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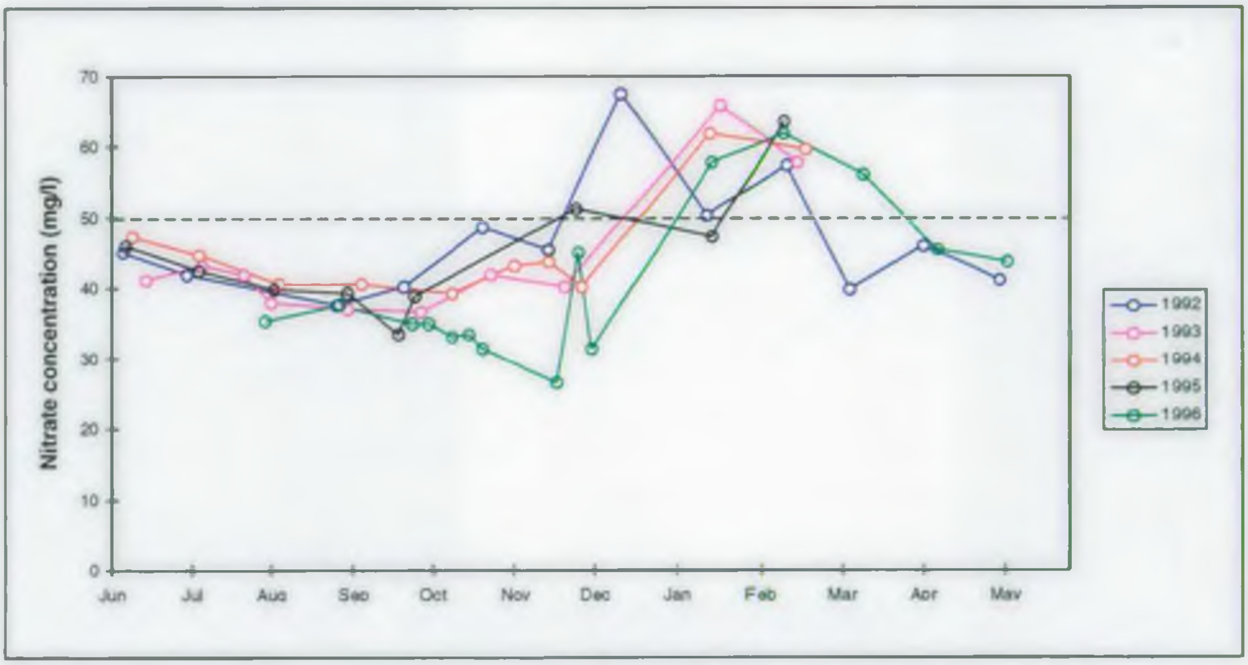
MODELLING THE CONTRIBUTION FROM NON-AGRICULTURAL SOURCES TO NITRATE POLLUTION IN THE SOR BROOK (THAMES REGION)



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MARCH 1998

EA – Thames Water Quality MOD

Modelling the contribution from non-agricultural sources to nitrate pollution in the Sor Brook (Thames Region)

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March 1998

MODELLING THE CONTRIBUTION FROM NON-AGRICULTURAL SOURCES TO NITRATE POLLUTION IN THE SOR BROOK (THAMES REGION)

EXECUTIVE REPORT

1. BACKGROUND

Under the Nitrates Directive (91/676/EC), Nitrate Vulnerable Zones (NVZs) were designated in April 1996 for protection from pollution by nitrates from agriculture. Surface water zones were designated on the basis of exceedances of 50 mg/l nitrate (as NO_3, equivalent to 11.3 mg/l nitrate nitrogen, NO_3-N) in more than 5% of samples at the abstraction point in 1992. The catchment extent was defined on the basis of exceedances at upstream sampling points over the preceding five year period, 1988 - 1992. In Thames Region of the Environment Agency, the Sor Brook was not designated as a NVZ in the 1992 round. However, river water quality data for the period, 1992 - 1996 demonstrates that the Sor Brook Catchment upstream of the Bodicote intake fails.

