Farming, nitrates and designations - what have we learnt from the last 30 years?

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Outline of presentation

Summary of lessons (both successes and failures) gained from various approaches to groundwater nitrate reduction in England & Wales

(1) The nitrate problem

(2) Engineering solution

(3) National policy for groundwater resource protection

Groundwater vulnerability maps

(4) Agricultural measures

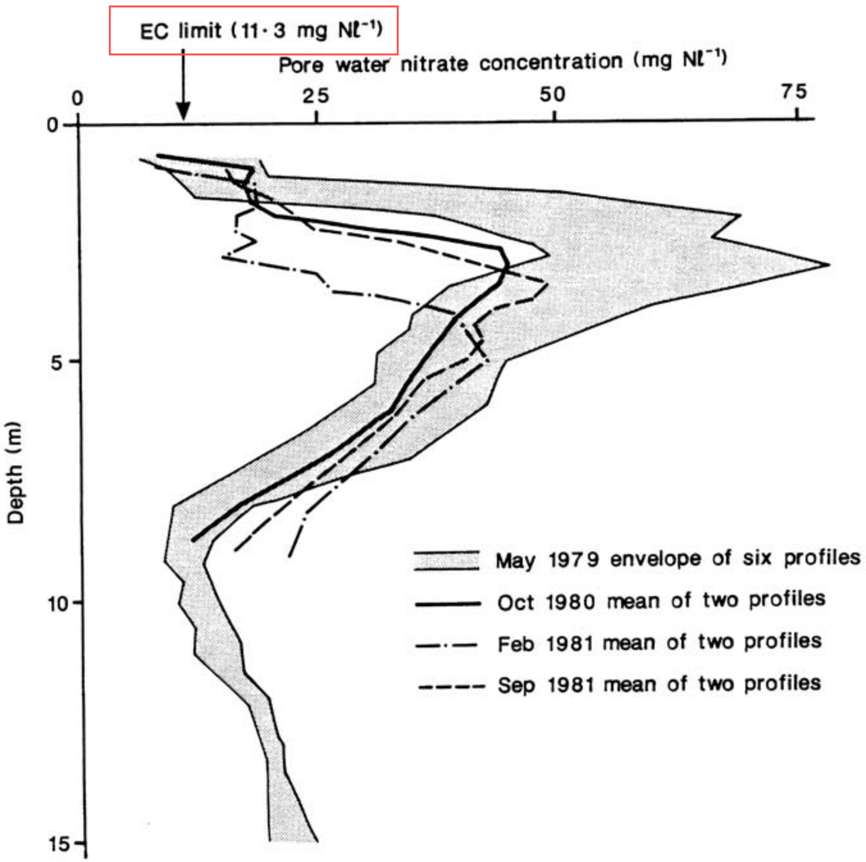
Nitrate Sensitive Areas (NSAs)

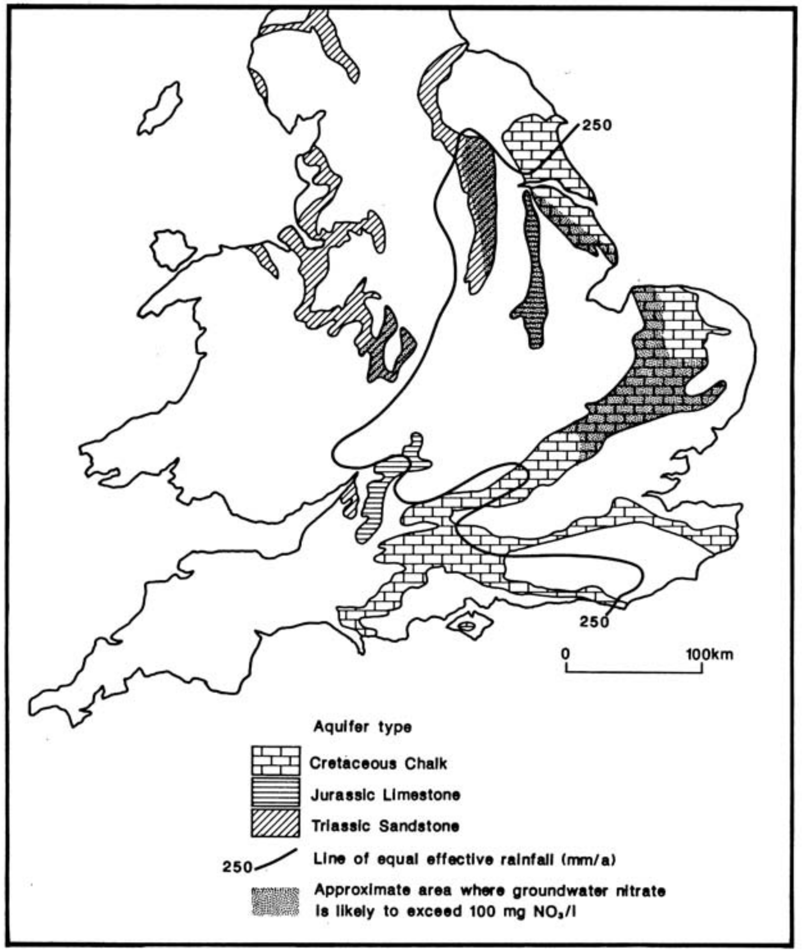
Nitrate Vulnerable Zones (NVZs)

(5) Catchment land use management

Past and present research

The nitrate problem





Pore water nitrate profiles in the Chalk unsaturated zone beneath an arable field, Cambridgeshire

Risk factors causing loss of NO_3^-

- Aquifer outcrop location
- Thin or sandy soils (no attenuation)
- Low rainfall (little dilution)
- Thin unsaturated zone (faster response)

Consequences of intensive farming using nitrogen fertilizers

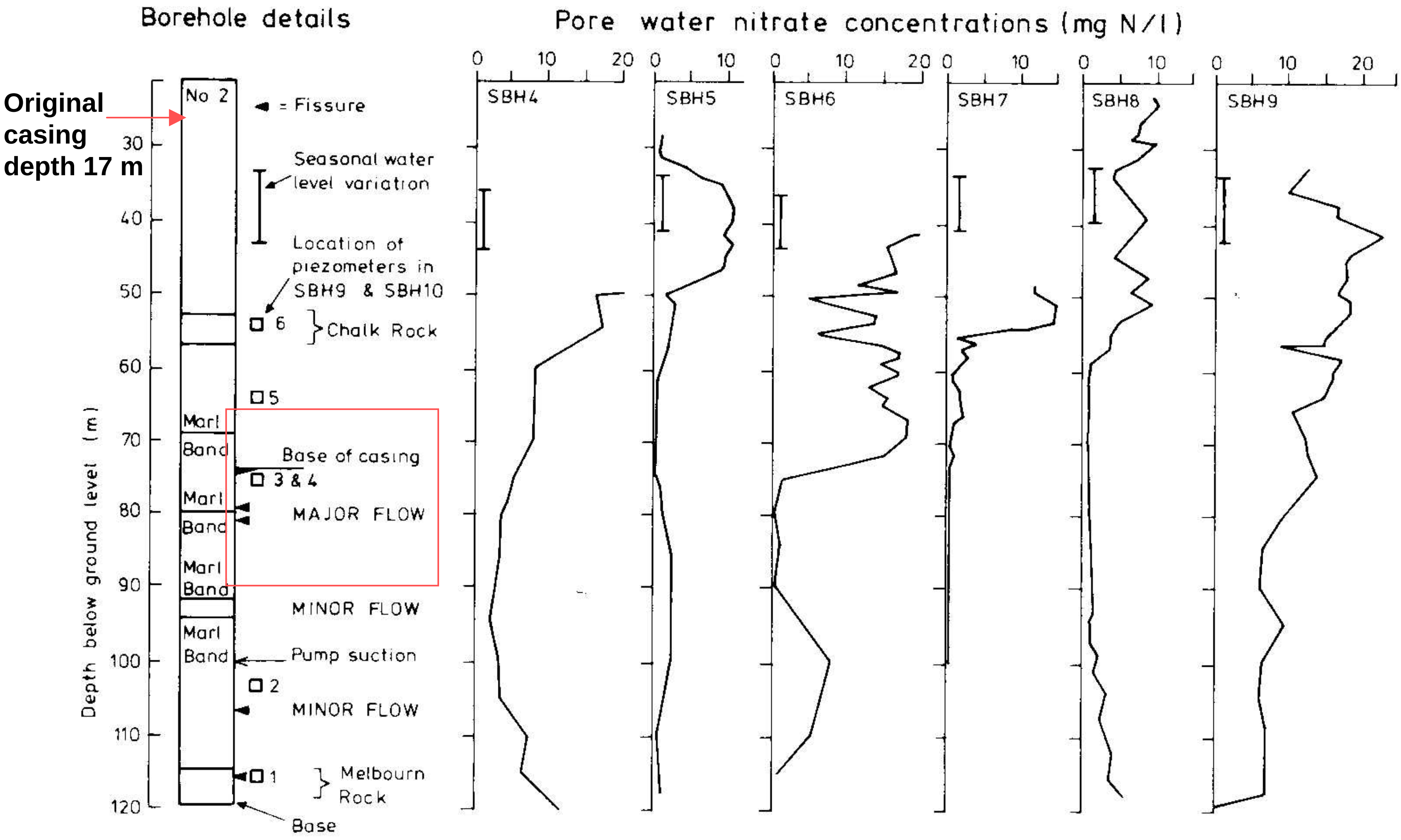
Groundwater nitrate concentrations in excess of 50 mg/L NO_3^-

