limit, with arguments that a higher level (for example, 100 mg NO_3/l) would be more appropriate (Addiscott 2005), but at present there appears to be little political momentum for change.

Concerned that many groundwater abstractions would exceed the 50 mg NO_3/l limit, the Ministry of Agriculture, Fisheries and Food (MAFF) established the Nitrate Sensitive Areas (NSAs) Scheme under the 1989 Water Act. A pilot NSA scheme launched in 1990 explored the effectiveness of measures to control nitrate loss on commercial farms and the practicalities of implementing these practices (Osborn and Cook 1997; Lord et al. 1999). The NSAs represented areas overlying vulnerable aquifers where nitrate concentrations in sources of public drinking water exceeded, or were at risk of exceeding, the 50 mg NO_3/l EC limit. Voluntary, compensated farm management measures were introduced in these areas under five-year agreements in an attempt to reduce the levels of nitrate reaching soil and groundwaters. There were two tiers to the scheme: the Basic Scheme was designed to reduce nitrate leaching within existing good agricultural practice (such as use of cover crops and restrictions on fertiliser applications), while the Premium Scheme involved more fundamental changes such as converting high-input arable land to zero or low-input grassland.

The ten pilot NSA areas included one in the western half of the Slea catchment. In 1994, the introduction of the main NSA scheme added a further 22 areas, including one at Aswarby adjoining part of the southern boundary of the Sleaford NSA (see Figure 1.2). Uptake of the scheme was high in both areas, covering 85 per cent of the eligible agricultural area in the Aswarby NSA and 93 per cent in the Sleaford NSA by 1998. The latter scheme also had a relatively high proportion (36 per cent) of eligible area in the Premium Arable option (Environment Agency 2003). Figure 1.2 shows the boundaries of the NSAs against a backdrop of land cover in the late 1990s and highlights the substantial areas classified as grassland within the NSAs. However, in 1998 a government funding decision resulted in all the NSA schemes being closed to new entrants and given the five year term, there was no land under such agreements after 2003. In both the Sleaford and Aswarby NSAs, the ending of the agreements resulted in many of the new grassland areas being re-ploughed for arable production, with associated releases of nitrate into the soil. Current grassland cover in these areas is therefore rather less than that shown in Figure 1.2.

The impact of NSAs on nitrate concentrations in abstracted water was not expected to be fully apparent for several decades. Therefore, changes in nitrate loss from the soil were monitored as an alternative means of assessment (Lord et al. 1999). The results suggest that the scheme had a measurable beneficial impact on reducing nitrate leaching from the soil zone, with land conversion from arable to grassland proving to be one of the most effective mitigation strategies (Environment Agency 2003; Silgram et al. 2005).



Note: The Land Cover Map 2000 was based on the classification of satellite imagery from the late 1990s. The image for the western part of this map was acquired in May 1998.

Figure 1.2 NSA boundaries and late 1990s land cover in the study area

Nitrate Vulnerable Zones (NVZs) were introduced in the UK in 1996 in response to the requirements of the EU Nitrates Directive (91/976/EC), which aimed to reduce existing water pollution or eutrophication from agriculturally-released nitrates and to prevent such pollution occurring in the future. Initially, some 8 per cent of England was covered by NVZs and farmers in these areas were required to comply with a number of uncompensated Action Programme measures, including restrictions on the extent and timing of fertiliser applications (Department of Environment, Transport and the Regions (DETR) and MAFF, 1998). In December 2000, however, the European Court of Justice ruled that the UK had failed to designate sufficient areas to protect all surface and groundwaters, rather than just drinking water sources, against diffuse nitrate pollution from agriculture. This ruling resulted in a substantial expansion of NVZs in 2002 and regulations now cover 55 per cent of England (including all of the Slea surface catchment). Unlike some other EU Directives (such as 80/68/EEC for groundwater), the Nitrates Directive will not be repealed under the WFD; thus, there will be a continued emphasis on both the reduction and prevention of nitrate pollution from agricultural sources. A further UK government review of NVZ boundaries and Action Programme measures is currently in progress.

The experience gained from such schemes means that there is now a substantial body of knowledge on land management practices that can reduce nitrate leaching. These have been documented in codes of good agricultural practice (such as MAFF and Welsh Office Agriculture Department 1998) and many (for example, those in NVZ Action Programmes) are now part of the cross-compliance standards that farmers must observe in order to obtain their Single Farm Payment (SFP) under the most recent CAP reforms (Rural Payments Agency and Defra 2004). Nevertheless, there is increasing recognition that additional actions will be necessary to meet the objectives of the WFD (for example, Defra and HM Treasury 2004) and several studies have suggested that considerable changes in land use could be required (for example, Haygarth et al. 2003). Altering land use to manage water quality in agricultural catchments is not a new idea (Severn-Trent Water, Department of Environment and MAFF 1988; Burt and Johnes 1997) and has precedents in other countries (Municipality of Aalborg 2001; Brouwer et al. 2003), but such a preventative strategy is rather different from the current UK emphasis on end-of-pipe water treatment.

Financing changes in land use is complicated by the private sector status of water utilities in the UK (Andrews 2003; Knapp 2005). However, given that the estimated annual cost of treating drinking water to meet EU nitrate standards is already at least £13 million (Environment Agency 2002; Pretty et al. 2003) and is expected to rise further in the future (UK Water Industry Research (UKWIR) 2004), such options merit serious consideration (Knapp 2005).

A number of water suppliers currently blend water sources with lower and higher contamination levels to remain within the 50 mg NO_3/l limit. For example, in the Sleaford area, water from a low nitrate source at Kirkby la Thorpe (in the confined section of the aquifer to the east of the town) is pumped to the Clay Hill works (on the western side of Sleaford) where it is mixed with higher nitrate water supplies from nearby boreholes prior to treatment. If nitrate contamination levels in ground and surface waters continue to rise, however, such mixing will become less effective. In any case, the use of blending and treatment by water utilities is contrary to the preventative ethos of the Nitrates Directive and may be restricted under Article 7 of the WFD. Recent research published by UKWIR (2004) suggests that such restrictions could lead to approximately one-third of current national groundwater supplies needing to be replaced by 2027, a task which might involve surface water impoundments or desalination and thus would be difficult and extremely expensive to carry out. A key aim of the Water4all study, therefore, was to assess the costs of changes in land management and compare these to the costs of water supply options.

1.3 Catchment study area

1.3.1 Hydrogeology

The presence of the Lincolnshire Limestone aquifer is a key feature of the solid geology in the Slea catchment. This feature runs north-south, with the limestone outcrop corresponding to areas of higher elevation shown in Figure 1.1. Below the surface, the limestone dips eastwards and is overlain by a sequence of relatively impermeable Middle to Upper Jurassic strata of the Ancholme Group (see Table 1.1 and Figures 1.3 and 1.4). The Lias Group of low permeability mudstones underlie the Lincolnshire Limestone Formation and outcrops to the west of the limestone escarpment as shown in Figures 1.3 and 1.4.

The Lincolnshire Limestone formation is the principal aquifer in the Sleaford district, with only small quantities of groundwater obtained from minor aquifers in the Quaternary fluvial sands and gravels and the Marlstone Rock Formation of the Lias Group. Some groundwater also comes from minor limestone units, such as the Blisworth Limestone and Cornbrash Formations, while the Lias and Middle to Upper Jurassic clays form regional aquitards (Table 1.1).

The hydrogeological nature of the Lincolnshire Limestone Formation is described by Downing and Williams (1969). The formation is subdivided into an upper unit composed mainly of cross-bedded oolitic limestone and a lower unit of carbonate mudstones, wackestones and packstones. The compact, oolitic limestones have low primary intergranular porosity and permeability, while high secondary fissure and micro-fissure permeabilities are present throughout much of the formation, being associated with a rectilinear fracture pattern of tectonic origin (Berridge et al. 1999). The porosity and permeability of the fissure zones have been enhanced by solutional weathering, with groundwater flow occurring along well-developed bedding plane fractures and joints, often of a karstic nature. Aquifer transmissivity is generally about 1,500 m^2/day but is locally as high as 5,000-10,000 m^2/day depending upon the degree of fissuring and karstic weathering (Downing et al. 1977).

A north-south regional groundwater divide crosses the central part of the study area parallel to and east of the Lincolnshire Limestone escarpment. The water table declines from over 80 m above Ordnance Datum (m OD) at the groundwater divide to less than 20 m OD, 10 km to the east within the unconfined zone of the aquifer. Further to the east, the aquifer is confined by Middle to Upper Jurassic strata and becomes increasingly artesian eastwards beneath the low lying fenland (Lawrence and Foster 1986). Regional flow in the aquifer is down-dip in an easterly direction, with groundwater transmitted predominately through fissure flow. This high transmissivity combined with a low aquifer storage coefficient results in large seasonal fluctuations in water table levels (Smith-Carington et al. 1983). Towards the east of the study area flow is limited, with groundwater becoming increasingly old and saline (Lawrence and Foster 1986).

Table 1.1 Geological succession and hydrogeological properties of the area around Sleaford. Based on Berridge et al. (1999)

Series	Group	Formation	Lithology	Thickness (m)	Hydrogeological Properties
Quaternary			Peat Alluvial silt and clay River terrace deposits Glacial deposits	<20	Minor aquifers in thicker sands and gravels, e.g. Sleaford Sand and Gravel
Middle to Upper Jurassic	Ancholme Group	Kimmeridge Clay Formation Ampthill Clay Formation West Walton Formation Oxford Clay Formation	Grey, shelly mudstones with thin limestones	>50	Aquitard
		Kellaways Formation	Grey mudstone and sandy mudstone	6.5-8	Minor aquifer in sandier portions
Middle Jurassic	Great Oolite Group	Cornbrash Formation	Rubbly limestone	1.6-3	Minor aquifer
		Blisworth Clay Formation	Green and grey clay	6.1-10	Aquitard
		Blisworth Limestone Formation	Limestone and calcareous sandstone	2-7.6	Minor aquifer
		Rutland Formation	Clay, silt and sand with limestone	5-11	Aquitard
	Inferior Oolite Group	Lincolnshire Limestone Formation	Fine-grained and ooidal limestones	25-33.5	Major and minor aquifers in hydraulic continuity
		Grantham Formation	Clay, silt and sand	0-13.6	
		Northampton Sand Formation	Sandy ironstone	0-4.6	
Lower Jurassic	Lias Group	Whitby Mudstone Formation	Grey mudstones with thin ironstone, sandstone and limestone horizons	42-54	Aquitard
		Marlstone Rock Formation		2.5-7.3	Minor aquifer
		Dyrham Siltstone Formation		0-15	Aquitard
		Brant Mudstone Formation		c.113	Aquitard
		Scunthorpe Mudstone Formation		c.111	Aquitard

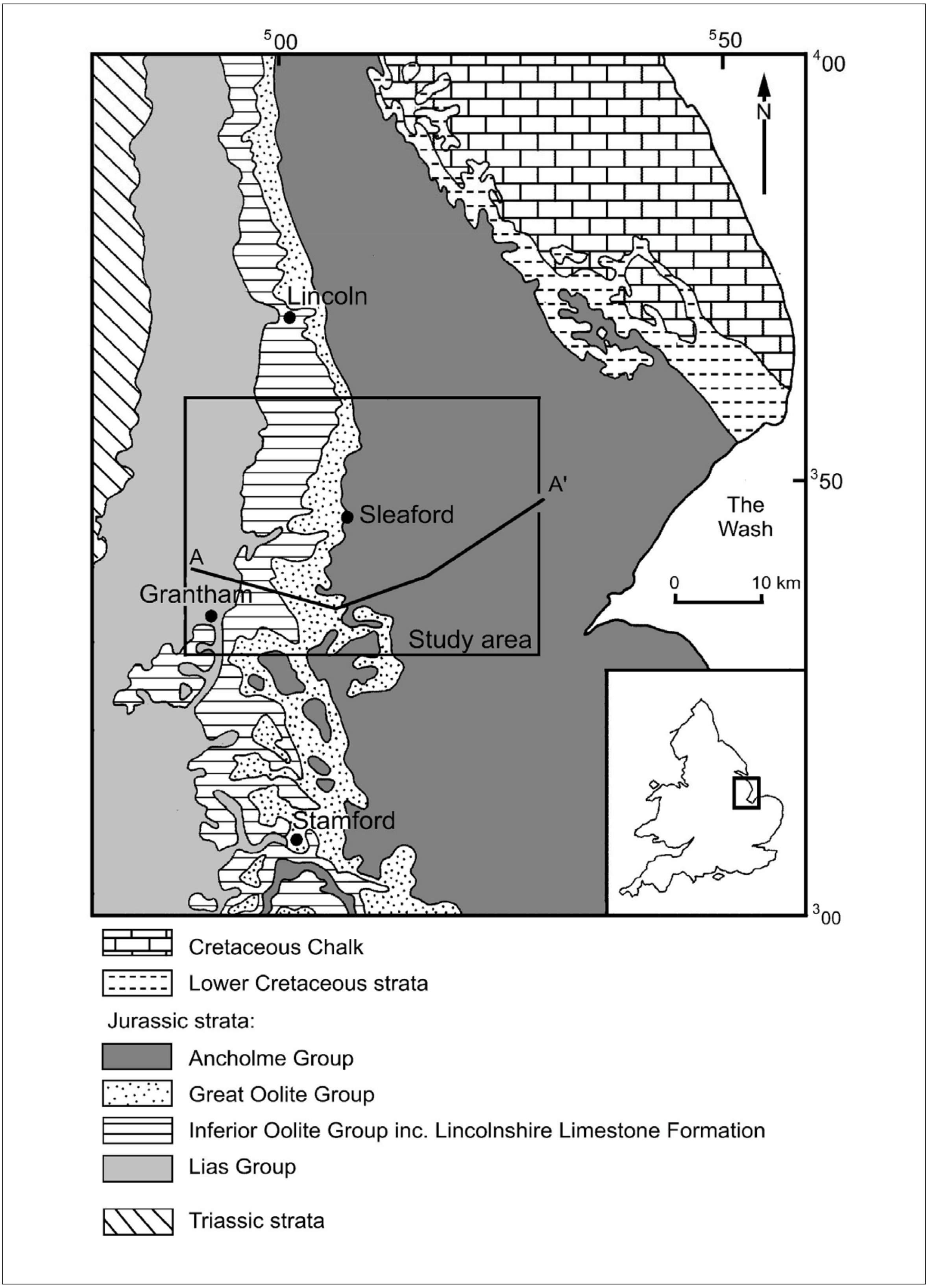


Figure 1.3 Map of the solid geology of Lincolnshire in the vicinity of the Sleaford study area. Based on Downing and Williams (1969)

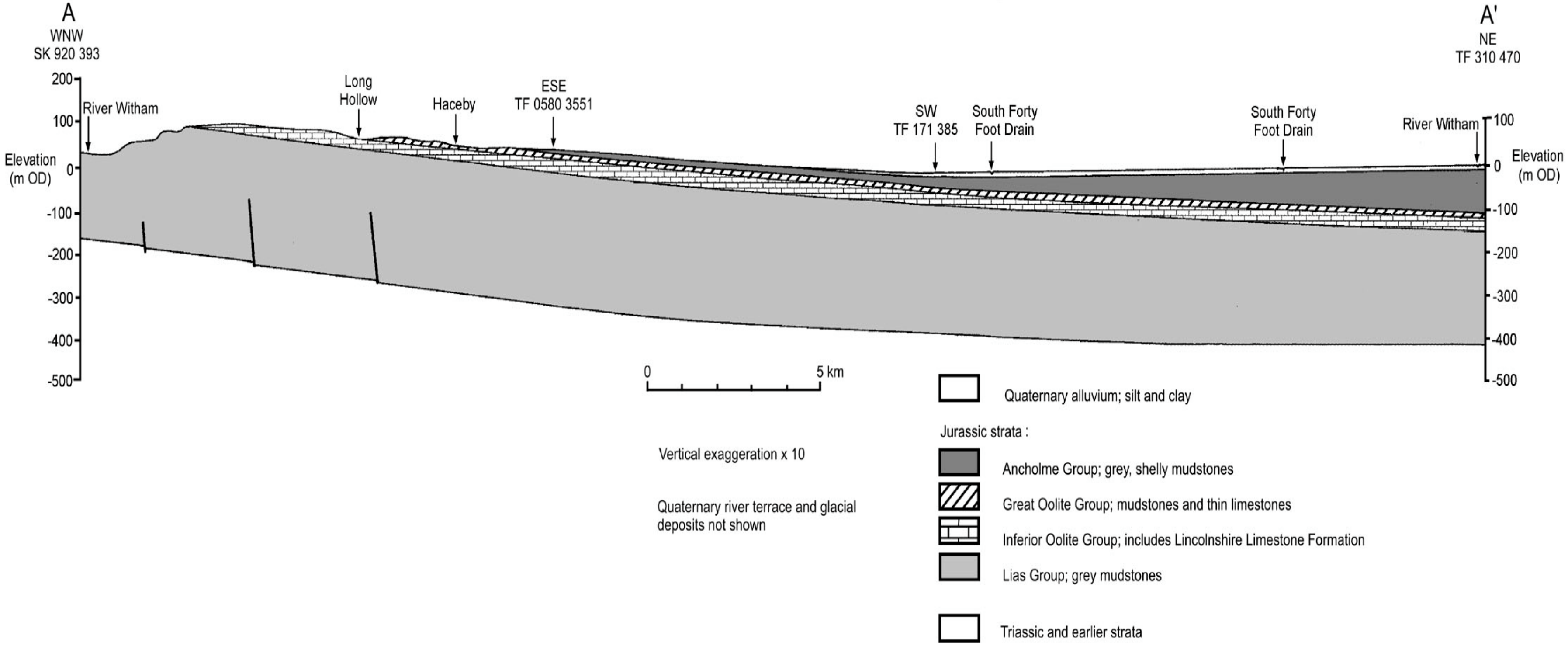


Figure 1.4 Geological cross-section of the Sleaford study area. The line of section A-A' is shown in Figure 1.3. Based on Geological Survey 1:50,000 Solid and Drift Edition Sheets 127 and 128

Annual average rainfall in the area is only 600 mm compared with 897 mm for England and Wales. Average effective rainfall in the Anglian Region can be as low as 147 mm per year and during the summer months evaporation rates can exceed rainfall (Environment Agency 2004b). Aquifer recharge occurs seasonally through direct infiltration over the outcrop (Rushton et al. 1994). In the east of the study area, the overlying confining beds inhibit conventional vertical recharge to the limestone (Bradbury et al. 1994).

Soils on the limestone outcrop are thin, well-drained loams or clay-loams that are well suited to certain arable crops such as cereals (Chilton and Shearer 1993). The leaching of nitrate from such land has, however, resulted in relatively high groundwater nitrate concentrations in the unconfined aquifer. Nitrate contamination in the central Lincolnshire Limestone aquifer was first investigated by a British Geological Survey study (Smith-Carington et al. 1983). Chilton and Shearer (1993) later updated this work by reviewing subsequent monitoring data and modelling results. Monitoring of water quality in and around the Sleaford NSA confirmed that groundwater nitrate concentrations in the unconfined limestone aquifer were in the range 70-120 mg NO_3/l. Groundwater nitrate concentrations varied seasonally and correlated with variations in groundwater levels. Nitrate concentrations at abstraction points were somewhat lower than the concentrations leached from the soil zone, suggesting that nitrate was being attenuated by matrix diffusion or denitrification (bacterial reduction of nitrate).

Lawrence and Foster (1986) considered the relative importance of matrix diffusion and denitrification as mechanisms for attenuating nitrate in groundwater as it moves down through the aquifer. They found that pore water nitrate concentrations were generally low for boreholes in the confined section, although the presence of thermonuclear tritium demonstrated that modern (post-1963) fissure water had diffused into the limestone matrix. The absence of associated nitrate thus suggested that bacterial denitrification was occurring and this was supported by the presence of denitrifying bacteria in fissure wall samples. Also, Wilson et al. (1990) observed an increase in the N_2/Ar ratio towards the redox boundary in the confined aquifer, which reflected additional N_2 production from nitrate reduction. This provided further evidence for denitrification in the confined zone.

A number of modelling studies have been undertaken on the Lincolnshire Limestone. Initial work by Rushton and Rathod (1979) outlined a two-layer aquifer system where the upper layer, with rapidly increasing transmissivity, only operates in periods of high recharge. Subsequent research at the University of Birmingham developed a numerical groundwater flow model of the Southern Lincolnshire Limestone area (Bradbury et al. 1994) and a fine grid model of the Slea catchment (the Sleaford Refinement Model; Rushton et al., 1994). These models have been used in a number of studies, including delimitation of the NSA boundaries.

Modelling work undertaken by the Water Research Centre for the National Rivers Authority was reported by Chilton and Shearer (1993). The model, which was first developed in 1984, was used to simulate groundwater nitrate concentrations in the central Lincolnshire Limestone and to investigate the impact of land-use changes under the NSA scheme. Modelling consisted of three components; a steady-state groundwater flow model, a nitrate leaching loss calculation, and a nitrate transport model. It also included a dual-porosity mechanism and was later modified to include a representation of denitrification. Predictive runs were carried out for several land-use scenarios, but only complete conversion to grass allowed some of the sources to achieve nitrate concentrations below 50 mg NO_3/l by 2040.

1.3.2 The River Slea and water abstraction

The main discharges from the Lincolnshire Limestone aquifer are spring flow and base flow to rivers. The River Slea rises in the Ancaster Gap at a junction between the Lincolnshire Limestone and the Lias Group mudstones and flows eastwards over older river terrace deposits (Belton sand and gravel) that cover the limestone outcrop in the river valley. Groundwater seeps into the Slea when the river intersects the water table. At the confining boundary to the west of Sleaford (where the limestone starts to become overlaid by more impermeable strata), three important springs support the river, namely Boiling Wells, Cobbler’s Hole and Guildhall. Spring discharges vary seasonally in response to changes in groundwater levels. Downstream of Sleaford where impermeable overlying beds are present, there is no interaction between the river and the limestone. The Slea is gauged at Leasingham Mill to the north east of the town. Figure 1.5 shows the locations of the key springs and the gauging site as part of a more detailed map of the Sleaford area.

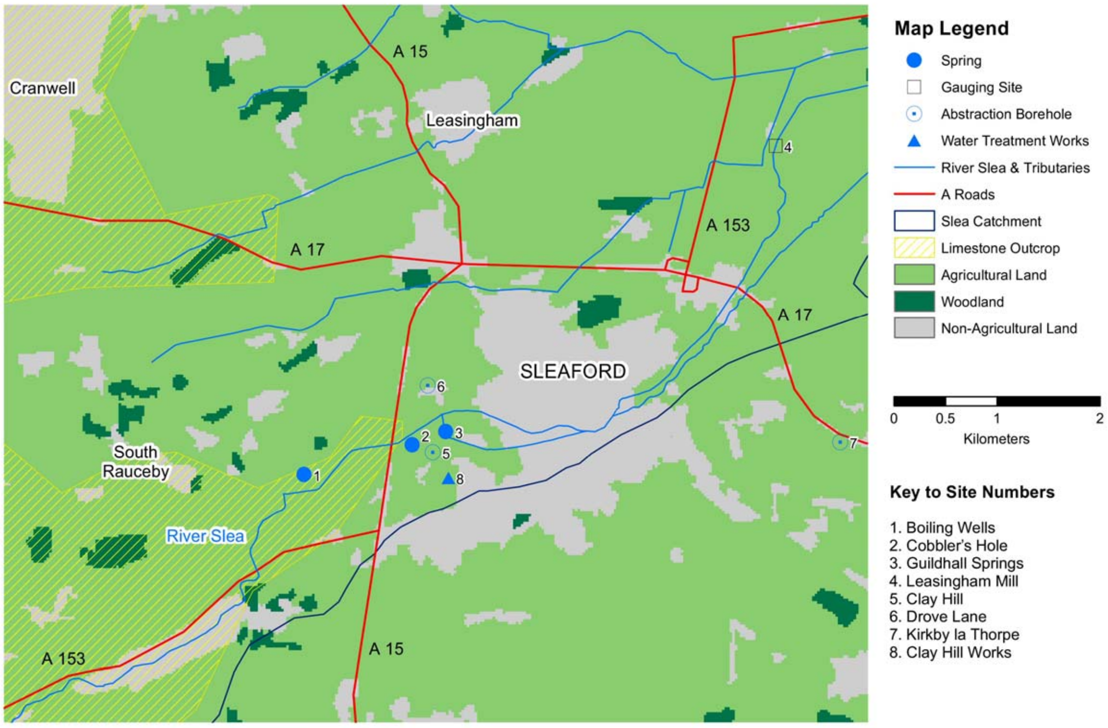


Figure 1.5 Key springs and abstraction borehole sites on the River Slea

Groundwater is abstracted for public supply and agricultural purposes, the major public abstractions in the study area being at Drove Lane and Clay Hill immediately to the west of Sleaford and at Kirkby la Thorpe to the east of the town (see Figure 1.5). As the name Sleaford implies, the flow of river water through the town has never been deep, but as abstraction rates increased in the 1960s and 1970s this reduced the spring flow and resulted in a number of occasions (such as in 1976 and 1984) where the river bed through the town dried up completely. This generated considerable local concern over the level of water abstraction and state of the aquifer, eventually leading to the commissioning in 1994 of a river support borehole to provide low-flow augmentation during the summer months (Gostick undated; Environment Agency 2004b).

The current Witham Catchment Abstraction Management Strategy (CAMS) classifies the Upper Slea Water Resource Management Unit (WRMU) as 'over-licensed' and the Confined Lincolnshire Limestone WRMU as 'no water available', which effectively means that there is no available capacity in the local water resource to meet further growth in demand (Environment Agency 2004b).

1.3.3 Socio-economic setting

Sleaford is the main population centre within the Slea catchment. Other settlements are predominantly nucleated villages with a scattering of more isolated farmsteads. The history of the town and countryside are intrinsically linked, with the presence of the River Slea and many aquifer-fed springs having played an important role. The town developed as a centre for the processing and trading of farm products and the use of local water resources has been central to many agricultural and industrial enterprises. The Domesday Book reported the presence of some dozen water mills at or near Sleaford and during subsequent centuries, such mills were used for a variety of tasks including grain processing and the production of ropes, paper and bonemeal fertilisers (Gostick undated). The local spring water has been bottled and sold and has supported commercial watercress beds. More recently, abstracted water has been used for secondary agricultural processes such as vegetable washing and food processing (Gostick undated; Environment Agency 2004b).

Farming activities have, as always, reflected economic and environmental conditions. Prior to the Second World War, around 50 per cent of the agricultural land in the Kesteven division of Lincolnshire (which extended from Stamford to Lincoln and included all of the study area) was producing annual crops, with 8-10 per cent in ley grassland (fallow) and some 40 per cent in permanent pasture (Stamp 1942; Smith and Richardson 1950). Sleaford itself had a corn exchange and wool and livestock markets, as well as barley-malting and seed-packing industries (Smith and Richardson 1950).

During the war, the proportion of farmland under tillage rose to over 65 per cent, while permanent pasture declined to less than 25 per cent. The main arable crops (in descending order of importance) were barley, wheat, sugar beet and potatoes, with oats and root crops also grown for livestock feed. The number of cattle reared and fattened in the area increased during the war at the expense of sheep, which were discouraged on lowland farms suitable for growing crops. This led to the demise of the wool market in Sleaford (Smith and Richardson 1950). Milk, pig and poultry production never featured highly in the area during the war, which surprised Smith and Richardson (1950) but this might have been due to a relatively high labour requirement compared to other enterprises.

Between 1936 and 1947, the density of working horses in Kesteven declined by about a third (Smith and Richardson 1950) and this trend accentuated in subsequent decades with the widespread introduction of the tractor and other forms of mechanisation. A general shift away from mixed farming in the Sleaford area (as described by Stamp 1942) and towards arable cultivation was associated with other aspects of agricultural intensification such as the installation of land drains on heavier soils, increases in fertiliser and pesticide applications and the expansion of cultivation onto areas that were previously grassland or heath.

The combined impact of these developments on land use and cropping is illustrated in Figure 1.6, which shows a pie chart of data for the Slea catchment as recorded in the June 2001 Agricultural Census. At this time, there was still some land under NSA agreements (see Section 1.2) but even so, less than 15 per cent of the catchment was covered by grass (of which 10 per cent was permanent grass). The chart also indicates that most of the important arable crops are still the same as in the late 1930s, though wheat has become more widespread than barley and oil seed rape has occupied a significant place in many rotations since the 1980s. With respect to livestock, there are still some cattle (mostly for beef production), pigs and sheep maintained in the area, but the major change has been an increase in poultry units, especially since the early 1990s.

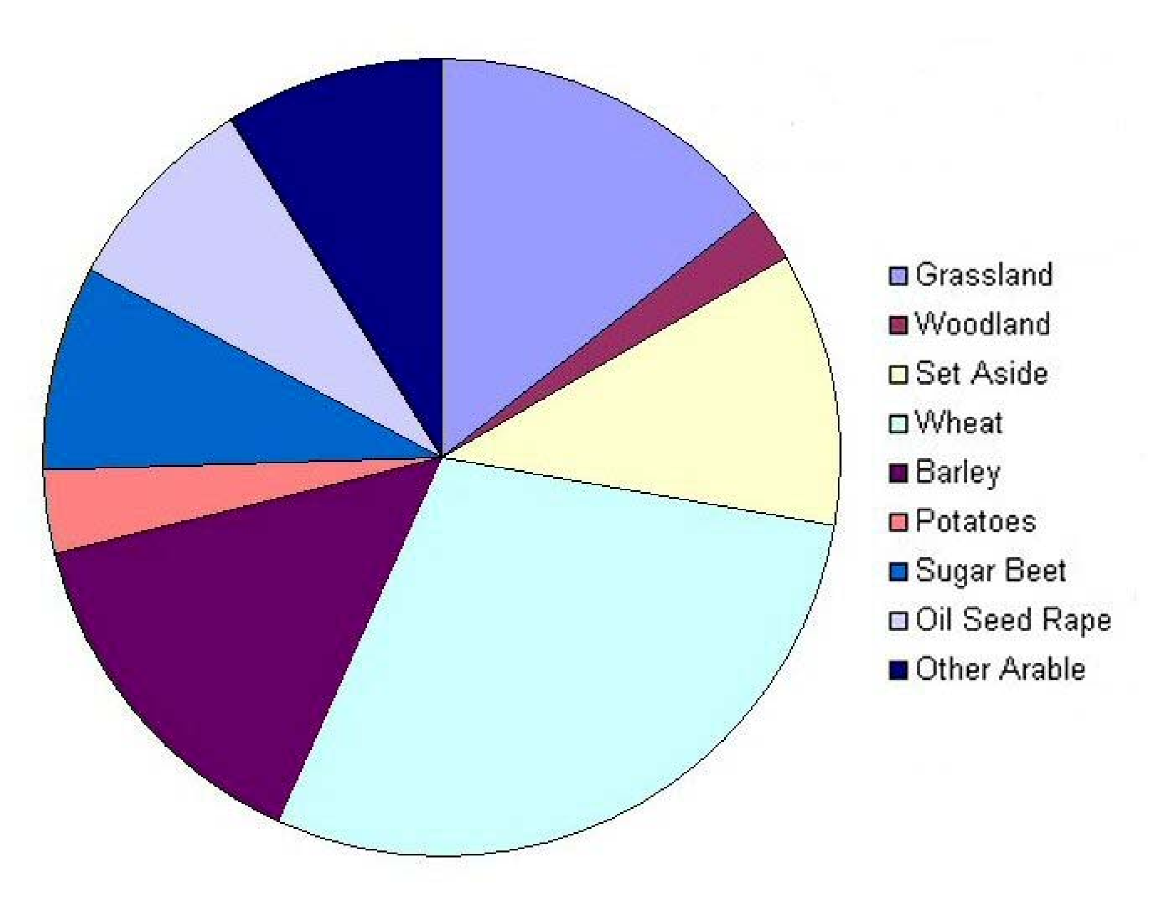


Figure 1.6 Agricultural land use in the Slea catchment, June 2001

Alongside the evolution of the agricultural economy, there have been other changes in Sleaford and surrounding villages. During the 1950s and 1960s, many of the villages that had previously depended on hand-pumped water and septic tanks gradually connected to mains water and sewerage systems. This, coupled with other aspects of modern lifestyles, contributed to the increased abstraction rates and subsequent river flow problems discussed in Section 1.3.2. More recently, the Sleaford area has attracted retirees and has been drawn into the commuting orbit of cities such as Peterborough, Cambridge and even London, with consequent house building and population growth. Table 1.2 shows that in the 16 years between 1975 and 1991, the resident population of North Kesteven District (which includes most of the Slea catchment) grew by less than 4,000, while in the subsequent 13 years it increased by over 20,000 to reach 100,500 by mid-2004.

Table 1.2 Population change in North Kesteven District 1975-2004 (from OPCS Series VS/PP1 Key Population and Vital Statistics and ONS Website http://www.statistics.gov.uk)

Date	Resident Population
Mid 1975	76,400
Mid 1980	79,600
Mid 1991	80,100
April 2001 (Census)	94,024
Mid 2004	100,500

There have been notable changes in the local environment to accommodate this growth, with new housing estates and loss of green space around Sleaford and several villages. Concern at the scale of such developments and a feeling that local infrastructure has not kept pace with growth also contributed to the lengthy debates over a new local plan in 2004-5 (see http://www.n-kesteven.gov.uk).

1.3.4 Summary

The preceding discussion has highlighted several features of the Slea catchment that made it a particularly suitable location for investigating different land-use measures to improve water quality management. These included the vulnerability of the limestone aquifer to diffuse nitrate pollution, the awareness among the farming community (through involvement in NSA and NVZ schemes) of such problems, and a real local interest in potential future water resource and land use management options. This situation was of considerable benefit in involving a wide variety of stakeholders in the activities and aims of the Water4all project.