A major criticism of the methodology used in the 1992 NVZ round for the definition of zones was that the contribution of non-agricultural sources of nitrate (for example, inputs from sewage treatment works (STWs) and atmospheric deposition) was not adequately assessed.

The Department of the Environment, Transport and the Regions (DETR) held a workshop in 1997 to identify a methodology that could be employed to estimate the contribution from agricultural and non-agricultural sources to nitrate pollution and, hence, address the criticism of the initial methodology.

Two possible approaches were identified:

(i) use of an ADAS model to predict the total annual input of flow and nitrate from agriculture at a catchment scale; and

(ii) use of the Environment Agency's SIMCAT river water quality model to consider the input of nitrate from STWs and the resulting impact on river water quality.

The ADAS model calculates agricultural nitrate loads. The SIMCAT model calculates STW nitrate inputs and assumes that any difference from measured concentrations and loads is due to other natural and agricultural inputs, plus the effects of self-purification (denitrification) in the river.

An initial consideration was to investigate proposed NVZ surface water catchments using both approaches to provide information to support designation in 1998. Subsequently, it became clear that the ADAS model predictions of agricultural nitrate inputs could be used as an agricultural source diffuse input to a SIMCAT model. This revised methodology has been adopted in carrying out this study in a manner similar to that used for a parallel study of the River Stour in Anglian Region.

2. STUDY OBJECTIVES

The overall study objective was to use SIMCAT to model the contribution from non-agricultural sources to nitrate pollution in the proposed Sor Brook NVZ. Subsidiary objectives were:

(i) to collate and analyse the flow and nitrate data for the Sor Brook provided by the Environment Agency to produce SIMCAT models;

(ii) to use the ADAS model estimates of agricultural nitrate inputs in a SIMCAT model to assess the relative impact of nitrate from STWs, agriculture, and other inputs and losses to the Sor Brook at the water supply abstraction point at Bodicote; and

(iii) to produce a report detailing the results from the SIMCAT modelling work.

3. PROGRAMME OF WORK

A SIMCAT model of the Sor Brook was built using Environment Agency data for the catchment. Three models were calibrated to reproduce summary statistics of estimated flows and observed nitrate concentrations at the Bodicote Gauging Station, which is a short distance downstream of the Bodicote abstraction point. ADAS model results were used to establish agricultural nitrate and flow inputs. These equated to an average input of 1029 tonnes per year, with 51% of the input occurring from December to March.

Summary statistics used for Bodicote were:

	Annual		Summer Period		Winter Period	
	Mean	95%ile	Mean	95%ile	Mean	95%ile
Estimated River Flow (ml/day) (95 percentile flow = 5 percentile low flow)	63	14	44	13	100	19
Nitrate concentration (mg/l NO_3)	44.6	61.4	41.5	52.6	55.1	74.7

The models were calibrated to annual, winter (December to March) and summer period (April to November) data. Flow calibration to estimated flows at Bodicote was based on the use of estimated headwater inputs to represent river and non-agricultural sources. Nitrate calibration was based on the estimation of headwater input quality and an in-river decay rate for the annual and summer models to match model predicted and estimated nitrate loads at Bodicote.

Following auto-calibration, the three SIMCAT models were used to represent a range of scenarios to identify the significance of STW inputs.

4. RESULTS

The SIMCAT results provided the following information to support the designation of the Sor Brook as a Surface Water NVZ.

1. Nitrate loads from STWs

Annual, winter and summer period average STW and agricultural loads, expressed as kg/day nitrate were:

	STWs	**Agriculture**	**Ratio**
Annual	106	2557	1:25
Winter	102	3940	1:39
Summer	111	1876	1:17

The proportions of all catchment inputs, excluding losses due to denitrification (in the annual and summer models only) were:

	Annual	**Winter**	**Summer**
Average Total Inputs (tonnes/day nitrate)	3.3	5.6	2.4
STW (%)	3	2	5
Agriculture (%)	77	79	70
Other (%)	20	19	25

Other inputs are non-agricultural inputs, headwater river inputs, tributary inputs and auto-calibration adjustments.