Health effects: methaemoglobinaemia (‘blue baby’ syndrome) in infants; stomach cancer

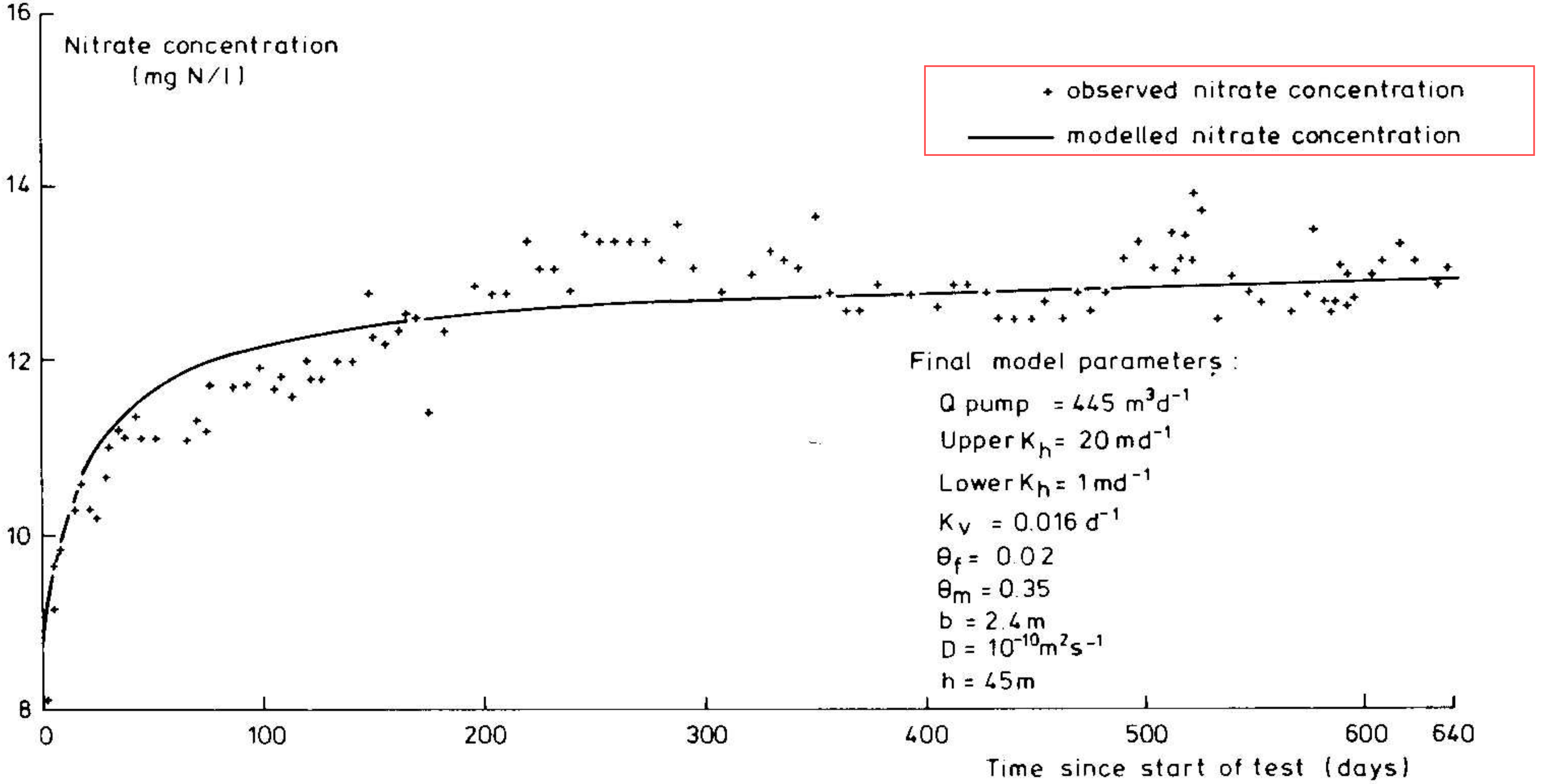
Environmental effects: eutrophication of nitrogen-deficient systems (eg wetlands and inland coastal waters) leading to loss of biodiversity

Failure to meet EU Drinking Water Quality standard and EU Nitrate Directive (50 mg/L NO_3^-) and EU Water Framework Directive (< 50 mg/L NO_3^-)

Engineering solution to the nitrate problem at a Chalk borehole



Hiscock et al. (1989)



Simulation of pumped nitrate concentrations for a long-term pumping test, Swaffham, Norfolk

Lessons from engineering solution

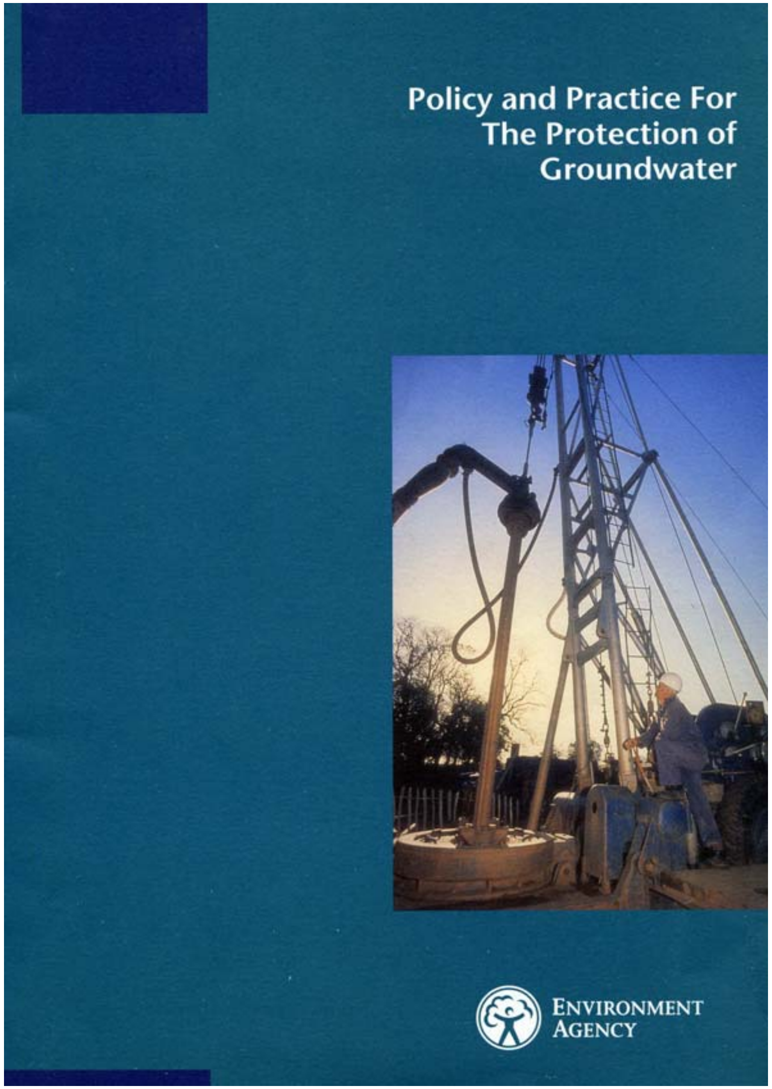
No. days since start of test	Pump discharge (m^3/day)	Mean nitrate conc. (mg/L)
0 (prior to casing)		20.0
1-180	470	11.0
181-510	455	13.0
511-576	285	13.2
577-636	484	13.0