2 Data and methods

2.1 Overall approach

The initial briefing document for the study envisaged five sub-projects:

- data collection/collation
- identifying and engaging with stakeholders
- modelling of land use scenarios
- developing options (including assessment of their cost-effectiveness)
- communication and stakeholder buy-in

This broad programme of work was implemented during the study, but in practice the boundaries between several sub-projects became blurred and the overall structure evolved slightly to resemble the arrangement shown in Figure 2.1

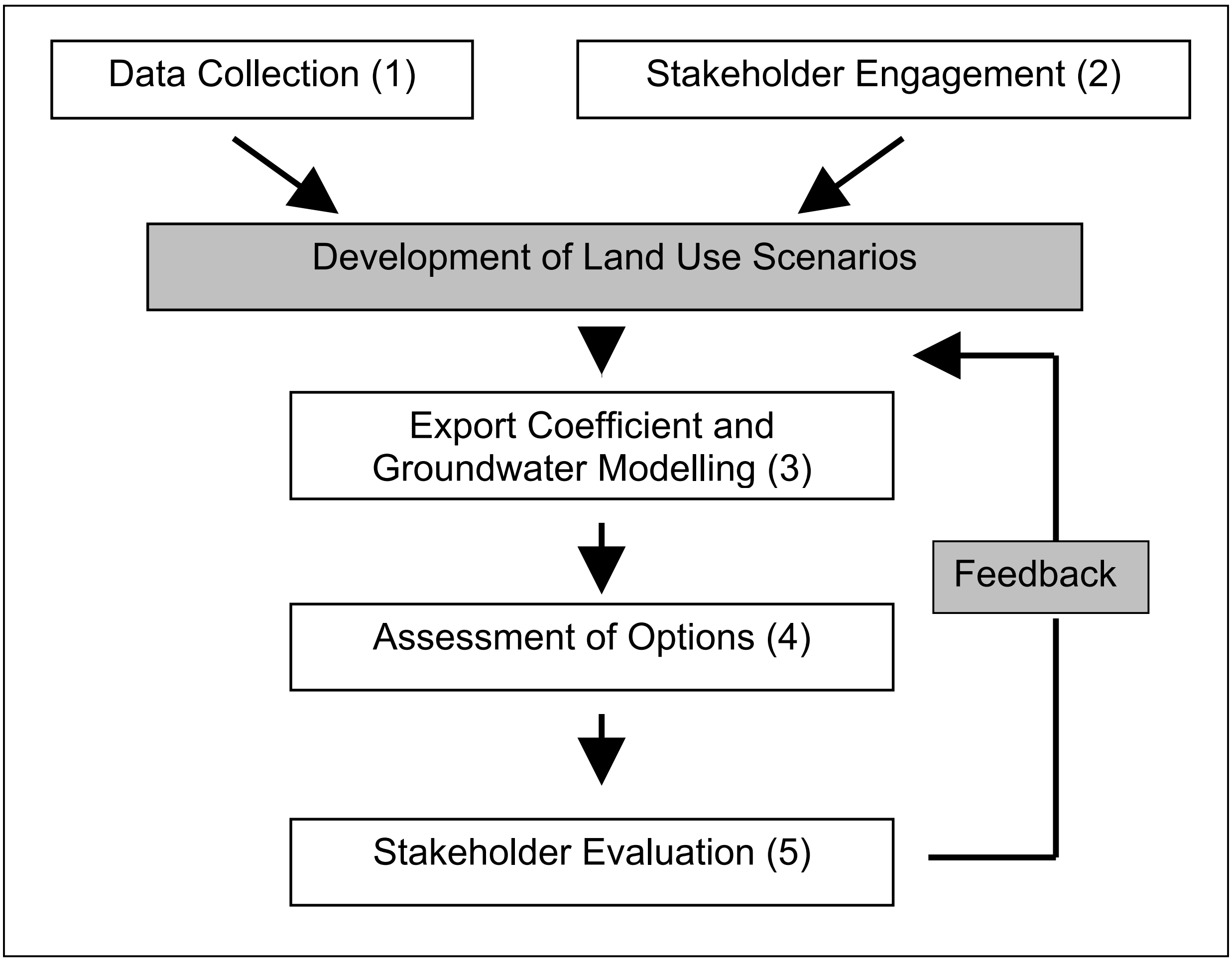


Figure 2.1 Overall project structure

Central to the project was the definition, modelling and assessment of land-use scenarios for the Slea catchment. A scenario can be defined as a “hypothetical sequence of events constructed for the purpose of focusing attention on causal processes and decision points" (Kahn and Wiener 1967, p6). Scenario-based frameworks have been used in a variety of studies on future patterns of land and water use (such as O'Riordan et al. 1993; UK Climate Impacts Programme 2001; Tress and Tress 2003; Haygarth et al. 2003; Hulse et al. 2004). According to Shearer (2005), the benefits of using scenarios as part of a decision-making process are that they:

- provide a structured means of organising information and comparing consequences;
- require a specificity of description (the who, what, where, when and why of actions) which increases awareness of implications;
- are not restricted to projections of the past;
- supply a focus to facilitate discussion and coordination between stakeholders.

The initial phase of the Slea case study involved two sub-projects being conducted in parallel, but with a shared goal of identifying potential future scenarios. Baseline information was collected on river flows, water quality, geological features, land use and other variables, while previous studies and current policy documents were reviewed. A database was compiled of individuals and organisations with an interest in land and water resource issues in the catchment (i.e. relevant stakeholders) and a series of individual interviews and group discussions were held to discuss the current situation, contemporary problems and possible courses of action. Altogether, this work was spread over some 18 months and resulted in a broad consensus on the types of scenarios that should be investigated.

A Geographical Information System (GIS) was used to integrate data, define each scenario in detail, prepare modelling inputs and present the results of the analysis. A GIS is based on computer software designed to handle spatially referenced information such as maps, site records, aerial photography and satellite imagery. This technology is now used for many different environmental applications (Longley et al. 2005). For the purposes of Water4all, it was deemed important to assess different geographical patterns of land-use measures within the study area, and this was reflected in a more spatially detailed approach than previous scenario modelling studies such as UKWIR (2001) which used average characteristics for entire catchments.

The involvement of local stakeholders was integral to the study. Based on the experience of previous studies (see discussions in Hemmati et al. 2002; Craig et al. 2002), it was considered important that stakeholders were involved at the earliest stage to ensure a sense of 'ownership' of the study. After defining the scenarios, modelling was used to estimate the effects of different land-use and management options on groundwater nitrate levels. Another sub-project explored the socio-economic implications of changing land use (such as the extent of farm income lost) and assessed the cost-effectiveness of this option compared with current water treatment.

Several stakeholder meetings (on both an individual and group basis) were held to review the evolving results and collect feedback, from which the groundwater modelling and socio-economic assessment were modified. As shown in Figure 1.7, the latter phase of the study (the last twelve months or so) had something of a cyclical structure. Stakeholder evaluation took place at several points during this stage of the study, with a final group meeting being held in late October 2005 to review all of the results available at that time.

2.2 Sources of data

Data were collected from a variety of primary and secondary sources. The main forms of primary data collection were interviews or focus group discussions with stakeholders; no field monitoring was conducted as part of the study. Secondary data included monitoring records for sites in the study area, map databases for use in a GIS (see further discussion below), and a wide range of reports or other publications, including a number of studies monitoring the progress and effectiveness of the Sleaford and Aswarby NSAs. Many of the secondary sources were supplied by (or via) Environment Agency offices in Lincoln and Peterborough, with other data coming from ADAS, Anglian Water Services, the Forestry Commission, the Meteorological Office, the University of Edinburgh Data Library (EDINA) and the University of Manchester (MIMAS).

The emphasis on the definition, modelling and assessment of scenarios required a baseline of environmental and socio-economic information for the study area. Details of the main variables and sources used are listed in Table 2.1. Much of the information was as current as possible (that is, up to 2003), but for some purposes (such as calibration of the groundwater model) it was also necessary to have historic records. The year 1988 was selected as the starting point for some datasets, as this preceded the introduction of NSAs and provided a sense of variability over a period of up to 15 years.

Basic topographic mapping for the study area was obtained from a number of Ordnance Survey (OS) products. These included mid-scale Meridian™ and more detailed Land-Line® vector maps, as well as the 50 metre grid Panorama™ digital elevation model (see http://www.ordnancesurvey.co.uk/oswebsite/products/index.html). The Environment Agency provided GIS data for the river and stream network, surface catchment boundaries, geological characteristics and various environmental designations (such as NSA and NVZ boundaries), as well as a 1992 land-use classification produced from Landsat satellite imagery supplemented by interpretation of OS maps. More recent land cover information was obtained from the LCM 2000 product (25 metre resolution) produced by the Centre for Ecology and Hydrology (CEH). Despite the name, this classification was based on satellite imagery from the late 1990s (see http://www.ceh.ac.uk/sections/seo/lcm2000_home.html). Initial scrutiny also revealed problems with the consistency of classification for some arable land categories across the study area (due to the absence of imagery at certain times) and so a combination of the 1992 map, the CEH LCM 2000 and more recent OS mapping (for instance, of built-up area boundaries) was used to generate a land cover framework.

The June Census conducted by Defra proved an important source of information on farming activities (see http://www.defra.gov.uk/esg/work_htm/publications/cs/farmstats_web/default.htm). This survey is based on a postal questionnaire and requires each farmer to record details of the crops, livestock and labour on their land as of June each year. Summaries of the census returns are released for different types of areas, such as parishes, wards and counties. However, the manner in which farms are allocated to single administrative areas (so that some land tabulated under one ward may well be in another), along with measures to protect confidentiality, means that users should be cautious when interpreting the data at a local scale (Clark 1982).

Researchers have developed procedures for converting the parish and ward returns to estimates for grid squares (see http://edina.ac.uk/agcensus/description.shtml), and since this format is particularly convenient for data integration and modelling, it was selected for use in the Water4all study. Details available via the EDINA service in Edinburgh included information aggregated to two, five and ten kilometre grid squares for a number of years. Given the aims of the project, the timespans of other datasets and the 40 km by 30 km size of the study area, it was decided to use the two kilometre product for 1988, 1994, 2000 and 2003 (the most recent processed).

Table 2.1 Types and sources of baseline data for the study area

Data Type	Scale or Resolution	Source
Gauging station records for Leasingham Mill 1988-2000	-	Environment Agency
Spring discharges 1988-2000	-	Environment Agency
Abstraction returns 1988-2000	-	Environment Agency
Groundwater levels 1988-2000	-	Environment Agency
Borehole records	-	Environment Agency
Groundwater quality data 1988-2000	-	Environment Agency
Surface water quality data 1988-2000	-	Environment Agency
River and stream network	1:50,000	Environment Agency
Surface catchment boundaries	1:50,000	Environment Agency
Groundwater units	1:250,000	Environment Agency
Groundwater vulnerability classification (solid geology and drift layers)	1:100,000	Environment Agency
NSA and NVZ boundaries	1:25,000	Environment Agency
1992 land use map	> 30 m	Environment Agency
MORECS (effective precipitation)	40 km cells	Meteorological Office (http://www.metoffice.co.uk/)
Land Cover Map 2000	25 m cells	Centre for Ecology & Hydrology (http://www.ceh.ac.uk/)
Meridian™ vector maps	Between 1:10,000 and 1:50,000 for different layers	Ordnance Survey (via http://edina.ac.uk/digimap/)
Land-Line® vector maps	1:1,250	Ordnance Survey (as above)
Panorama™ digital elevation model	50 m cells	Ordnance Survey (as above)
Agricultural census data 1988, 1994, 2000 and 2003	2 km grid	University of Edinburgh (http://edina.ac.uk/agcensus/)
Population census data 1991 and 2001	200 m grid	Office for National Statistics (via online services at the Universities of Edinburgh and Manchester)

To supplement the information on agricultural sources of nitrate, data on the distribution of the human population were generated from the Decennial Census statistics (see http://www.statistics.gov.uk/census/), using totals of residents for Enumeration Districts in 1991 and Output Areas in 2001 (the most detailed spatial scales published). Previous work by other researchers (see Martin 2002) had created 200 metre grid population surfaces from the 1991 Census data, so this information was downloaded from http://census.ac.uk/cdu/software/surpop/. An equivalent surface was created for the 2001 data using similar procedures with boundary and centroid details from http://www.census.ac.uk/casweb/ and http://edina.ac.uk/ukborders/. Transforming the census information in this way made it easier to integrate the population data with other data sources.

2.3 Outline of methods

2.3.1 Interviews and focus groups

The nature of the Water4all project meant that it was necessary to have a large number of meetings with individuals and groups of people. Stakeholder interviews were an important means of collecting primary data, particularly when confidential matters needed to be discussed or individuals were unable to attend group meetings. These interviews were designed according to advice from the literature (such as Silverman 2001; Valentine 2005) and typically involved one member of the research team leading the discussion through a structured list of questions, while a second person took notes of the conversation.

Five group discussion sessions were held during the project. These typically involved 10-20 participants, lasted two to three hours and took the form of an introductory presentation followed by a refreshment break and discussions organised in a focus group. The focus group format followed published advice (such as Krueger and Casey 2000; Flick 2002), with one member of the research team leading the participants through a series of pre-organised questions, while a second acted as a ‘scribe’ to record the discussion. In all five meetings, the participants were divided into two sets for the focus group element (with around 10 individuals in each) and the discussions usually lasted for 60-75 minutes. The initial three meetings involved separate sectors of stakeholders (such as farmers or civic groups), while the latter two brought all the interested parties together. This arrangement helped to build relationships as the research progressed and contributed to some positive and very helpful discussions.

2.3.2 Export coefficient modelling

The impact of different land-use scenarios on groundwater nitrate levels was explored in a two-stage approach. An export (or release) coefficient procedure was used to estimate the amount of nitrate from different sources entering the soil zone, while a groundwater model was used to calculate how these inputs would pass through the hydrogeological system and alter the nitrate levels at specific locations (such as abstraction boreholes) over time. Combining the two modelling tools proved beneficial, because export coefficients were a relatively quick and efficient means of estimating the consequences of a particular pattern of land use, but as a steady-state method could not readily predict changes over time in the way that the groundwater model could.

In order to implement the export coefficient model, it was necessary to decide on the spatial resolution at which soil nitrate estimates should be produced. Initial work in 2004 produced single estimates for units such as the entire study area or the Slea catchment, but as the research progressed it became apparent that more spatially disaggregated outputs would be needed. As discussed in Section 2.2, the source data were at a variety of scales and it was ultimately decided to generate estimates for 2 km grid cells. Since the study area was 40 km by 30 km this meant that there were 300 such cells in total.

A major factor in selecting the 2 km grid cells was the resolution of the Agricultural Census data. Given the way in which these details are compiled (see Section 2.2.), it was considered potentially misleading to interpolate them to any finer scale and thus, wiser to aggregate other datasets (for example, on land cover and population) to be consistent with the Agricultural Census grid squares. The 2 km grid also provided a more stable representation of the broad crop rotations in use, whereas smaller cells would have shown much more variability in farming activities from year to year.

Export coefficient modelling has been employed in many studies of diffuse agricultural pollutants such as nitrates or phosphates (Johnes 1996; Worrall and Burt 1999; Whitehead et al. 2002; Haygarth et al. 2003) and is based on the following equation:

$$L = \sum_{i=1}^{n} E_i \, [A_i \, (I_i)] + P$$

where L is the sum of the annual loss of nitrogen for n land use type

A_i is the area occupied by land use type i (or number of livestock type i)

I_i is the annual nitrogen input to land use type i (or number of livestock type i)

E_i is the export coefficient for land use type i (or number of livestock type i)

P is the input of nitrogen from precipitation

Figure 2.2 summarises the stages involved in the export coefficient calculations and indicates that the first step involved using GIS software (ArcGIS v9, see http://www.esri.com) to derive profiles of land-use areas (including crops), livestock and population counts, and precipitation levels for each 2 km grid square in the study area. This was carried out for each of the four baseline years (1988, 1994, 2000 and 2003) and the resulting tables were exported to Microsoft Excel (http://office.microsoft.com/), where further calculations generated similar profiles for each 2 km cell under the different land-use scenarios.

The second step was to add estimated nitrogen inputs and export coefficients for the different land-use and livestock categories to the Excel spreadsheets. These parameters were derived primarily from a range of published sources (see further discussion in Section 4.2.3) and included variants to reflect modifications in land management practices under some of the scenarios. Functions in Excel were then used to multiply the parameters by their corresponding areas or counts and the results were summed to produce estimates of total annual nitrogen loss for each 2 km grid cell. Subsequently, these sets of figures were imported back into the GIS software for mapping and also formed one of the key inputs for the modelling of changes in groundwater nitrate concentrations.

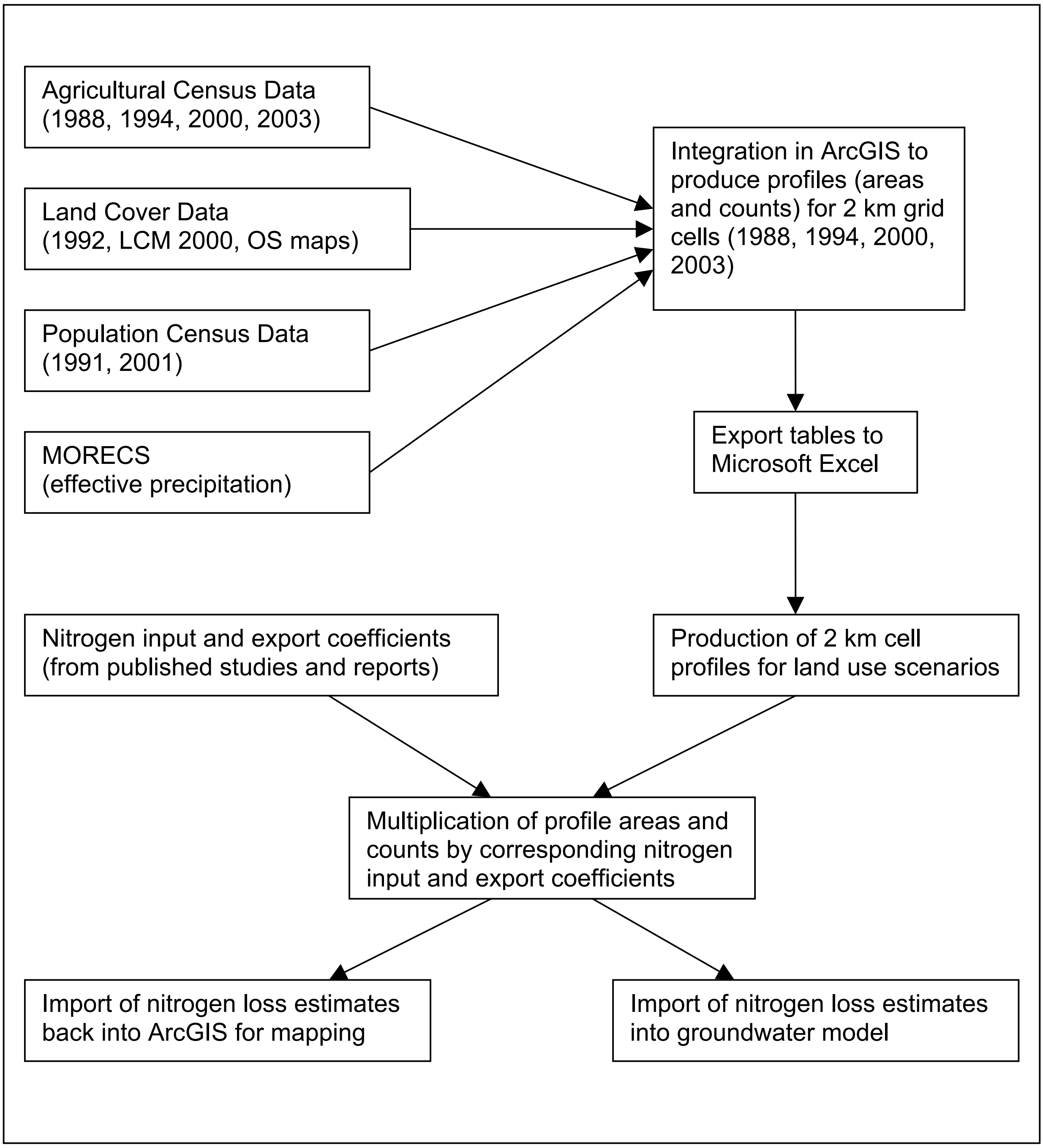


Figure 2.2 Steps involved in the export coefficient modelling

2.3.3 Groundwater modelling

The main data sources and methods in the groundwater modelling are summarised in Figure 2.3. Visual MODFLOW v3.1 (Waterloo Hydrogeologic, 2003) was the main software used and the initial strategy involved developing a steady-state groundwater flow model calibrated to average conditions for the period 1988-1998. The particle-tracking scheme MODPATH (Pollock 1989) was then used to define capture zones for the main public water supply abstraction boreholes, springs and the River Slea. A transient state flow model was developed for the period 1988-2030 which provided the flow distribution for the solute transport model, with a calibration period of 1988-2000. The transport model (MT3DMS; Zheng and Wang 1999) was used to simulate nitrate concentrations in the aquifer and assess the impacts of different land-use scenarios through to 2030. The groundwater flow and transport models are described at greater length in Section 4.3. For software details see http://www.waterloohydrogeologic.com.

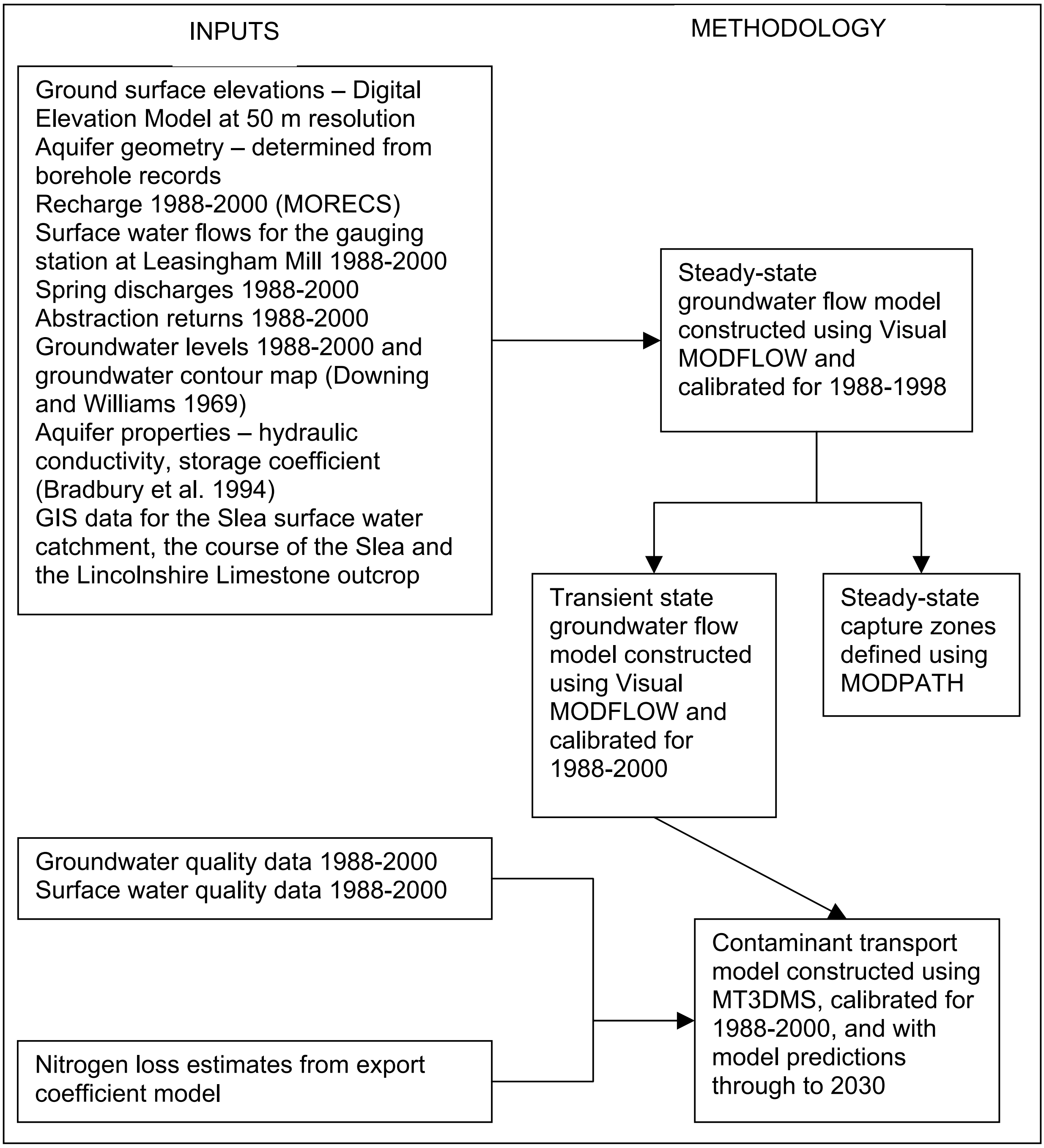


Figure 2.3 Data sources and methods for groundwater modelling

2.3.4 Socio-economic implications of changing land use

The economic consequences for farmers of alterations in land use and management practices was evaluated by calculating changes in total agricultural gross margins (GMs). The GM measure is not the same as profitability, since the gross margin of a particular enterprise (such as a crop) is the income (for example, yield x market price per hectare) minus variable costs (such as seed, fertiliser, sprays, casual labour for harvesting and other sundry items), usually expressed in Sterling pounds per hectare or £/ha. Fixed costs (such as specialist machinery and other overheads) are therefore excluded, but as these vary from farm to farm, the gross margin is widely used as a farm planning tool (see Nix et al. 2004) and has also been used in other scenario studies (for example, UKWIR 2001).

Gross margin totals were obtained for the 2 km grid cells covering the Slea catchment by using the same land-use and livestock profile data that formed the basis of the export coefficient modelling, but multiplying the areas and counts by estimates from the annual Nix Farm Management Pocketbook and other published sources rather than nitrate input and export parameters. These calculations were carried out in Microsoft Excel and the results (in terms of GM income foregone) were compared with estimates of water treatment costs for the catchment using information from Anglian Water Services and published reports. Other potential benefits from changes in land use (such as for recreation and biodiversity) were also briefly explored and GIS-based landscape visualisation techniques (Appleton et al. 2002; Bishop and Lange 2005) were used to depict how the visual appearance of part of the Slea catchment might change under certain scenarios.

2.4 Summary

This chapter has discussed the principal data sources and methods used in the Slea catchment case study. The following chapter describes the process of stakeholder engagement and how this led to the definition of a series of land-use scenarios which were subsequently modelled and evaluated.

3 Stakeholder engagement and scenario development

3.1 Introduction

This chapter begins by outlining the initial stakeholder engagement, reviewing the main opinions expressed and insights gained. It then lists the most important drivers identified from the literature search, and explains how land use scenarios were developed and then refined through further group discussions.

3.2 The engagement process

Gathering local knowledge on existing projects and relationships (collaborative or competitive) between organisations and individuals helped establish the best strategy for introducing Water4all to the local community. The contribution of a research team member (Paddy Johnson) with long-established links in the Sleaford area was also invaluable. An initial network of contacts was developed over a period of some nine months (but was further supplemented as the study progressed) and included representatives from the following sectors:

- Defra (including the Rural Development Service)
- Environment Agency
- farm produce quality assurance organisations
- farmers
- farming organisations and consultants
- Government Office for the East Midlands
- internal drainage boards
- landowning organisations
- local civic organisations
- local planning authorities
- nature conservation and countryside organisations
- navigation and waterways associations
- water companies (Anglian Water Services)
- water watchdogs
- woodland and forestry organisations

Water pollution can be an emotive issue (see O'Riordan and Bentham 1993; Addiscott 2005), and there was a relatively high degree of sensitivity locally, primarily arising from the following: awareness of high nitrate readings and problems with local water supply boreholes; concerns about the level of flow in the River Slea; the inclusion of the area in the Nitrate Sensitive Areas scheme in the 1990s; the abrupt manner in which the NSAs were terminated in 1998; and a recent large-scale river chemical pollution incident.

A rather simplified division between those regarded as ‘polluters’ (such as the farming community) and others who do not perceive themselves to contribute to the problem can sometimes arise. A broader view would argue that in fact everyone is culpable (as consumers of farm produce) and that community collaboration is needed to provide a solution that will not penalise one sector unfairly - this point also features in the WFD which espouses a principle of sectorial even-handedness.

These sensitivities were taken into account when devising the best way to collect information and opinions from all sectors. Consequently, a combination of group meetings and individual interviews was used to obtain information on current land or water management issues and views on how the situation might change in the future.

3.2.1 Initial meetings with stakeholders

For the initial introduction to the project, separate meetings were organised for the following sectors:

- Interested organisations - on 17 November 2003, eleven organisations attended the meeting including representatives from local district councils, the Environment Agency, Defra Rural Development Service, ADAS, the National Farmers Union, Anglian Water Services, the Forestry Commission, the Woodland Trust and the Lincolnshire Wildlife Trust
- Farmers and landowners – held on 16 January 2004 where 17 attended
- Civic groups - held on 1 November 2004 where 22 people attended

Three questions were posed at the meetings:

- Do we agree that there is a water quality issue that we need to address by land use management or change?
- What sorts of future land use changes should we be trying to investigate and why?
- How could land use change be achieved?

All meetings began with a presentation on the aims of the study, followed by focus group discussions where comments were recorded by scribes. Summaries of the discussion were subsequently circulated to attendees to ensure that all opinions had been captured and accurately recorded. Further details of the meetings are given in Lovett et al. (2004).

3.2.2 Additional visits

As a supplement to the initial meetings, a dozen visits to individuals were undertaken to make contact with people unable to attend the group sessions, or where contact details were obtained after the meetings had taken place. These visits typically took the form of a structured interview, covering similar questions to those posed at the group meetings but also designed to add further to the information already obtained.

Visits to representatives of organisations

The dual purpose of these visits was to introduce the Water4all project and to elicit views to guide the development of future land-use scenarios for the catchment. Many of the meetings were also helpful in improving the understanding of local issues and practices. Topics covered during the discussions are listed below:

- current land and water resource issues in the catchment;
- how land and water use may change in the future;
- how these changes could affect water quality;
- types of changes that might improve water quality;
- ways of achieving these changes;
- possible difficulties involved.

Visits to key farmers

Four local farmers (selected to represent the main types of enterprise prevalent in the Slea catchment) were interviewed in more detail about their current activities and how they saw their business evolving in the future. These discussions were very helpful in providing insights that would have been difficult to obtain in a group setting (due to confidentiality considerations) and in evaluating the extent to which opportunities or difficulties envisaged by other farmers would be generally applicable throughout the area.

3.3 Land-use issues and drivers of change

The main aims of the activities described in the previous section were to collect information on current land or water management issues and views on how the situation might change in the future. Opinions on the former were relatively straightforward to obtain, but stakeholders were generally less certain about how land use in the area might change over coming years. One constraint at the time of the discussions in 2003-2004 was the uncertainty regarding the outcomes of CAP reforms (such as the details of new agri-environment and Single Farm Payment schemes); consequently, most farmers were unsure how these changes would affect their activities. There also appeared to be relatively little awareness of the WFD and how this might influence farming practices. The information collected was thus more speculative than definitive regarding future land-use trends.

3.3.1 Issues and trends identified from the discussions

From the three initial meetings, it emerged that one or two groups felt they were perceived more negatively than was actually the case. For example, there was a greater degree of understanding about the issues of and empathy towards the respective positions of townspeople and farmers than each group seemed to expect. There was also a good degree of consensus between the responses given in the formal meetings and individual interviews, apart from the acceptability of different policy mechanisms to bring about land-use change to reduce diffuse pollution.

As previously mentioned, three key questions were put to the group meetings. A summary of the responses to these is given below.

Do we agree that there is a water quality issue that we need to address by land use management or change?

Both the organisations and farmers chose to interpret this question in terms of public perception of water quality. The view was that water supply and river flow was of greater public concern than nitrate levels. Whilst the civic groups did indeed express concern about these issues, they also felt constrained by a lack of information on what research was currently being or had previously been conducted to support the designation of NVZs, or the purported health risks from high nitrate levels (such as blue-baby syndrome).

There was some surprise and irritation that we should be asking this question on the back of the termination of the Nitrate Sensitive Areas scheme. Both farmers and organisations expressed their disappointment at the ending of this compensated scheme, which brought about large-scale conversion of arable land to grassland for the sole purpose of reducing nitrate levels in groundwater. Since the end of the scheme, the majority of the land has been converted back to arable production. Regret was expressed in all three meetings that the NSA scheme was not allowed to run for long enough to prove one way or another whether taking land out of arable production would reduce groundwater nitrate levels.

The civic groups identified diffuse pollution from agriculture as an important issue and felt that it was not acceptable simply to treat drinking water, given that damage to the wider environment was also being done. The groups believed there should be a move towards the prevention of pollution.

What sorts of future land use changes should we be trying to investigate and why?

Although it was not possible for the farming community to state with any certainty how their businesses (and hence land use) might change over the next few years, it was possible to identify the main factors that would be the drivers of land-use change. These are listed below in descending order of the emphasis given:

- The market price of different crops.
- Effects of CAP reforms – some farmers predicted more variability on what would be grown year on year as they chased profit, and foresaw greater intensification in some enterprises. Other farmers may retire and lease out land (depending on the size of farm and quality of land).
- Effects of world market and EU trade policies, particularly for sugar beet.
- Constraints imposed by supermarket buyers on crop management practices.
- Constraints imposed by other assured produce schemes (based on public food safety concerns).
- Water availability and the frequency of dry summers (based on concerns about global warming and the adequacy of water supply for irrigation).

- New environmental stewardship schemes which would be likely lead to wider prevalence of features such as field margins, although they might otherwise have little influence on land use.

It was suggested that many of these factors could lead to switches between crop types, though several of the interviewees thought a switch from arable farming to grassland and livestock systems would be unlikely, due to the loss of expertise in this type of farming from the area in recent decades, and the loss of agricultural supply companies (such as fencing companies) that support livestock farming. The costs of converting to this farming system were considered too great for it to be reinstated. In the Sleaford area, where the quality of most land is moderate to good, it was felt that arable farming is likely to continue and that farm sizes will continue to increase as the land of smaller, more marginal farms is leased to larger enterprises.

From interviews with individual farmers, it emerged that proposals to reform the EU sugar regime, which in turn were expected to lead to a reduction in prices, could be a serious issue for some farmers in the area and might lead to land-use change. Also, there was a high level of concern about climate change, particularly any increased incidence of dry summers which would affect the viability of some crops because of increased irrigation needs and costs. One farmer thought that the drier summers and wetter winters forecast under climate change scenarios would have a bigger influence on hydrogeology than changes in land use, and that water availability would be a big constraint on future land-use possibilities in the area.

Some meeting participants and interviewees saw the construction of winter storage reservoirs as the way forward, along with the installation of trickle irrigation which would produce better control and targeted use of water. However, many felt that the costs of trickle irrigation and reservoir construction were currently too high and would require government support to implement. There was also a view that without careful management, widespread increases in crop irrigation could lead to greater nutrient leaching (though the major risk period for nitrate leaching is not during the irrigation season).

Civic groups viewed increased access to the countryside as their main preferred change in the future. They expressed a desire for recreational use of farm reservoirs and river corridors, and hoped to see more riverside walks as well as the re-naturalisation of river corridors to benefit wildlife/wetlands and associated leisure or tourism (in conjunction with the restoration of navigation along the Slea up to Sleaford).

The overall consensus from the meetings and interviews was that arable farming, largely unchanged from its current form, would continue to dominate in the Slea catchment. The future land-use scenarios therefore needed to focus on the potential environmental impacts associated with this activity and ways of minimising them, such as through use of minimum tillage, cover crops and grass margins around watercourses. Some interest was expressed in growing biofuel crops if future economic conditions proved favourable.

How could land use change be achieved?

This question was used to identify policy measures and inducements (regulations, taxes, voluntary agreements, provision of information and advice) that would be acceptable means of bringing about land-use changes to reduce diffuse pollution. There was general agreement that compensatory measures would find most favour, with the former NSA scheme named as a good example of this. Amongst the farming group there was more support for a public water tax payable across the community to cover compensation for land-use change, rather than a pollution tax levied on the producers. However, organisations tended to favour regulatory control of land use in sensitive areas rather than taxation. Civic groups preferred the diversion of funding from water treatment to agri-environmental schemes to support land-use change.