The STW inputs represent the following proportions of the estimated average river nitrate load at Bodicote:

	Annual	**Winter**	**Summer**
Load at Bodicote (tonnes/day)	2.5	5.6	1.7
STW contribution (%)	4	2	6

The Bodicote abstraction point fails the Nitrate Directive threshold of 50 mg/l Nitrate for 27 percent of the annual period; 66 per cent of the winter period; and, 10 per cent of the summer period. An annual failure of 5 percent is permitted. STWs provide a minor contribution to nitrate loads in the catchment. No STWs exceed the 10,000 population equivalent criterion.

2. Contribution of STW and agricultural inputs to the 95 percentile nitrate concentration at the abstraction point during the failure period

The estimated winter (main) failure period 95 percentile nitrate concentrations with and without STW nitrate inputs (with and without STW flows retained) and without agricultural nitrate inputs (flows retained) are:

	Predicted winter 95 percentile nitrate concentration at Bodicote (mg/l nitrate)	Failure Period % of year
Current - with STW inputs	74.7	22
With STW nitrate inputs removed	71.6	21
With STW nitrate and flow inputs removed	74.3	22
With agricultural nitrate inputs removed	34.6	1

The annual failure period based on the winter only results is also indicated. This is the duration of the exceedance of the 50 mg/l nitrate threshold.

The abstraction point will still fail with STW nitrate and flow inputs removed. However, the abstraction point will not fail if the agricultural inputs are removed.

3. Conclusions

The SIMCAT results, summarised in Figure 1, are based on historic catchment data and ADAS model estimates of agricultural inputs of nitrate and flow. The results clearly indicate the relatively minor contribution of STW inputs to nitrate concentrations and loads at the Bodicote water supply abstraction point. Bodicote would still fail the Nitrate Directive threshold if STW inputs are removed. There are no large STWs (population equivalent greater then 10,000) in the catchment. The abstraction point would not fail if the estimated agricultural nitrate inputs are removed. The results support the proposed designation of the Sor Brook as a surface water NVZ. Further SIMCAT modelling could be carried out to identify the reductions in nitrate levels that would be required to enable the abstraction point to comply with the Nitrate Directive requirements.