Considerable reduction (45%) in nitrate concentration immediately after completion of casing

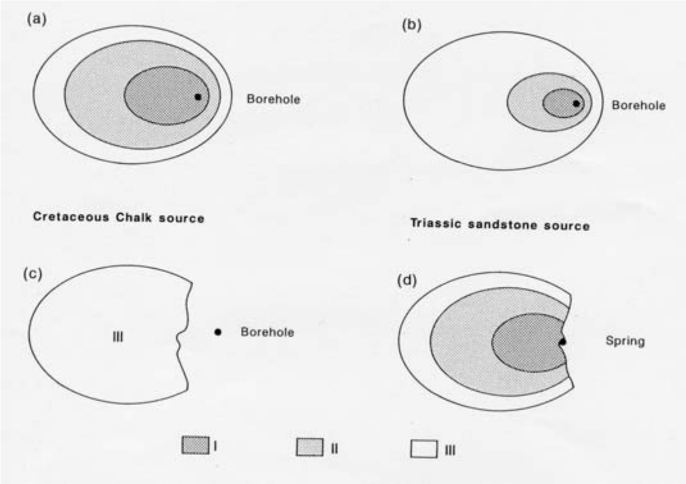
Nitrate concentration predicted to increase to 13.6 mg/L in five years due to downward leakage of polluted upper layer groundwater

Significant loss in borehole yield experienced after casing-out the permeable upper aquifer layer. Maximum pumping rate reduced by 60%

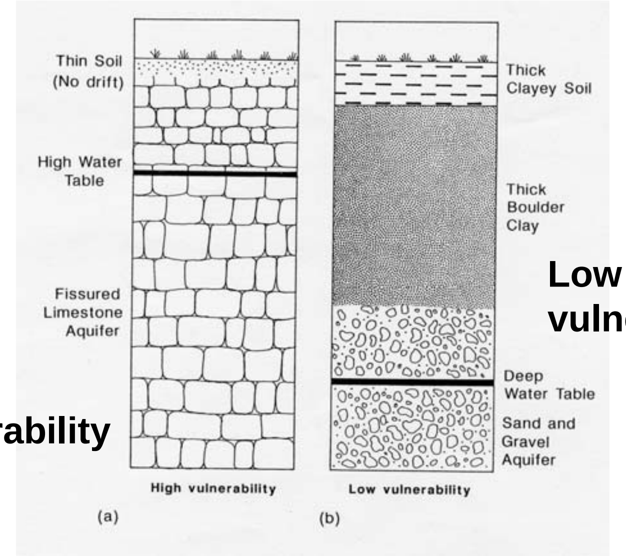
Groundwater protection in England & Wales (Environment Agency 1998)



Source protection



Resource protection



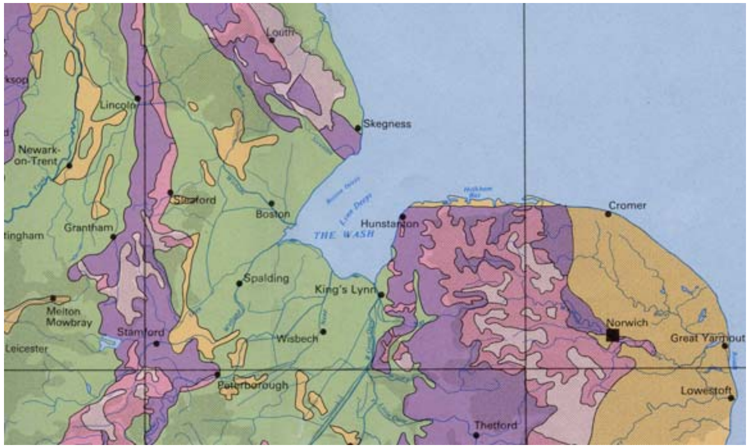
High vulnerability

Low vulnerability

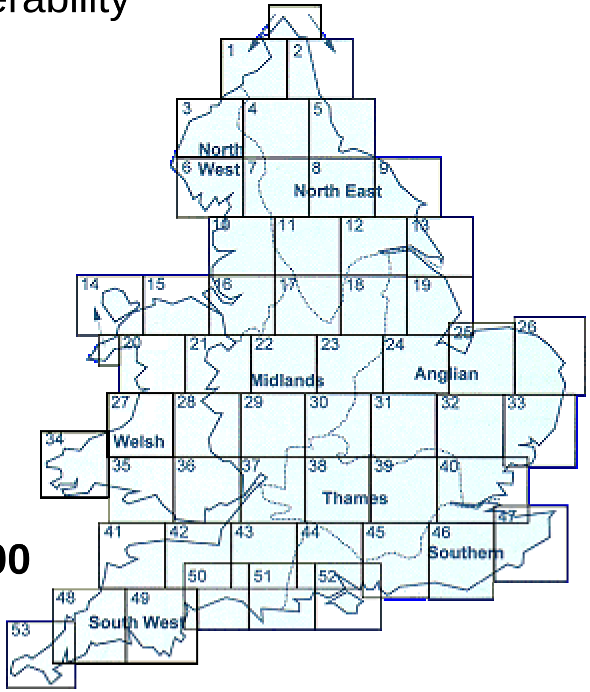
Groundwater vulnerability maps

Series of 53 regional groundwater vulnerability maps

Intention of encouraging the development of potentially polluting activities in those areas where it will present least concern. As regional maps, the control of diffuse pollution can be readily related to zones of aquifer vulnerability



Scale 1:1,000,000



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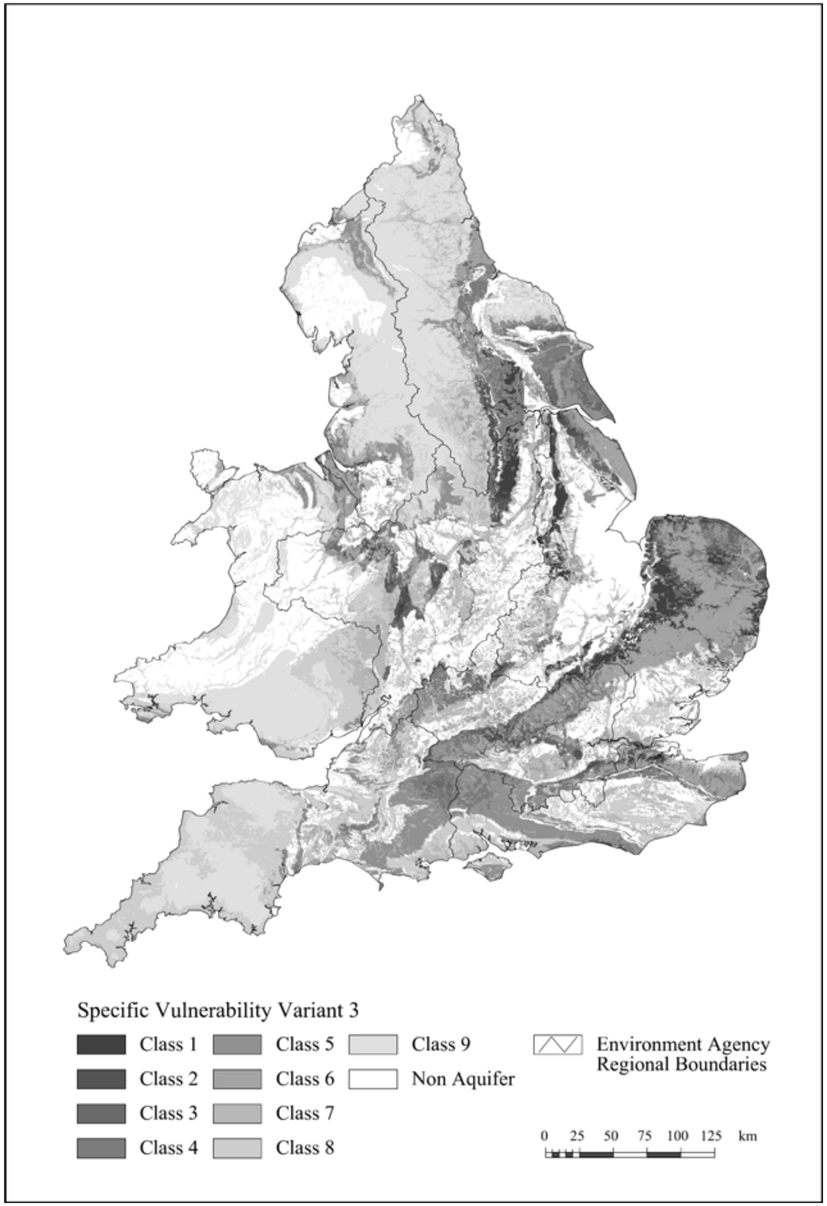
Vulnerability classes determined from the overlay of hydrogeological and soils information