3.3.2 Key drivers of land-use change identified from the literature

A substantial review of policy, planning and research literature was conducted (see sources listed in Lovett et al. 2004). The main findings, summarised below, provided important additional insights into possible future land-use changes.

The review identified a wide range of policy areas that can influence individual decisions on future land use, of which Figure 3.1 illustrates the main drivers. At the global scale these include world trade agreements and market prices for crops, the latter a response to policy/trade conditions, buyer behaviour and natural environmental conditions influencing yield. The impacts of such factors are mediated at the European scale by the CAP and a series of directives implemented at the national scale through further policies, strategies, schemes and incentives. Some of these have a greater direct effect on decisions made by land managers than others. Incentive-led policies, such as payments under CAP, currently have more influence than opt-in agri-environmental schemes, though closer integration of these over the next few years through cross-compliance requirements is intended to improve land management.

The policy likely to have the greatest immediate effect on land-use decisions is the introduction of the Single Farm Payment (SFP). This is an area-based payment decoupled from the current production-linked system that features cross-compliance rules on animal welfare, public health and environmental benefits (Defra 2004b). There is considerable uncertainty on how individual farmers/landowners will respond to this situation (Centre for Rural Economics Research 2004). Nevertheless, there seems to be a general expectation (by policy advisors) that introduction of the SFP will lead to extensification of production. For example, a review for Defra co-ordinated by the Royal Agricultural College (GRA-RACE and IEEP 2003) suggested a polarisation between farms able to continue to operate profitably (and likely to expand and grow further) and those likely to be better off by reducing their farming activities. In addition, the arable sector could see a switch towards more simplified systems with fewer break crops, less rotational set-aside and larger areas of winter wheat. Within the Slea catchment, the view of most stakeholders was that land is unlikely to come out of production with the introduction of the SFP; if some individuals do decide to stop farming, it is more probable that their land will be leased to other farm businesses and continue to be intensively managed.

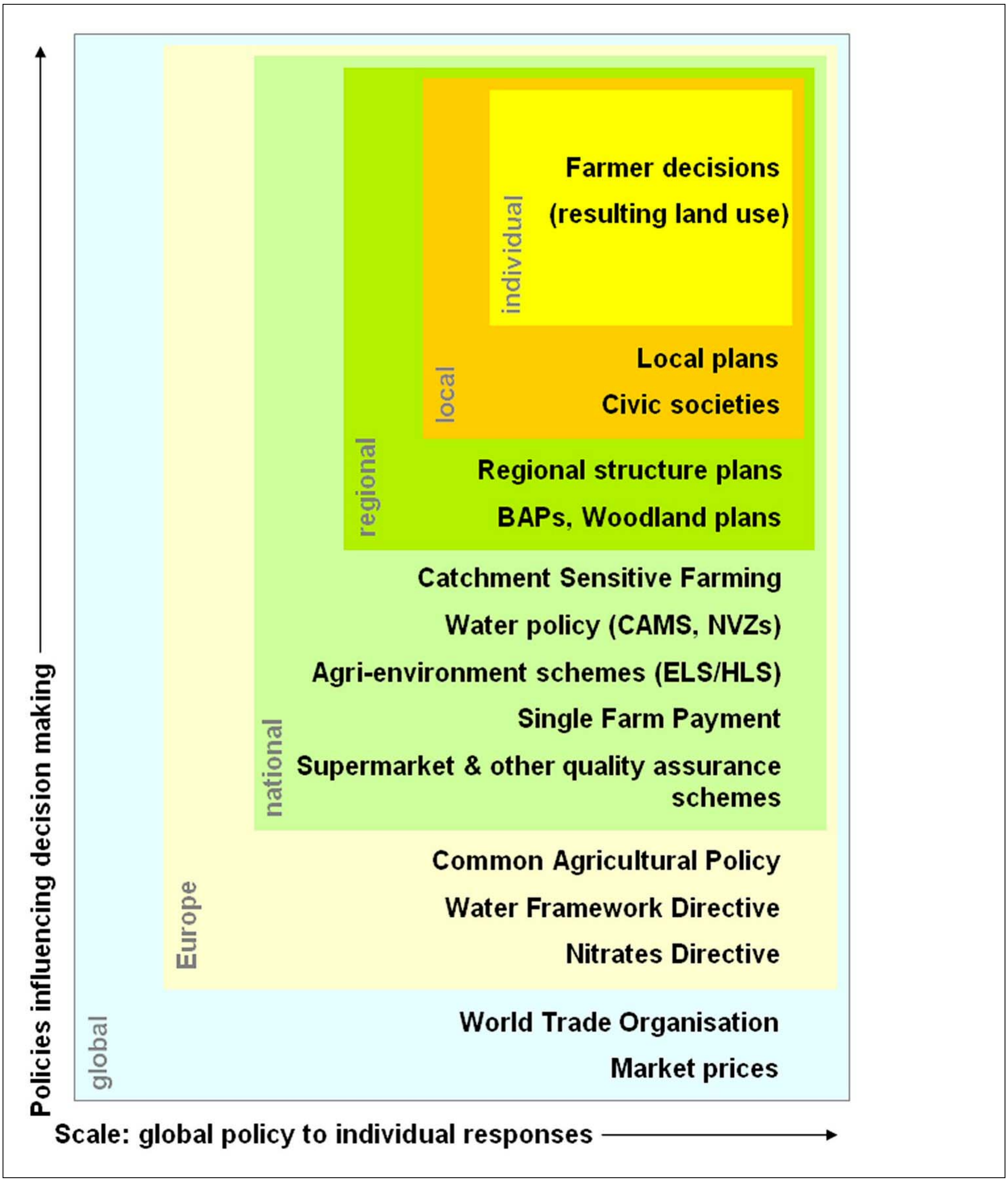


Figure 3.1 Key policy drivers influencing land use

Changes in the system of direct payments are being accompanied by the introduction of new agri-environmental schemes. Entry Level Stewardship (ELS) is a whole-farm scheme, open to all farmers and land managers, which pays a flat rate of £30/ha per year for implementing land management measures (including crop protection, nutrient or soil plans) that meet a specified points target (Defra 2005a). Experience from the pilot ELS sites (such as at Market Deeping in Lincolnshire) suggests that the scheme will have limited impact on land use in lowland England, though it could well increase the prevalence of uncultivated margins along hedgerows and water courses (Boatman et al. 2004). Uptake of the ELS has been hindered by administrative problems, but as of November 2005 approximately 40 per cent of English farmers entering ELS had included crop protection, manure, nutrient or soil management plans among the options on their applications (Clare Blackledge, Environment Agency, personal communication).

Alongside the ELS there is also a Higher Level Stewardship (HLS) scheme to support more complex types of land management (including arable reversion to grassland to prevent erosion or run-off), but admission to this programme is discretionary and targeted at high priority situations (Defra 2005b). Regional targeting guidelines have been published (see http://www.defra.gov.uk/erdp/schemes/jca-ts/default.htm), but those encompassing the Slea catchment (JCA 047: Southern Lincolnshire Edge) emphasise biodiversity issues and do not explicitly mention groundwater protection.

Local stakeholders were very aware of the likely changes in agricultural policies, but less familiar with those relating to water resources, such as the WFD. As a response to the requirements of the WFD, in June 2004 Defra launched a Catchment Sensitive Farming (CSF) initiative with an extensive consultation on ways to deal with diffuse pollution from agriculture, ranging from no action through early regulation, advice and information campaigns (similar to the pesticides Voluntary Initiative), to taxes on nutrient inputs (Defra and HM Treasury 2004). A combination of these approaches appeared to be favoured, with early action targeted at priority catchments identified by English Nature (Defra 2004c).

In response to comments collected during consultation (Defra 2004d), further work was carried out in 2005 to develop a package of measures, with an emphasis on voluntary action and increasing awareness. This was followed in December 2005 by the announcement that forty catchments in England had been named priority areas for action, with the appointment of advisors who would work with farmers to encourage best practice (see http://www.defra.gov.uk/news/2005/051219a.htm). The Slea catchment was not included in these areas and more generally, the CSF seems to be focused on problems of surface water pollution rather than groundwater protection.

Overall, changes in agricultural policy are generally accepted as likely to have a beneficial effect on levels of diffuse pollution. For instance, a study by GFA-RACE and IEEP (2004) developed scenarios of farming changes (based on the CAP reform agreement as of June 2003) and assessed the implications for diffuse pollution. Under a scenario of full de-coupling of CAP payments from production, the introduction of a SFP based on historic entitlements, cross-compliance orientated at environmental protection and the introduction of ELS, these measures were predicted to reduce overall levels of nitrogen and phosphate (mainly via a reduction in cropped land and an increase in fallow). An update of these findings following the February 2004 announcement on CAP implementation indicated that the revised proposals were likely to be more beneficial in reducing diffuse pollution in the arable sector than indicated by the illustrative scenario.

Other studies have examined the potential costs of implementing agricultural practices that would help to meet the good ecological and chemical status requirements of the WFD. A report for Defra by Risk and Policy Analysts (2003) identified four main types of measures – reducing inputs, preventing enrichment from run-off, reducing vulnerability to erosion and containing run-off contaminants. Three regional assessments were then extrapolated to estimate national costs to farm businesses of £80-£200m per annum. This is less than the damage costs (at least £250m per year) estimated by the Environment Agency (2002), suggesting that there would be a net benefit in undertaking such action. Research for English Nature and the Environment Agency (see Dwyer et al. 2002 and Withers et al. 2003) indicated that farmers would be supportive of a grant-aided system to instigate controls, but estimated that the financial resources required would be greater than those then envisaged (and subsequently made available) under the Entry Level Stewardship scheme.

National and Local Biodiversity Action Plans, resulting from the Convention on Biological Diversity agreed at the Earth Summit in Rio de Janeiro in 1992, represent another policy sector likely to have an increasing influence on both agri-environmental schemes and planning guidance that will undoubtedly lead to some, though probably relatively minor, changes in agricultural land use. For example, measures in the new ELS relating to the creation of field margins are in line with a Biodiversity Action Plan (BAP) target to maintain, improve and restore the biodiversity of some 15,000 hectares of cereal field margins in the UK by 2010 (see http://www.lincsbap.org).

Regional Planning Guidance (RPG8) for the East Midlands reflects BAP policy guidance and identifies a need to increase biodiversity in the landscape through linking corridors and buffer zones, while reducing flood risk through drainage management. There is also an emphasis on increasing woodland cover (Policy 33) and protecting high-quality farmland from development (Policy 32). RPG8 Policy 46 on water use and development states: “Development should only proceed if the necessary water supplies, drainage and sewerage are available and can be provided without significant environmental impact or economic costs within the development time-scale.” RPG8 also pledges to “reduce unsustainable abstraction from watercourses and aquifers to sustainable levels” and “lessen the impacts of abstraction when river flows are low, especially by encouraging winter abstractions and storage reservoirs, particularly for agriculture” (Government Office for the East Midlands 2002, p58). This latter point suggests that there may be a sympathetic hearing for winter storage reservoir proposals, should funding be available for construction.

The local Witham Catchment Abstraction Management Strategy (CAMS) (Environment Agency 2004b), part of a new framework for managing water resources covered by the Water Act 2003, includes policies to encourage farmer collaboration on abstraction schemes and winter storage reservoirs. A resource assessment exercise undertaken as part of the CAMS process found that all of the water in the Lincolnshire Limestone aquifer “is already fully committed and has been for some time” (Environment Agency 2004b, p25); over the six-year lifetime of the CAMS, the Environment Agency intends to explore voluntary ‘resource recovery’ options that include revoking unused licences, reducing licensed abstraction quantities, and agreements to impose low flow controls.

At the local level, despite considerable new housing and expansion around Sleaford in recent years, a draft local plan in 2004 suggested that there was over-capacity in land allocated for housing development and that future growth was unlikely to be at the same rate (see http://www.n-kesteven.gov.uk). A sustainability appraisal of the North Kesteven Local Plan Deposit Draft (Litchfield Planning 2002) included objectives relating to water resources and concluded that the proposals compared favourably with the existing local plan, though the measures related more to water conservation and drainage rather than pollution control. The North Kesteven Local Strategic Partnership also re-launched their Community Strategy in 2005 which prioritises environmental issues and advocates working with the farming community to encourage better use of the countryside and the drafting of a charter for agriculture and horticulture (see http://www.nkcommunitystrategy.org.uk/Environment.html).

In conclusion, the review of policy, planning and research literature identified a number of factors likely to influence land use in the Slea catchment. These included changes in farm support mechanisms and agri-environmental schemes, as well as a greater emphasis on the sustainable use of resources in the planning system. Nevertheless, it did not appear that any of the currently envisaged changes would lead to dramatic alterations in farm practices and land use within the study area.

3.4 Developing and refining land-use scenarios

Following the meetings, visits and literature review, a draft set of five potential land-use change scenarios was devised (see Table 3.1). Some initial export coefficient modelling was also carried out (based on generalised land-use profiles for areas such as the limestone outcrop) to identify the type and magnitude of land-use change needed to reduce groundwater nitrate levels. The analyses suggested that conversions of at least half the arable land to grassland would be necessary to reduce nitrate leachate levels below the 50 mg NO_3/l EU limit.

Table 3.1 Initial land-use scenarios

Scenario	Description
Recent past (RP)	A continuation of existing measures (such as the NVZ).
Impact of current policy reforms (CP)	As scenario RP, but also incorporating likely land-use changes arising from the introduction of the Single Farm Payment, the Environmental Stewardship Scheme and so on.
Nitrate best practice (BP)	Supplementing scenario CP with agricultural best practice measures (such as the use of cover crops, avoidance of the 'leakiest crops') that would have the effect of reducing nitrate leaching.
Region-wide NSA (NSA)	Replicate the agricultural practices adopted under the 1990s NSA scheme on a catchment-wide basis.
Land use protection zones (PZ)	Investigate the effects of creating land use protection zones (such as low input grassland and/or woodland) in targeted areas (such as well capture zones and the upper River Slea). This scenario would also consider the scope for using such zones to provide public amenity or recreation facilities.

Details of the draft scenarios and initial export coefficient modelling were presented at another meeting held on the 1 March 2005. For the first time, stakeholders from all sectors (farming, organisations and civic groups) were invited to the same event. The meeting attracted 24 participants (in addition to the research team), including farmers and landowners, representatives of farming, farm advisory and forestry organisations; the water company and others with an interest in waterway management; local authority and civic group members.

The meeting began with a short update on progress on the Water4all project. Participants were then allocated to one of two focus group discussions (with even representation of people from different sectors within each). The groups were asked to consider three main questions and the discussions are summarised below.

Which of the scenarios do you think we should be working towards?

Based on the earlier presentation of the export coefficient modelling results, there was some acceptance – though with little enthusiasm - that the NSA and Protection Zone scenarios were the only ones likely to achieve the desired outcome. There was some support for targeted land use protection zones, given successes in other European countries with this approach. However, participants were concerned that the farming community would find implementing either of these scenarios difficult, and would require a very long commitment from government to financially support these land-use changes, beyond that seen in the previous NSA scheme.

Changes in farmers' investment plans and practices are difficult and need a long lead time and wind-down period. Alterations in such practices can also have knock-on impacts; for instance, the NSA scheme resulted in a number of long-serving farm employees being made redundant. The question was raised as to whether the water companies could invest in land-use change and management to improve water quality but it was explained that this is extremely difficult under the current regulatory arrangements.

Should anything else be included in them?

It was suggested that in addition to water quality, scenarios should consider implications for the quantity of water resources (such as the effect of land-use change on flow levels in the River Slea). A concern was also expressed that the scenarios were too simplistic – that is, that there was a need to look at overall sustainability, for example by bringing in urban areas and being more creative on water re-use and conservation, for truly holistic solutions involving the whole community rather than sectors of it. 'Win-win' packages were suggested, such as government support for land-use change such as planting trees, where landowners would benefit from the trees through timber sales or even the manufacture of timber products.

In a discussion of the merits or otherwise of new woodland planting, several participants voiced concerns over poor growth of previous tree plantings and were not convinced the land would be suitable for woodland. Nevertheless, there was some support for new recreational areas such as country parks with a mix of broadleaf trees and grassland.

How could the preferred scenarios best be achieved?

Several new policy measures (such as the SFP and ELS schemes) show a change in ethos towards a more sustainable, environmentally friendly approach which will help improve the nitrate situation. A long-term support scheme was favoured, but there was little confidence this could be achieved - "the depressing thing is the constant change" said one participant. A driver for change was urged, along with the money to make it possible, agencies to implement it and a local 'champion'. The point was made that farmers can work together - the pesticides Voluntary Initiative has demonstrated this - but there is a need for education to convince people living in towns - farmers will supply whatever is wanted if they are paid for it. However, farmers are increasingly working in a national and global economy, so planning and opinion-changing must happen at this scale. Concern was expressed that environmental issues are not as well understood as they should be in the UK, compared to countries like Denmark which promote 'pesticide-free towns'.

Overall, the meeting was constructive in bringing local groups together and allowing them to appreciate different sides of the arguments and possible options. It also helped to confirm that the scenarios were broadly appropriate and credible as far as the stakeholders were concerned.

3.4.1 Finalising the scenarios

Following discussions of the initial export coefficient modelling and comments made at the stakeholder meeting, a number of refinements were made to the scenarios and more detailed specifications produced. The main features of the final set of scenarios are listed in Table 3.2.

Table 3.2 Final land-use scenarios

Scenario	Description
Recent past (RP)	A continuation of the situation existing in 2003 (the most recent year for which Agricultural Census data was available).
Impact of current policy reforms (CP)	As scenario RP, but also incorporate likely land-use changes arising from the introduction of the Single Farm Payment, the Environmental Stewardship Scheme and so on. Two variants, reflecting differences in land being taken out of production and uptake of new agri-environmental schemes CPa: 5% of arable area converted to unfertilised grass. CPb: 10% of arable area converted to unfertilised grass.
Nitrate best practice (BP)	Supplement scenario CP with agricultural best practice measures that would have the effect of reducing nitrate leaching. Options based on 'intermediate' and 'protective' regimes, but also incorporating the CP variants giving four in total. BP1a: Intermediate measures with CPa. BP1b: Intermediate measures with CPb. BP2a: Protective measures with CPa. BP2b: Protective measures with CPb.
Regional NSA (NSA)	Replicate the agricultural practices adopted under the 1990s NSA scheme across the limestone outcrop. Incorporate the CP variants as two different starting points NSAa: NSA practices with CPa. NSAb: NSA practices with CPb.
Land use protection zones (PZ)	Supplement scenario CP with land use protection zones (such as low input grassland and/or woodland) in targeted areas (such as well capture zones and upper River Slea). Two variants. PZa: Priority area with substantial conversion to grass or woodland; scenario NSAa in remainder of a protection zone and scenario CPa elsewhere. PZb: Priority area with substantial conversion to grass or woodland; scenario NSAb in remainder of a protection zone and scenario CPb elsewhere.
Whole catchment change (WC)	Extend scenario CP by converting 40 per cent of the arable area in the Slea surface catchment to low input grassland or woodland and reduce livestock numbers by 40 per cent. Two variants. WCa: Conversion starting from CPa. WCb: Conversion starting from CPb.

The Recent Past (RP) scenario was included to provide an indication of how nitrate trends might continue in the absence of any changes to agricultural and environmental policy. For the Current Policy Reforms (CP) scenario, an important issue was uncertainty regarding the impacts the reforms might have. For instance, at the time the scenarios had to be finalised (summer 2005) it was unclear what the outcome of proposals to reform the EU sugar regime would be (see European Commission 2005) and how many farmers would apply to join the new environmental stewardship schemes. Thus, it was decided to include some sensitivity analysis in the scenarios by defining two variants based on a five per cent and ten per cent conversion of arable land to grassland. These proportions were based upon findings or predictions in the research literature (such as GRA-RACE and IEEP 2003; Boatman et al. 2004) and discussions with local farmers as to what they anticipated in the Sleaford area.

All of the other scenarios were built upon the CP variants and so evaluated the impact of introducing additional measures. For the Nitrate Best Practice scenario (BP), the aim was to explore what could be achieved by modifying farming practices without resorting to major land-use change. The details of this scenario were based primarily on several field studies conducted at sites on the Lincolnshire Limestone (or similar conditions elsewhere in the East Midlands) to monitor nitrate leaching under different husbandry regimes for up to ten years (Shepherd and Lord 1996; Johnson et al. 1997, 2002). Examples of the husbandry used for different crops are given in Table 3.3, with the distinction being made between ‘standard’ practice, a ‘protective’ regime representing the best nitrate management option and an ‘intermediate’ course of action that was a compromise between the two. For the purposes of Water4all, it was decided to evaluate the impacts of ‘intermediate’ and ‘protective’ regimes on key crops, though it was recognised that while the former would be fairly straightforward to implement, the latter would be more difficult to incorporate in a commercial business due to restrictions on the timing of certain activities.

Details of the NSA scenario were based on the practices and outcomes documented in Entec (1998), Lord et al. (1999) and ADAS and BGS (2003). For the Protection Zones (PZ) scenario, the boundary of the modelled groundwater catchment for a key set of boreholes and springs was combined with information on soil characteristics (George and Robson 1978), the Defra Agricultural Land Classification and a map of potential land for woodland planting (supplied by the Forestry Commission) to identify a priority area for land-use conversion. This area consisted of eight 2-km grid cells (that is, 3,200 hectares) to the west of Sleaford and under the scenario, the proportion of grass cover in this area was increased from some 14 per cent to 30 per cent and woodland from 3 per cent to 20 per cent. Other land within the groundwater catchment, but outside the priority area, was modelled in the same way as under the NSA scenario.

The final scenario represented substantial land-use change (that is, converting 40 per cent of the arable area to low-input grassland or woodland) at a whole catchment (WC) scale. This radical scenario was not considered a realistic or likely outcome, but it was added to the original list to provide a benchmark against which the alternatives could be compared. Overall, the scenarios were envisaged to provide an envelope of options (from the RP scenario at one end to WC at the other); subsequent modelling and evaluation examined the balance of benefits that each would provide compared with the costs incurred.

3.5 Summary

Engaging with the stakeholders interested in land use and water resource issues in the Slea catchment was a process that required some careful planning and took a considerable period of time. Nevertheless, the results of the exercise were very helpful in identifying key drivers of change and in developing a set of land-use scenarios. Subsequently, these scenarios were refined through further stakeholder discussions and Section 4 discusses how their implications for nitrate levels were investigated using a combination of export coefficient and groundwater modelling.

Table 3.3 Crop husbandry under different regimes for nitrate management

Crop	Standard	Intermediate	Protective
Wheat (Milling)	Ploughed within one week of pea harvest Seedbed cultivation as necessary Drill early October, apply N late Feb GS31, GS37 Chop & spread straw	Ploughed just before drilling Seedbed cultivation as necessary Drill late September Apply N GS31, GS37 Chop & spread straw	Minimal cultivate and seedbed cultivation as necessary Drill mid September Apply N GS31, GS32 Chop & spread straw
Wheat (Feed)	Plough mid August Seedbed cultivation as necessary Drill early October Apply N late Feb, GS31 Chop & spread straw	Plough just before drilling Seedbed cultivation as necessary Drill late September Apply N l GS31 Chop & spread straw	Minimal cultivate and seedbed cultivation as necessary Drill mid September Apply N l GS31 GS32 Chop & spread straw
Barley	Plough early September Seedbed cultivation as necessary Drill early October Apply N late Feb, GS31 Straw swathed and baled	Plough early September (minimal cultivated in years 1 to 3) Seedbed cultivation as necessary Drill late September Apply N late Feb, GS31 Straw swathed and baled	Plough early September (minimal cultivated in years 1 to 3) Seedbed cultivation as necessary Drill mid September Apply N late Feb, GS31 Straw swathed and baled
Oilseed Rape	Plough mid August Seedbed cultivation as necessary. Drill late August with 30kg N per ha Apply N half late Feb and half late March. Haulm chopped and spread	Minimal cultivate Drill late August with 30kg N per ha Apply 50kg N Feb and remainder late March Haulm chopped and spread	Minimal cultivate Drill late August with 30kg N per ha Apply 50kg N Feb and remainder late March Haulm chopped and spread
Peas	Plough December Spray re-growth if necessary Seedbed cultivation as necessary Drill mid March Haulm chopped and spread	Plough February Spray re-growth if necessary Seedbed cultivation as necessary Drill mid March Haulm chopped and spread	Sow cover crop by end of August Spray re-growth if necessary Plough mid March Seedbed cultivation as necessary Drill mid March Haulm chopped and spread
Potatoes *	Same husbandry for all three systems; plant March/April and harvest mid-late September		
Sugar Beet *	Plough and drill all crops in March/April Harvest mid-November	Plough and drill all crops in March/April Harvest mid-November	Plough and drill all crops in March/April Harvest mid-October

Sources: Johnson et al. (2002); * Shepherd and Lord (1996).
Note: GS = growth stage

4 Nitrate modelling

4.1 Introduction

Assessing the effects of changes in land use on groundwater nitrate levels was a central aim of the Water4all project. This section presents the results of an assessment based on two modelling techniques. The initial discussion focuses on the use of an export coefficient approach to produce estimates of nitrate leaching into the soil under different land-use scenarios. An explanation follows of how a two-step groundwater flow and transport model was constructed and calibrated for the Slea catchment. The last part of this chapter describes how different leaching estimates were incorporated into the groundwater model, and reviews the resulting predictions of changes in aquifer nitrate levels over time.

4.2 Export coefficient modelling

4.2.1 Compiling baseline data

Agricultural Census data for four years spanning the baseline period (1988, 1994, 2000 and 2003) were downloaded from the EDINA Agcensus service (http://edina.ac.uk/agcensus/). These data consisted of counts for livestock types and areas (in hectares) for different crop or other land-use categories at a 2-km grid square resolution. There were 300 such grid squares in the entire study area (40 km by 30 km), 74 of which intersected the limestone outcrop to some degree and 67 the Slea surface catchment.

Scrutiny of the data tables and some initial mapping using the ArcGIS software revealed several matters that required attention. Two minor issues were a level of detail (for example, for types of livestock enterprise) that was much greater than was suitable for the nitrate modelling and some slight differences in the coding schemes between years. These were resolved by amalgamating data to produce more appropriate and temporally consistent categories. Table 4.1 lists the categories and abbreviations used to represent them. Livestock data were treated quite simply (where for example, census data did not distinguish between indoor or outdoor pigs and poultry).

Table 4.1 Categories used to summarise the Agricultural Census data

Abbreviation	Description	Abbreviation	Description
Wheat	Wheat (Milling & Feed)	Hortcrop	Horticulture, Fruit, Veg.
Wbarley	Winter Barley	Pgrass	Permanent Grass
Sbarley	Spring Barley	Tgrass	Temporary Grass
Ocereals	Other Cereals (Oats)	Rgraz	Rough Grazing
Potatoes	Potatoes	Bfallow	Bare Fallow
Sbeet	Sugar Beet	Setaside	Set-aside
Fbeans	Field Beans	Cattle	Cattle (Beef & Dairy)
Peas	Peas	Sheep	Sheep
Osr	Oilseed Rape	Pigs	Pigs
Otharable	Other Arable (Fodder Crops, Maize, Linseed)	Poultry	Poultry

Note: Spring and winter wheat are not reported separately in the Agricultural Census returns.

Another difficulty was that information was missing for a few categories in 1994 and 2000. The relevant details were collected for the June census, but for unknown reasons had not been processed to produce estimates for 2-km grid squares. However, data were available for the years before and after those where the information was missing; thus, assuming linear trends over time, it was possible to estimate the missing values. For example, there were no poultry totals for 2000 but 2-km grid square values existed for 1994 and 2003. Differences between the 1994 and 2003 totals were calculated for each 2-km grid square and estimates for 2000 were produced by calculating the value two-thirds of the way along the trend. Similar procedures were used to estimate other missing data. Table 4.2 shows the totals for the Agricultural Census categories in the four years, the underlined numbers being those where values were estimated through linear trend calculations.

A further problem with the statistical information was the considerable number of grid cells that had total areas of agricultural land (excluding categories such as woodland) which exceeded the 400 hectares physically possible in a 2-km grid square. For instance, in the 2003 data there were 71 cells (24 per cent) with recorded totals greater than 400 hectares and the largest had a value of 629 hectares. This situation was not unexpected given the manner in which Agricultural Census statistics are compiled (see Section 2.2), but some corrective action was required to prevent exaggerated variations in the geographical pattern of nitrate leaching estimates.

More spatially detailed sources of land cover information were used to standardise the Agricultural Census data so that the total area (across all categories) for each cell equalled 400 hectares. The first step was to re-class the 25 m resolution LCM 2000 data into three categories - agricultural, non-agricultural and woodland - which also eliminated the problem of inconsistency in the classification of arable land types mentioned in Section 2.2. Subsequently, the Environment Agency 1992 land-use map was used to code areas such as airfields, parks and playing fields (categorised as agricultural due to their grass cover in LCM 2000) as non-agricultural and the OS Meridian™ data were employed to update the boundaries of a few built-up areas.

Table 4.2 Agricultural Census data for the study area 1988-2003

Land Use	1988 Total Ha	1994 Total Ha	2000 Total Ha	2003 Total Ha
Wheat	42384.7	39211.7	43010.6	37683.4
Wbarley	9461.5	6187.0	6047.9	4742.4
Sbarley	9269.8	3907.3	3909.9	5223.5
Ocereals	568.6	388.0	265.4	559.7
Potatoes	3695.1	3089.6	2361.5	2334.6
Sbeet	9675.7	8437.0	8106.6	7342.8
Fbeans	2467.4	3492.7	1871.6	3139.7
Peas	2714.2	1942.0	2187.1	2551.3
Osr	7421.9	6738.5	5457.6	7794.2
Otharable	667.9	1958.2	1792.2	1383.9
Hortcrop	9048.5	8055.5	7062.4	8172.5
Pgrass	7184.1	6558.2	6980.7	7557.1
Tgrass	2152.1	2872.4	2341.7	1928.5
Rgraz	454.5	489.5	524.4	541.9
Bfallow	553.6	463.5	373.4	323.6
Setaside	0.0	11943.2	8233.1	12169.7
Total Ha	107719.6	105734.3	100526.1	103448.6
Livestock	**Numbers**	**Numbers**	**Numbers**	**Numbers**
Cattle	18103.2	17454.5	15410.0	11971.3
Sheep	45112.9	41594.0	41347.6	33767.7
Pigs	42867.1	50390.1	45597.8	34816.1
Poultry	2082739.0	2261049.8	4606710.2	5777782.0

The result of these manipulations in ArcGIS was a revised land-use map that could be used to determine the proportion of agricultural land in each 2 km grid square. These values were then used to scale the Agricultural Census data so that the total area across all the arable or grassland categories in each 2-km square matched the figure derived from the land cover sources. This meant that if the existing Agricultural Census total was larger then all the category values were proportionally reduced and if it was lower then they were increased. The same multipliers were also applied to the livestock numbers to adjust them in a manner consistent with the changes in arable and grassland areas. In the absence of more specific information, all four years of census data were processed using the same land cover proportions, which had the effect of eliminating the variations in total agricultural area shown in Table 4.2. This situation was not ideal, but given the overall aims of the analysis it was considered a compromise worth making to smooth out substantial artefactual differences in recorded areas between grid cells.

Table 4.3 lists the standardised Agricultural Census totals for the study area, also adding two rows for woodland and non-agricultural areas derived from the land cover information. Several trends are apparent in the statistics, including the importance of cereals, the changes in set-aside (reflecting CAP requirements) and the substantial increase in poultry numbers since the mid-1990s. Mapping the data at a 2-km grid cell resolution reveals other patterns, such as the concentration of horticultural crops in the south east of the study area (outside the Slea catchment). By contrast, crops such as sugar beet and barley are grown more on the lighter soils in the western part of the

Slea catchment and on the limestone outcrop. The distribution of winter barley in 2003 is illustrated in Figure 4.1, which uses a graduated symbol in the centre of each 2-km grid square to show the amount of the crop (standardised totals) recorded as being grown there.

Table 4.3 Standardised Agricultural Census data for the study area 1988-2003

	1988	**1994**	**2000**	**2003**
Land Use	**Total Ha**	**Total Ha**	**Total Ha**	**Total Ha**
Wheat	41916.72	38145.11	45467.48	39145.44
Wbarley	9155.01	6289.87	6363.72	5007.54
Sbarley	9312.60	3888.06	4167.43	5564.60
Ocereals	557.34	393.29	279.80	556.59
Potatoes	3551.37	2955.81	2560.09	2308.08
Sbeet	9522.91	8424.93	8700.52	7676.07
Fbeans	2496.65	3416.32	1969.23	3014.86
Peas	2514.69	1895.42	2386.86	2805.25
Osr	7283.88	6708.67	5791.78	8076.31
Otharable	640.93	2151.09	1945.39	1366.43
Hortcrop	9658.05	9914.57	7777.99	8278.47
Pgrass	7327.89	6554.67	7404.52	7503.20
Tgrass	1912.45	2862.55	2491.51	2108.28
Rgraz	495.94	788.77	555.43	573.99
Bfallow	597.71	693.50	423.60	312.30
Setaside	0.00	11861.49	8658.78	12646.72
Total Agricultural	106944.13	106944.13	106944.13	106944.13
Woodland	4200.75	4200.75	4200.75	4200.75
Non-Agricultural	8855.12	8855.12	8855.12	8855.12
Total Area	120000.00	120000.00	120000.00	120000.00
Livestock	Numbers	Numbers	Numbers	Numbers
Cattle	18496.00	18421.53	17228.53	12388.39
Sheep	42622.75	41250.44	46519.73	33108.25
Pigs	45767.66	52442.26	49630.17	36208.54
Poultry	2123016.42	2210943.48	5322537.44	5860040.69

A similar map design in Figure 4.2 shows the distribution of standardised poultry numbers in 2003. It is evident from this illustration that the distribution of large scale poultry production is concentrated in a relatively small number of locations (such as to the north and west of Sleaford), but the map also highlights the smoothed and 'blocky' nature of the Agricultural Census data. It is important to keep this characteristic in mind during the analysis which follows, since it means that while the available data are a reasonable reflection of agricultural activities in groups of adjoining grid cells, it would be unwise to place much reliance on estimates for a single cell in isolation.

Human population totals were added to the agricultural and land-use information by using details from the 1991 and 2001 Censuses. The 1991 Census population surface (see Section 2.2) was used to provide estimates for the 2-km squares in 1988 and 1994, and the 2001 information performed a similar function for 2000 and 2003. According to the 1991 Census, there were 95,884 residents in the study area and this figure increased to 112,171 in 2001. Each 2-km grid cell was also assigned a code for the 40 km MORECS (Met Office Rainfall and Evaporation Calculation System) square that it fell within (117 or 118) as this allowed rainfall and effective precipitation data (1961-2000 averages) to be incorporated into the baseline information.