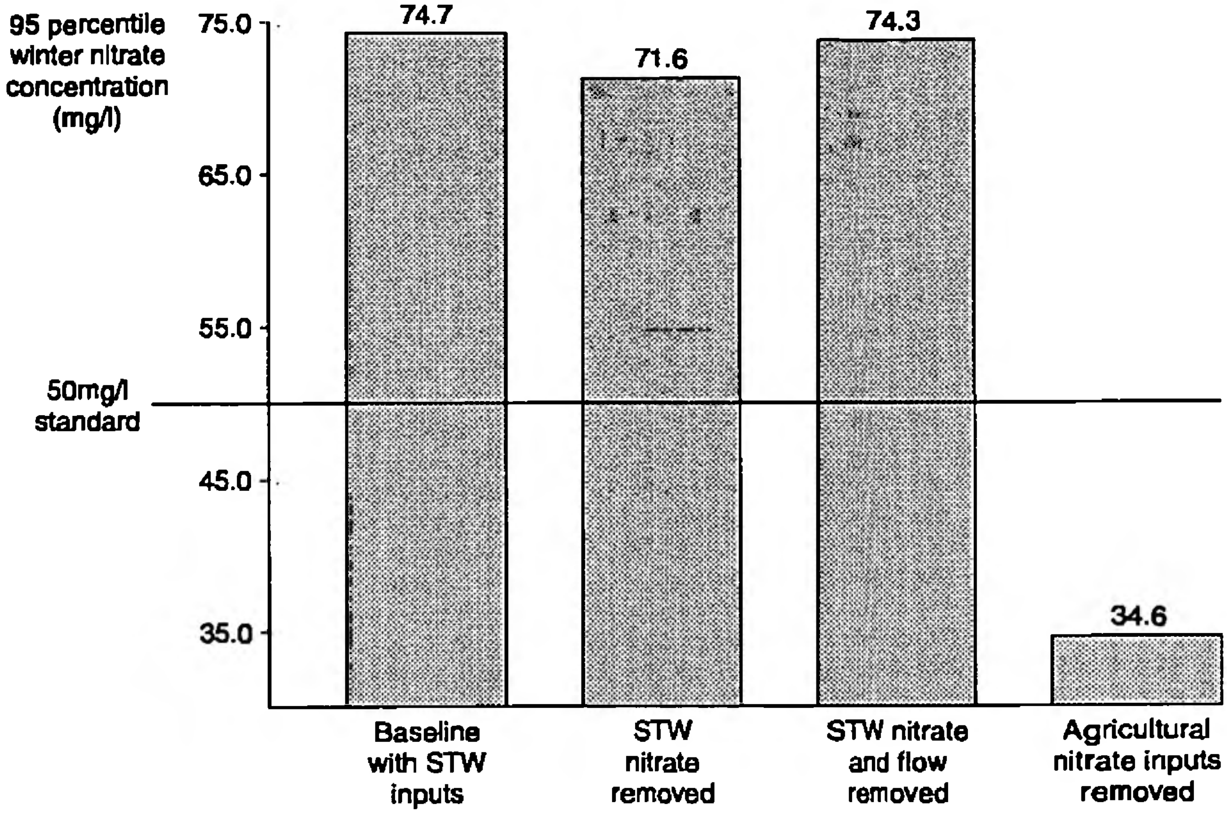

Figure 1 Predicted Winter 95 percentile nitrate concentrations (mg/l NO_3) for modelled scenarios

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1. INTRODUCTION

1.1 Background

Under the Nitrates Directive (91/676/EC), Nitrate Vulnerable Zones (NVZs) were designated in April 1996 for protection from pollution by nitrates from agriculture. Surface water zones were designated on the basis of exceedances of 50 mg/l nitrate (as NO_3, equivalent to 11.3 mg/l nitrate nitrogen, NO_3-N) in more than 5% of samples at the abstraction point in 1992. The catchment extent was defined on the basis of exceedances at upstream sampling points over the preceding five year period, 1988 - 1992. In Thames Region of the Environment Agency the Sor Brook was not designated as a NVZ in the 1992 round. However, river water quality data for the period, 1992 - 1996 demonstrates that the Sor Brook Catchment upstream of the Bodicote intake fails.

A major criticism of the methodology used in the 1992 NVZ round for the definition of zones was that the contribution of non-agricultural sources of nitrate (for example, inputs from sewage treatment works (STWs) and atmospheric deposition) was not adequately assessed. The Department of the Environment, Transport and the Regions (DETR) held a workshop in 1997 to identify a methodology that could be employed to estimate the contribution from agricultural and non-agricultural sources to nitrate pollution and, hence, address the criticism of the initial methodology.

Two possible approaches were identified:

(i) use of ADAS model to predict the total annual input of flow and nitrate from agriculture at a catchment scale; and

(ii) use of the Environment Agency's SIMCAT river water quality model to consider the input of nitrate from STWs and the resulting impact on river water quality.

The ADAS model calculates agricultural nitrate loads. The SIMCAT model calculates STW nitrate inputs and assumes that any difference from measured concentrations and loads is due to other natural and agricultural inputs, plus the effects of self purification (denitrification) in the river.

An initial consideration was to investigate proposed NVZ surface water catchments using both approaches to provide information to support designation in 1998. The Sor Brook catchment was selected to trial the proposed methodology to address criticism of the previous methodology and to support the designation of the Sor Brook. Subsequently, it became clear that the ADAS model predictions of agricultural nitrate inputs could be used as an agricultural source diffuse input to a SIMCAT model. This revised methodology has been adopted in carrying out the study on the Sor Brook, using an approach similar to that applied to the River Stour in Anglian Region.

1.2 Study Objectives

The overall study objective was to use SIMCAT to model the contribution from non-agricultural sources to nitrate pollution in the proposed Sor Brook NVZ. Subsidiary objectives were:

(i) to collate and analyse the flow and nitrate data for the Sor Brook provided by the Environment Agency to produce SIMCAT models;

(ii) to use the ADAS model estimates of agricultural nitrate inputs in a SIMCAT model to assess the relative impact of nitrate from STWs, agriculture, and other inputs and losses to the Sor Brook at the water supply abstraction point at Bodicote; and

(iii) to produce a report detailing the results from the SIMCAT modelling work.