Soil classes are divided on the basis of leaching potential (high, intermediate and low) depending on the physical and chemical properties of soil types with respect to diffuse source pollutants and liquid discharges



Specific groundwater nitrate vulnerability map

The vulnerability classes are derived from a GIS overlay operation of:

(i) simulated mean nitrate concentrations in land drainage assuming a uniform nitrogen loading of 100 kg N/ha

(ii) soil types

(iii) presence or absence of low permeability superficial deposits and

(iv) aquifer types

Regions of high groundwater vulnerability to nitrate pollution (classes 1-4) are in areas of major aquifers

Effects of crop husbandry and nitrogen fertiliser rate

Site in Lincolnshire on a shallow stoney, calcareous sandy clay loam soil (30 cm deep) over fractured limestone

Five course crop rotation of winter barley, oilseed rape, winter wheat (feed), peas and winter wheat (milling)

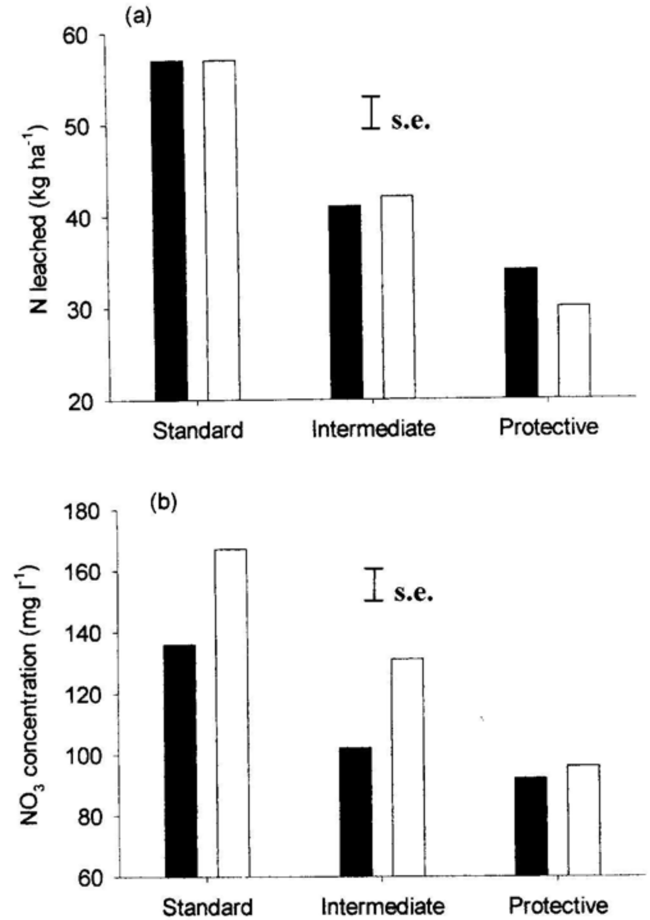
3 husbandry regimes:

Standard - local farming practice

Protective - aim to decrease nitrate loss (but with saleable crop)

Intermediate

Variations in cultivation depth and timing, drilling date, use of autumn sown cover crops and timing of N fertiliser applications (Johnson et al. 2002)



(a) Average annual N leaching loss

(b) Average annual flow-weighted mean nitrate concentration in drainage for years 1-5 (solid bars) and 6-10 (open bars)

Lessons from husbandry trials

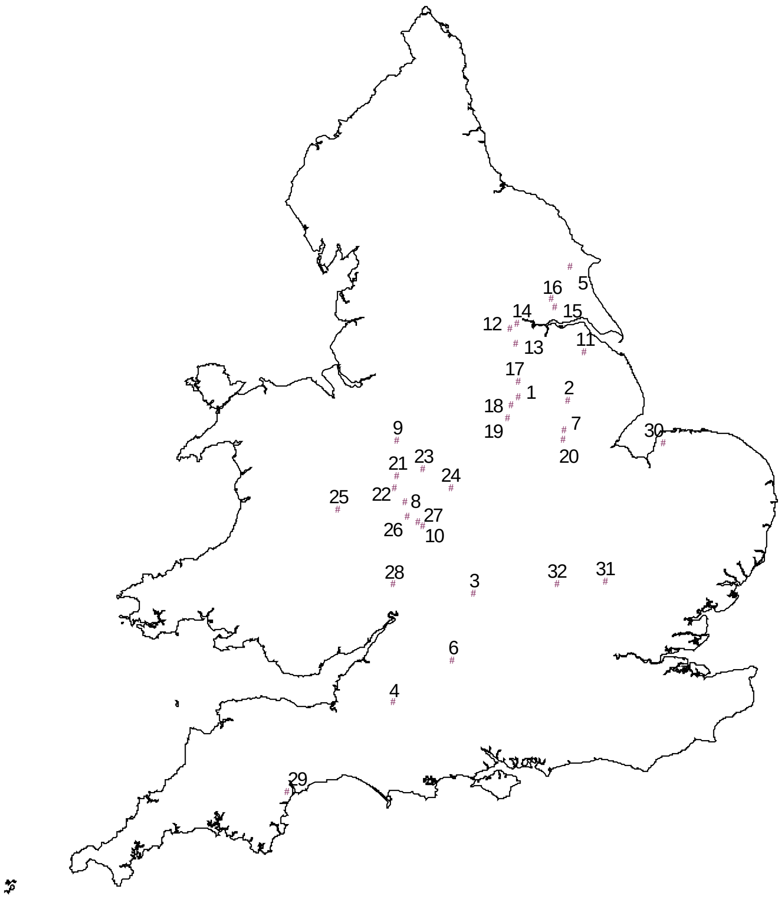
Protective system reduced nitrate concentrations by 42%

Not possible to achieve a average nitrate concentration below 50 mg/L, even when fertiliser rates were halved

Continued minimal cultivation caused serious problems of weed build-up, making cereal production uneconomic in some years

More radical changes in land use (e.g. unfertilised grass) required to achieve lower nitrogen loss

Nitrate Sensitive Area (NSA) scheme



Location of Nitrate Sensitive Area (NSA) schemes (no. 7 = Sleaford Pilot Scheme)

Pilot NSA scheme started in 1990 (10 catchments) with further 22 catchments (Main NSA scheme) added in 1994. By 1998, 80% of the 35,000 ha of eligible agricultural land included in this voluntary, compensated agri-environment scheme.