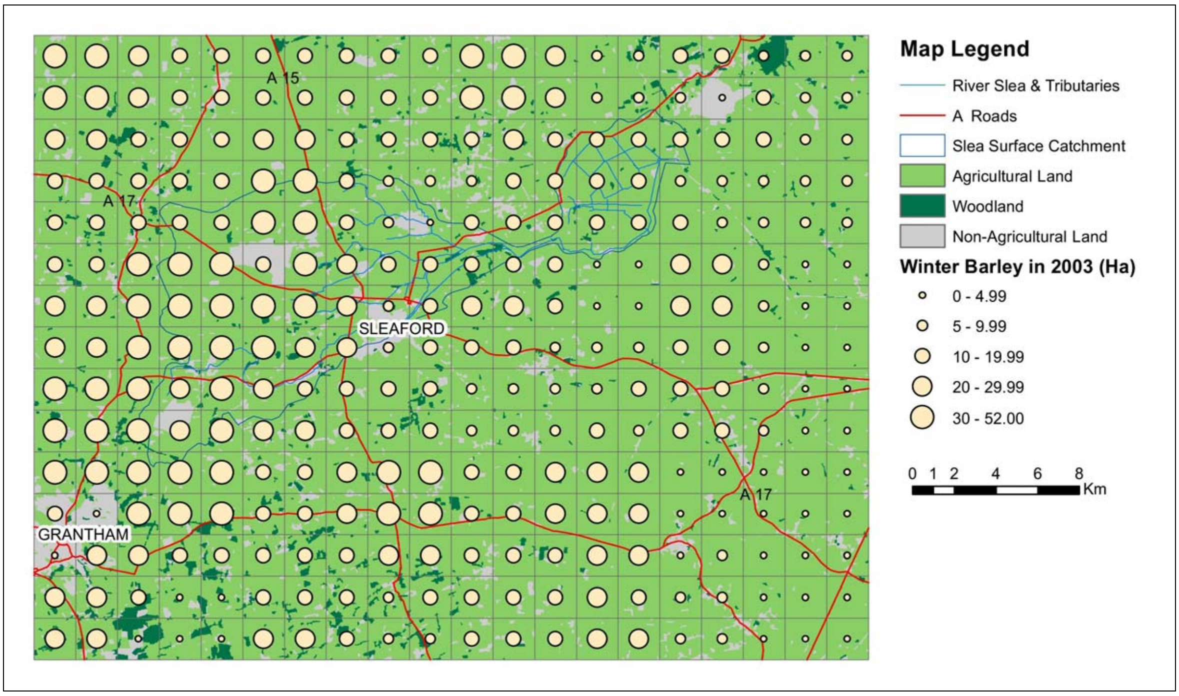


Figure 4.1 Distribution of winter barley in 2003

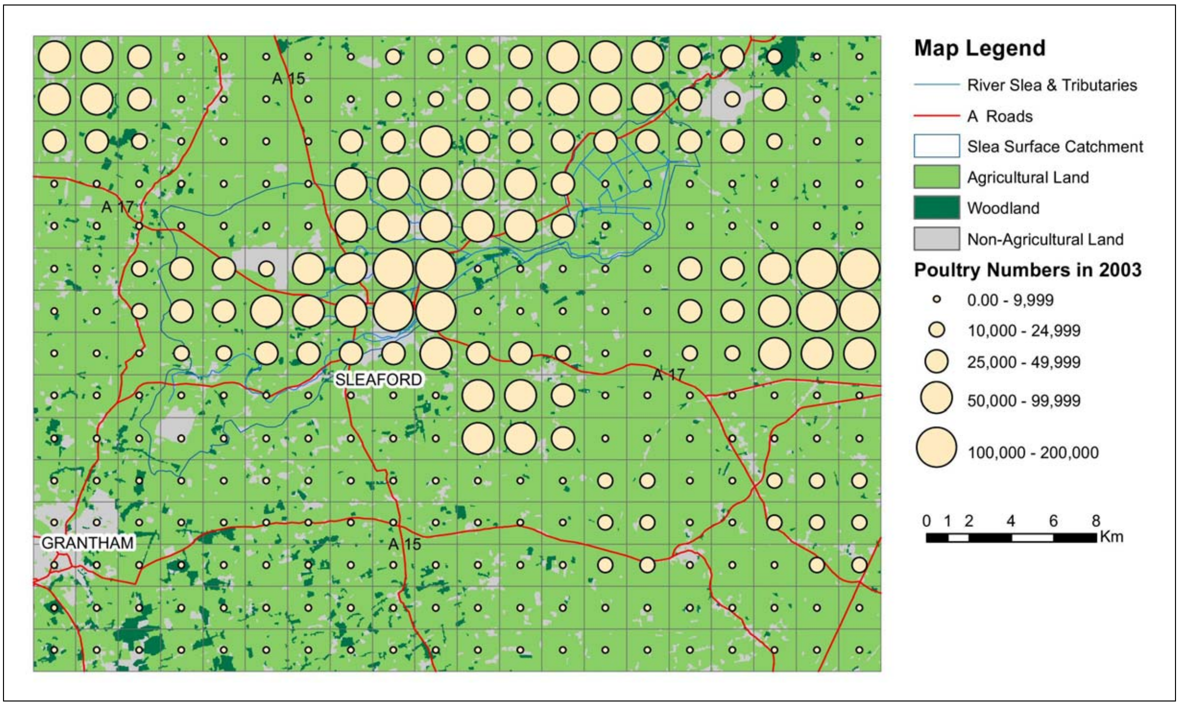


Figure 4.2 Distribution of poultry in 2003

4.2.2 Generating scenario land-use profiles

Baseline data were needed to produce estimates of nitrate leaching that could be used to calibrate the groundwater model. In order to assess the impacts of possible changes in land use, similar profiles of agricultural activities were generated for each of the different scenarios summarised in Table 3.2. This data processing was carried out through a series of spreadsheet operations in Microsoft Excel. For the Recent Past (RP) scenario, no further calculations were required as the necessary data already existed in the form of the standardised information for 2003.

The second scenario (Impact of Current Policy Reforms) assessed the effects of measures such as the SFP and Environmental Stewardship schemes. As previously explained in Section 3.4.1, there were two variants to this scenario (CPa and CPb) involving a five per cent and ten per cent conversion of arable land to grassland respectively. Areas of high margin crops (such as potatoes and sugar beet) were not reduced when scaling down the arable totals, as farmers would be less likely to take such fields out of production. The steps involved in generating the scenario variants were as follows:

- start with a spreadsheet of the 2003 data, with 2-km grid squares as rows and different attributes as columns;
- calculate the total cropped area for each 2-km square, then the target share (for example, 5 per cent) of that total to give the area which needs to be converted to grass;
- reserve the area of high-value crops by subtracting it from the total cropped area to give a residual cropped area;
- derive revised areas for other crops using the following formula:

  revised area = initial area – ((initial area / residual area) * target grass area)
- repeat this calculation for all relevant crops in each 2-km square;
- add another column to represent the areas converted to unfertilised grass.

Overall, this procedure generates the required grass target area by reducing the extent of each relevant crop in proportion to its share of the residual area. It was used to create separate spreadsheets for the five per cent and ten per cent variants, which then became the starting points for subsequent scenario calculations. For the Nitrate Best Practice (BP) scenario, ‘intermediate’ or ‘protective’ husbandry regimes were used, and areas of two crops prone to high levels of nitrogen (N) loss - namely peas and oilseed rape - were replaced with cereals. This was carried out using a similar approach to the steps outlined above and had the effect of allocating the land in high N-loss crops to different cereals in proportion to the relative importance of the latter in each grid cell. Ultimately this produced four spreadsheets, since there were variants based on the CPa and CPb alternatives for both the ‘intermediate’ and ‘protective’ regimes.

The Regional NSA scenario evaluated the impact of re-introducing agricultural practices adopted under the 1990s NSA scheme across the limestone outcrop (the key area for nitrate leaching to the underlying aquifer). Using information from NSA monitoring statistics, Entec (1998) and ADAS and BGS (2003), it was determined that approximately 35 per cent of the eligible arable land in the two NSA areas (Sleaford and Aswarby) was in the Premium Arable scheme in 1998, of which approximately half was in categories AA-AC (converted to grass with no fertiliser inputs) and the remainder had relatively low N inputs. To represent this change, land use in the 74 grid squares covering the limestone outcrop was altered by replacing cereals (but not sugar beet, oilseed rape or other crops) equivalent to 35 per cent of the arable area with a balance of unfertilised and fertilised grass. The reduction in arable area focused on cereals, due to trends apparent in reports such as Entec (1998). These calculations again used the proportional procedure outlined previously and were used for both the CPa and CPb alternatives to generate two NSA scenario variants.

An important measure for groundwater protection in several European countries has been targeted land-use change in areas above aquifers and in the vicinity of water supply boreholes (Brouwer et al. 2003). For instance, the Drastrup project in Denmark has seen the conversion of a substantial area of farmland above an aquifer to a mixture of grassland and woodland (Municipality of Aalborg 2001). This concept was central to the Land Use Protection Zones (PZ) scenario and it was therefore necessary to determine where such changes might be best located.

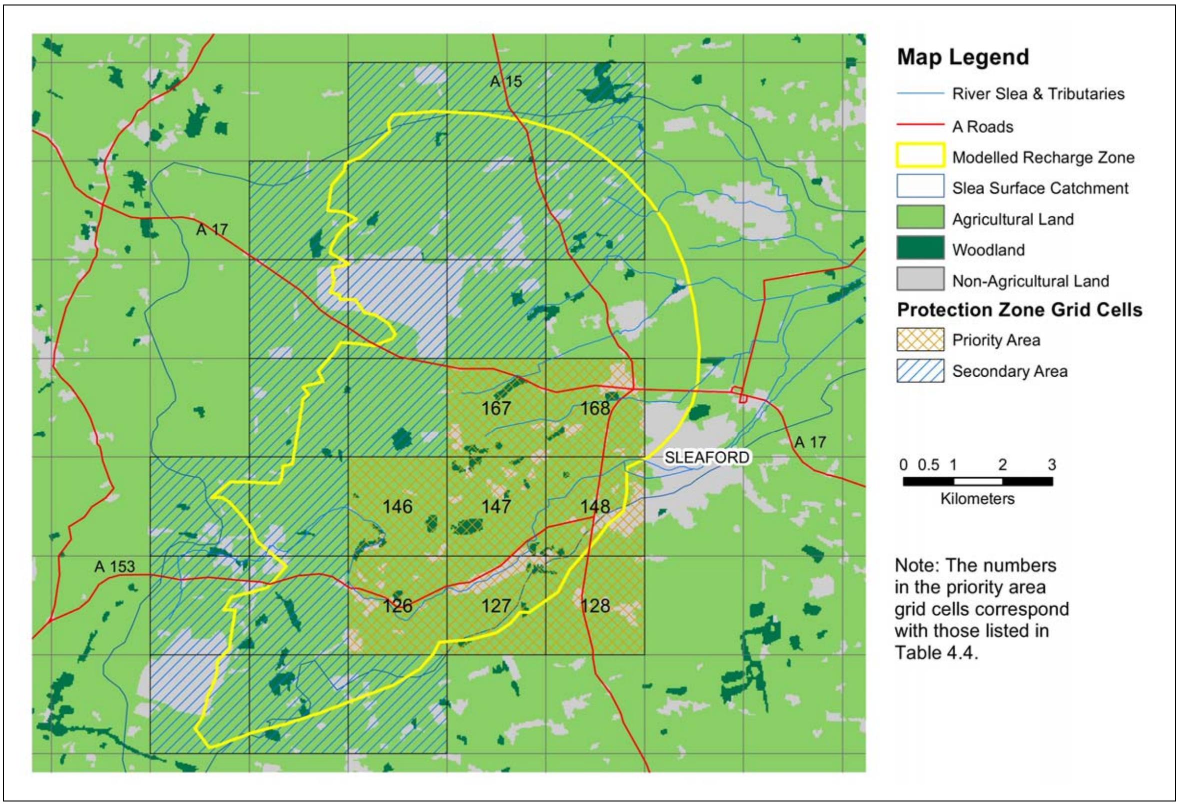
Potential protection areas were identified from a sequence of map overlays using the ArcGIS software. A starting point was provided by the calibrated groundwater model (see Section 4.3.5) which defined the steady-state (long-term average for 1988-98) recharge zone for the key springs and water supply boreholes west of Sleaford (see Figure 1.5). This zone intersected 27 of the 2-km grid squares on the limestone outcrop and could be interpreted as the average groundwater catchment for the set of springs and boreholes.

Other map information was then overlaid onto the recharge zone to see if there were areas within this boundary where conversion might be economically feasible. The sources used were the Defra Agricultural Land Classification (obtained from http://www.magic.gov.uk/), soil capability details for the Sleaford area (George and Robson 1978) and a map of low, medium and high potential zones for woodland planting supplied by the Forestry Commission. The latter reflected the criteria used in the Forestry Commission grant schemes and so gave priority to factors such as amenity and recreation benefits in the vicinity of urban areas. From the overlay exercise, it was evident that there were areas where the criteria appeared to coincide and eight 2-km cells in the recharge zone were identified as having at least one of the following characteristics:

- over a third of their area in grades 3b or 4 (poorer land less suitable for crop production);
- more than a third of their area rated as of high potential for woodland planting by the Forestry Commission.

All of these cells were situated in a single continuous zone west of Sleaford (see Figure 4.3) and so were selected as a priority area for land-use change. Together these grid squares had a total area of 3,200 ha, of which 14 per cent was grass and 3 per cent woodland under the 2003 baseline. To simulate the impact of a Drastrup-style scheme, these proportions were changed to 30 per cent grass (960 ha) and 20 per cent woodland (640 ha). However, these target areas were not spread evenly across cells, but allocated differently according to existing geographical characteristics. This assignment process was based on site visits and resources such as the OS Land-Line® mapping and Panorama™ elevation data, as well as the proportion of each cell within the recharge zone. Table 4.4 lists the resulting target areas and shows that cells 146 and 147 (around South Rauceby) were selected for particular increases in woodland cover, because of their appropriate topography and the largest existing amounts of woodland that could be linked through new planting.

Spreadsheet calculations were carried out to implement the desired changes. For the eight priority cells, these involved proportionally scaling down the arable crop totals to meet the required increases in grass and woodland areas. In cell 148, this also incorporated a small increase in the non-agricultural area to represent ongoing housebuilding around Sleaford. In addition, all pigs and poultry were removed from the priority area as the associated livestock units were unlikely to be compatible with the land-use changes envisaged. Another alteration was the secondary measure of setting the land use in the remaining 19 grid cells within the recharge zone to that already calculated for the NSA scenario. These steps were repeated using both the CPa and CPb alternatives to generate two PZ scenario variants.



Note: The numbers in the priority area grid cells correspond with those listed in Table 4.4.

Figure 4.3 Priority grid cells in the Protection Zone (PZ) scenario

Table 4.4 Target areas for land-use change in the Protection Zone (PZ) scenario

Grid Cell ID	Grass Target (hectares)	Woodland Target (hectares)
167	120	40
168	120	80
146	140	140
147	140	140
148	80	60
126	140	80
127	140	60
128	80	40
Total	960	640

Note: The grid cells are listed in north to south order. For locations see Figure 4.3.

Table 4.5 Land-use areas and livestock numbers under different scenario variants

Land Use	RP (hectares)	CPa (hectares)	CPb (hectares)	BP1a (hectares)	BP1b (hectares)	BP2a (hectares)	BP2b (hectares)	NSAa (hectares)	NSAb (hectares)	PZa (hectares)	PZb (hectares)	WCa (hectares)	WCb (hectares)
Wheat	39145	36944	34742	45135	42454	45135	42454	33069	31071	35698	33587	33128	31127
Wbarley	5008	4720	4433	5740	5391	5740	5391	3781	3543	4286	4027	4001	3751
Sbarley	5565	5232	4899	6183	5791	6183	5791	3746	3492	4607	4314	4287	4004
Ocereals	557	526	495	640	602	640	602	467	440	516	486	494	464
Potatoes	2308	2308	2308	2308	2308	2308	2308	2308	2308	2282	2283	2308	2308
Sbeet	7676	7676	7676	7676	7676	7676	7676	7676	7676	7571	7577	7676	7676
Fbeans	3015	2850	2685	2850	2685	2850	2685	2850	2685	2797	2637	2646	2492
Peas	2805	2646	2487	0	0	0	0	2646	2487	2627	2470	2321	2179
Osr	8076	7630	7183	0	0	0	0	7630	7183	7553	7115	6903	6495
Otharable	1366	1285	1204	1285	1204	1285	1204	1285	1204	1259	1180	1134	1061
Hortcrop	8278	7794	7309	7794	7309	7794	7309	7794	7309	7782	7299	7794	7309
Pgrass	7503	7503	7503	7503	7503	7503	7503	7503	7503	7503	7503	7503	7503
Tgrass	2108	2108	2108	2108	2108	2108	2108	2108	2108	2108	2108	2108	2108
Rgraz	574	574	574	574	574	574	574	574	574	574	574	574	574
Bfallow	312	312	312	312	312	312	312	312	312	312	312	312	312
Setaside	12647	12647	12647	12647	12647	12647	12647	12647	12647	12647	12647	12647	12647
Unfgrass	0	4190	8380	4190	8380	4190	8380	7369	11391	5400	9446	8514	12476
Fgrass	0	0	0	0	0	0	0	3179	3011	801	758	0	0
Woodland	4201	4201	4201	4201	4201	4201	4201	4201	4201	4742	4742	6795	6659
Non-Agricultural	8855	8855	8855	8855	8855	8855	8855	8855	8855	8935	8935	8855	8855
Livestock	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**	**(numbers)**
Cattle	12388	12388	12388	12388	12388	12388	12388	12388	12388	12388	12388	11327	11327
Sheep	33108	33108	33108	33108	33108	33108	33108	33108	33108	33108	33108	29474	29474
Pigs	36209	36209	36209	36209	36209	36209	36209	36209	36209	36148	36148	32693	32693
Poultry	5860041	5860041	5860041	5860041	5860041	5860041	5860041	5860041	5860041	5601960	5601960	4978067	4978067

The final scenario (WC) involved substantial land-use change across the whole of the Slea surface catchment. This was defined as replacing 40 per cent of the arable area in each of the 67 grid squares with unfertilised grassland (25 per cent) or woodland (15 per cent), as well as reducing all livestock numbers by 40 per cent. These changes were implemented using similar spreadsheet calculations to those described previously so that, for example, the scaling down of arable crop totals excluded high margin activities such as potatoes, sugar beet and horticulture

Table 4.5 summarises the outcome of all the spreadsheet processing by listing the total crop or other land-use areas and livestock numbers under the different scenario variants. These figures highlight that some of the crop or land-use areas are very stable across the scenarios whilst others (such as wheat) vary appreciably. The implications of these changes for nitrogen losses are presented in Section 4.2.4.

4.2.3 Derivation of nitrate inputs, export coefficients and loadings

As discussed in Section 2.3.2, export coefficient modelling requires estimates of typical nitrogen inputs and losses for the different types of nutrient sources (such as crops or livestock) under consideration. Many studies have published estimates of such parameters (for example, Johnes 1996), but it is also recognised that appropriate values (especially for crops) can vary widely between geoclimatic regions (see Haygarth et al. 2003). The approach taken in the Water4all study was therefore to use locally relevant information (such as from the NSA monitoring studies) wherever possible, supplemented by national statistics or other published estimates where these were considered reliable. Given the identified scenarios, it was not a matter of compiling a single ‘standard’ set of estimates, but also considering variations associated with the NSA scheme and the ‘intermediate’ and ‘protective’ husbandry regimes.

Table 4.6 lists the final set of parameters used in the modelling. For many sources there is an estimate of nitrogen input (such as that applied to a crop), the proportion leached (the export coefficients in Table 4.6) and the consequent amount entering the soil (the loading or loss). In some cases, however, only the loading is listed, either due to the nature of the land use (where for example, leguminous crops such as peas can fix nitrogen in the soil without any application of fertiliser) or the form of the available data. The following paragraphs explain the sources of these parameters and some key assumptions in more detail.

Information on standard nitrogen inputs for different types of crops and permanent and temporary grassland was derived from the British Survey of Fertiliser Practice, as this was considered the most authoritative and comprehensive source of data (see http://www.defra.gov.uk/environ/pollute/bsfp/). The estimates in Table 4.6 were produced by averaging reported field rates for 2000-2002 and were also used for the ‘intermediate’ and ‘protective’ husbandry regimes. Different sources were needed for the NSA scenario, where the input levels were derived primarily from the summaries for the Sleaford and Aswarby NSAs in ADAS and BGS (2003) along with other unpublished NSA monitoring data for 1996-2001.

Estimates of export coefficients for arable and grassland categories relied heavily on the results of soil water monitoring using porous ceramic cups carried out during the NSAs or the Gleadthorpe or ASWAN field trials (Shepherd and Lord 1996; Johnson et al. 1997, 2002). These data were considered the best available because they used a similar measurement methodology and were directly relevant to the environmental conditions in the study area. Details from the Gleadthorpe and ASWAN studies also provided a means of evaluating the effects of ‘intermediate’ and ‘protective’ husbandry regimes on nitrate leaching.

Nitrogen losses under other categories of land use were based on a mixture of NSA data and the results of a review by Silgram et al. (2004). The livestock parameters drew upon the values used by Haygarth et al. (2003), though the export coefficients for pigs and poultry were reduced because many of these are housed indoors in the study area and in some cases the litter is transported away for use as fuel in a power station. An estimate of nitrogen losses from human sources (such as sewage systems and septic tanks) was initially taken from Johnes (1996), but was subsequently reduced following information on discharges from the South Rauceby works by Anglian Water Services.

An important point about Table 4.6 is that nitrogen inputs from atmospheric sources were not included as a separate category. Initially, the calculation was incorporated (using the MORECS data and details from NEGTAP 2001), but during an evaluation that compared predicted losses for the baseline years (1988-2003) against monitoring data (such as from ADAS and BGS 2003), it became apparent that the former values were too high. One reason for this was double counting, because atmospheric inputs were measured in the porous cup data used to generate export coefficients and also included in the typical nitrogen losses reported by reviews such as Silgram et al. (2004). Thus, it was not appropriate to include such inputs separately and once they were removed, a more acceptable match was obtained between predictions and observed data.

Table 4.6 Estimates of nitrate inputs, export coefficients and loadings

Land Use	Baseline			NSA			Intermediate			Protective		
Nutrient Source	**Input (N kg/ha)**	**Export Coefficient**	**Loading (N kg/ha)**	**Input (N kg/ha)**	**Export Coefficient**	**Loading (N kg/ha)**	**Input (N kg/ha)**	**Export Coefficient**	**Loading (N kg/ha)**	**Input (N kg/ha)**	**Export Coefficient**	**Loading (N kg/ha)**
Wheat	192.3	0.23	44.23	163.3	0.18	29.39	192.3	0.21	40.38	192.3	0.12	23.08
Winter Barley	146.7	0.19	27.87	120.0	0.19	22.80	146.7	0.12	17.60	146.7	0.14	20.54
Spring Barley	112.7	0.31	34.94	94.7	0.31	29.36	112.7	0.23	25.92	112.7	0.19	21.41
Other Cereals	118.8	0.30	35.64	102.1	0.30	30.63	118.8	0.23	27.32	118.8	0.18	21.38
Potatoes	179.8	0.34	61.13	207.1	0.34	70.41	179.8	0.31	55.74	179.8	0.31	55.74
Sugar beet	109.0	0.14	15.26	123.7	0.14	17.32	109.0	0.10	10.90	109.0	0.10	10.90
Field Beans			50.00			50.00			35.00			35.00
Peas			80.00			80.00			50.00			49.00
Oilseed Rape	197.7	0.39	77.10	146.0	0.20	29.20	197.7	0.28	55.36	197.7	0.21	41.52
Other Arable	81.3	0.20	16.26	111.9	0.20	22.38	81.3	0.20	16.26	81.3	0.20	16.26
Horticultural Crops	116.5	0.35	40.78	109.9	0.35	38.47	116.5	0.35	40.78	116.5	0.35	40.78
Permanent Grass	117.3	0.10	11.73	100.0	0.10	10.00	117.3	0.10	11.73	117.3	0.10	11.73
Temporary Grass	181.7	0.10	18.17	50.0	0.10	5.00	181.7	0.10	18.17	181.7	0.10	18.17
Rough Grazing			5.00			5.00			5.00			5.00
Bare Fallow			5.00			5.00			5.00			5.00
Set-aside			25.00			25.00			25.00			25.00
Fertilised Grass			8.00			8.00			8.00			8.00
Unfertilised Grass			5.00			5.00			5.00			5.00
Woodland			8.00			8.00			8.00			8.00
All Other Land			5.00			5.00			5.00			5.00
Livestock	**(N kg/head)**		**(N kg/head)**	**(N kg/head)**		**(N kg/head)**	**(N kg/head)**		**(N kg/head)**	**(N kg/head)**		**(N kg/head)**
Cattle	70.2	0.17	11.93	70.2	0.17	11.93	70.2	0.17	11.93	70.2	0.17	11.93
Sheep	10.1	0.17	1.72	10.1	0.17	1.72	10.1	0.17	1.72	10.1	0.17	1.72
Pigs	18.8	0.09	1.69	18.8	0.09	1.69	18.8	0.09	1.69	18.8	0.09	1.69
Poultry	0.55	0.05	0.03	0.55	0.05	0.03	0.55	0.05	0.03	0.55	0.05	0.03
Humans			1.40			1.40			1.40			1.40

4.2.4 Modelling results

The last stage of the export coefficient modelling involved multiplying the land-use areas, livestock numbers and population totals for different scenario variants by their corresponding nitrogen loadings. These calculations were carried out in Microsoft Excel using the 2-km grid square data, so that it was possible to derive predictions of total nitrogen losses for individual grid cells or nutrient source categories in a flexible manner. For some scenario variants, it was necessary to use different loadings for particular sets of grid cells. These combinations are specified in Table 4.7.

Calculations of total nitrogen losses were produced for the entire study area and subsets of grid cells such as the limestone outcrop, the Slea catchment and the Sleaford and Aswarby NSAs. For these different regions, the total nitrogen values were also converted to average soil leachate concentrations (N mg/l) via the formula:

$$\frac{\text{total nitrogen loss (kg)} \times 100}{\text{zone area (hectares)} \times \text{average effective precipitation (mm/a from MORECS data)}}$$

Table 4.8 summarises the nitrogen loss estimates for the four baseline years. Unsurprisingly, crops such as wheat (35 per cent) and oilseed rape (12 per cent) are the largest individual sources of nitrogen, with livestock accounting for around nine per cent and the human population three per cent . Another feature highlighted by the average leachate concentrations for different zones is the impact of the NSA scheme in the 1990s. This is particularly pronounced for the NSA areas themselves, but the same pattern (including an increase in nitrogen losses in 2003) is also apparent for the Slea catchment as a whole.

Results for the different scenario variants are presented in Tables 4.9 to 4.11. As anticipated, there is a general decline in nitrogen losses through the sequence of scenarios, with the ‘a’ variants (five per cent conversion of arable land to grass under current policy) always generating slightly higher values than the ‘b’ ones (10 per cent). The varying geographical impacts of different measures are also evident. For example, the Best Practice regimes produce ‘across the board’ reductions in leachate concentrations, while the impacts of subsequent scenarios are more concentrated in regions such as the limestone outcrop or Slea catchment.

Since the nitrogen loss estimates were related to 2-km grid squares, it was also possible to display them as maps. Figure 4.4 uses graduated symbols to illustrate the spatial pattern of nitrogen losses under the Recent Past (RP) scenario (for 2003 data). This map shows a general tendency for higher nitrogen losses in the east of the study area than the west, with some of the lowest values corresponding to land uses such as airfields (for example, RAF Cranwell). Other high loss estimates occurred in residential areas (from the contribution by human sources) or locations used for pig and poultry production.

Table 4.7 Nitrogen loadings used in the scenario variants

Scenario	Nitrogen loadings used
Recent past (RP)	Standard throughout.
Impact of current policy reforms (CP)	Standard throughout.
Nitrate best practice (BP)	BP1a: Intermediate throughout. BP1b: Intermediate throughout. BP2a: Protective throughout. BP2b: Protective throughout.
Regional NSA (NSA)	NSAa: NSA for limestone outcrop cells, Standard elsewhere. NSAb: NSA for limestone outcrop cells, Standard elsewhere.
Land use protection zones (PZ)	PZa: NSA in the 27 recharge zone grid cells, Standard elsewhere. PZb: NSA in the 27 recharge zone grid cells, Standard elsewhere.
Whole catchment change (WC)	WCa: NSA in the 67 Slea catchment cells, Standard elsewhere. WCb: NSA in the 67 Slea catchment cells, Standard elsewhere.

Table 4.8 Nitrogen loss estimates for the four baseline years

	1988		1994		2000		2003	
Source	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**
Wheat	1853935	37.7	1660106	35.8	1959085	41.4	1731364	36.0
Wbarley	255178	5.2	173469	3.7	170420	3.6	139575	2.9
Sbarley	325354	6.6	133929	2.9	140802	3.0	194410	4.0
Ocereals	19863	0.4	13903	0.3	9828	0.2	19837	0.4
Potatoes	217102	4.4	181528	3.9	157678	3.3	141098	2.9
Sbeet	145320	3.0	129653	2.8	134539	2.8	117137	2.4
Fbeans	124833	2.5	170816	3.7	98461	2.1	150743	3.1
Peas	201176	4.1	151634	3.3	190949	4.0	224420	4.7
Osr	639160	13.0	508619	11.0	426605	9.0	622707	12.9
Otharable	10422	0.2	35923	0.8	33089	0.7	22218	0.5
Hortcrop	361569	7.4	402844	8.7	316980	6.7	337554	7.0
Pgrass	85956	1.7	76038	1.6	84201	1.8	88013	1.8
Tgrass	34749	0.7	45881	1.0	36928	0.8	38307	0.8
Rgraz	2480	0.1	3944	0.1	2777	0.1	2870	0.1
Bfallow	2989	0.1	3467	0.1	2118	0.0	1562	0.0
Setaside	0	0.0	296537	6.4	216470	4.6	316168	6.6
Wood	33606	0.7	33606	0.7	33606	0.7	33606	0.7
Nonagric	44276	0.9	44276	1.0	44276	0.9	44276	0.9
Cattle	220731	4.5	219843	4.7	205605	4.3	147843	3.1
Sheep	73183	1.5	70827	1.5	79874	1.7	56847	1.2
Pigs	77439	1.6	88732	1.9	83974	1.8	61265	1.3
Poultry	58383	1.2	60801	1.3	146370	3.1	161151	3.4
Humans	134238	2.7	134238	2.9	157039	3.3	157039	3.3
Total	4921940	100.0	4640615	100.0	4731674	100.0	4810010	100.0
Region	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**
Study Area	4921940	29.7	4640615	28.0	4731674	28.6	4810010	29.0
Lstone Outcrop	1107470	25.4	1019651	23.4	988291	22.6	1067437	24.5
Slea Catchment	1050941	28.3	960633	25.8	981605	26.4	1064789	28.6
Sleaford NSA	220997	22.0	185482	18.5	189428	18.9	244535	24.4
Aswarby NSA	228663	25.8	205160	23.2	170374	19.3	215359	24.3

Note: To convert the average leachate values to NO_3 concentrations, multiply by 4.429.