A range of SIMCAT models were produced and modelling scenarios were carried out to address the following specific issues.

(i) How much of the nitrate load is from STWs:-
   a) during the period when the abstraction point fails; and,
   b) at times when agricultural inputs are at a minimum (e.g. summer low flows)?

(ii) What is the contribution of all STWs to the 95 percentile nitrate concentration at the abstraction point during the period when it fails?

(iii) If the nitrate load from all STWs is excluded, either by (a) removing all effluent nitrate but retaining effluent flow, or (b) removing all effluent, does the abstraction point still fail?

(iv) If the estimated nitrate load from agriculture is excluded, does the abstraction point still fail?

1.3 Report Structure and Content

Following this introductory section, which establishes the requirements and objectives for the study, Section 2 provides an overview of the SIMCAT modelling approach adopted by WRc to incorporate the output from the ADAS model and to carry out the specific study objectives. Section 3 presents the methodology as applied to the Sor Book. Section 4 presents the results in relation to the specific issues identified in Section 1.2. Further details of the ADAS model and results are provided in the Appendix. All SIMCAT model input and output files for the modelling scenarios, plus ADAS model results, are contained within a supporting diskette.

2. OVERVIEW OF SIMCAT MODELLING APPROACH

2.1 SIMCAT

A river water quality simulation model should represent the major processes which affect water quality in the river and should take account of variability of river quality and flow. The model should operate within a framework compatible with the water quality standards being applied; such as, predictions of effluent discharge quality and resulting river quality expressed as the summary statistics of flow and pollutant concentration distributions.

SIMCAT is a mathematical model which describes the quality of river water through out catchment. It is used to help plan the measures needed to improve river water quality by predicting the behaviour of the summary statistics of water quality, such as the mean and 90 or 95 percentile. Hence, the model recognises the fact that predictions must be defined as statistics in order to allow a correct assessment of compliance with quality objectives while also recognising the variability of river flow and quality.

SIMCAT has special features, such as auto-calibration, which enables it to produce reliable results quickly. It also controls the effect of the statistical uncertainties associated with water quality data on decision making.

SIMCAT has been widely used in the UK over a number of years and is recognised as being a cost-effective, practical water quality management tool to support catchment management and discharge control decision making on a routine basis.

The advantages of the SIMCAT approach are:

(i) proven Environment Agency software;

(ii) is readily applied at a catchment scale;

(iii) makes best use of existing available, but often limited, data; and,

(iv) allows rapid assessment of management options.

SIMCAT offers a significant insight into catchment behaviour based on the use of existing routine monitoring of river and effluent quality for continuous discharges. SIMCAT is designed to minimise the recognised limitations of these data and produce results with identified confidence levels for comparison against water quality standards and planning criteria. SIMCAT also produces pollutant source load results, in addition to predicted river concentrations.

Inputs to SIMCAT can be defined as:

- point source inputs, such as river headwaters, tributaries, and STW discharges;
- diffuse inputs;

- abstractions; and
- unknown inputs.

Each type of input is represented by summary statistics, based on available data for the period represented by the model; for example, the mean and the standard deviation. Inputs are represented as selected probability distributions; for example, Normal or Lognormal distributions, based on the results of distribution fitting to the original data. Unknown inputs (or losses) are calculated by the model during auto-calibration to represent the difference between the input data from all sources, known abstractions, self-purification and the measured flows and pollutant loads at points in the catchment.

SIMCAT represents self-purification in the river (the loss of a pollutant; denitrification in the case of nitrate) by an exponential decay function of the form:

$$C = C_0e^{-kt}$$

where C_o is the initial concentration (t=0) and k is a temperature dependent rate constant.

At a discharge (input) point SIMCAT uses a Monte-Carlo simulation approach to mix the flow and quality distributions of the discharge with the upstream river flow and quality distributions. This produces downstream flow and quality distributions which are routed down the model, applying a decay to pollutant concentrations, as appropriate. Further details of SIMCAT are provided in "SIMCAT 4.15 - A GUIDE TO USERS, August 1997" available from the Environment Agency.