NSA agreements for 5 years with payments under **Basic** and **Premium Schemes**:

Basic: £55-£95/ha/a for sowing winter cover crops, restricting organic manure inputs and their timing, limiting N fertiliser inputs to below the optimum recommendation

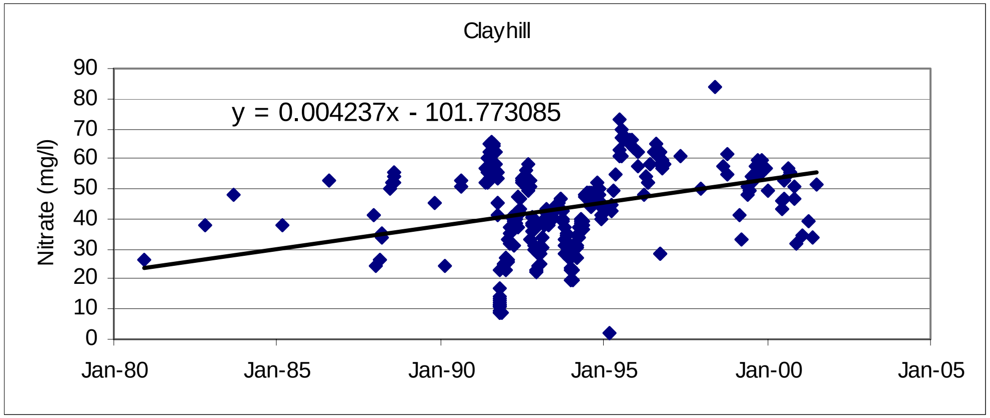
Premium: £165-£455/ha/a for arable land conversion to grass with total N inputs <150 kg/ha

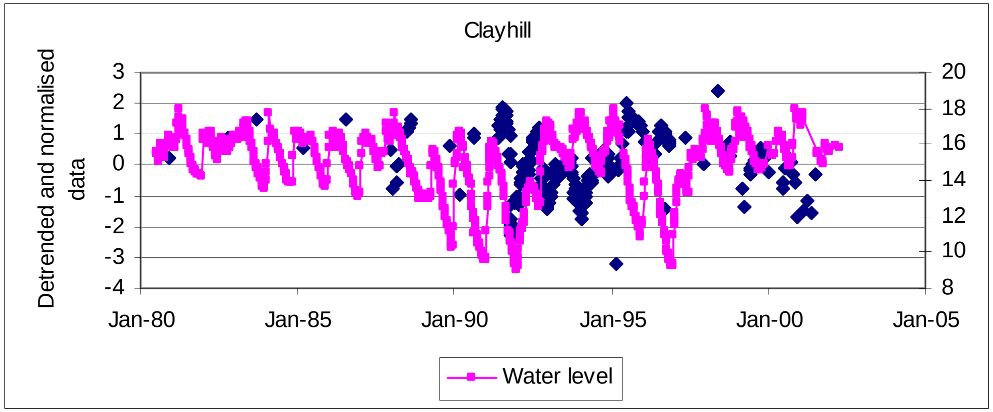
Summary of measured soil nitrate losses prior to and during the Pilot NSA Scheme. Fluxes have been adjusted to mean rainfall conditions (ADAS 2003)

Previous Crop	Winter 1990/91			Mean of winters 1992/3, 1993/4, and 1994/5		
N loss:	kg/ha N (adjusted)	mg/l NO_3	n	kg/ha N (adjusted)	mg/l NO_3	n
Potatoes, Sugar beet	92 ± 23	228 ± 52	10	38 ± 4	87 ± 9	46
Cereals	40 ± 4	102 ± 11	61	53 ± 3	85 ± 5	142
Grass	44 ± 7	102 ± 16	27	42 ± 8	69 ± 14	79
Premium	-	-	0	6 ± 4	9 ± 6	70
All sites	65 ± 12	163 ± 29	108	47 ± 3	79 ± 5	380

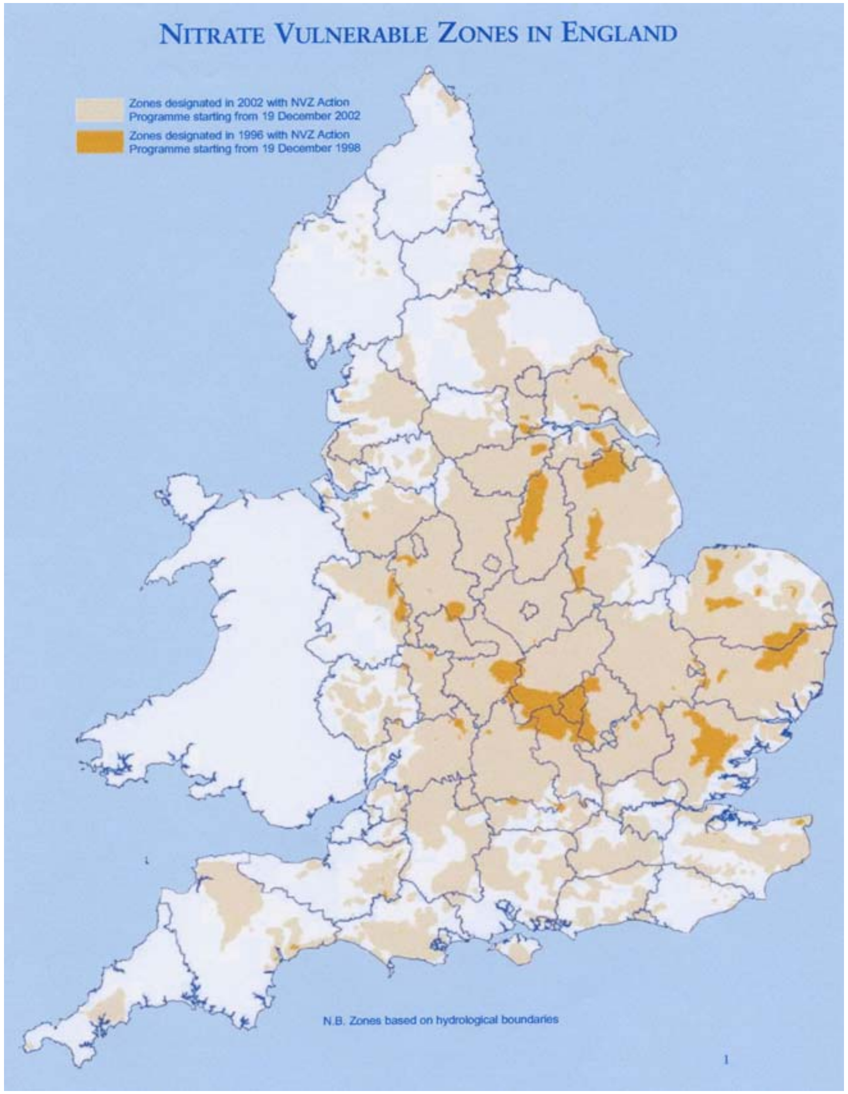
Results indicate an overall reduction of about 50% in nitrate concentrations and 28% in nitrogen fluxes leaving the root zone compared to baseline values. Corresponding values for the further 22 areas introduced under the Main NSA scheme are 34% and 16%, respectively, between 1994-96 and 1998-00

Comparison of nitrate concentration (Clay Hill borehole), water level (Boiling Wells South) and rainfall in the Sleaford NSA





The nitrate concentration shows a large amount of variation, some of which is seasonal. The Slea catchment shows an increasing trend in nitrate concentration at 9 out of 11 monitoring boreholes after the implementation of the NSA in 1990/91. One site showed no trend and the remaining borehole a decreasing trend



Department for Environment, Food & Rural Affairs (2002)

Nitrate Vulnerable Zones (NVZs)

Mandatory, uncompensated measures based on "Good Agricultural Practice"

(a) **Closed periods** (Inorganic N: arable, 1 Sept - 1 Feb; grass, 15 Sept - 1 Feb; Organic N: arable, 1 Aug - 1 Nov; grass, 1 Sept - 1 Nov)

(b) **Nitrogen limits** (Inorganic N: not to exceed crop requirement, arable and grass; Organic N: 210 kg/ha arable; 250 kg/ha grassland)

(c) **Spreading controls**, e.g. do not apply fertiliser/manure to steep slopes or close to water courses