Table 4.9 Nitrogen loss estimates for scenario variants RP to BP1b

	Recent Past (RP)		**Current Policy (CPa)**		**Current Policy (CPb)**		**Best Practice (BP1a)**		**Best Practice (BP1b)**	
Source	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**
Wheat	1731364	36.0	1633976	35.2	1536589	34.4	1822693	47.0	1714428	45.7
Wbarley	139575	2.9	131561	2.8	123547	2.8	101039	2.6	94907	2.5
Sbarley	194410	4.0	182786	3.9	171161	3.8	160259	4.1	150101	4.0
Ocereals	19837	0.4	18734	0.4	17631	0.4	17480	0.5	16455	0.4
Potatoes	141098	2.9	141098	3.0	141098	3.2	128648	3.3	128648	3.4
Sbeet	117137	2.4	117137	2.5	117137	2.6	83669	2.2	83669	2.2
Fbeans	150743	3.1	142487	3.1	134231	3.0	99741	2.6	93962	2.5
Peas	224420	4.7	211701	4.6	198982	4.5	0	0.0	0	0.0
Osr	622707	13.0	588271	12.7	553835	12.4	0	0.0	0	0.0
Otharable	22218	0.5	20895	0.5	19572	0.4	20895	0.5	19572	0.5
Hortcrop	337554	7.0	317786	6.9	298018	6.7	317786	8.2	298018	7.9
Pgrass	88013	1.8	88013	1.9	88013	2.0	88013	2.3	88013	2.3
Tgrass	38307	0.8	38307	0.8	38307	0.9	38307	1.0	38307	1.0
Rgraz	2870	0.1	2870	0.1	2870	0.1	2870	0.1	2870	0.1
Bfallow	1562	0.1	1562	0.1	1562	0.1	1562	0.1	1562	0.1
Setaside	316168	6.6	316168	6.8	316168	7.1	316168	8.1	316168	8.4
Unfgrass	0	0.0	20950	0.5	41900	0.9	20950	0.5	41900	1.1
Fgrass	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Woodland	33606	0.7	33606	0.7	33606	0.8	33606	0.9	33606	0.9
Nonagric	44276	0.9	44276	1.0	44276	1.0	44276	1.1	44276	1.2
Cattle	147843	3.1	147843	3.2	147843	3.3	147843	3.8	147843	3.9
Sheep	56847	1.2	56847	1.2	56847	1.3	56847	1.5	56847	1.5
Pigs	61265	1.3	61265	1.3	61265	1.4	61265	1.6	61265	1.6
Poultry	161151	3.4	161151	3.5	161151	3.6	161151	4.2	161151	4.3
Humans	157039	3.3	157039	3.4	157039	3.5	157039	4.1	157039	4.2
Total	4810010	100.0	4636329	100.0	4462648	100.0	3882107	100.0	3750607	100.0
Region	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**
Study Area	4810010	29.04	4636329	27.99	4462648	26.94	3882107	23.44	3750607	22.6
Lstone Outcrop	1067437	24.46	1029052	23.58	990667	22.70	836875	19.17	809575	18.5
Slea Catchment	1064789	28.64	1027716	27.64	990643	26.64	856924	23.05	829764	22.3

Table 4.10 Nitrogen loss estimates for scenario variants BP2a to NSAb

	Best Practice (BP2a)		Best Practice (BP2b)		Regional NSA (NSAa)		Regional NSA (NSAb)	
Source	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**
Wheat	1041720	33.8	979843	32.6	1414112	33.1	1329106	32.3
Wbarley	117890	3.8	110735	3.7	101608	2.4	95266	2.3
Sbarley	132369	4.3	123979	4.1	124517	2.9	116133	2.8
Ocereals	13677	0.4	12875	0.4	16369	0.4	15393	0.4
Potatoes	128648	4.2	128648	4.3	144401	3.4	144401	3.5
Sbeet	83669	2.7	83669	2.8	121817	2.9	121817	3.0
Fbeans	99741	3.2	93962	3.1	142487	3.3	134231	3.3
Peas	0	0.0	0	0.0	211701	5.0	198982	4.8
Osr	0	0.0	0	0.0	502290	11.8	472990	11.5
Otharable	20895	0.7	19572	0.7	22671	0.5	21233	0.5
Hortcrop	317786	10.3	298018	9.9	316076	7.4	296417	7.2
Pgrass	88013	2.9	88013	2.9	83898	2.0	83898	2.0
Tgrass	38307	1.2	38307	1.3	26166	0.6	26166	0.6
Rgraz	2870	0.1	2870	0.1	2870	0.1	2870	0.1
Bfallow	1562	0.1	1562	0.1	1562	0.1	1562	0.1
Setaside	316168	10.2	316168	10.5	316168	7.4	316168	7.7
Unfgrass	20950	0.7	41900	1.4	36844	0.9	56957	1.4
Fgrass	0	0.0	0	0.0	25430	0.6	24092	0.6
Woodland	33606	1.1	33606	1.1	33606	0.8	33606	0.8
Nonagric	44276	1.4	44276	1.5	44276	1.0	44276	1.1
Cattle	147843	4.8	147843	4.9	147843	3.5	147843	3.6
Sheep	56847	1.8	56847	1.9	56847	1.3	56847	1.4
Pigs	61265	2.0	61265	2.0	61265	1.4	61265	1.5
Poultry	161151	5.2	161151	5.4	161151	3.8	161151	3.9
Humans	157039	5.1	157039	5.2	157039	3.7	157039	3.8
Total	3086292	100.0	3002149	100.0	4273014	100.0	4119709	100.0
Region	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**
Entire Study Area	3086292	18.6	3002149	18.1	4273014	25.8	4119709	24.9
Lstone Outcrop	678314	15.5	660581	15.1	665737	15.3	647727	14.8
Slea Catchment	689475	18.5	672620	18.1	876406	23.6	848211	22.8

Table 4.11 Nitrogen loss estimates for scenario variants PZa to WCb

	Protection Zones (PZa)		Protection Zones (PZb)		Whole Catchment (WCa)		Whole Catchment (WCb)	
Source	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**	**Total N (kg)**	**% of Total**
Wheat	1562838	34.7	1470293	33.9	1406076	33.4	1321711	32.6
Wbarley	117771	2.6	110662	2.5	108125	2.6	101434	2.5
Sbarley	158278	3.5	148214	3.4	144991	3.4	135488	3.3
Ocereals	18360	0.4	17284	0.4	17450	0.4	16418	0.4
Potatoes	141171	3.1	141255	3.3	146175	3.5	146175	3.6
Sbeet	117359	2.6	117447	2.7	121695	2.9	121695	3.0
Fbeans	139826	3.1	131854	3.0	132296	3.1	124577	3.1
Peas	210121	4.7	197572	4.6	185649	4.4	174301	4.3
Osr	567725	12.6	534704	12.3	495264	11.8	466341	11.5
Otharable	20966	0.5	19661	0.5	19187	0.5	17931	0.4
Hortcrop	316930	7.0	297251	6.8	316310	7.5	296636	7.3
Pgrass	86092	1.9	86092	2.0	84811	2.0	84811	2.1
Tgrass	36066	0.8	36066	0.8	32341	0.8	32341	0.8
Rgraz	2870	0.1	2870	0.1	2870	0.1	2870	0.1
Bfallow	1562	0.1	1562	0.1	1562	0.1	1562	0.1
Setaside	316168	7.0	316168	7.3	316168	7.5	316168	7.8
Unfgrass	26998	0.6	47230	1.1	42570	1.0	62382	1.5
Fgrass	6404	0.1	6067	0.1	0	0.0	0	0.0
Woodland	37940	0.8	37940	0.9	54361	1.3	53269	1.3
Nonagric	44676	1.0	44676	1.0	44276	1.1	44276	1.1
Cattle	147843	3.3	147843	3.4	135173	3.2	135173	3.3
Sheep	56847	1.3	56847	1.3	50607	1.2	50607	1.2
Pigs	61163	1.4	61163	1.4	55316	1.3	55316	1.4
Poultry	154054	3.4	154054	3.5	136897	3.3	136897	3.4
Humans	157039	3.5	157039	3.6	157039	3.7	157039	3.9
Total	4507066	100.0	4341811	100.0	4207209	100.0	4055417	100.0
Region	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**	**Total N (kg)**	**Av N (mg/l)**
Study Area	4507066	27.2	4341811	26.2	4207209	25.4	4055417	24.5
Lstone Outcrop	899789	20.6	869830	19.9	831351	19.0	802982	18.4
Slea Catchment	898452	24.2	869806	23.4	598595	16.1	583412	15.7

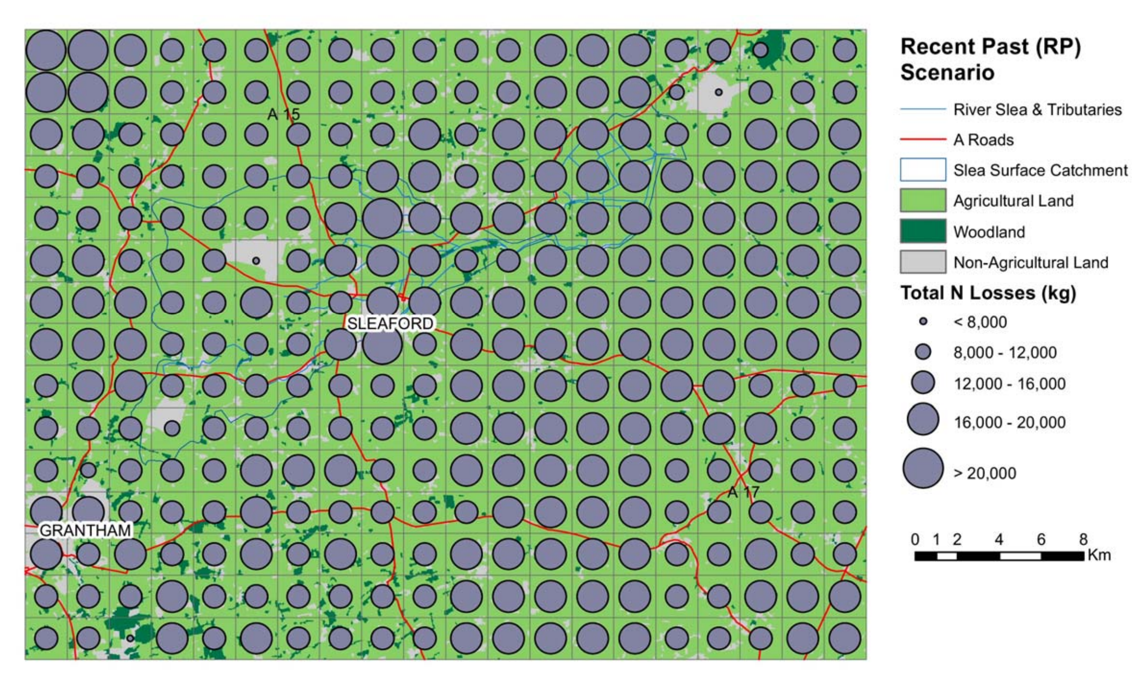


Figure 4.4 Estimated nitrogen losses under the recent past (RP) scenario

Figure 4.5 uses the same symbol scale with the results of the BP1b scenario (‘intermediate’ husbandry regime) and depicts a reduction in circle size across rural areas, with some urban and livestock production sites becoming more prominent. This map can also be contrasted with the more geographically focused impact of the Protection Zone scenario shown in Figure 4.6, where there is a distinct ‘hole’ in the nitrogen loss pattern immediately to the west of Sleaford. Using a GIS in this way is therefore an effective means of highlighting the varying spatial impacts of different policy options.

Overall, the export coefficient modelling succeeded in estimating nitrogen losses for a wide range of scenarios. It also helped to clarify the relative importance of different nutrient sources and identified geographical variations in scenario impacts. The loss estimates were subsequently imported into a groundwater model - this further analysis is described in the following section.

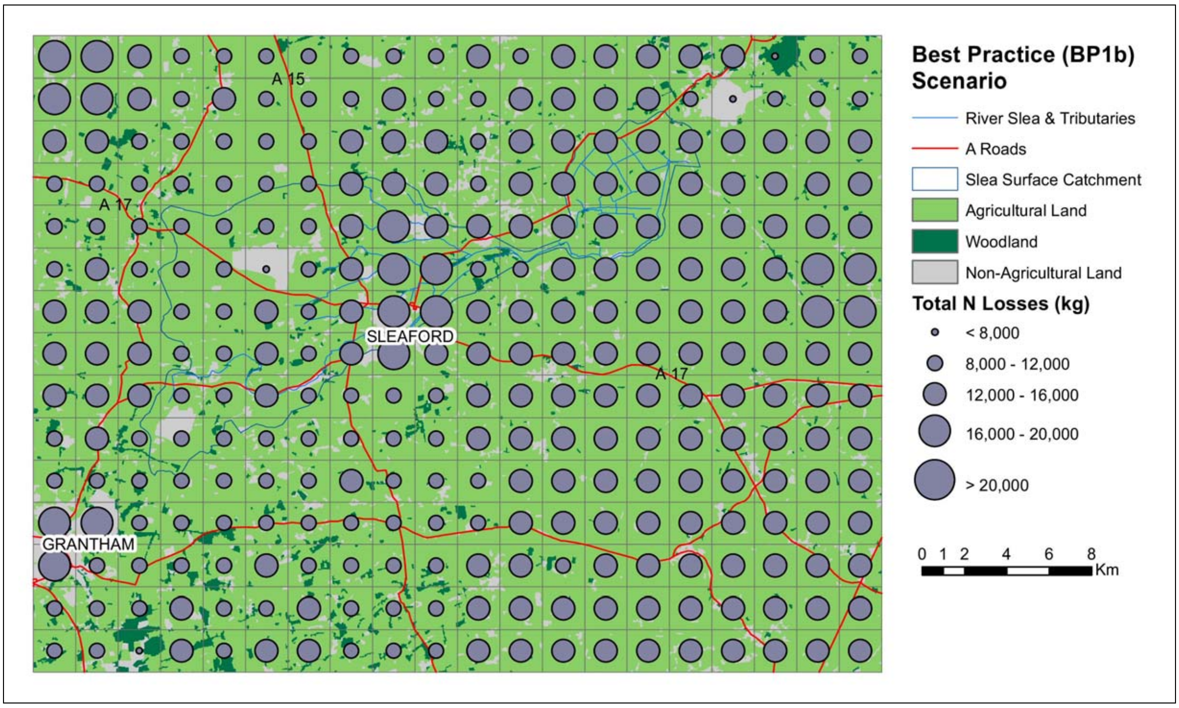


Figure 4.5 Estimated nitrogen losses under the Best Practice (BP1b) scenario

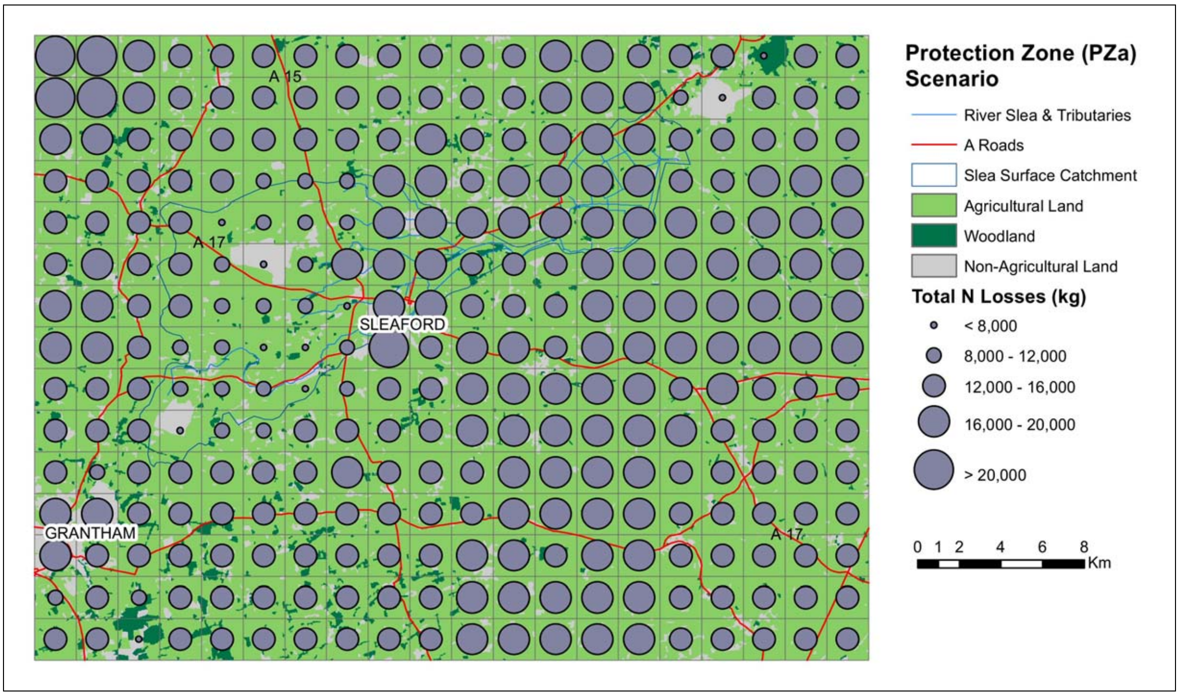


Figure 4.6 Estimated nitrogen losses under the Protection Zone (PZa) scenario

4.3 Groundwater modelling of scenarios

4.3.1 Groundwater flow model construction

The groundwater flow model constructed to simulate flow conditions and nitrate concentrations in the Lincolnshire Limestone aquifer was based to a large extent on that developed by Bradbury et al. (1994), whose geological and hydrogeological conceptualisation drew upon the work of Downing and Williams (1969). In this study, a two-layer transient state Visual MODFLOW model was developed for the groundwater model domain shown in Figure 4.7. The lower layer of the model represented the Lincolnshire Limestone Formation (unconfined in the west and confined towards the east) and the top layer represented the overlying confining beds of Middle to Upper Jurassic strata in the east of the study area (Table 1.1, Figure 1.3). Since MODFLOW requires layers to be continuous across the entire model domain, the top layer in the west of the study area, where the limestone outcrops, was modelled as a thin 'transparent' layer one metre thick, assigned the same vertical hydraulic conductivity as the underlying limestone and a storativity of zero. Ground surface elevations were obtained from the OS Panorama™ digital elevation model at 50 m resolution. The elevations of the base of the limestone and the division between the limestone and the overlying beds were interpreted from borehole records provided by the Environment Agency. Where borehole records were sparse, in the east and west of the study area, the thickness of the limestone was interpolated from a folded map presented by Downing and Williams (1969).

The model domain covered a total area of 1,200 km^2. The grid was discretised at a cell resolution of 250 m by 250 m. The northern and southern model boundaries represented no-flow boundaries. Cells to the west of the limestone scarp, which represent the relatively impermeable Lias Group mudstones, were designated as inactive (non-calculating) cells. The extent of the limestone to the east is uncertain; Emery et al. (1987) proposed that the limestone stretches 50 km east of the coast, but modelling work suggests that it may not reach the coastline (Bradbury et al. 1994). Towards the east the groundwater becomes increasingly saline and old, indicating limited flow (Lawrence and Foster 1986). Hence, following the approach of Bradbury et al. (1994), the eastern boundary was modelled as a no-flow boundary, accompanied by a decrease in hydraulic conductivity.

The River Slea was modelled using the MODFLOW Drain Package (McDonald and Harbaugh 1988). The Drain Package was chosen in preference to the MODFLOW River Package since it more closely resembles the behaviour of the River Slea, which is observed to dry up west of Sleaford during summer and autumn months when groundwater levels, already impacted by groundwater abstractions, are low. The drain cells in the model remove water from the aquifer at a rate proportional to the difference in head between the aquifer and the drain. When the head in the aquifer falls below that of the drain, there is no flow of water from the model. The drain head was related to the cell top elevation. Comparisons of modelled and gauged flows at Leasingham Mill were used to estimate the drain conductance during the steady-state calibration.

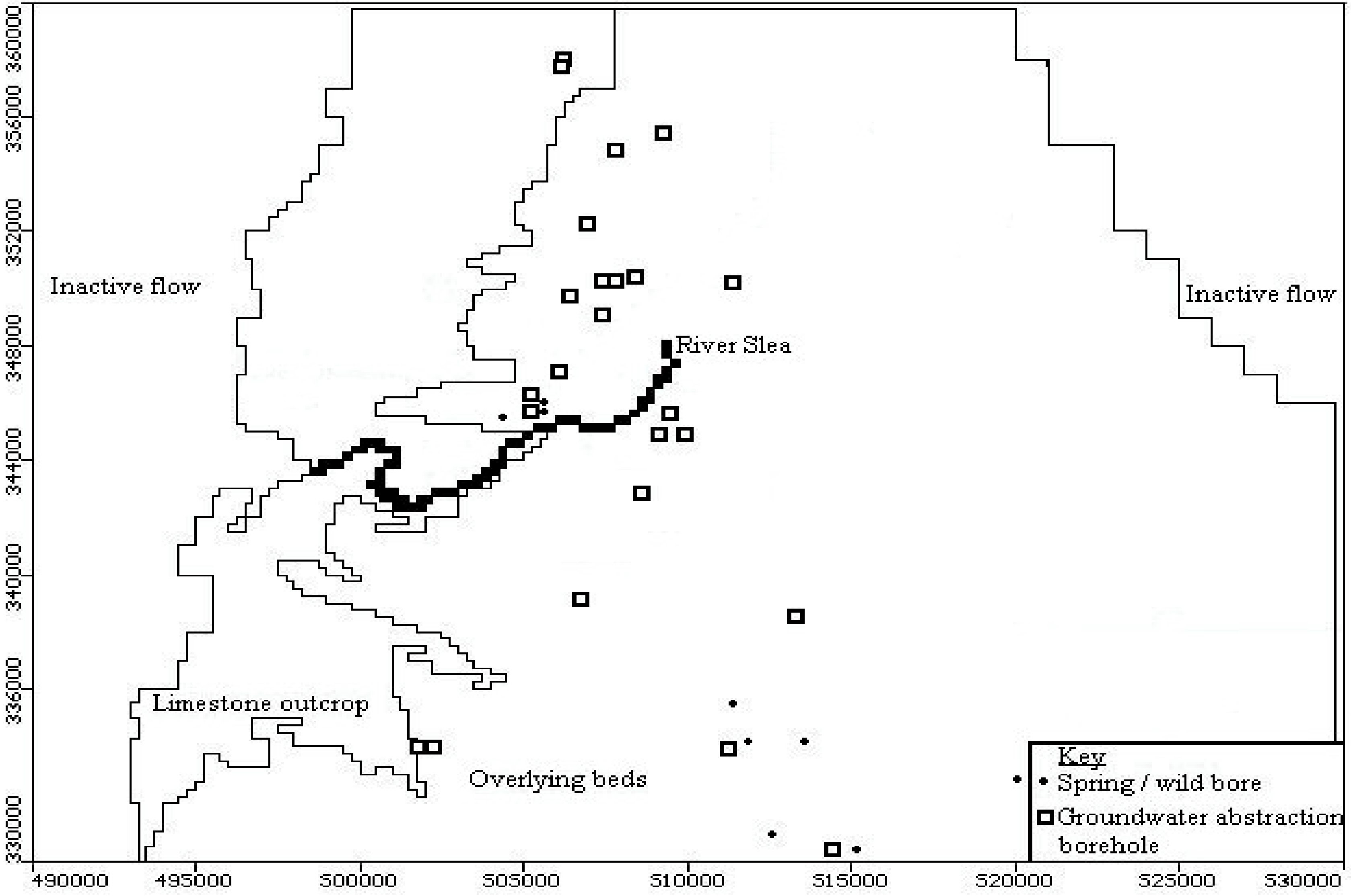


Figure 4.7 Map of the groundwater model domain showing boundary conditions and the location of abstraction boreholes

There are a number of unused, overflowing artesian boreholes in the confined region of the aquifer which are referred to as 'wild bores'. These and the key springs that feed the Slea - namely Boiling Wells, Cobbler's Hole and Guildhall - were also simulated using the Drain Package. The drain heads were taken from Bradbury et al. (1994) and Rushton et al. (1994). Details of actual groundwater abstractions within the model domain were obtained from the Environment Agency.

Recharge to the limestone occurs directly at the outcrop. Effective precipitation values from MORECS were used as estimates of recharge. These data are interpolated from synoptic weather stations and provide weekly estimates averaged over 40 km resolution grid squares. For the purposes of this project, the estimates were converted to a monthly time-step for the period 1988-2000 and fed into the groundwater model using the Recharge Package (McDonald and Harbaugh 1988). There are two zones of recharge which correspond to MORECS squares 117 and 118 and are separated along National Grid easting 500,000. The average annual groundwater recharge for the period 1988-1998 was 128 mm for square 117 and 88 mm for 118. Conventional recharge does not occur to the overlying beds (Bradbury et al. 1994) and hence no recharge was assigned to this area. For the transient simulations, the calibrated model was run with a monthly stress period for 1988-2030. An initial steady-state stress period with average conditions for 1988-1998 was used to allow the model to reach dynamic equilibrium. One time-step was assigned to each stress period. Recharge was applied to the uppermost active cells and the average monthly recharge for 1988-2000 was used for the period 2001-2030.

MODFLOW is intended for simulation of groundwater flow in porous media and it was assumed that regional flow in the Lincolnshire Limestone aquifer could be modelled using the equivalent porous media concept. The primary and secondary porosity and hydraulic conductivity distributions are replaced by a continuous porous medium having equivalent hydraulic properties (Anderson and Woessner, 1992). Initial values for hydraulic conductivity were estimated from the transmissivity values used by Bradbury et al. (1994). Hydraulic conductivities were determined by dividing these transmissivity values by the saturated aquifer thickness estimated from the maps of Downing and Williams (1969). Hence, zones of hydraulic conductivity were assigned in which the aquifer was assumed to be isotropic. Initial estimates for the specific yield and the specific storage were also taken from Bradbury et al. (1994). Zones of initial head were interpreted from the groundwater contour map of the southern Lincolnshire Limestone (Downing and Williams, 1969). Following data input, the model was run using the MODFLOW 2000 numerical engine using the WHS solver with a head change error criterion of 0.01 m.

4.3.2 Groundwater flow model calibration

Model calibration is the process of adjusting parameters, boundary conditions and stresses to produce simulated heads and fluxes that match field-measured values within a pre-established range of error (Anderson and Woessner 1992). Two types of calibration targets were used in this study: groundwater levels at selected monitoring boreholes and measured flows for springs and the River Slea. Manual trial-and-error adjustments of aquifer parameter values were made to obtain simulated groundwater levels and flows within the calibration targets.

The initial estimates of aquifer property values were adjusted (within the same order of magnitude) during the calibration process. Hydraulic conductivities for the calibrated model are shown in Table 4.12 and for the limestone range from 0.3 m/day in the eastern confined region to 300 m/day in the Slea Valley where the gravel deposits are present. The specific yield and specific storage for the calibrated model are shown in Table 4.13.

Table 4.12 Values of hydraulic conductivity for the calibrated groundwater flow model

	Overlying Beds	Lincolnshire Limestone
Horizontal hydraulic conductivity (m/day)	0.1	0.3-300
Vertical hydraulic conductivity (m/day)	0.00005	0.3-300

Table 4.13 Values of specific yield and specific storage for the calibrated groundwater flow model

	Overlying Beds	Lincolnshire Limestone (outcrop)	Lincolnshire Limestone (beneath Overlying Beds)
Specific yield (-)	0.00005	0.01	0.001
Specific storage (/m)	0.00005	0.00025	0.00025

The steady-state model calibration compared modelled groundwater levels in 24 observation boreholes (Figure 4.8) to mean observed groundwater levels for 1988-1998. The model showed an adequate agreement with a mean error of 2.8 m, mean absolute error of 2.9 m and root mean squared (RMS) error of 3.7 m. These calibration criteria were used to evaluate the average error in groundwater levels, while the spatial distribution of error was qualitatively assessed through a comparison of modelled groundwater level contours with the map prepared by Downing and Williams (1969). The groundwater level contours show a good fit, being deflected in the river valley where groundwater flows towards the watercourse.

Osiensky and Williams (1997) found that model convergence for a small head change convergence criterion was not a good indicator of accurate results unless the water balance error (WBE), calculated using the following equation, was also small:

$$\mathrm{WBE} = \frac{\mathrm{Inflow} - \mathrm{Outflow}}{(\mathrm{Inflow} + \mathrm{Outflow}) \times 0.5} \times 100\%$$

Hence, the water balance error was similarly used to check the validity of the solution. A water balance error of less than one per cent was achieved for the calibrated steady-state model, which was considered acceptable (Anderson and Woessner 1992).

The transient model calibration (1988-2000) also aimed to reproduce the observed groundwater levels and river flows. The observed and modelled groundwater levels versus time for three observation boreholes (denoted 2_519, 2_617 and 2_524 on Figure 4.8) are shown in Figure 4.9. Modelled groundwater levels were on average higher than the observed record. The pattern of high and low groundwater levels was well simulated, although the modelled fluctuations in groundwater levels were damped in comparison with the observed data.

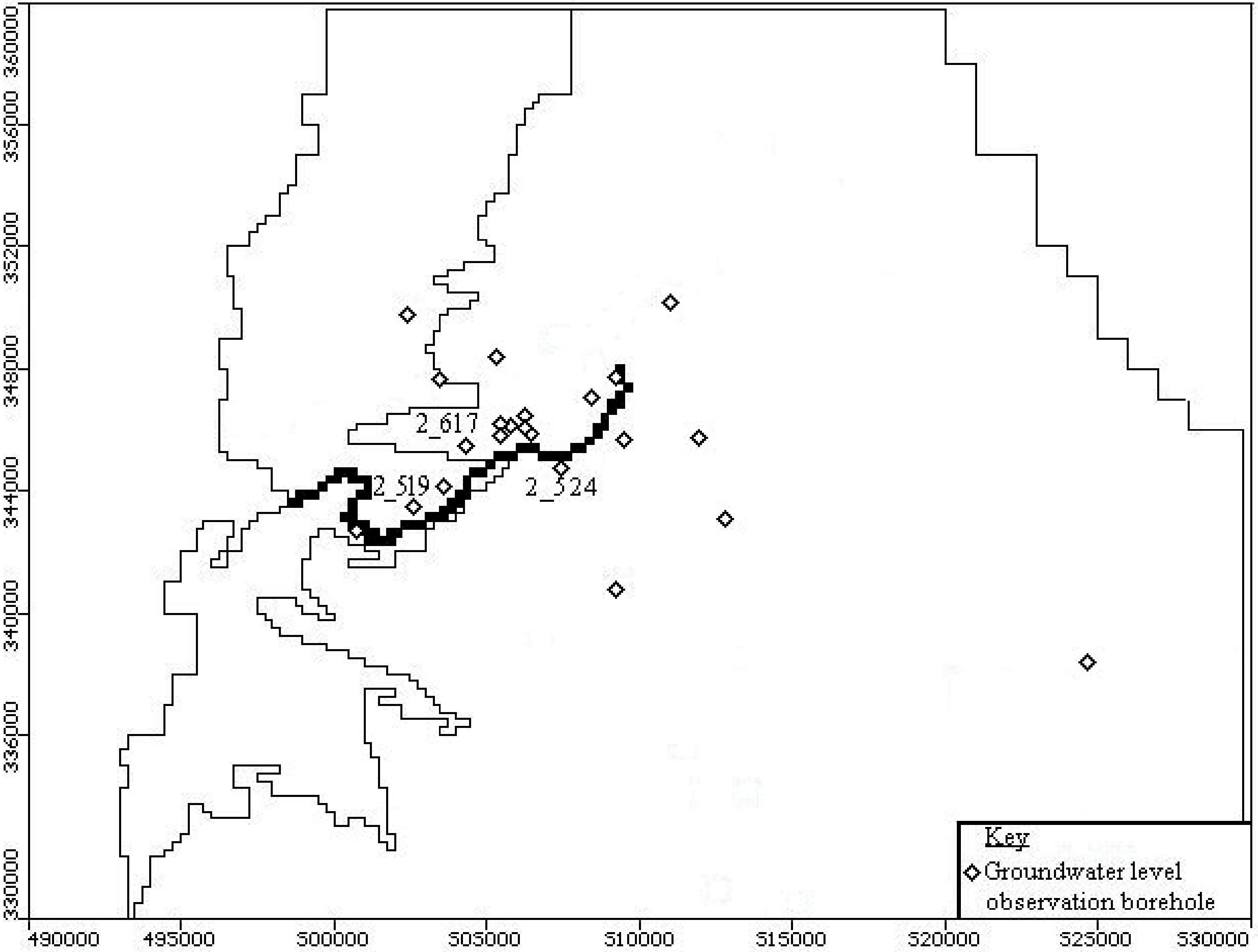
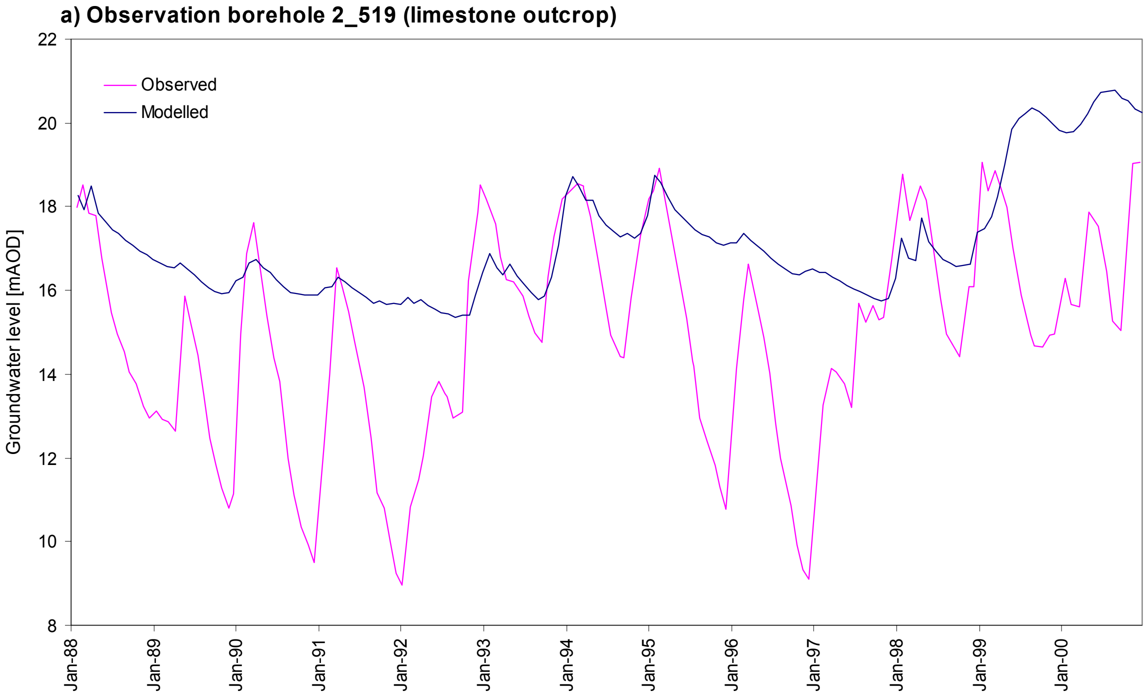
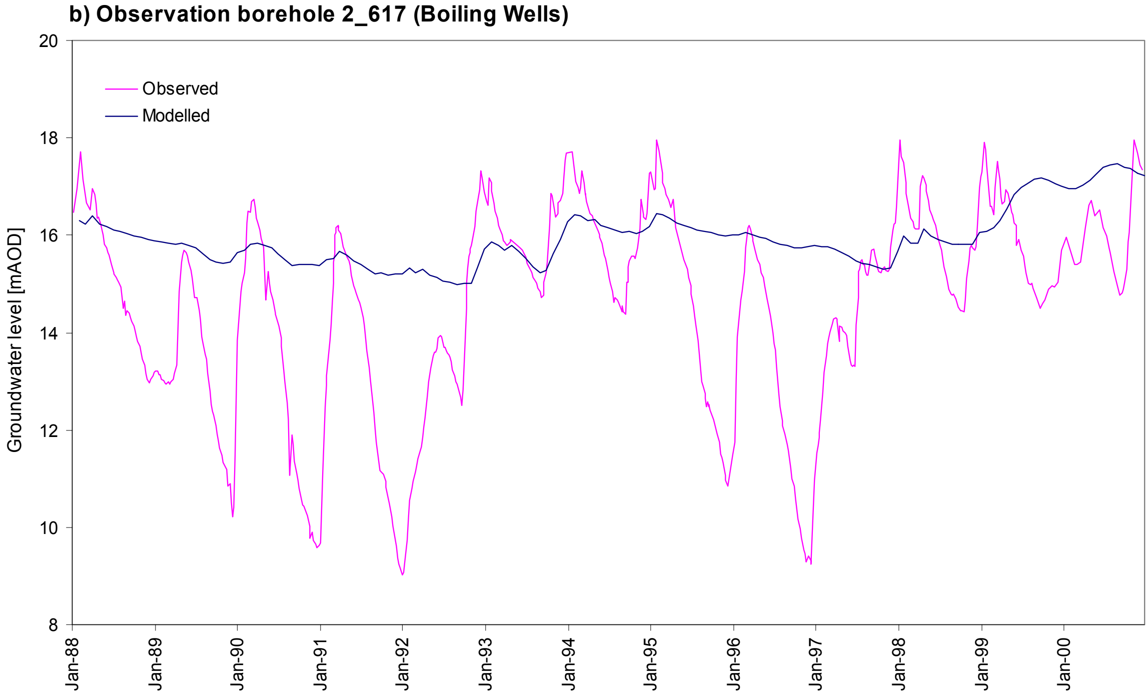


Figure 4.8 Location of the groundwater level observation boreholes


a) Observation borehole 2_519 (limestone outcrop)


b) Observation borehole 2_617 (Boiling Wells)