2.2 Modelling Approach

Flow and nitrate data were provided for the Sor Brook Catchment for the period 1992-96. This included all river and STW effluent data. These data were analysed to produce SIMCAT input statistics (mean, standard deviation and 95 percentile low flow for river flow data). The downstream boundary of the model was at the Bodicote Gauging Station which is about 300 m below the water supply abstraction point at Bodicote. There are no point source inputs between these locations. Nitrate data were provided in the form of TON (Total Oxidised Nitrogen) as mg/l N. It was assumed, on the basis of river chemistry data, that all TON would be in the form of nitrate. Therefore, nitrate modelling inputs and results are reported as NO_3-N (**Note: results are presented in the Summary Report as NO_3, by conversion of NO_3-N values to NO_3 by using a multiplication factor of 4.42**). In addition to an annual model, winter and summer models were built based on partitioning the data into winter and summer seasons. The winter season of December to March was selected on the basis of observed exceedances of the 11.3 mg NO_3-N/l standard at Bodicote. Figure 2.1 shows the observed nitrate data at this location. No observed exceedances occurred during the summer period (April to November). Summary statistics are presented in Table 2.1 for nitrate quality.

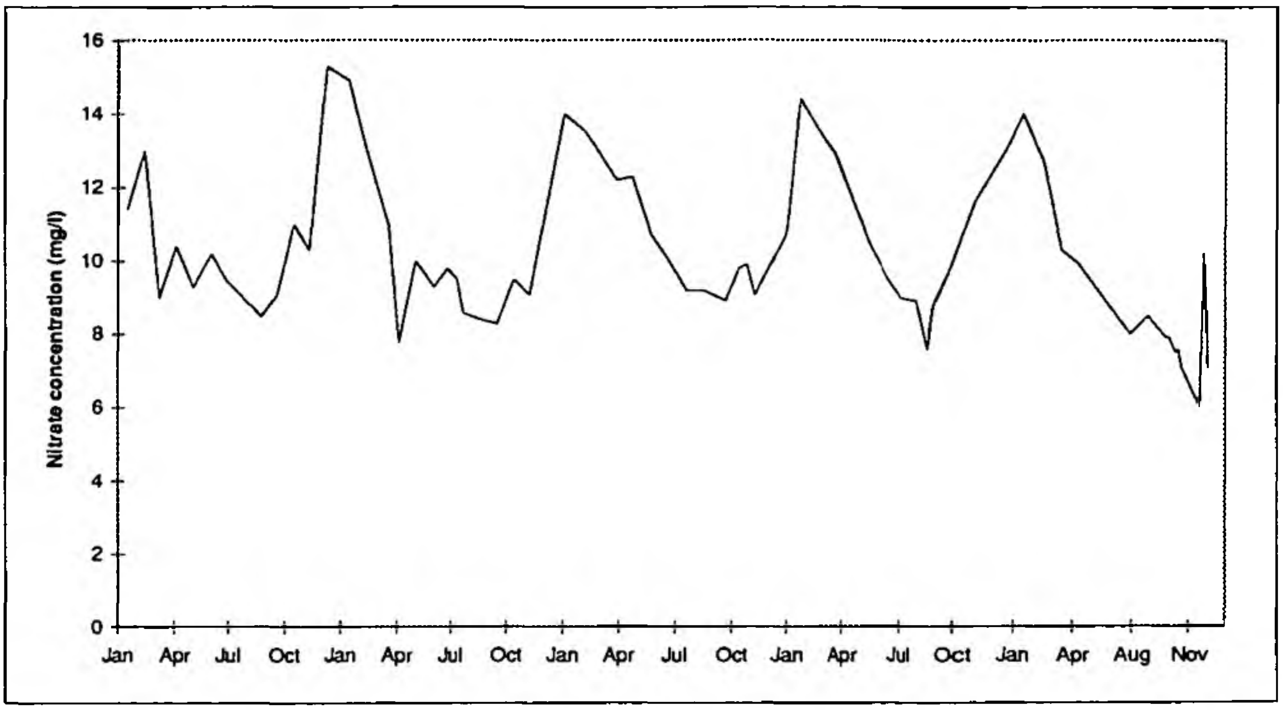


Figure 2.1 **Observed nitrate concentration data at Bodicote (1992-1996)**

Table 2.1 **Observed nitrate concentrations at Bodicote 1992-96, mg/l NO_3-N**

	Mean	95 percentile
Annual	10.1	13.9
Winter Period	12.5	16.9
Summer Period	9.4	11.9

The observed STW data and river quality data provided by the Environment Agency were used to identify the STW and headwater flows. ADAS model results were used to represent estimates of diffuse agricultural inputs to the catchment as described in the Appendix.