(d) **Slurry storage** during autumn closed period

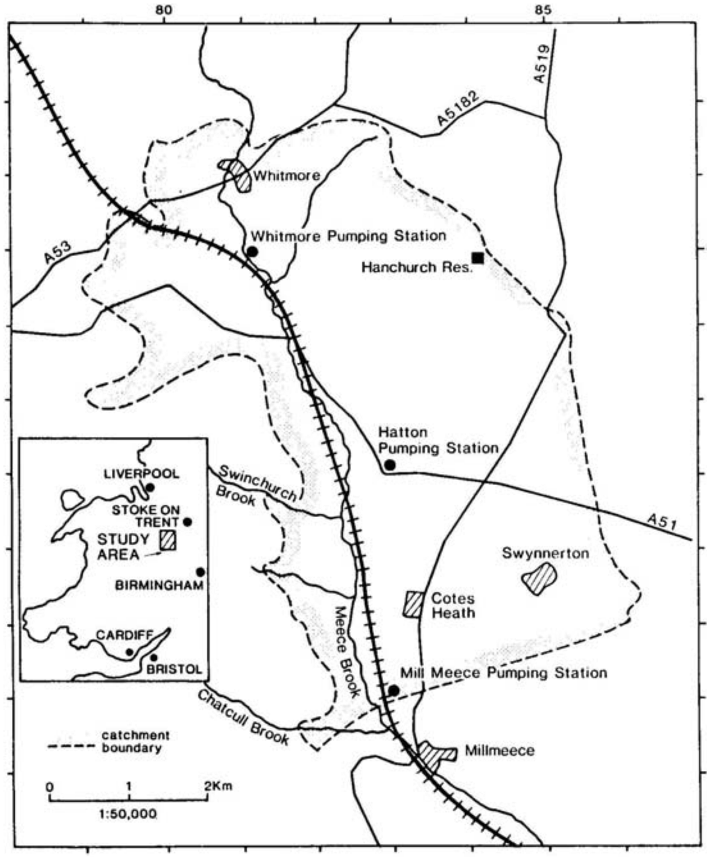
(e) **Record keeping** for at least 5 years

Lessons from NSAs and NVZs

It is likely that the impact of NVZs on reducing nitrate leaching will be modest and probably smaller than the 16-28% reduction in nitrate leaching fluxes reported for NSAs

NSA study showed that nitrate loss control measures can be incorporated within commercial farming systems, subject to compensation for lost income and the extra costs incurred

Water treatment versus land management options - the Hatton Catchment Nitrate Study



Hatton catchment part of Meece Brook

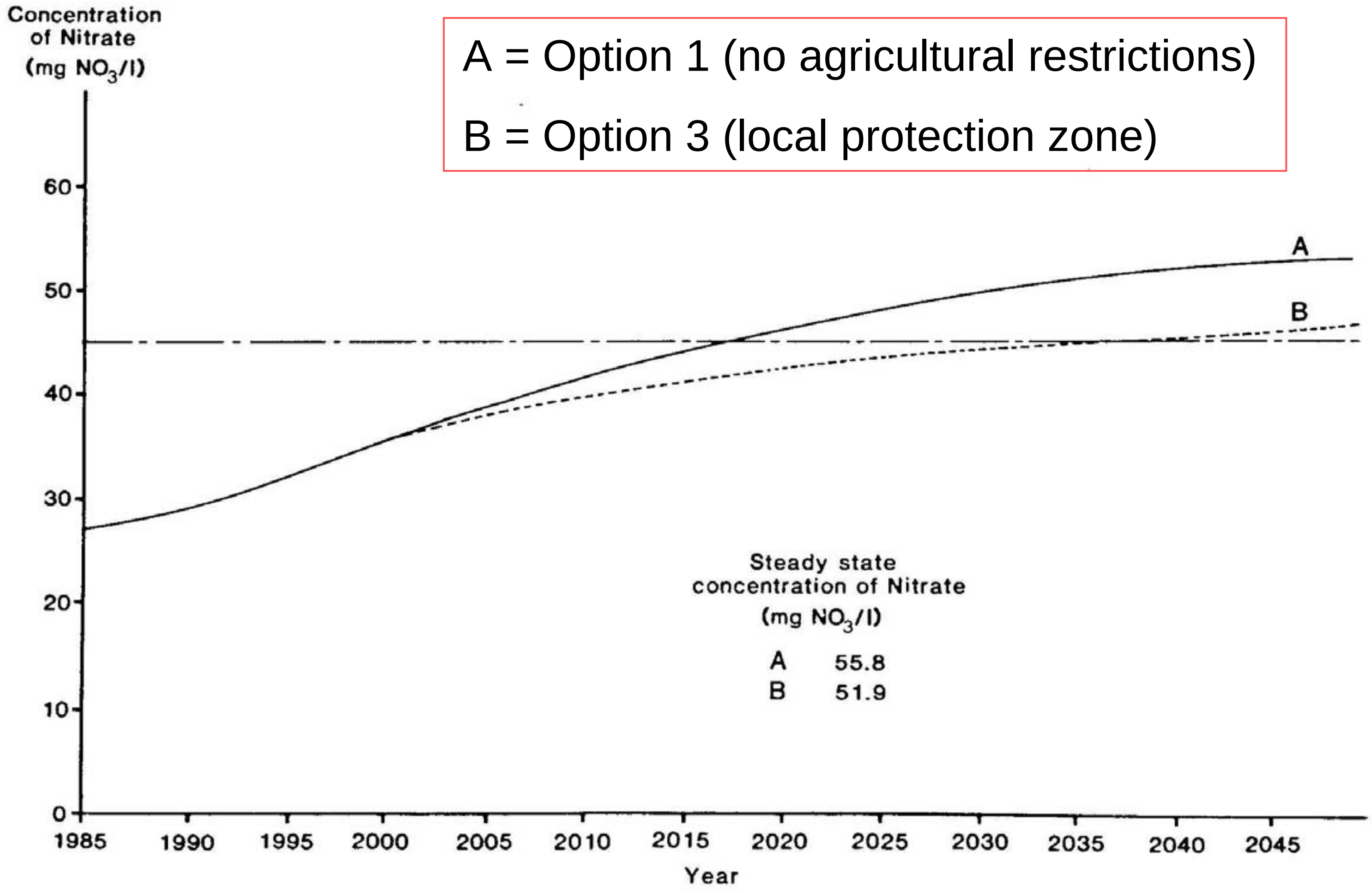
Mixed arable and grassland farming

Outcrop of the Triassic Sherwood Sandstone aquifer

Nitrate concentrations high (>20 mg/L) and rising

Option	Objective	Strategy
1	Water supply below 45 mg/L until 2040	Blend and treat water, current land use maintained
2	Water supply below 45 mg/L until 2040	Change land use (replace oilseed rape, potatoes, sugar beet), 20% less fertilizer on cereals, keep livestock at present levels. Apply to whole 3000 ha
3	Water supply below 45 mg/L until 2040	Convert localized areas to permanent grass cut for hay, broadleaved forestry or other non-agricultural use. Apply to protection zone of 220 ha. Combine option with treatment by blending
4	Stabilise water in supply at 45 mg/L	Educe area of arable crops and keep livestock numbers at present levels. Apply to whole catchment
5	Stabilise water in supply at 45 mg/L	Convert localized areas to permanent grass cut for hay, broadleaved forestry or other non-agricultural use. Apply to protection zone of 809 ha.