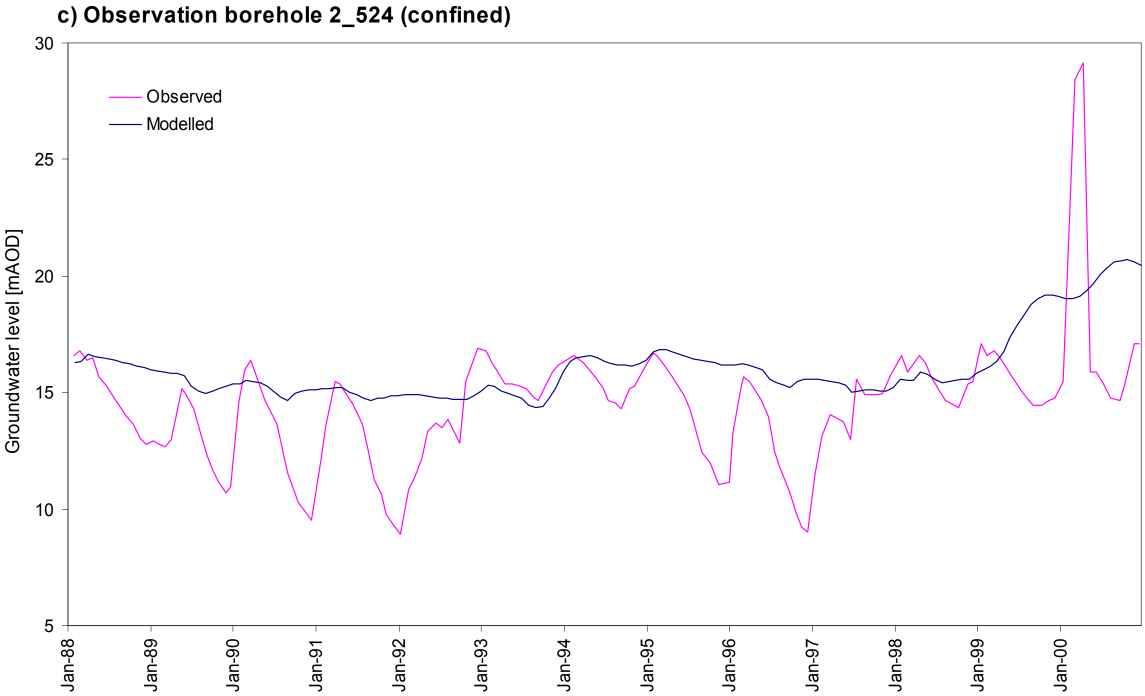


Figure 4.9 Observed and modelled groundwater level hydrographs for three observation boreholes for the transient model calibration period 1988-2000

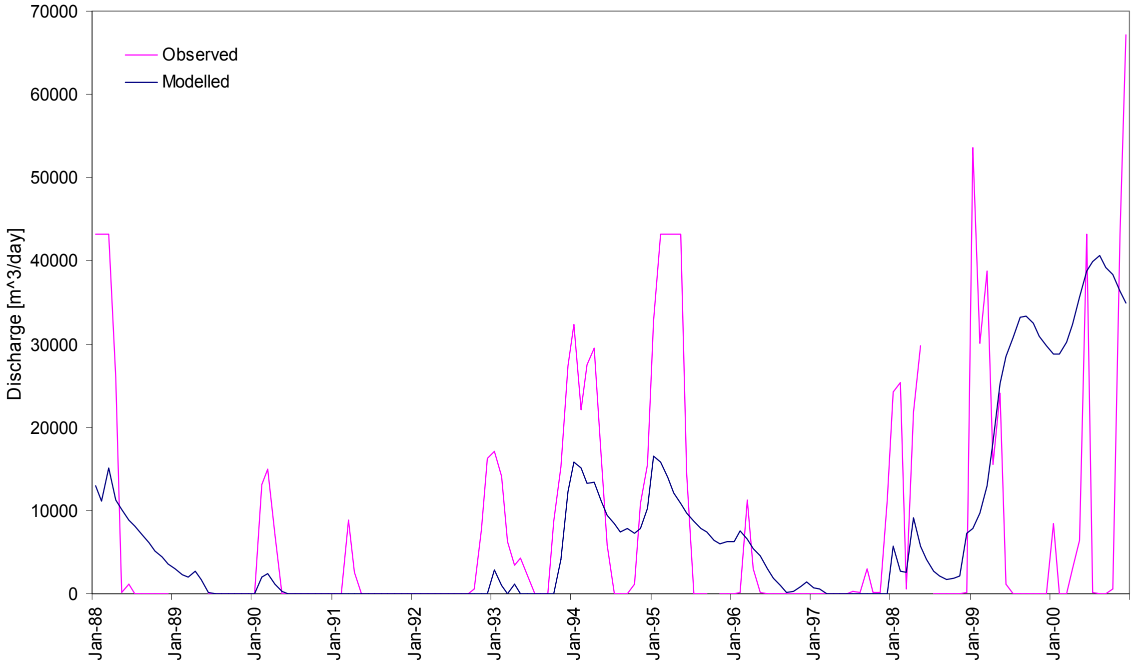
Discharge from Boiling Wells Spring and the Nine Foot Drain (which is supported by the outflows from Guildhall and Cobbler's Hole springs) was calibrated by minimising the percentage discrepancy between simulated and observed values as follows:

$$\text{Percentage Discrepancy} = \left| \frac{Q_{obs} - Q_{mod}}{Q_{obs}} \right| \times 100\%$$

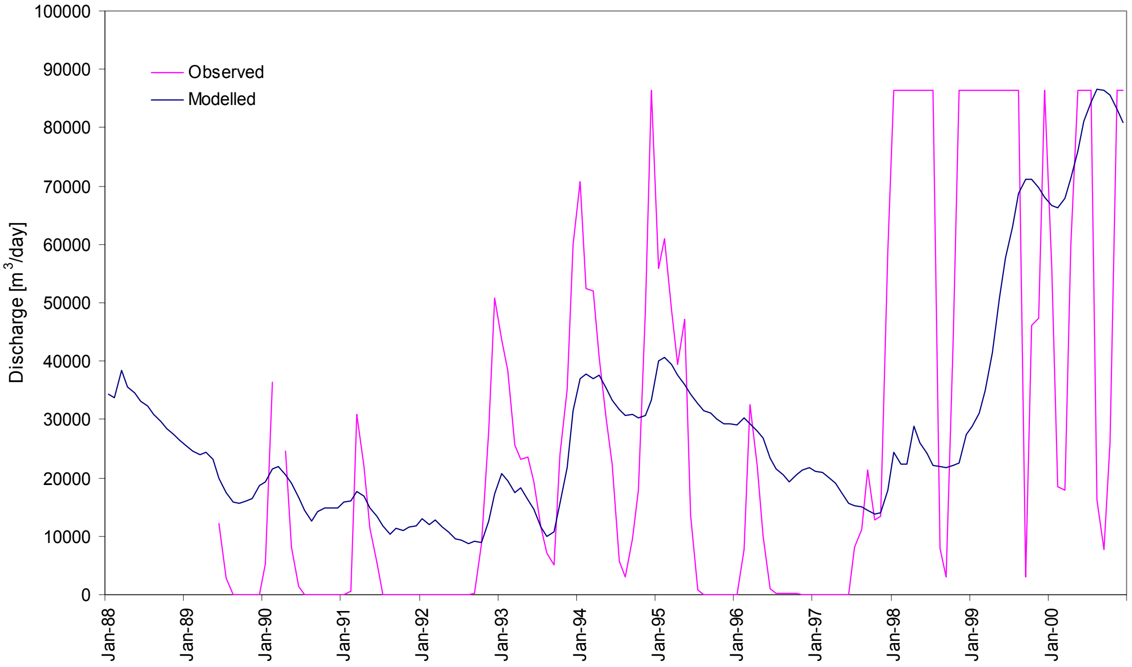
where Q_{obs} is the observed flow and Q_{mod} is the modelled drain cell leakage. The percentage discrepancy was two per cent for Boiling Wells and five per cent for the Nine Foot Drain. River discharge for the Slea was also calibrated in this way, with a seven per cent discrepancy between average modelled and observed discharges.

The observed and modelled hydrographs for the Boiling Wells Spring, the Nine Foot Drain and the River Slea are shown in Figure 4.10. Fluctuations in modelled flows were damped in comparison with the observed data, but the calibration was deemed acceptable given the above percentage discrepancies. However, a discharge for the Nine Foot Drain is obtained by the model even though the springs are known to be dry. This anomaly arises because the fluctuations in modelled groundwater levels are small enough such that the groundwater level does not fall below the specified head in the cell representing the Nine Foot Drain. Consequently, the low river flows measured in the drought period 1989-1992 were overestimated by the model. Also, high flows were lower than the observed records since once again modelled fluctuations in head were smaller than observed. These disparities in model behaviour compared with actual flows are probably both a function of adopting only one model layer for the Lincolnshire Limestone aquifer which is known to comprise two lithologically distinct layers with different aquifer property values (Rushton and Rathod 1979), and also the absence of a simulation of observed surface run-off from the beds overlying the limestone.

(a) Boiling Wells Spring



(b) Nine Foot Drain



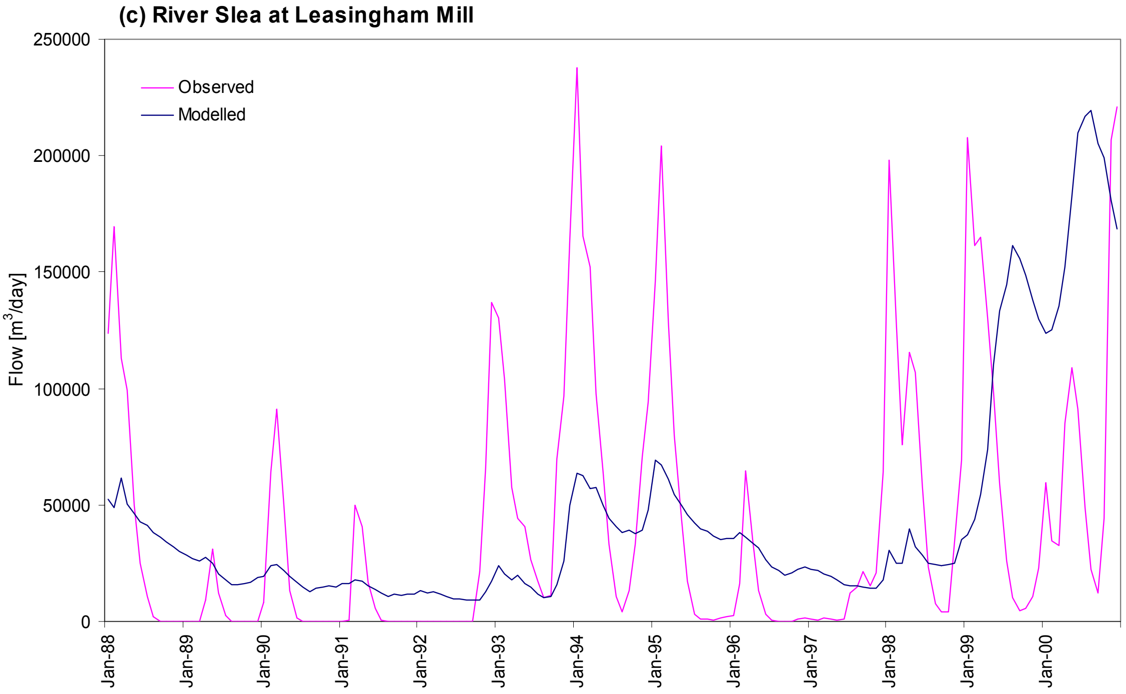


Figure 4.10 Observed and modelled flows for (a) Boiling Wells Spring, (b) the Nine Foot Drain and (c) the River Slea

Following calibration of the groundwater flow model, the particle-tracking program MODPATH was used to simulate flow paths from the steady-state flow simulation with average conditions for 1988-1998. A circle of backward tracking particles was assigned around each of the main public water supply abstractions and the key springs in order to determine capture zones for these features. Similarly, a line of backward tracking particles was assigned to the course of the River Slea to delineate its capture zone (see Section 4.3.5).

4.3.3 Groundwater transport model construction

The active transport model domain was identical to the active flow model domain. A recharge concentration boundary condition was used to simulate nitrate leached to the groundwater system. The concentration of nitrate accompanying the recharge flux at the limestone outcrop was specified for each monthly stress period and was based on the results of the export coefficient modelling discussed in Section 4.2. This meant that the annual 2-km grid square nitrogen loss estimates for the baseline years and scenarios had to be converted to equivalent monthly values at a 250 m cell resolution. Zones of initial nitrate concentrations were produced by taking the measured nitrate concentrations at selected boreholes at the beginning of 1988 and distributing these values spatially using a Thiessen polygon method (see Longley et al, 2005, pp.333-334).

Nitrate transport through the Lincolnshire Limestone can be thought of as a dual-porosity system, with both movement through the fissure network and diffusion into the limestone matrix (Chilton and Shearer 1993). The mass transport engine used for groundwater transport modelling (MT3DMS) can be used to simulate advection, dispersion and chemical reactions (such as denitrification approximated by first order-irreversible decay) of contaminants in groundwater, and in addition allows simulation of dual-domain mass transfer in fractured media or extremely heterogeneous porous media. Dual-domain mass transfer is thought to occur primarily by advection through the fractures or zones of high hydraulic conductivity filled by mobile water (mobile domain), whereas transport is primarily by diffusion through the non-fractured matrix or zones of low hydraulic conductivity filled with immobile or relatively stagnant water (immobile domain) (Zheng and Wang 1999).

4.3.4 Groundwater transport model calibration

The transport model calibration compared observed nitrate concentrations at 11 groundwater monitoring points (Figure 4.11) obtained from the Environment Agency to modelled concentrations for the period 1988-2000. Concentrations observed in the River Slea at Sleaford were also compared to groundwater nitrate concentrations in the unconfined limestone model cell closest to the observation point.

Model calibration was considered to have been achieved once the transport model simulated both dual-domain advection-diffusion mass transfer within the Lincolnshire Limestone model layer and denitrification in the confined section of the aquifer. In the process of calibration, values for the effective (fissure) and matrix porosities of 2.5 per cent and 16 per cent were determined, respectively, based on Smith-Carington et al. (1983) and Allen et al. (1997). Furthermore, examination of trends for boreholes on the limestone outcrop, such as Rauceby (Figure 4.12d), was important in determining the amount of matrix diffusion of nitrate, with the first-order mass transfer rate constant between the mobile (fissure) and immobile (matrix) domains determined during the model calibration to equal 2×10^{-5} per day. Boreholes in the confined aquifer, such as Padleys (Figure 4.12e), were useful in determining the degree of denitrification. If the rate of denitrification was too low, a flushing through of nitrate was observed at this borehole. A value for the denitrification rate constant of the mobile water phase of 0.01 per day was adopted in the calibrated model based on an estimate by Lawrence and Foster (1986). The denitrification process was activated approximately one km downdip of the limestone outcrop, where dissolved oxygen concentrations are found to be lower (Lawrence and Foster 1986).

Observed and modelled nitrate concentrations versus time for six of the observation points are shown in Figure 4.12. The model results show an adequate agreement between observed and modelled average nitrate concentrations with a mean error of -2.5 mg NO_3/l, mean absolute error of 14.7 mg NO_3/l and RMS error (equivalent to the standard deviation assuming a normal distribution of the error about the mean) of 20.5 mg NO_3/l. These measured errors are explained by the fact that the model does not simulate very well the observed seasonal fluctuation of nitrate concentrations (for example, the low values for the River Slea in the early 1990s). This outcome is not unexpected since the export coefficient model estimates of nitrate leaching to groundwater used for the transport model are calculated as annual losses and therefore seasonal fluctuations are not apparent in the simulated values. Also, Rushton et al. (1994) found that at Drove Lane, nitrate concentrations increased with groundwater heads since water moves rapidly through the more permeable fissures and solution channels which operate under higher groundwater conditions. Since the groundwater model did not simulate variable transmissivity with saturated depth, this may also help explain the smaller range in the modelled groundwater nitrate concentrations.

Overall, the calibrated model was considered to be an adequate representation of the hydrogeological system for use in assessing the impacts of land-use change scenarios on groundwater nitrate concentrations.

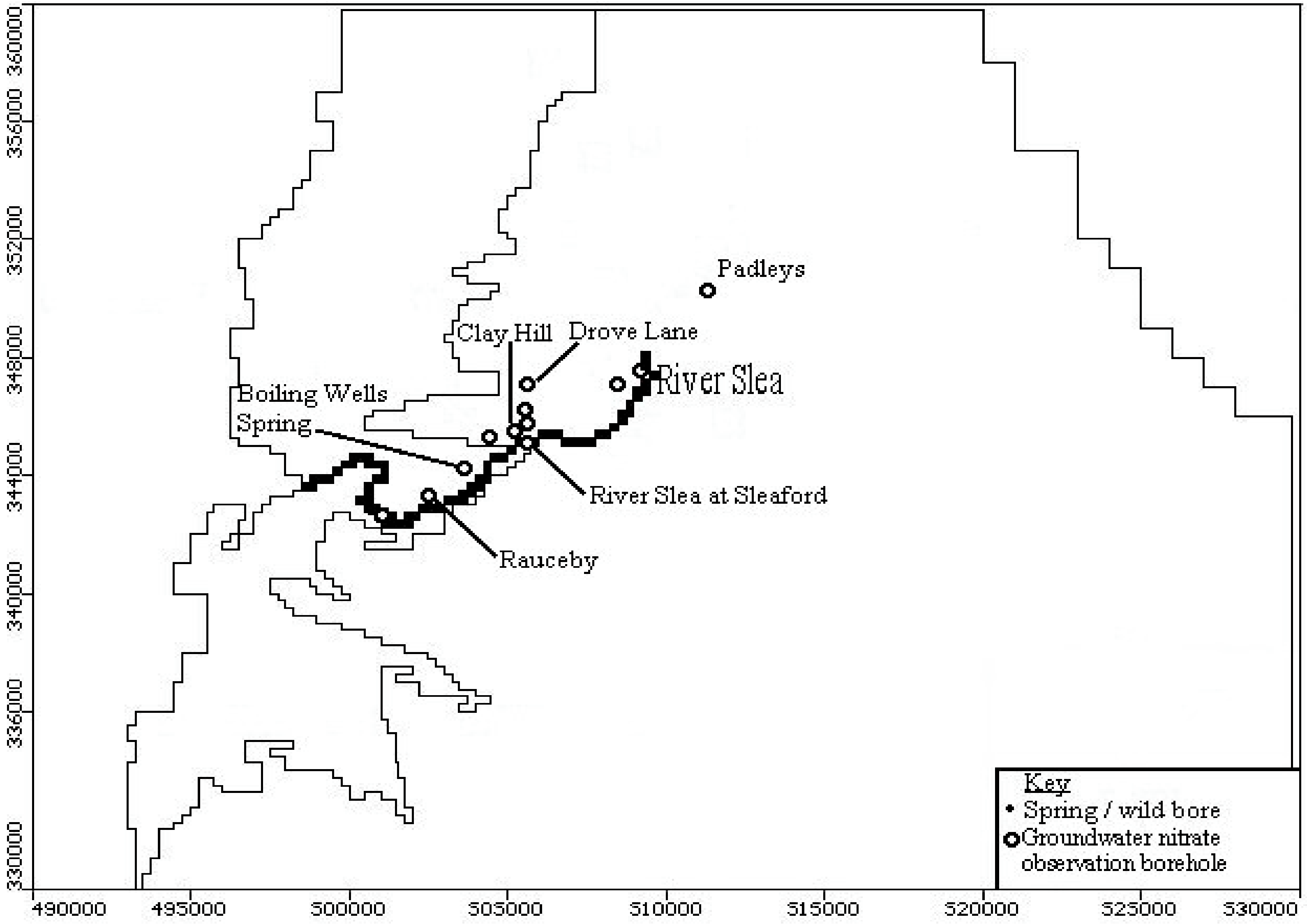
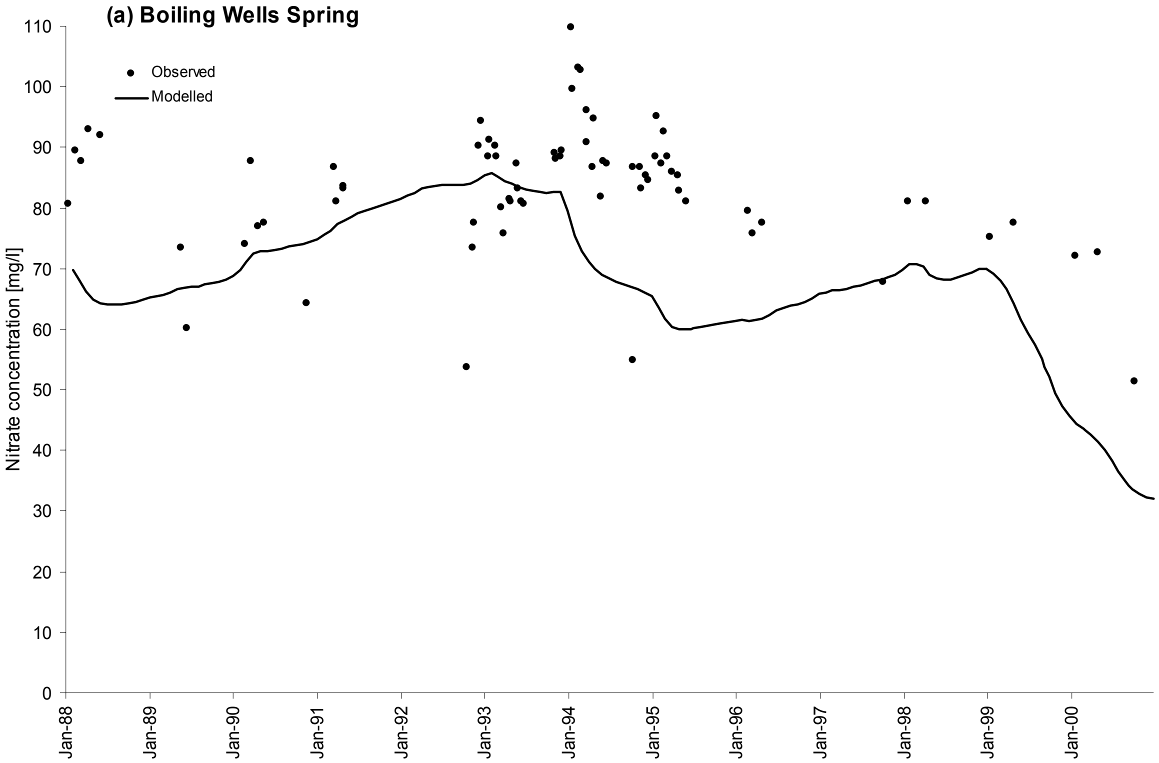
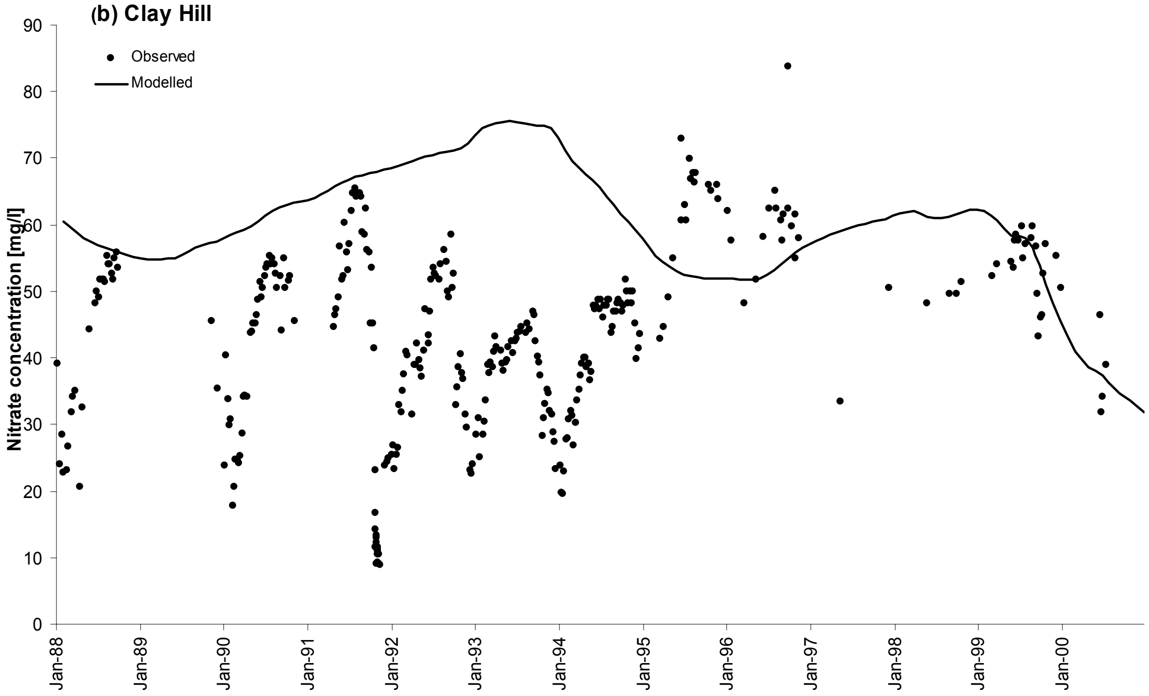


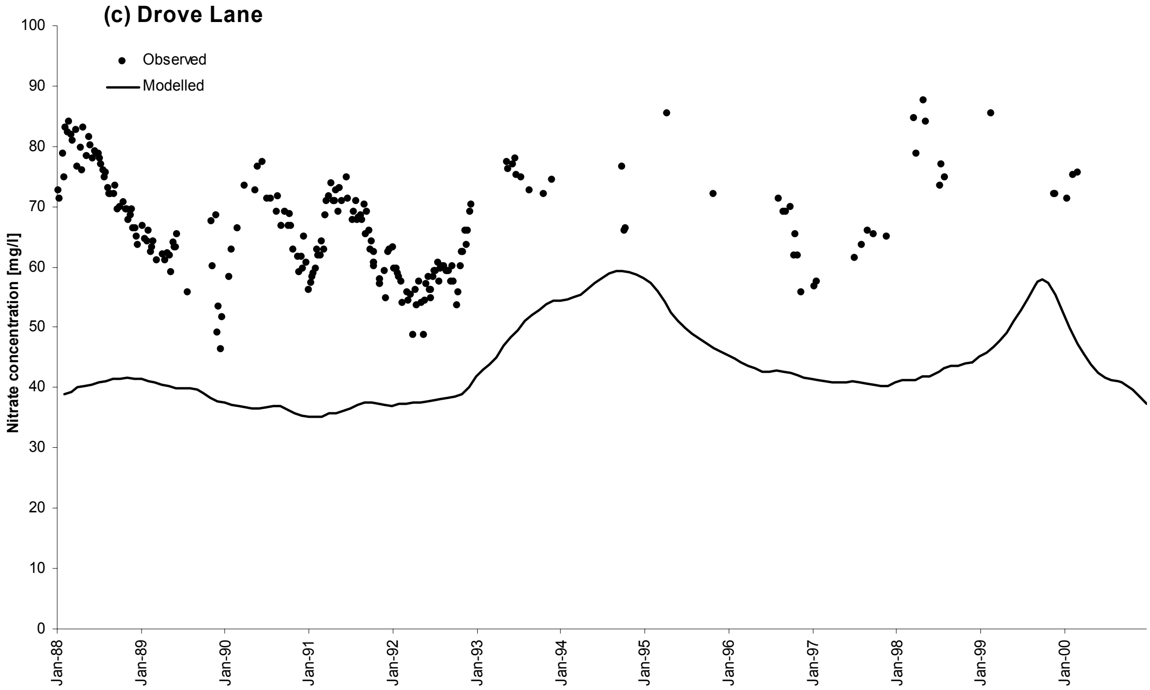
Figure 4.11 Location of the nitrate concentration observation points

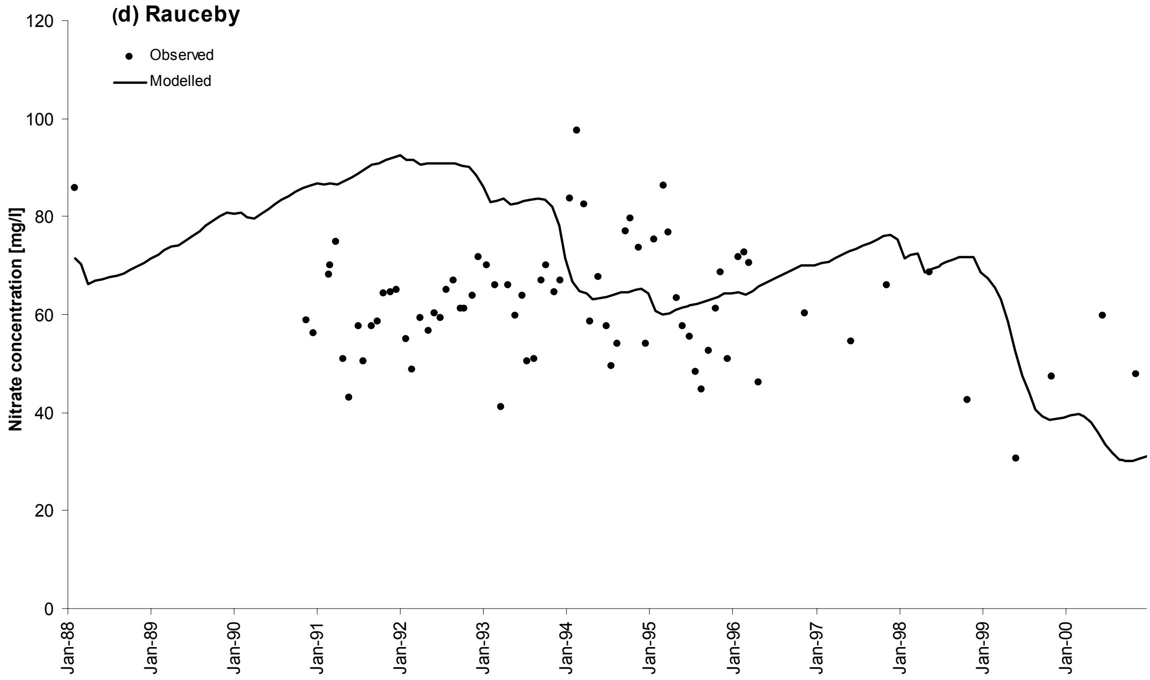


(a) Boiling Wells Spring



(b) Clay Hill


(c) Drove Lane
Observed
Modelled
Nitrate concentration [mg/l]
0
10
20
30
40
50
60
70
80
90
100
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00


(d) Rauceby
Observed
Modelled
Nitrate concentration [mg/l]
0
20
40
60
80
100
120
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

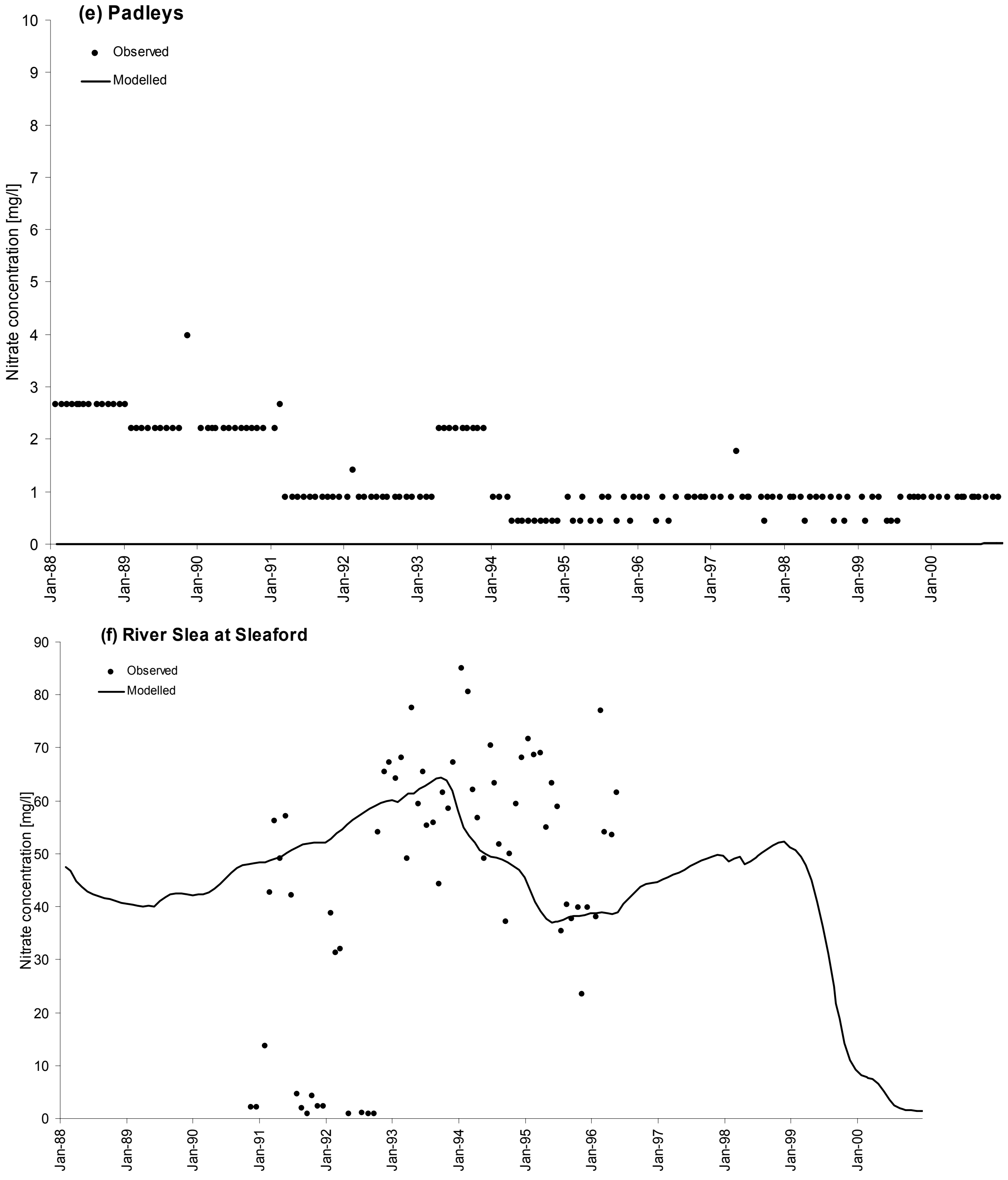


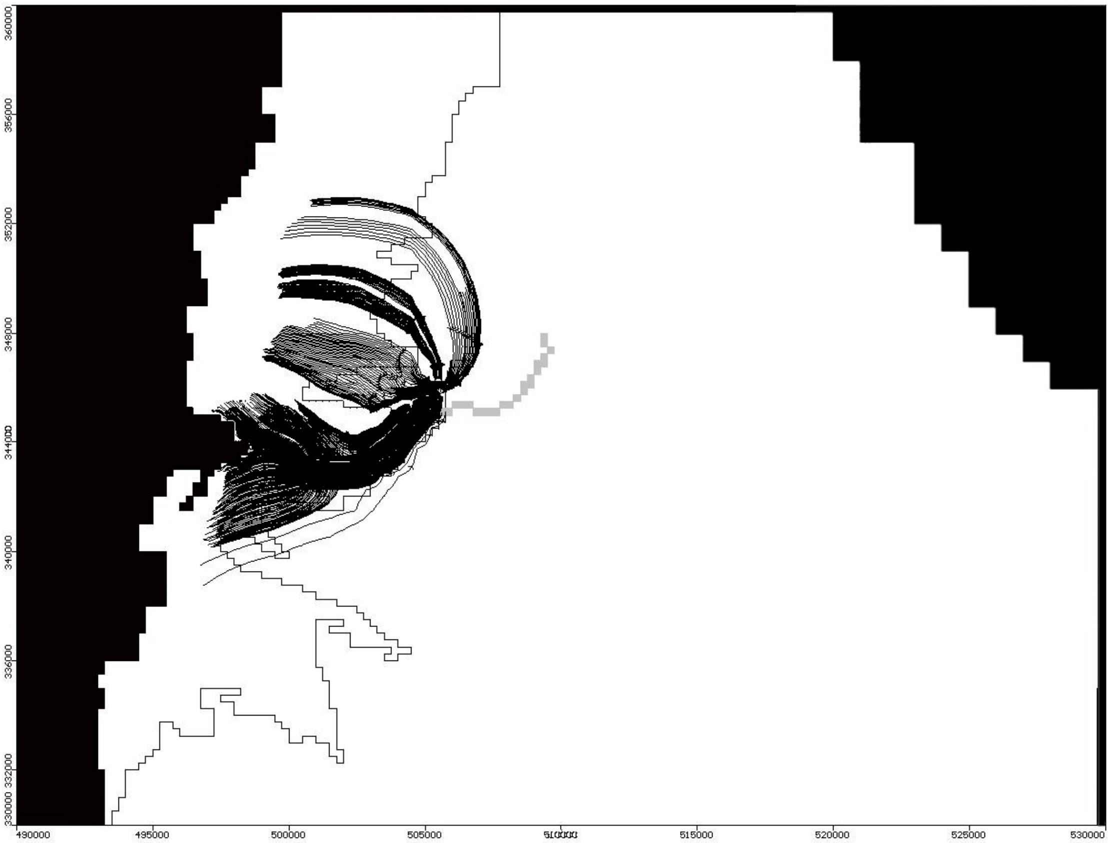
Figure 4.12 Observed and modelled groundwater nitrate concentrations for (a) Boiling Wells Spring, (b) Clay Hill, (c) Drove Lane, (d) Rauceby, (e) Padleys and (f) the River Slea at Sleaford

4.3.5 Scenario results

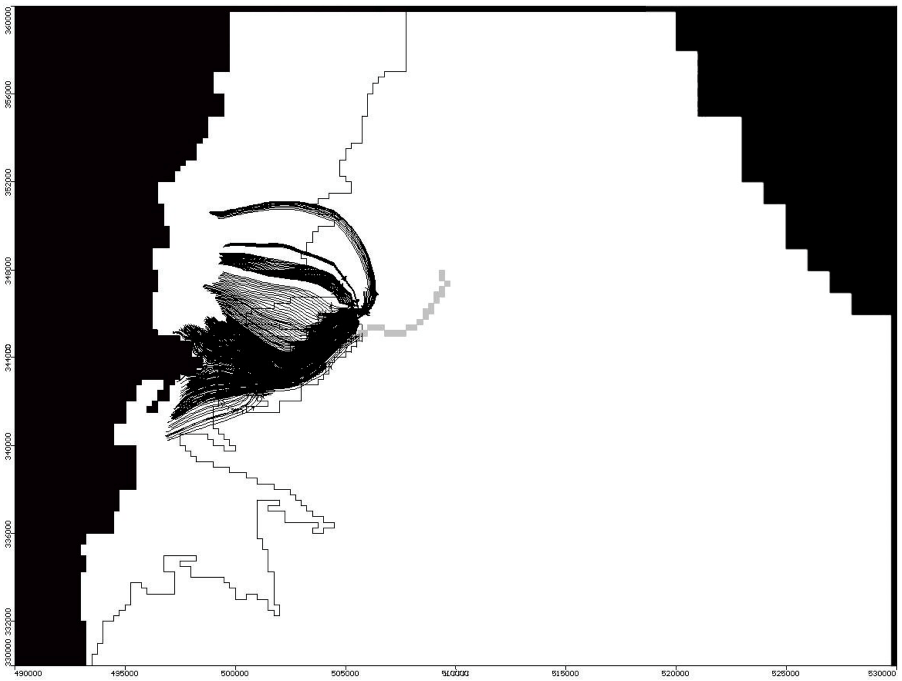
The calibrated transport model was used to assess the impact of a series of land-use change scenarios on groundwater nitrate concentrations. These scenarios are the same as those listed in Table 3.2 and discussed in the export coefficient model analysis. From the perspective of the groundwater model, the key grid cells were those above the limestone outcrop. Trends in total nitrogen losses and average leachate concentrations for this region are listed in Tables 4.9 to 4.11.

In the Protection Zone (PZ) scenario, it was necessary to define a steady-state capture zone (that is, groundwater catchment) for the upper River Slea, the main public water supply abstractions and key springs. This zone was generated using the calibrated groundwater model (see Figure 4.13a). Figures 4.13b and 4.13c indicate that the capture zone was fairly stable under varying climatic conditions, though it did expand during the relatively wet year of 1993 as groundwater was drawn from further away, causing increased flows.

a) Average conditions (1988-1998 average)



b) Dry conditions (1990)



c) Wet conditions (1993)

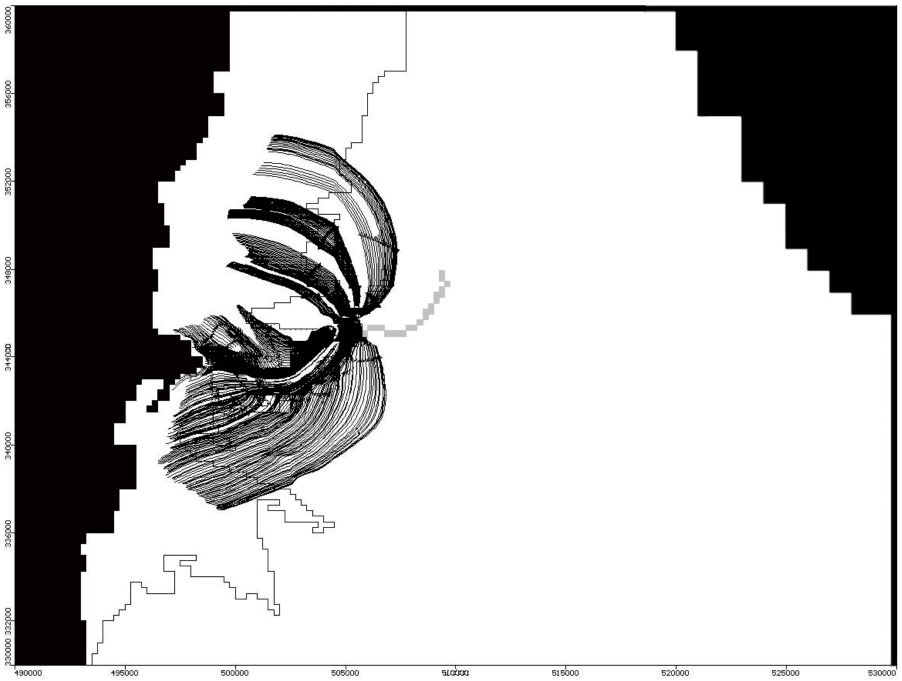


Figure 4.13 Groundwater capture zones under varying climatic conditions

The scenarios were implemented as a sudden change of land use in 2006. In practice, features such as woodland would not become established immediately, but would actively take up nitrate during the initial stages of development and so have an impact in reducing soil and groundwater nitrate concentrations. Predictive runs through to 2030 were based on average monthly groundwater recharge and abstraction rates for the period 1988-2000. Standardising for such factors made trends in nitrate concentrations across the different scenarios easier to examine. Plots of predicted groundwater nitrate concentrations over time at three key boreholes are shown in Figures 4.14 to 4.16, while Table 4.14 lists the predicted changes in nitrate concentrations by 2030 for a number of other sites.

All three plots display an 'envelope' of outcomes associated with the different scenarios. Although nitrate concentrations drop initially in the more restrictive land use scenarios in response to reduced nitrate concentrations entering the fissure water, the long-term trend in nitrate concentrations is a gradual increase due to matrix diffusion controlled by the dual-domain mass transfer mechanism. The nitrate concentrations do not reach equilibrium before 2030, which suggests it will take time for the total pore water volume to be flushed through as a result of the dual-porosity nature of the aquifer.

Comparison of the outcomes in Table 4.14 suggests that current policy reforms (scenarios CPa and CPb) will result in a reduction in nitrate concentrations compared to a projection of the Recent Past (RP) scenario. However, the decrease is minor and suggests that by 2030 nitrate concentrations at Clay Hill and Boiling Wells Spring would be only three per cent less under scenario CPa and five per cent less under CPb.

More substantial changes are evident under the best practice husbandry regimes. The 'intermediate' scenario variants typically produce reductions of 15 per cent and the 'protective' ones 25 per cent. Outcomes for the NSA options are similar to the latter, but would involve considerable changes to farming across the limestone outcrop. The protection zone scenarios represent an even more geographically focused approach and produce reductions of up to 30 per cent by the end of 2030.

Whole catchment land-use change was not considered a realistic option and was included in the analysis primarily to provide a benchmark against which alternatives could be compared. Nevertheless, only under the Protection Zone and Whole Catchment scenarios were nitrate concentrations reduced to a level where water supply companies might begin to feel reasonably confident of meeting the regulatory 50 mg NO_3/l limit without the need for source treatment (allowing for variations in nitrate concentrations resulting from inter-annual climatic variations).

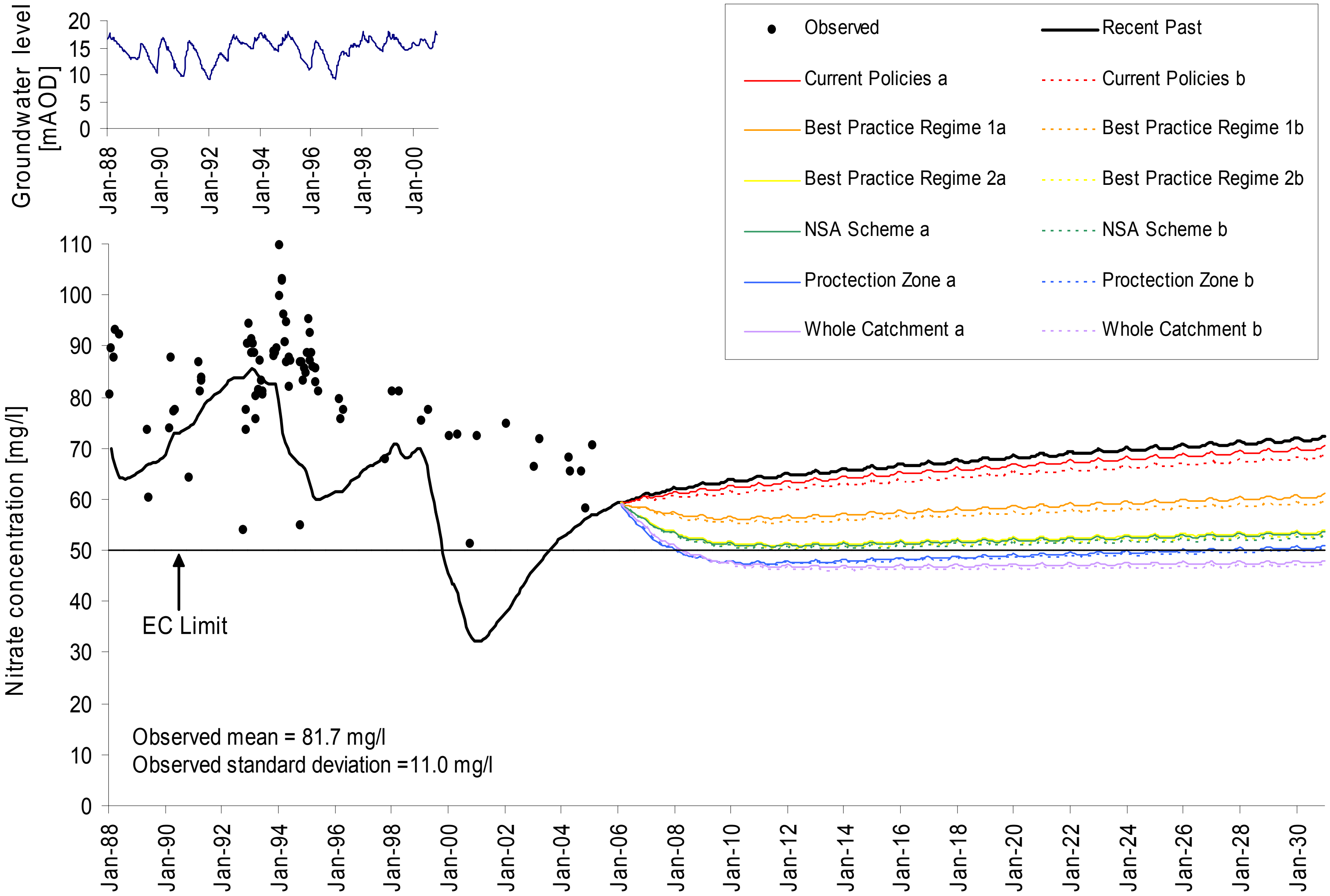


Figure 4.14 Modelled groundwater nitrate concentrations under different land-use change scenarios for Boiling Wells Spring. Observed groundwater levels for the calibration period (1988-2000) are shown for observation borehole 2_617

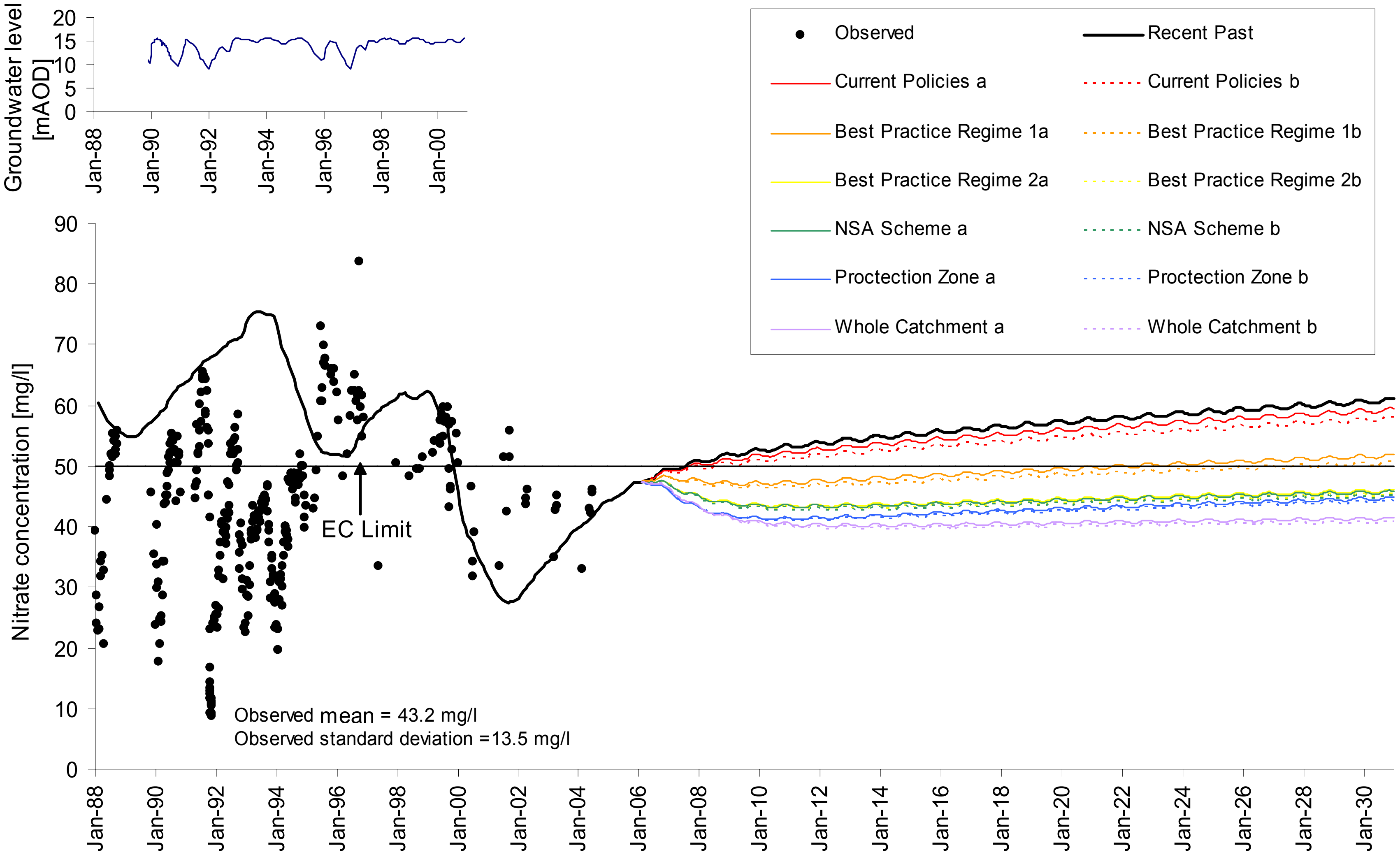


Figure 4.15 Modelled groundwater nitrate concentrations under different land-use change scenarios for Clay Hill. Observed groundwater levels for the calibration period (1988-2000) are shown for observation borehole 2_701

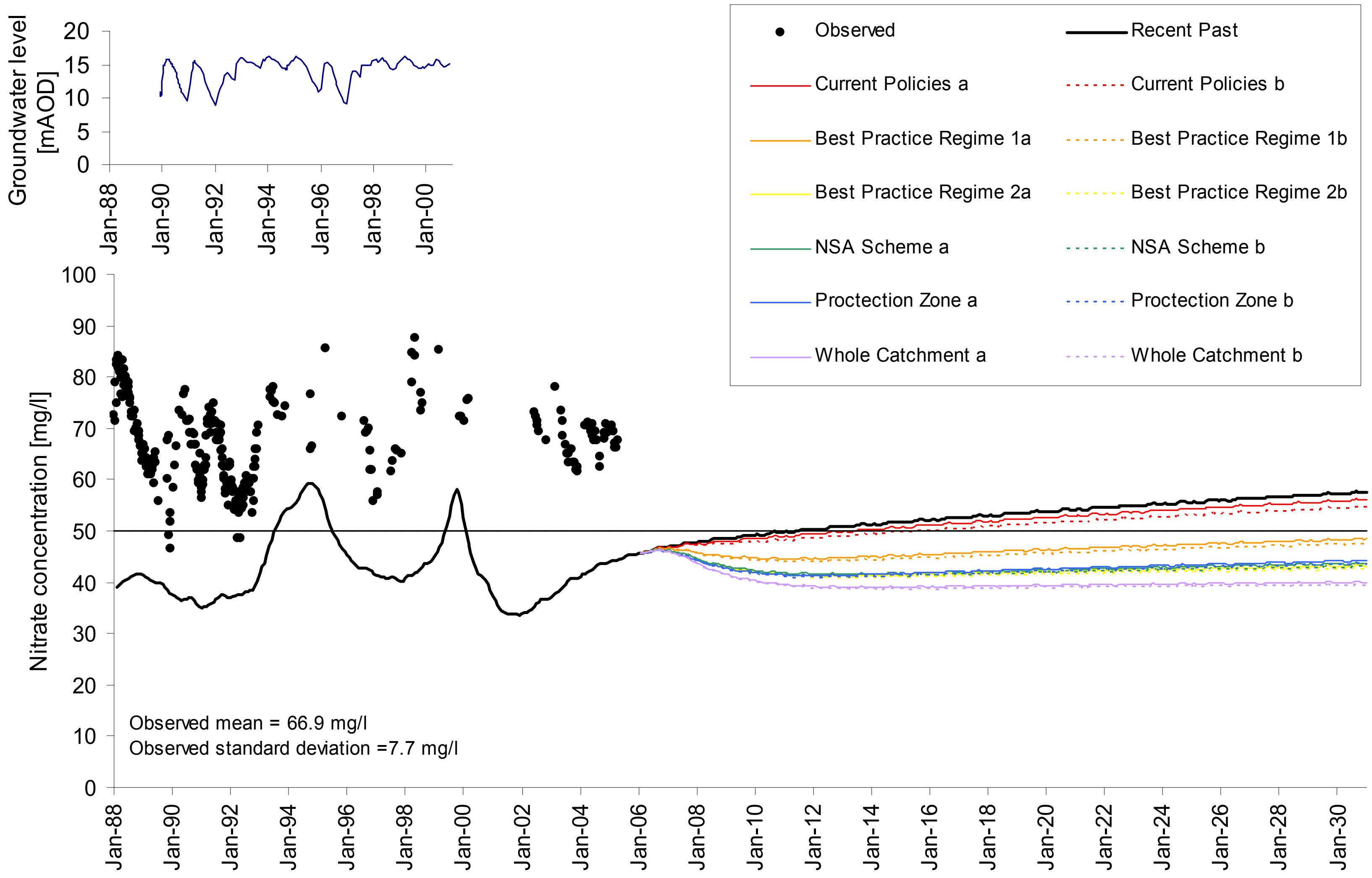


Figure 4.16 Modelled groundwater nitrate concentrations under different land-use change scenarios for Drove Lane. Observed groundwater levels for the calibration period (1988-2000) are shown for observation borehole 2_702

Table 4.14 Predicted nitrate concentrations at selected observation boreholes by December 2030 and the percentage change compared to a projection of the Recent Past (RP) scenario

		RP	CPa	CPb	BP1a	BP1b	BP2a	BP2b	NSAa	NSAb	PZa	PZb	WCa	WCb
Boiling Wells	Concentration [mg/l]	72.4	70.5	68.5	61.0	59.5	54.0	53.0	53.6	52.7	50.9	50.3	48.0	47.2
	Percentage difference	-	-3	-5	-16	-18	-25	-27	-26	-27	-30	-31	-34	-35
Bone Mill	Concentration [mg/l]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Percentage difference	-	-3	-5	-15	-17	-25	-27	-25	-26	-12	-14	-17	-19
Clay Hill	Concentration [mg/l]	61.1	59.5	57.9	51.9	50.6	46.1	45.4	45.9	45.1	44.8	44.3	41.5	40.8
	Percentage difference	-	-3	-5	-15	-17	-24	-26	-25	-26	-27	-28	-32	-33
Cobblers Spring	Concentration [mg/l]	27.6	26.9	26.2	23.8	23.1	21.1	20.7	20.9	20.6	20.4	20.1	19.1	18.8
	Percentage difference	-	-2	-5	-14	-16	-24	-25	-24	-26	-26	-27	-31	-32
Drove Lane	Concentration [mg/l]	57.5	56.1	54.6	48.4	47.4	43.2	42.5	43.7	42.9	44.2	43.5	40.0	39.4
	Percentage difference	-	-3	-5	-16	-18	-25	-26	-24	-25	-23	-24	-30	-32
Guildhall	Concentration [mg/l]	30.1	29.3	28.5	25.3	24.7	22.6	22.2	22.7	22.4	22.8	22.4	20.7	20.4
	Percentage difference	-	-3	-5	-16	-18	-25	-26	-24	-26	-24	-26	-31	-32
Rauceby	Concentration [mg/l]	72.1	70.2	68.2	61.0	59.5	53.8	52.9	53.4	52.4	50.6	50.0	47.8	46.9
	Percentage difference	-	-3	-5	-15	-17	-25	-27	-26	-27	-30	-31	-34	-35
R. Slea Sleaford	Concentration [mg/l]	29.5	28.8	28.1	25.7	25.0	22.8	22.4	22.5	22.2	22.0	21.7	20.8	20.5
	Percentage difference	-	-2	-5	-13	-15	-23	-24	-24	-25	-26	-26	-30	-31
Warren	Concentration [mg/l]	74.6	72.5	70.5	62.8	61.3	55.9	54.9	55.5	54.5	53.6	52.9	49.5	48.6
	Percentage difference	-	-3	-5	-16	-18	-25	-26	-26	-27	-28	-29	-34	-35

4.4 Summary

The analyses presented in this chapter have shown how a combination of export coefficient and groundwater modelling can be used to evaluate a range of land-use scenarios. One important feature of the local situation which became apparent in the groundwater modelling was the dual-porosity nature of the Lincolnshire Limestone in controlling the flushing time of the aquifer in response to changes in groundwater nitrate input. This key factor suggests that while short-term reductions in nitrate could be achieved, there is likely to be a steady long-term rise in nitrate levels that might require additional measures to keep concentrations within acceptable limits until a new equilibrium nitrate concentration is achieved.

Results for the different scenarios suggest that current policy reforms will have a beneficial, but relatively minor effect. Significant reductions in groundwater nitrate concentrations appear to require major changes to agricultural practices or substantial land-use change in particular targeted areas. However, these will also have considerable socio-economic consequences for agricultural activities and other sections of society. The following section examines several of these impacts, focusing particularly on the costs to farmers, current water treatment costs and other potential benefits of changes in land use.

5 Assessment of scenarios

5.1 Introduction

Stakeholder engagement was integral to the Water4all project, providing valuable input to the development of the land-use scenarios used in the modelling phase. The final phase of the project (see Figure 2.1) once again called upon stakeholders to contribute their views on the results of the analysis, the acceptability of the different measures and opinions on the way forward. To enable stakeholders to fully evaluate the merits of each scenario, it was necessary to provide additional information on the cost-effectiveness of different options. In particular, given the prospective scale of the changes required to meet EU directive targets (such as the 50 mg NO_3/l limit), it was necessary to estimate the likely income foregone by farmers through altering their husbandry practices and land use in the manner prescribed by different scenarios. These values needed to be compared with the costs that water suppliers incur to remove nitrate from drinking water, in order to identify the extent of any additional financial resources (for example, a possible agricultural compensation scheme or additional water charge) that might be required to support land-use measures for groundwater quality management.

Existing literature was reviewed to examine how economic evaluations of these types of costs and benefits have been conducted. Work by Pretty et al. (2000, 2003) at the national scale is widely cited in this context. Other studies focus on a regional or catchment scale (Laurence Gould Consultants Ltd 1985; Severn-Trent Water, DoE and MAFF 1988), but very few give precise details of the methods. A report published by UKWIR (2001) presents a cost-benefit analysis for four case study catchments (including one on the Lincolnshire Limestone), comparing water treatment costs with farm income foregone through changing land use. This study is the closest known comparison to the approach adopted below. However, the entire methodology of the UKWIR study could not be replicated because certain data and calculations were not reported in sufficient detail.

The assessment outlined in this section compares the costs of treating water supplies to remove nitrate with projected income losses to farming resulting from altering land use as prescribed under each scenario. There are, of course, other potential water quality benefits from taking land out of arable production (such as reductions in phosphate and pesticide levels). In addition, switching to a less intensive form of farming or to other land uses may also bring biodiversity and landscape aesthetic benefits, and enhance opportunities for countryside recreational activities (see Environment Agency 2002; Pretty et al. 2003; Bateman et al 2005). These issues are discussed later in this section, but a full economic evaluation was outside the scope of the project.

Another difficulty which arises in this type of appraisal is trying to ensure that the geographical units over which costs and benefits are evaluated are consistent. This is often difficult for several reasons. For example, the catchments of rivers or boreholes may not coincide with administrative units (such as water supply zones); benefits, such as new areas for informal recreation, may be used by people living some distance away; and pricing mechanisms (for example, for domestic water supplies) may be regional or national in structure and so not reflective of local fluctuations in cost. In the analysis which follows, an effort was made to address this problem by focusing on a defined geographical region, but there are limits to the extent that any such relatively small area can be considered an entirely closed system.

5.2 Evaluating costs

5.2.1 Measuring farming income

The Defra Farm Business Survey (http://statistics.defra.gov.uk/esg/asd/fbs/default.htm) provides statistics on the economic and physical performance of farms in England. Farm enterprise yields, costs and profit margins are analysed in a number of regional publications produced for Defra by eight universities and agricultural colleges and these are summarised in a number of Defra reports (such as Farm Accounts in England 2003/04). In addition, John Nix produces an annual Farm Management Pocketbook (Nix et al. 2004). In this, most of the figures are *projected one year forward*, as the pocketbook is designed as an aid to farm planning.

There does not appear to be a prescribed way of estimating the likely income changes that an average farm would experience in switching from one land use to another. The most appropriate measure is probably the alteration in the gross margin (GM) achieved by each farming enterprise. This is not the same as profitability, since the GM of a particular enterprise (such as a crop) is the income (yield x market price per hectare) less variable costs (seed, fertiliser, sprays, casual labour for harvesting and other sundry items), usually expressed in £/ha. Fixed costs (specialist machinery and other overheads) are therefore excluded, but as these can be so variable from farm to farm, the gross margin is widely used as a farm planning tool (see Nix et al. 2004) and has also been employed in other scenario studies (such as UKWIR 2001).

Regional farm economic reports were obtained for the East Midlands (such as Rural Business Research Unit 2004) and the Eastern Counties (such as Lang 2004). Although the Eastern Counties report does give gross margin data for different farm enterprises, these values were higher than would be typical in the Slea catchment (Paddy Johnson, personal communication). Unfortunately, in the East Midlands report, which appeared more representative of conditions in the Slea catchment, the data presented were summarised by farm type (for example, arable-mainly cereals or arable-roots and vegetables) rather than by enterprise. The Nix Pocketbook provided enterprise gross margin information under different yield conditions and the average values listed were considered appropriate for the study area. Estimates on income foregone in the UKWIR (2001) scenario study were also based on GM data obtained from the Nix Pocketbook.

Gross margin data for the range of crop enterprises relevant to the Slea catchment were therefore extracted from the Nix Farm Management Pocketbooks (such as Nix et al. 2004) for the forecast years 2000 to 2005. Area payments were removed from the margins to leave the actual return from each crop, which was averaged across the six-year period. Livestock enterprises were slightly more difficult to estimate as the Nix Pocketbooks provide figures for each specialisation, whereas the 2-km grid cell data consisted simply of totals for cattle, sheep, pigs and poultry. Average GMs were therefore extracted from Nix et al. (2004) for livestock categories that appeared to be broadly representative of the activities currently carried out in the Slea catchment. Table 5.1 summarises the yields and gross margins used in the economic analysis.

5.2.2 Impacts of changes in husbandry regimes on farming incomes

The gross margins in Table 5.1 were taken to represent current or 'standard' conditions and farming methods. However, several scenarios also involved alterations in crop husbandry regimes to reduce nitrate leaching (see Table 3.2). These included practices required in the NSA Scheme (see Entec 1998; Lord et al. 1999) and measures tested in field experiments by Shepherd and Lord (1996) and Johnson et al (1997; 2002) (see Table 3.3).

The expected effect of these more demanding or restrictive husbandry measures would be a reduction in yield (or increase in costs) and hence an impact on enterprise gross margins. However, it is not straightforward to identify the magnitude of these economic impacts. For example, Johnson et al. (1996) reported changes in yield under the 'intermediate' and 'protective' husbandry regimes, but the results obtained (Table 5.2) did not show a clear trend due to a variety of year-on-year factors within the study period. Similarly, while there were broad yield reductions under the NSA scheme, the data presented in Entec (1998) suggest that the effects varied between crops and did not show particularly consistent associations with different husbandry options.

Table 5.1 Estimates of 'standard' enterprise gross margins in the Slea catchment

Arable	**Notes**	**Yield t/ha**	**£/ha**
Wheat	Value for winter wheat	8.00	300
Winter Barley	Same margin for feed and malt barley	6.42	215
Spring Barley	Same margin for feed and malt barley	5.65	210
Other Cereals	Nix 2005 value for winter sown feed oats	6.50	200
Potatoes	Value used relates to maincrop potatoes	42.67	1,320
Sugar Beet	Standard 16 per cent sugar content	54.58	1,070
Field Beans	Average of winter and summer sown	3.66	165
Peas	Value for dried peas not vining peas	3.74	120
Oilseed Rape	Value for winter sown	3.25	400
Other Arable	Nix 2005 value for linseed	1.4	125
Horticultural Crops	Average GM of all field vegetable crops	-	2,050
Livestock			**£/head**
Cattle	18 month beef		149
Sheep	Lowland spring lambing ewe		16.3
Pigs	Per 30 kg pig reared		10.35
Poultry	Per brown egg layer		1.72

Table 5.2 Effect of husbandry regimes on yield

Crop	Mean Yield (t/ha) 1991-95 Standard	Mean Yield (t/ha) 1991-95 Intermediate	Mean Yield (t/ha) 1991-95 Protective
Peas	3.7	3.8	3.5
Wheat (milling)	7.5	6.9	7.9
Barley	7.1	7.0	6.6
OSR	2.9	2.6	2.5
Wheat (feed)	8.7	8.7	8.8

Source: Johnson et al. (1996). Full fertiliser application (none on peas).

Johnson et al (1996) also reported the mean gross margin for the whole crop rotation under the ‘standard’, ‘intermediate’ and ‘protective’ regimes, as well as with full and half-N applications. Excluding support payments of £260/ha, the values are as shown in Table 5.3. In addition, the authors suggested that the ‘protective’ N half-treatment provided a basis against which NSA compensatory payments could be assessed (that is, a drop of £100 (£448 to £348) compared to an NSA Basic Arable Option A payment of £105/ha). However, the N inputs for the NSA husbandry regime in the export coefficient modelling (see Table 4.3) are rather higher than the half-N applications in the experiments run by Johnson et al. (1996) (see Table 5.4). This suggests that in terms of estimating the income foregone under the NSA regime, it might be reasonable to place reductions in gross margin under a Basic Arable Option A scheme at halfway between the ‘protective’ full and half rates (that is 382.5/448 = 85 per cent). Such a calculation also matches the conclusion in Entec (1998, p.80) that the NSA Basic Scheme payment level exceeded the average income foregone and costs incurred.

Table 5.3 Mean gross margins under different husbandry regimes

	Net GM £/ha (Full N)	% of Full Standard	Net GM £/ha (Half N)	% of Full Standard
Standard	448	100%	373	83%
Intermediate	434	97%	372	83%
Protective	417	93%	348	78%

Source: Calculated from data in Johnson et al. (1996) and based on product prices at the time.

Table 5.4 Nitrogen inputs under different husbandry regimes

	Full N (kg/ha)	Half N (kg/ha)	NSA Scenario (kg/ha)	Scenario – Half / Full – Half Range
Wheat	210	105	163	0.55
Winter Barley	160	80	120	0.50
Peas	0	0	0	-
OSR	190	95	146	0.54

Source: Johnson et al. (1996) and Table 4.6.

With respect to the economic impacts of adopting a ‘protective’ husbandry regime, it is recognised that cover crops can cost £35-50/ha to establish (Entec 1998; Environment Agency 2002; Withers et al. 2003), but this may be compensated to some degree by reductions in other costs (Environment Agency 2002, p32, suggests a saving of £11-

26/ha when using minimum rather than conventional tillage, though this can vary appreciably depending on soil type).

Withers et al. (2003), in their study for the Environment Agency and English Nature on *Grant Aid Proposals for the Control of Diffuse Agricultural Pollution,* estimated a combined Basic and Plus scheme costing of £30/ha (this included some cover crops, and minimum tillage). Another indication of the impacts on gross margins of stricter management practices is given in the cost-benefit study by UKWIR (2001). This research included an Integrated Catchment Management (ICM) scenario that involved measures similar to the 'intermediate' regime specified in Table 3.3 and with gross margins for all crops reduced by five per cent.

Based on the above calculations and reviews, it was decided to adjust gross margins for the different husbandry regimes in the following way. Some arable crops (such as horticultural) had no alterations in their husbandry practices or N inputs across the different regimes, so their gross margins remained unchanged. For the BP scenario incorporating 'intermediate' measures, the gross margins for all other arable crops were reduced by five per cent from the standard values. With the 'protective' BP variant, a few crops (such as potatoes) were assigned the same gross margin as in the 'intermediate' case because the husbandry did not alter, but in most cases the margin was set at either £10 less than 'intermediate' or a 10 per cent reduction from the standard return. These decisions reflected judgements on the costs of husbandry recommendations (as discussed in Environment Agency 2002; Withers et al. 2003) and details of yield and gross margin impacts from Johnson et al. (1996).