DoE, STW, MAFF (1988)



Modelled nitrate concentration in blended groundwater from the Hatton catchment

Lessons from the Hatton Catchment Nitrate Study

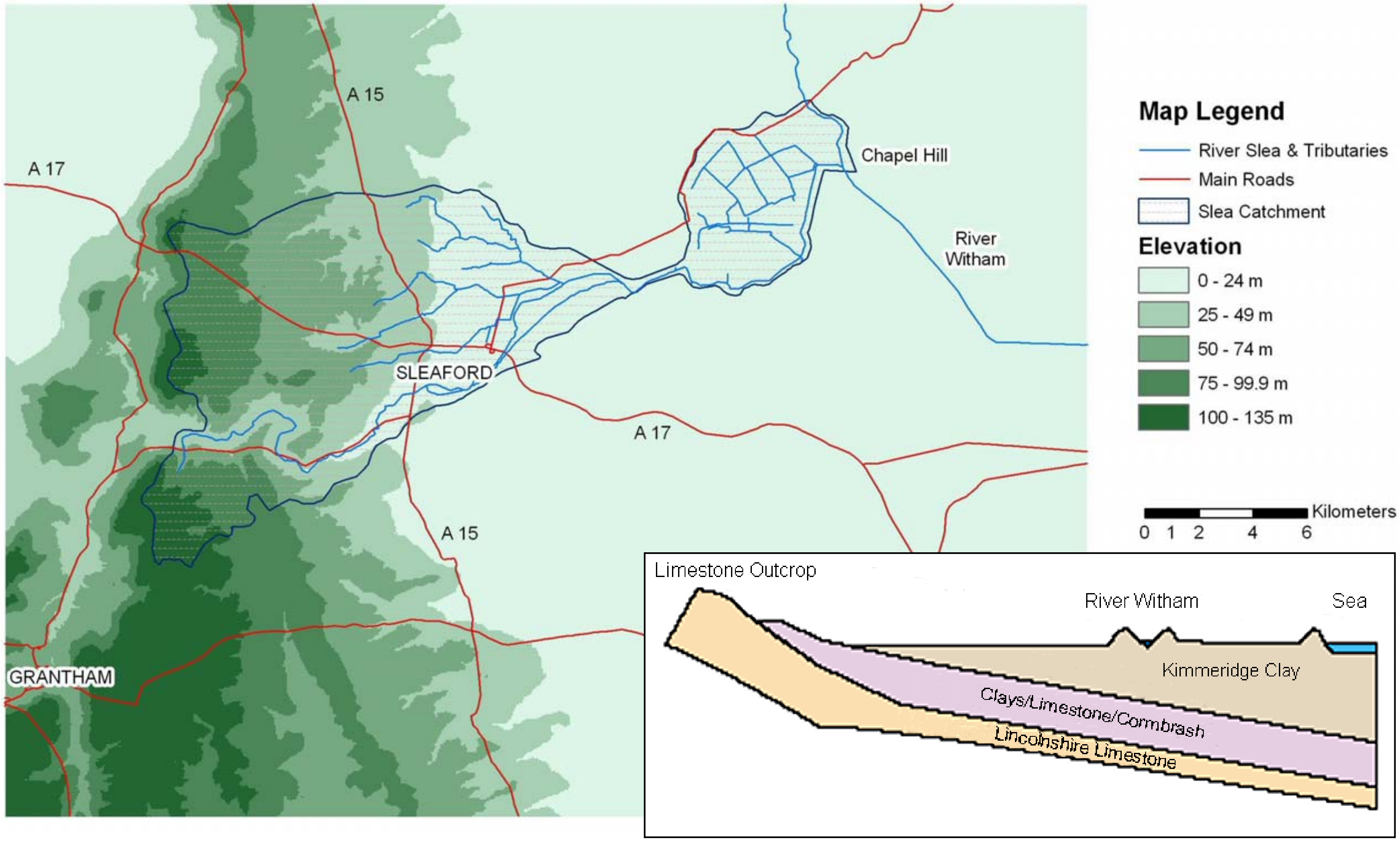
Chemical treatment to remove nitrate can be avoided with catchment land use change

Necessary nitrate reductions will only be achieved with a smaller area of arable cropping and an extensification of grassland management

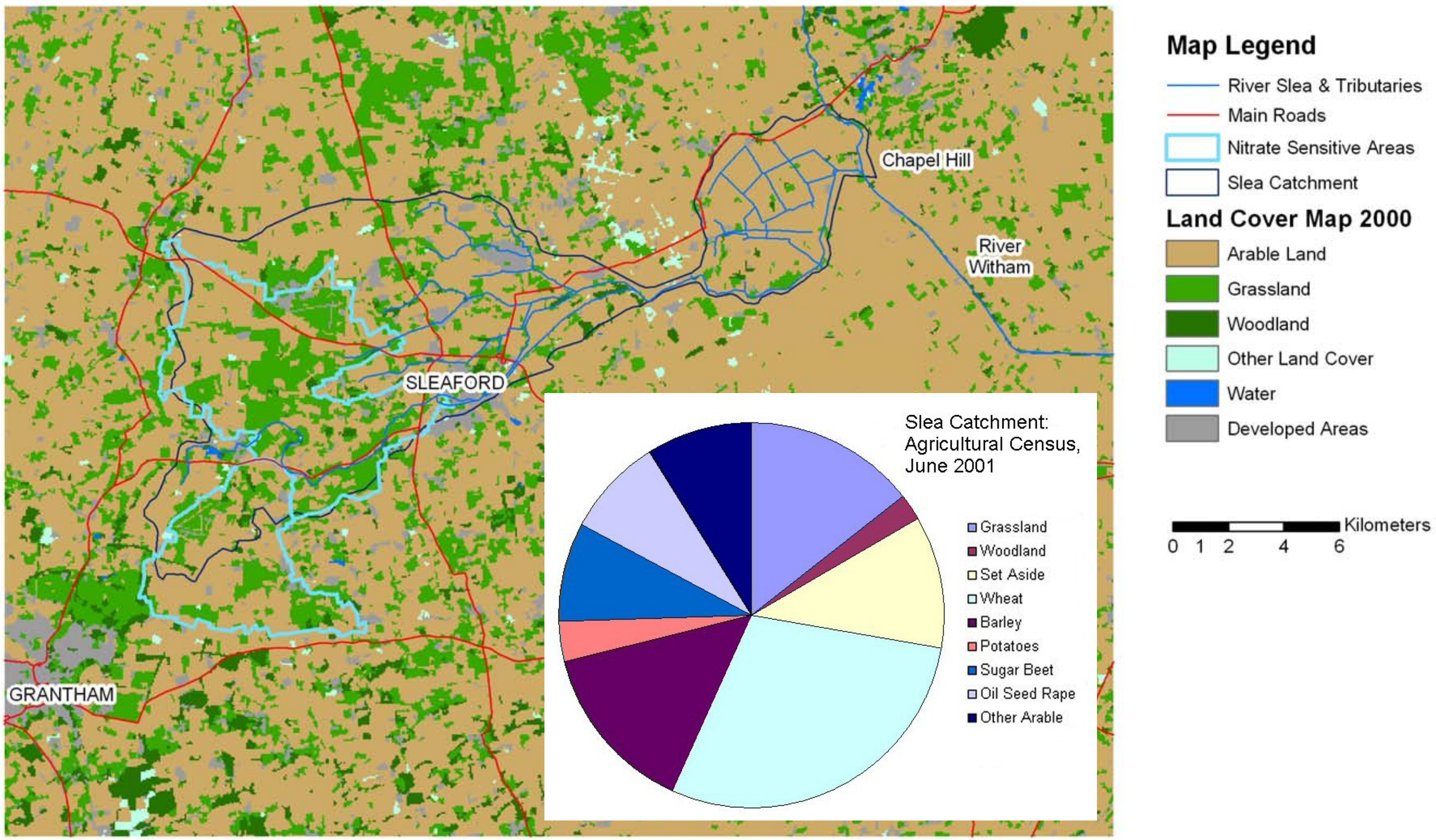
Costs of solving the nitrate problem by blending and treatment are not significantly less than the costs of combined solutions involving a contribution by land use controls

The financial costs to farmers collectively of catchment-wide restrictions are less than for local protection zones but the costs of implementing and policing the former can result in higher total costs