All the gross margins for the NSA husbandry regime were set at the same or a lower level than those for 'protective' measures. The greatest reductions involved a 15 per cent decline from the standard return, reflecting the information on N inputs in Table 5.4 and advice on the sensitivity of certain crops (such as wheat and oil seed rape) to lower N inputs. Table 5.5 summarises the final set of gross margins.

Table 5.5 Estimated enterprise gross margins under the different husbandry regimes

Categories	Standard * £/ha	Intermediate £/ha	Protective £/ha	NSA £/ha	Low Yield ** £/ha
Approx. Ratio	100%	95%	90%	85%	
Arable Crops					
Wheat	300	285	270	255	220
Winter Barley	215	205	195	185	140
Spring Barley	210	200	190	180	150
Other Cereals	200	190	180	170	125
Potatoes (maincrop)	1320	1250	1250	1250	780
Sugar Beet	1070	1020	1020	1000	745
Field Beans	165	155	145	140	115
Peas	120	110	105	100	55
Oilseed Rape	400	380	360	340	125
Other Arable	125	125	125	125	55
Horticultural Crops	2050	2050	2050	2050	

Note: Livestock gross margins were the same across all regimes. * Based on 6-year mean of Nix Pocketbook enterprise gross margins; average yield. ** Based on 6-year mean of Nix Pocketbook enterprise gross margins; low yield; given for comparison.

5.2.3 Costs of treating nitrate in groundwater

It is not a simple matter to estimate water treatment costs that can be compared against agricultural income foregone (£/ha) within a defined geographical area such as a catchment. Pretty et al. (2000, 2002, 2003) have produced the most comprehensive national assessment of the environmental costs of diffuse pollution, including nitrate. They estimated that the annual cost of treating nitrate from agricultural sources to meet EU drinking water standards was at least £13 million. These calculations were based on treatment cost data compiled from OFWAT returns, but these are not publicly available and Pretty et al. obtained copies from individual water companies supplied in confidence for their research (Professor Jules Pretty, University of Essex, personal communication).

A more recent report published by UKWIR (2004) summarises the costs incurred by the UK water supply industry in response to a range of groundwater quality problems (arising from nitrates, pesticides and other chemicals, salinity, metals, bacteria and so on) during the years 1975-2004. Total capital (CAPEX) and operating (OPEX) expenditure associated with these problems is estimated at £754 million (2003 prices). In addition, an item in the ENDS report (April 2004) is cited which suggests that the capital expenditure by water companies to reduce nitrate levels in ground and surface water will be about £300m to £400m during the Asset Management Plan (AMP) 4 investment period ending in 2009. The report also mentions a small number of previous studies that have attempted to estimate the costs of maintaining water quality and comments (p.31) that “the considerable differences within and between these estimates reflect the difficulty of undertaking such a task and the wide range of assumptions involved and/or components included”.

Results from the groundwater modelling presented in Section 4 indicate the types of land-use and management changes that would be necessary to reduce borehole nitrate concentrations below the required 50 mg NO_3/l limit. For the purposes of this study, Anglian Water Services kindly provided information on the typical treatment costs that are currently incurred to reduce nitrate levels in drinking water to below the same limit. At present, some 86 per cent of the population in the Sleaford Water Supply Zone (WSZ) are served from the Clay Hill treatment works on the western side of the town. This works has an average daily source output of 8 Ml/d [1] and is fed from the boreholes at Clay Hill, Drove Lane and Kirkby la Thorpe (see locations in Figure 1.5). The present arrangement is that low nitrate water from Kirkby la Thorpe is pumped to the Clay Hill works where it is mixed with higher nitrate supplies from the other boreholes prior to treatment (see previous discussion in Section 1).

If a blending scheme was not possible (as may be increasingly the case in the future, see UKWIR 2004) and only high nitrate sources were available, then one option would be to construct an ion exchange plant to treat 50 per cent of the water and mix it with the untreated half to achieve compliance with the 50 mg NO_3/l limit. According to the information provided by Anglian Water Services, a typical example of such a plant would involve CAPEX of £2.9 million and OPEX of £164,000 per annum, giving a Whole Life Cost over 40 years of £9.46 million (£5.196 million as a Net Present Value). Taking a simple average (£9.46 million / 40) produces a cost of £236,500 per annum. The current population served by the Clay Hill works is some 29,500, so this total is equivalent to £8 per person per year (Simon Eyre, Anglian Water Services, personal communication).

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[1] Ml/d = megalitre per day or 1,000,000 litres per day or 1000m^3 per day or 220,000 gallons per day

As a comparison, another useful estimate cited by UKWIR (2004, p.57) is an OFWAT benchmark cost (used by OFWAT to evaluate capital investment programmes submitted by water companies in the periodic reviews) that the capital cost of nitrate removal at a small borehole works is £222,000 per Ml/d. This estimate can be used in conjunction with the Clay Hill daily output (8 Ml/d) in a second calculation of the cost of treating nitrate in the public water supply. Eyre (2004) stated that Anglian Water Services has spent around £32 million on ion exchange plant to remove nitrate from the water supply. This equipment has running costs of around £3.5 million per year (where the operating cost is around 10 per cent of the capital cost). A water treatment cost calculation based on these details is shown in Box 1. The result is similar to that derived directly from the Anglian Water Services information, which is reassuring given the uncertainties and assumptions in such calculations.

Box 1: 'Ballpark' water treatment costing

Water Treatment Cost = Capital Expenditure + Annual Operating Cost

Capital Expenditure: Installation of nitrate removal at a small borehole works per OFWAT = £222,000 per Ml/d. Output from the Clay Hill treatment works averages 8 Ml/d. Therefore the cost of nitrate removal = 8 Ml/d x £222,000 = £1,776,000. Spread over 40 years this equals **£44,400 per year**.

Annual Operating Cost: Based on Anglian Water Services figures for expenditure on water treatment - £32m (capital) and £3.5m (annual operating costs). Running costs are some 10% of capital costs; therefore 10% of £1,776,000 = **£177,600 per year**.

Water Treatment Cost = £44,400 + £177,600 = **£222,000 per year**

An economic appraisal of diffuse pollutants in groundwater by UKWIR (2001) used a similar method of water treatment cost estimation. The UKWIR (2001) values were based on median values of CAPEX and OPEX from water company 1999 returns to OFWAT. In the UKWIR (2001) cost-benefit analysis, all costs were expressed in terms of £/Ml/d of water supplied. The cost-benefit value was obtained by:

- calculating the total agricultural gross margin for each catchment by multiplying gross margins for each crop type by the percentage area of the catchment that they occupied;
- taking the quantity of water per hectare for each catchment and dividing it by the corresponding agricultural gross margin per hectare (UKWIR 2001, pp.36-7).

Unfortunately, the UKWIR (2001) report only presents the net values of agricultural gross margin income less water treatment costs and not the totals used to derive them. In addition, all the results are presented as Net Present Values, with discounting over a 20-year period. This means that it is difficult to directly compare the results of the UKWIR (2001) analysis (including a case study of a Lincolnshire Limestone public water supply borehole) with the findings reported below, but there are sufficient similarities in the methods and data sources to support the validity of the approach adopted.

5.3 Comparing farm income foregone with water treatment costs

As mentioned in Section 5.1, an important issue in making such a comparison is trying to ensure that the geographical units over which costs and benefits are evaluated are consistent. In the Sleaford area, the situation is complicated by the fact that the Slea catchment and the Sleaford WSZ served from Clay Hill only partially intersect. Figure 5.1 shows that the WSZ extends some way to the south east of the Slea surface catchment, while the latter includes areas to the west and north east in other supply zones. However, some 75 per cent of the resident population in the Sleaford WSZ is also in the Slea catchment and, as shown in Figure 5.1, the intersection of the two areas coincides with the great part of the modelled average recharge zone for the key springs and abstraction boreholes west of Sleaford. It was therefore decided that it would be most appropriate to compare water treatment costs with estimates of changes in farming gross margins for the Slea catchment 2-km grid squares that intersected the Sleaford WSZ. This intersection represented 39 of the 67 Slea catchment grid squares and covered a total area of 15,600 hectares.

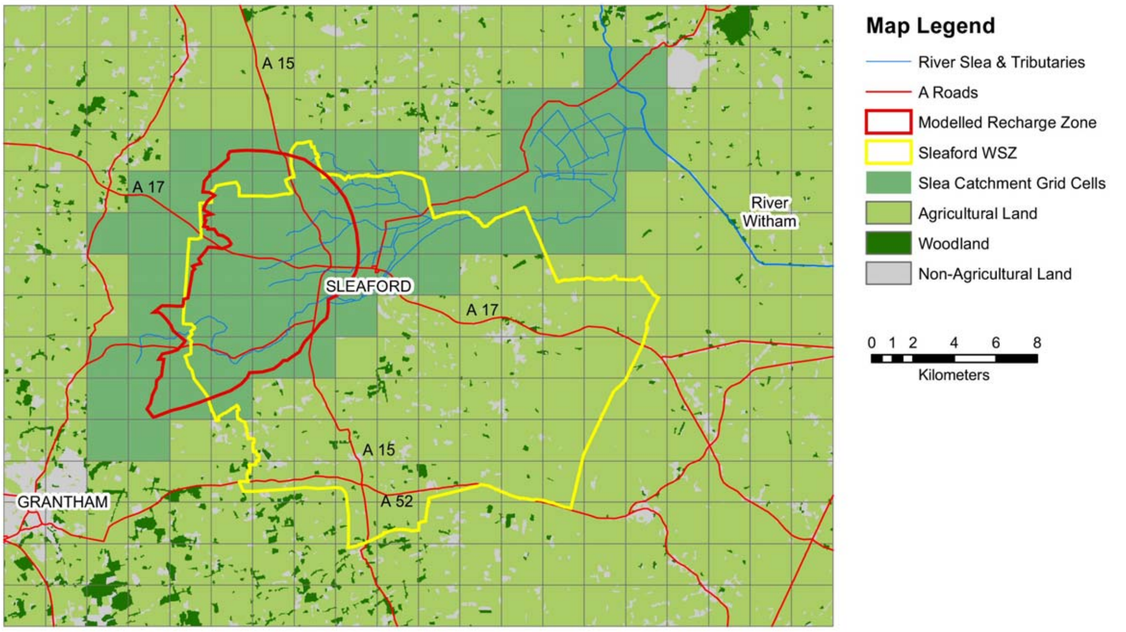

Figure 5.1 Sleaford Water Supply Zone

To calculate the changes in gross margins, the values for the different husbandry regimes listed in Table 5.5 were applied to the 2-km resolution grid square data for the different scenario variants. These calculations were conducted in Microsoft Excel using similar spreadsheet procedures to those employed in the export coefficient modelling. The results indicated the total gross margin under different scenario variants for each agricultural enterprise in the 39 selected grid cells. Non-agricultural land uses were excluded from the calculation. Table 5.6 summarises the findings and highlights the importance of cereals, sugar beet and poultry as sources of income. The table also lists total gross margins for all agricultural activities (including livestock) and for arable crops alone, calculated across the entire area and per hectare of farmland.

The cost of implementing any of the scenario variants (and compensating the income foregone by farmers) can be estimated by calculating the difference between the gross margin achieved under Current Policy (a) which can be considered the present day situation, and each of the other options. These differences, on both a total and per hectare basis, are listed in Table 5.7. The table also includes estimated nitrate levels (from the groundwater modelling) for the Clay Hill borehole in 2015 to provide a sense of the potential benefits associated with the agricultural costs.

From these results, it is clear that that the only scenarios with changes in total agricultural gross margin similar to or less than the estimated water treatment costs (£222,000 or £236,500) are the CPb and BP1a variants. However, neither of these reduce predicted groundwater nitrate levels sufficiently to make a reduction in treatment possible. Furthermore, if the treatment cost estimates were reduced by 25 per cent to reflect the proportion of the WSZ population living outside the Slea catchment (to £166,500 or £177,375), then even the CPb option might be more expensive. The conclusion therefore is that it would not be possible to support sufficient land-use change simply through a transfer of financial resources equivalent to current water treatment costs.

Table 5.6 Summary of scenario gross margin calculations for intersection of the Slea catchment and water supply zone

	RP	CPa	CPb	BP1a	BP1b	BP2a	BP2b	NSAa	NSAb	PZa	PZb	WCa	WCb
Activity	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**	**GM (£)**
wheat	1425648	1343484	1261320	1496349	1404982	1417593	1331036	970066	908482	963726	908919	589459	548699
wbarley	187722	176372	165022	195729	183144	186181	174210	91845	85194	90864	85290	74962	69238
sbarley	231223	217145	203068	240577	224981	228549	213732	99347	91818	98074	91772	90931	83875
ocereals	8652	8137	7622	8973	8406	8500	7964	6202	5795	6151	5780	3384	3133
potatoes	352899	352899	352899	334184	334184	334184	334184	341584	341584	308968	310463	334184	334184
sbeet	1279329	1279329	1279329	1219547	1219547	1219547	1219547	1222141	1222141	1117567	1122631	1195634	1195634
fbeans	47090	44454	41818	41760	39284	39066	36749	40542	38143	33091	31487	20078	18770
peas	45636	42916	40196	0	0	0	0	38636	36195	36661	34433	17739	16421
osr	307305	289710	272115	0	0	0	0	269085	252800	243039	229536	127899	119173
otharable	19181	18042	16902	18042	16902	18042	16902	18042	16902	14770	13972	9152	8480
hortcrop	676012	636116	596220	636116	596220	636116	596220	636116	596220	612209	575558	636116	596220
Livestock													
cattle	210549	210549	210549	210549	210549	210549	210549	210549	210549	210549	210549	126329	126329
sheep	116984	116984	116984	116984	116984	116984	116984	116984	116984	116984	116984	70190	70190
pigs	39516	39516	39516	39516	39516	39516	39516	39516	39516	38892	38892	23709	23709
poultry	2837019	2837019	2837019	2837019	2837019	2837019	2837019	2837019	2837019	2393121	2393121	1702211	1702211
Total GM	**7784764**	**7612670**	**7440577**	**7395344**	**7231718**	**7291845**	**7134612**	**6937673**	**6799342**	**6284664**	**6169386**	**5021979**	**4916266**
Arable GM	4580696	4408602	4236509	4191276	4027650	4087778	3930544	3733605	3595274	3525119	3409840	3099539	2993825
Ag Area (ha)	13352	13352	13352	13352	13352	13352	13352	13352	13352	12731	12731	11982	11982
Tot GM / ha	583	570	557	554	542	546	534	520	509	494	485	419	410
Arb GM / ha	343	330	317	314	302	306	294	280	269	277	268	259	250

Table 5.7 Estimates of agricultural income foregone under different scenario variants

	Clay Hill	Slea Catchment 39 Grid Cells			
Scenario	Predicted Borehole Nitrate in 2015 (NO_3 mg/l)	Change in Total Agricultural Gross Margin (£m)	Change in Total Agricultural Gross Margin (£/ha)	Change in Total Arable Gross Margin (£m)	Change in Total Arable Gross Margin (£/ha)
Current Policy b	53	-0.17	-13	-0.17	-13
Best Practice 1a	49	-0.22	-16	-0.22	-16
Best Practice 1b	48	-0.38	-28	-0.38	-28
Best Practice 2a	44	-0.32	-24	-0.32	-24
Best Practice 2b	44	-0.48	-36	-0.48	-36
NSA a	44	-0.67	-50	-0.67	-50
NSA b	43	-0.81	-61	-0.81	-61
Protection Zones a	42	-1.33	-76	-0.88	-53
Protection Zones b	42	-1.44	-85	-1.00	-62
Whole Catchment a	40	-2.59	-151	-1.31	-71
Whole Catchment b	40	-2.70	-160	-1.41	-80

In order to achieve a sufficient lowering of groundwater nitrate levels to reduce reliance on water treatment, a change in land use equivalent to at least the PZ scenario would probably be necessary. Based on the results for the PZa variant in Table 5.7, this option would involve reductions in total gross margins of some £1.33 million. Box 2 provides an illustration of what would be required in terms of increased water charges to cover such a cost. The result suggests that the costs of preventing nitrate pollution through changing land use (£30 per person) are currently nearly four times higher than the costs of treating water to reduce the pollution to within regulatory limits (£8 per person). Such an outcome is consistent with the UKWIR (2001) report, which concluded that the monetary benefits from continued agricultural activity exceeded water treatment costs in three of their four case study catchments.

Box 2: Costs of providing lower nitrate water through land-use change

The difference between total gross margins for the current Policy (CPa) and Protection Zones (PZa) scenarios is £1.33 million per year.

£1.33 million equates to 0.046p per litre of water (based on an output of 8 Ml/d) or 8p per person per day (based on average per person use of 180 l/d) or approximately £30 per person per year

Nitrate water treatment costs in the Sleaford WSZ are approximately £8 per person per year so the additional cost would be £30 - £8 = **£22**.

It is important to emphasise that the calculation in Box 2 is a theoretical exercise, since in practice water supply charges are not estimated at such a local level and reflect average costs over much larger areas. The estimates also reflect current conditions and both agricultural returns and treatment costs may well change in the future. Indeed, it seems most likely that the difference between the two will become smaller. For example, sugar beet is an important contributor to the total gross margins in Table 5.6, but as a consequence of reforms to the EU sugar regime (see http://www.defra.gov.uk/farm/arable/sugar/eu/index.htm) the return to UK growers could decline by some 20 per cent in the next four years. This would be equivalent to a reduction of over £200,000 in the gross margin totals listed in Table 5.6. Similarly, the costs of water treatment may well rise substantially if groundwater contamination problems continue to increase and the WFD leads to restrictions on the use of source blending (UKWIR 2004).

5.3.1 Other impacts and benefits

The above comparison focuses on agricultural returns and nitrate treatment costs, but in several respects this is a relatively narrow perspective. For instance, the EU Nitrates Directive emphasises reducing nitrate levels in all surface and ground waters rather than just protecting water supply sources. Similarly, the land-use changes envisaged in a number of scenarios would also reduce problems of siltation, phosphate and pesticide pollution. Nationally, the damage costs attributed to these contaminants are at least as large as those for nitrates (Environment Agency 2002; Pretty et al. 2003).

A number of scenarios involve increases in the area of grassland or woodland that would provide a number of biodiversity or amenity benefits. In particular, the introduction of grassland margins and areas would tie in with several targets for BAP priority habitats under the Environmental Stewardship Higher Level Scheme (HLS) for the South Lincolnshire Edge. This calls for the re-creation, enhancement or extension of grassland, green lanes, verges and cereal field margins and the buffering and extension of native woodland (Rural Development Service 2005). There is also a new English Woodland Grant Scheme (EWGS) from the Forestry Commission (see http://www.forestry.gov.uk/forestry/infd-6dcegu) which could provide financial support for the type of planting envisaged under the PZ scenario. The landscape implications of this scenario are potentially considerable, so detailed OS Land-Line® data for the area immediately west of Sleaford were processed in ArcGIS to provide basemaps from which indicative landscape visualisations could be produced using the Visual Nature Studio software (see http://www.3dnature.com and discussion in Appleton et al. 2002). Example images are shown in Figures 5.2 and 5.3, the former representing a view looking west from Sleaford along the Ancaster valley based on 2003 land use and the latter a possible outcome of the Protection Zone scenario. The Protection Zone view should not be interpreted as showing exactly where woodland might be planted, but more as an attempt to indicate the overall magnitude of landscape change.

Figure 5.2 View looking west from Sleaford along the Ancaster valley based on 2003 land use

Figure 5.3 Potential view looking west from Sleaford under the Protection Zone scenario

It is not straightforward to put monetary values on such biodiversity or amenity benefits, but it is important to recognise that they can be considerable. For example, a study by the Environment Agency (2004c) on the benefits of new water company schemes planned for 2005-2010 produced estimates of household monetary values shown in Table 5.8. There are many reasons why such valuations need to be treated with caution (for example, see Bateman et al. 2002), but with a total benefit valuation of £10 - £18 per household per year, it is evident that such factors could go a considerable way towards providing societal justification for the land-use change costs estimated earlier.

Table 5.8 Total benefits per household by benefit category – England and Wales (£ pa)

Type of Benefit	MEC/ABM + BEC/SBA schemes
Informal recreation	0.23 – 0.51
Angling	0.74 – 0.77
Amenity	0.62
Bathing	0.72
Groundwater	1.39
Ecosystems and natural habitats – rivers, lakes	5.88 – 13.24
Ecosystems and natural habitats – wetlands	0.39 – 0.90
Total	**9.97 – 18.15**

Source: Reproduced from Environment Agency (2004c) Table 8, page 14. Based on 21.9 million households in England and Wales, 2001 Census data. Uses Environment Agency Benefits Assessment Guidance methodology. Overall benefit values for schemes are derived from the following estimated values MEC = Meet Existing Commitments; ABM = Agreed By Ministers; BEC = Beyond Existing Commitments; SBA = Still to Be Agreed.

5.4 Stakeholder responses

A final meeting for stakeholders took place on 25 October 2005. The objective of this meeting was to give stakeholders the opportunity to evaluate the results of the modelling work and economic costs of implementing the scenarios as they stood at the time. There were 16 participants at the meeting including farmers and landowners, representatives of farming, farm advisory and forestry organisations, waterway management, local authority and civic group members.

Following the previous format, the meeting began with a presentation to update everyone on progress. This included a recap on the five initial land-use change scenarios and an introduction to the sixth, the Whole Catchment Change scenario; maps of modelling results showing nitrate exports to soil in grid cells across the study area; graphs of the results of the different scenario outcomes in terms of likely changes in groundwater nitrate levels; and changes in farming enterprise gross margins plus a comparison of this with estimated costs of water treatment to remove nitrate contamination. Some of the economic estimates were slightly different from those presented in Sections 5.2 and 5.3, but the general trends were similar.

Once again, the two discussion groups had even representation of people from different organisations. A summary of the discussion is given below along with individual comments resulting from a questionnaire handed out at the end of the meeting to invite further views.

What do you think of the scenario results? Are there any aspects which surprise you?

Most participants felt that the scenarios were reasonable. Views were expressed that the current uncertainty in farming meant it would take several years before changes in support measures would produce a difference in the landscape, although the benefits would come from these changes alone.

The new Whole Catchment Change scenario attracted considerable comment – the consensus from the farming community was that viable farming would be impossible under such a regime, that it would not be at all achievable though voluntary opt-in schemes unless they were extremely well funded, and that it would have a negative impact on the asset value of land. Others thought it possible that world market influences might negatively impact on farm incomes, making a compensated scheme more attractive. There was some comment on the suitability of Nix Pocketbook enterprise gross margin values and a suggestion that average values could conceal considerable variations within the study area. Individual comments included:

- "I'm not surprised that the best scenario is taking land out of production because we have been there before. I was surprised to see how fast the nitrate level at the boreholes fell according to your model" [farmer]
- "Only the more radical scenarios do the job" [civic group member]
- "Fascinate rather than surprise perhaps. Very interesting and worthwhile research" [farming organisation representative]
- "As expected" [land manager]

Do you think any of the scenarios are achievable?

Some support was expressed for the Protection Zones scenario and it was thought that this would fit in with existing projects to improve the river valley, and offer the opportunity for the development of 'horsiculture'. All agreed that implementation would depend on the money being made available. If there was a move towards reinstating an NSA equivalent, it would need long-term investment and not a return to the previous scheme. Comments were made that farmers may not be in favour of the increased demand for public access that might be created by a reversion of land to grass and woodland and it was suggested that the demand for such recreational open space needed to be assessed in more detail.

Should any of the scenarios be implemented? (in part or completely)

There was some concern that taking land out of production under the PZ or WC scenarios would lead to a loss of farming skills from the area, making it difficult to start it up again should food production become a higher priority in the future. It would be particularly difficult and costly to reclaim the land if woodland were created. A question remained as to whether trees would actually do well in the catchment, based on previous experience of poor outcomes with woodland plantings, though this was countered by the view that the benefit in tree planting would be for amenity and water conservation purposes as opposed to timber value. It was recognised that only the extreme scenarios involving considerable land-use change would generate a real difference to nitrate levels and might need to involve some sort of land purchase options. There was some support for targeting the more sensitive areas for land-use change (the PZ scenario). However, it was also suggested that perhaps the 50 mg

NO_3/l nitrate level is too low – none of these proposals would be needed if the level was set at 100 mg NO_3/l. Also, the introduction of biomass crops (such as short rotation coppice or miscanthus) needs to be examined as an alternative land use. Individual comments were as follows:

- "As a farmer with land in the area we will be in the front line and therefore I would be reluctant to take land out of production especially looking at the cost benefit as opposed to water treatment" [farmer]
- "Yes, whole catchment" [civic group member]
- "Current policy reforms plus best practice with catchment officer will do a lot. If the move is to protection zones I'm worried about the political will to pay for it" [farming organisation representative]
- "Initially protection zones but aim to expand to whole catchment" [land manager]

How should implementation be paid for?

It was generally thought that as farming support is shifting from production to stewardship, this would be the way to fund any land-use change. Any changes to farming support should be through existing schemes. It was generally felt that the idea of the 'water penny' - adding costs to water bills - would probably encourage more people to conserve water (which would effectively reduce the amount of income raised, leading to the need to increase the levy further – an unexpected side-effect). However, the view was also expressed that water is currently too cheap, which is why there is a lot of wastage. Fuel is not wasted because the cost is high. The participants thought that any money raised by the water companies in this way should be put into a separate pot and that a local consortium of organisations should allocate the money to the local farming community. Individual comments were as follows:

- "Has to be government led. General public will complain if it goes on the price of water even at a very low level" [farmer]
- "Cannibalise the CAP" [civic group member]
- "Via water bills would be an attractive idea but it would require hard work and money to convince the bill paying public and I'm not sure this administration has the will to do that. If not via water bills, I think the future looks bleak for farmers in some areas" [farming organisation representative]
- "Charge on water use paid to local community organisation that distributes to land owners for appropriate, community acceptable land use. Water companies to raise awareness of water saving/harvesting etc at their expense (their contribution)" [land manager]

Who should be responsible for implementation?

Most participants agreed that some form of governmental body – possibly Defra – should be responsible for implementation, rather than water companies and farmers. There was a preference for implementation carried out at a local level, with the involvement of local stakeholders or a local catchment officer. If land was to be compulsorily purchased this should be through a locally constituted 'community interest company' to be community-accountable. The view was also expressed that as much as possible should be done through existing organisations or programmes – in other words, avoid new schemes that might conflict with existing requirements. Individual comments were as follows:

- "If it is government-led, then the government. The Environment Agency may like to look at it but in my view they have taken a huge amount of extra work on just recently" [farmer]
- "Government" [civic group member]
- "Defra ultimately devolving responsibility enshrined in law to the Environment Agency and water companies. Again, I'm not sure Defra will have the will to do this" [farming organisation representative]
- "Not water companies. Defra initially but hand over management to local community group – small but representative council including CLA/NFU representatives + agencies + elected + other appropriate organisations" [land manager]

Overall, the results of the groundwater modelling and economic assessment were accepted in a positive manner. It was evident that the type of land-use change envisaged in the Protection Zones scenario had the greatest support, though it was recognised that considerable financial resources would be required along with appropriate local administrative and support arrangements.

5.5 Summary

Evaluating the economic costs and benefits associated with the different land-use scenarios was not straightforward and it is clear that further research on several aspects of the calculations would be useful. Nevertheless, the analysis established that the changes in agricultural gross margins associated with scenarios predicted to produce substantial reductions in groundwater nitrate levels were substantially larger than typical water treatment costs.

Further calculations suggested that expenditure might need to be up to four times greater to support the necessary land-use changes, though it was also recognised that this differential could become smaller in the future and would be closer to being bridged if other benefits arising from land-use change were taken into account. Stakeholder discussions indicated that there was most interest in, and support for, some form of the Protection Zone scenario, though it was apparent that important practical issues would need to be addressed before any form of implementation could begin to be considered.

6 Conclusions

6.1 Summary of findings

A key feature of the study was the manner in which it brought together the use of scenarios, stakeholder engagement processes, GIS, groundwater modelling and economic assessment methods. Overall, the project was a positive experience and a success; the combination of these tools is thus viable and opens up new possibilities for addressing land and water management issues. In particular, the use of GIS within such a framework provides a means of developing scenarios and evaluating impacts in a more spatially explicit way than has been possible in previous studies (see UKWIR 2001).

With respect to the study's findings, the following conclusions are particularly important:

- considerable changes in land use (beyond those likely from current policy reforms) would be necessary to generate future reductions in groundwater nitrate concentrations that would meet the objectives of EU directives and remove (or reduce) the need for water treatment.
- the combination of export coefficient and groundwater modelling suggests that reductions in borehole NO_3 concentrations of up to 30 per cent by 2015 could be achieved, but these would require conversion of some 40 per cent of the arable area in the Slea catchment or more targeted measures in the vicinity of the main springs and boreholes.
- calculations of changes in agricultural gross margins under different scenarios suggest that it would not be possible to support sufficient land-use change simply through a transfer of financial resources equivalent to current water treatment costs.
- at present, the costs of preventing nitrate pollution through changing land use (£30 per person) are nearly four times higher than the costs of treating water to reduce the pollution to within regulatory limits (£8 per person). However, this difference could well become smaller in the future and would be closer to being bridged if other benefits arising from land use change were taken into account.
- stakeholder discussions indicated that there was most local support for some form of Protection Zone scenario, though it was apparent that some important practical issues would need to be addressed before any implementation would be feasible.

The results regarding the scale of land-use change needed to reduce groundwater nitrate levels are not surprising and reflect the findings of several previous studies (such as Severn-Trent Water, DoE and MAFF 1988; UKWIR 2001). Calculations showing that the current costs of land-use change exceed treatment also have precedents (such as UKWIR 2001), but the present study suggests that the difference may well be narrowing to the extent that from a societal perspective supporting such conversion and management measures may well be advantageous in the near future. It is evident that buying land (or use rights) in source zones and engaging in co-operative agreements with farmers on such land is attracting increasing interest for strategies for water resource management (see Brouwer et al. 2003; Kemper 2003).

6.2 Lessons learned

The stakeholder engagement and dialogue process proved to be a very interesting and promising exercise. For such a process to be successful, it needs to begin at an early stage and continue throughout the project. Existing local knowledge and/or contacts can be very useful and it is important to build confidence and working relationships gradually. Ultimately, some 28 different organisations and 18 farmers were involved in Water4all interviews or meetings; it is sensible to recognise that such stakeholder networks can take time to build and become quite large. Based on the experience of Water4all, it is also possible that if individuals and groups are brought together in a phased and careful way, they may also find that they agree more than they initially expected.

Issues of data availability and quality arose at a number of points during the study. Section 4 discusses a number of difficulties that arose with Agricultural Census and land-use data and improvements to such information would clearly be useful. In this context, one particularly valuable innovation may be work by the Defra Observatory Programme to develop a method for producing agricultural data on a kilometre square grid using a combination of IACS and June Survey/Census data (see http://www.defra.gov.uk/farm/observatory/index.htm). The availability of such data on a routine basis would be a major benefit to the type of spatial modelling used in the Water4all project.

Other data limitations arose in the economic assessment, such as obtaining information on water treatment costs. Notwithstanding the assistance provided by Anglian Water Services, it is clear that access to such details is difficult due to commercial confidentiality. In one respect these constraints are understandable, but they do little to facilitate debate on wider questions of land and water resource management. If the objectives of the WFD are to be met in an effective manner, there will need to be more transparency regarding treatment costs.

Assessment of the implications of land-use scenarios for farm enterprises was based on changes in gross margins. It was recognised that this excluded consideration of fixed costs, but these need to be examined on a farm-by-farm basis which was not possible within this study. Nevertheless, farm infrastructures and business strategies may start to change radically (for example, through greater leasing or contract farming) as the impacts of the recent CAP reforms become more apparent; an obvious extension of this study would be a more detailed investigation incorporating fixed costs.

6.3 The way forward

Perhaps the most important question is whether there is a case for further action. The answer has to be a qualified ‘yes’. It is clear from the modelling work that land-use changes could produce substantial reductions in groundwater nitrate levels on a timescale of 10 to 20 years. The cost of supporting such changes (in terms of the income foregone by farmers) is currently several times more than equivalent costs of treatment, but the economics of agriculture and water supply appear to be moving in favour of land-use measures all the time. It is also evident from stakeholder discussions that there is local interest in such measures, particularly the idea of creating more grass and woodland areas to the west of Sleaford, and that this could involve farmers if the financial terms are right.

Implementing such initiatives will require considerable financial resources and changes in institutional arrangements. At present, it does not seem politically likely that water charges could be increased to generate the budget required and costs are probably beyond the resources of any single organisation. A more viable solution, therefore, is likely to be collaboration between several organisations that would provide 'win-win' outcomes. From the stakeholder discussions, it is clear that there would be local support for such an approach and interest from organisations such as the Forestry Commission and the Environment Agency. It is also important that water utility companies should participate in, and provide financial support for, such activities, but this is likely to require alterations in the arrangements under which these businesses are regulated by OFWAT. More generally, collaboration should be made easier by the creation of Natural England as a new integrated agency taking on functions that are currently the responsibility of English Nature, the Countryside Agency and the Rural Development Service (see http://www.defra.gov.uk/rural/ruraldelivery/natural-england.htm).

If an initiative to support land-use management for water resource protection is taken further in the Sleaford area, then it is important that it should have a 'local champion'. This could take the form of an adviser similar to those currently being appointed for the Defra Catchment Sensitive Farming Delivery Initiative (see http://www.defra.gov./uk/news/2005/051219a.htm). It would probably be sensible to begin with some relatively small-scale pilot activities and include a local educational campaign to explain the purpose of such measures. The UK is some way behind many European countries in the public promotion of water resource issues (such as groundwater protection) and this needs to be rectified if more sustainable management strategies (including likely higher costs) are to be successfully put in place.

Looking beyond the Slea catchment, this project has developed and demonstrated a methodological framework which is clearly applicable to land and water resource management issues in other parts of the UK. Given current activities to implement the WFD, measures to maintain landscape character and biodiversity, and continued concern regarding the economic viability of many types of agriculture, these matters are only going to become more important in the next few years. The approach illustrated in this report therefore has wider significance as an example of stakeholder engagement to generate and evaluate strategies for more sustainable rural futures.

6.4 Recommendations

Four recommendations are made below; the first two concern more general (national) matters and the latter two are more specific to the Slea study area:

- investigate means of improving the quality and spatial resolution of the types of land-use and agricultural data used in the spatial modelling in this study.
- explore the applicability of the methodological framework adopted in this study for other types of hydrogeological environments (such as sandstone aquifers) and wider issues of WFD implementation.
- undertake a more in-depth economic analysis of options including fixed agricultural costs and other benefits associated with land-use change (such as recreation, biodiversity, reductions in other diffuse pollutants).
- evaluate the scope for a pilot implementation scheme in the Slea catchment. This should be based on the ideas in the Protection Zone scenario and involve investment (financial or other) from a number of different organisations. It should also include a local education campaign and, ideally, the appointment of a catchment adviser or other 'local champion'.

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