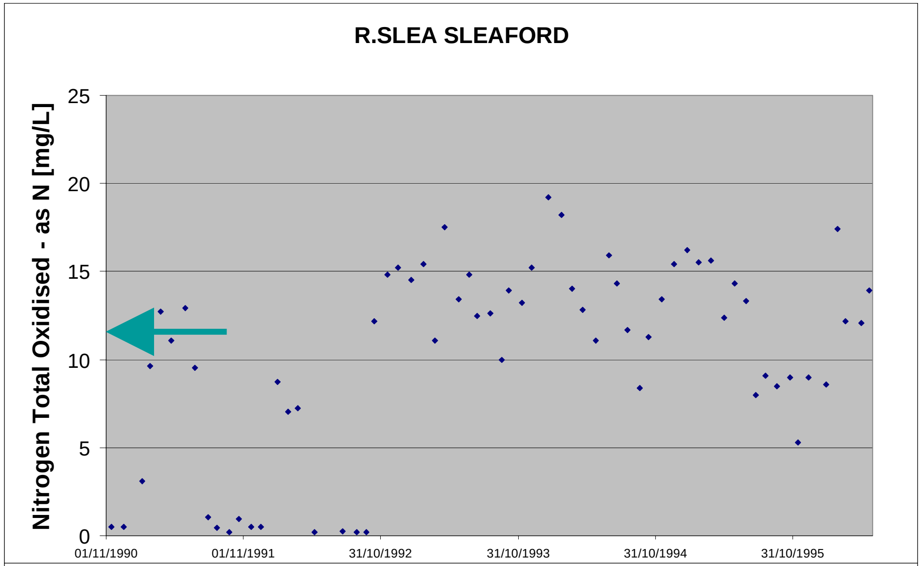
The Slea catchment study area

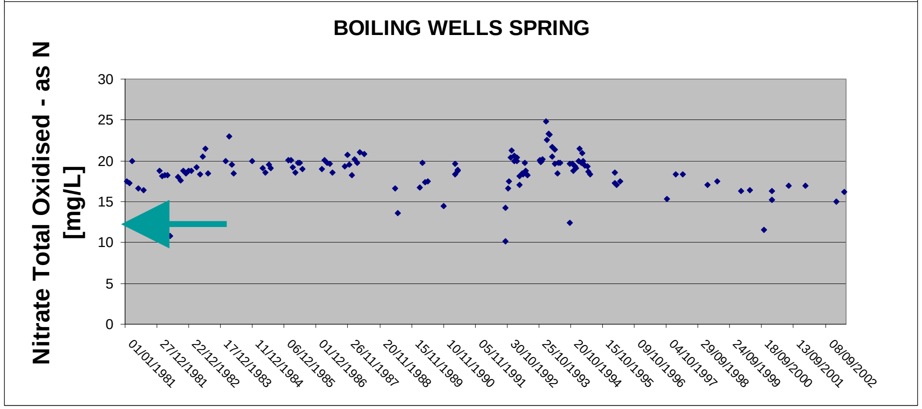


Slea catchment land use

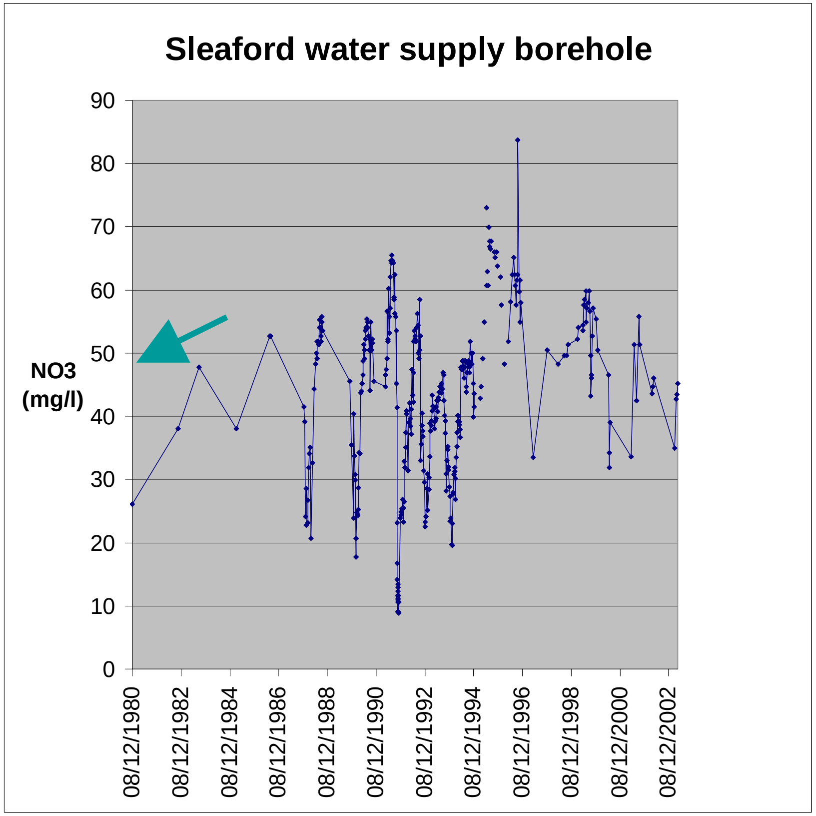


Trends in Slea catchment river and groundwater nitrate concentrations





EU nitrate standard



Export (release) coefficient model equation

Annual nitrogen loss per hectare = sum of ($A_i E_i I_i + R$)

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

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

I_i is the annual nitrogen input to land use type *i* (or from livestock type *i*)

R is the input of nitrogen from precipitation

Results of nitrate loss to groundwater with Land Cover Map 2000 land use

LAND COVER 2000 Scenario		
	Limestone Outcrop	Outcrop in Slea
Leachate conc as N (mg/L)	13.6	13.1
	16.5*	15.9*
Leachate conc as NO3 (mg/L)	60.2	58.0
	73*	70.6*
*Assumes *Other Arable Crops* = *Cereals* with a fertiliser application of 140 kg/ha/a		

Mean nitrate concentration values (mg/L as N) for comparison:

River Slea at Sleaford = 13.3
Boiling Wells Spring = 18.6
Clay Hill B/H 1 = 9.8
Drove Lane B/H 1 = 15.6
Drove Lane B/H 2 = 14.8

Data sources:

- CEH Land Cover Map 2000
- British survey of fertiliser practice: Fertiliser use on farm crops for crop year 2000
- The June 2002 Agricultural Census
- NEGTAP 2001
- UK Met Office MORECS
- Worrall, F. & Burt, T.P. (1999) *Journal of Hydrology* **221**, 75-90.
- Johnes, P.J. (1996) *Journal of Hydrology* **183**, 323-349.

Land use scenarios to reduce nitrate loss to groundwater in the Slea catchment

	Scenario for Outcrop in Slea	Leachate N (mg/L)	Leachate NO3 (mg/L)
2000	Current land use	15.9	70.6
1	Cereals converted to Improved Grassland	7.8	34.5
2	Improved Grassland converted to Calcareous Grass	15.4	68.3
3	Cereals converted to Calcareous Grass	6.3	28.0
4	Cereals and Improved Grassland converted to Calcareous Grass	5.8	25.7
5	Cereals converted to Broadleaf Woodland	9.9	43.7
6	Cereals and Improved Grassland converted to Broadleaf Woodland	10.6	47.0
7	Cereals decreased in area by 50% and converted to Calcareous Grass	11.1	49.3
8	NSA (72% uptake, N appl to Cereals = 125 kg/ha/a, Improved Grass = 85 kg/ha/a)	14.2	62.9

Assuming *Other Arable Crops* = *Cereals* and receive 140 kg/ha/a of fertiliser N

Unconfined aquifer flushing time = groundwater volume/recharge rate

= (aquifer area x thickness x effective porosity)/(area x recharge rate)

= 2 – 20 years (porosity range 1 – 10%)

Conclusions

Engineering solutions expensive and impractical

Groundwater vulnerability maps useful but will not deliver solutions without land use controls

NSAs achieved a 16-28% reduction in nitrate leaching fluxes but requiring compensation payments to farmers

NVZs will produce only a modest (<30%) reduction in nitrate leaching fluxes but without compensation payments

Hatton and Slea catchment studies illustrate that nitrate reductions can be achieved with a smaller area of arable cropping and an extensification of grassland

Costs of solving the nitrate problem by blending and treatment are not significantly less than the costs of combined solutions involving a contribution by land use controls