The following modelling approach was used to produce the three SIMCAT models.

(i) carry out manual calibration of flows for all known and assumed input data to match observed flows at Bodicote;

(ii) carry out auto-calibration of flows to replicate flow balance at Bodicote;

(iii) identify nitrate decay rate to match assumed and known nitrate source concentrations with observed nitrate concentrations at Bodicote; and,

(iv) auto-calibrate the model to observed nitrate concentrations at Bodicote.

The "unknown" flows and loads produced by auto-calibration are maintained in the model when representing the management scenarios. It was assumed that these would indicate inputs from additional non-agricultural sources, plus uncertainties associated with the input data and use of the selected decay rate. The decay rate was used to minimise the unknown load inputs produced by auto-calibration. This approach to SIMCAT calibration was adopted to identify the comparative levels of STW and agricultural diffuse inputs.

3. SIMCAT MODELLING

3.1 Catchment Conceptualisation

The basic Sor Brook SIMCAT model was constructed using data received from Thames Region of the Environment Agency. The model included all major watercourses and was comprised of 11 reaches and one tributary input, as shown in Figure 3.1. Reach details are summarised in Table 3.1 and the river and effluent monitoring sites are summarised in Table 3.2.

Table 3.1 Catchment conceptualisation

Reach No.	Reach Name	Distance (Km)	Tributary
1	Sor Brook 1	1.9	
2	Sor Brook 2	1.9	
3	Sor Brook 3	5.5	
4	Hornton Stream	4.6	
5	Sor Brook 4	6.2	
6	Shutford Stream 1	10.2	Balscote Brook
7	Tadmarton Stream 1	7.7	
8	Holywell Brook	2.2	
9	Tadmarton Stream 2	2	
10	Shutford Stream 3	0.1	
11	Sor Brook 5	7.6	

Table 3.2 Flow and quality monitoring sites in the Sor Brook catchment

Reach No.	Feature code	Feature name	Distance from head of reach
1	SORBK18	Ratley STW	1.5
4	SORBK17	Hornton STW	1.5
4	SORBK16	Hornton stream above Sor Brook	4.5
5	SORBK15	Horley STW	0.2
5	SORBK14	Broughton STW	5.2
6	SORBK9	Home Farm STW	0.8
6	SORBK5	Shutford STW	5.5
6	SORBK8	Shutford stream, above Alkerton	1.5
6	SORBK7	Shutford stream roadbridge Alkerton	2.5
6	SORBK6	Shutford Stream below Alkerton	3.7
6	SORBK4	Shutford Stream Wroxton mill	6.4
6	Balscote Brook	Tributary of Shutford stream	6.0
7	SORBK10	Lower Tadmarton	7.7
8	SORBK12	Tadmarton Heath Golf Club STW	0.2
11	SORBK3	Wykham mill STW	3.2
11	SORBK1	Sor Brook at Bodicote	7.3
11	GS 1	Bodicote gauging station	7.6

This conceptualisation enabled the agricultural inputs to be incorporated into the model as diffuse inputs per kilometre of river.

Balscote Brook was modelled as a tributary since its confluence with Shutford Stream is situated very close to the river quality monitoring site SORBK4. Thus, Balscote Brook is a tributary input with flow and quality data from SORBK13, situated on Balscote Brook.

No abstraction points were included in the SIMCAT model. The abstraction at Bodicote pumping station is not continuous. Data were provided by the Environment Agency for average monthly abstractions for May, June and July (see Table 3.3). These data were added back into the flow data available at Bodicote.

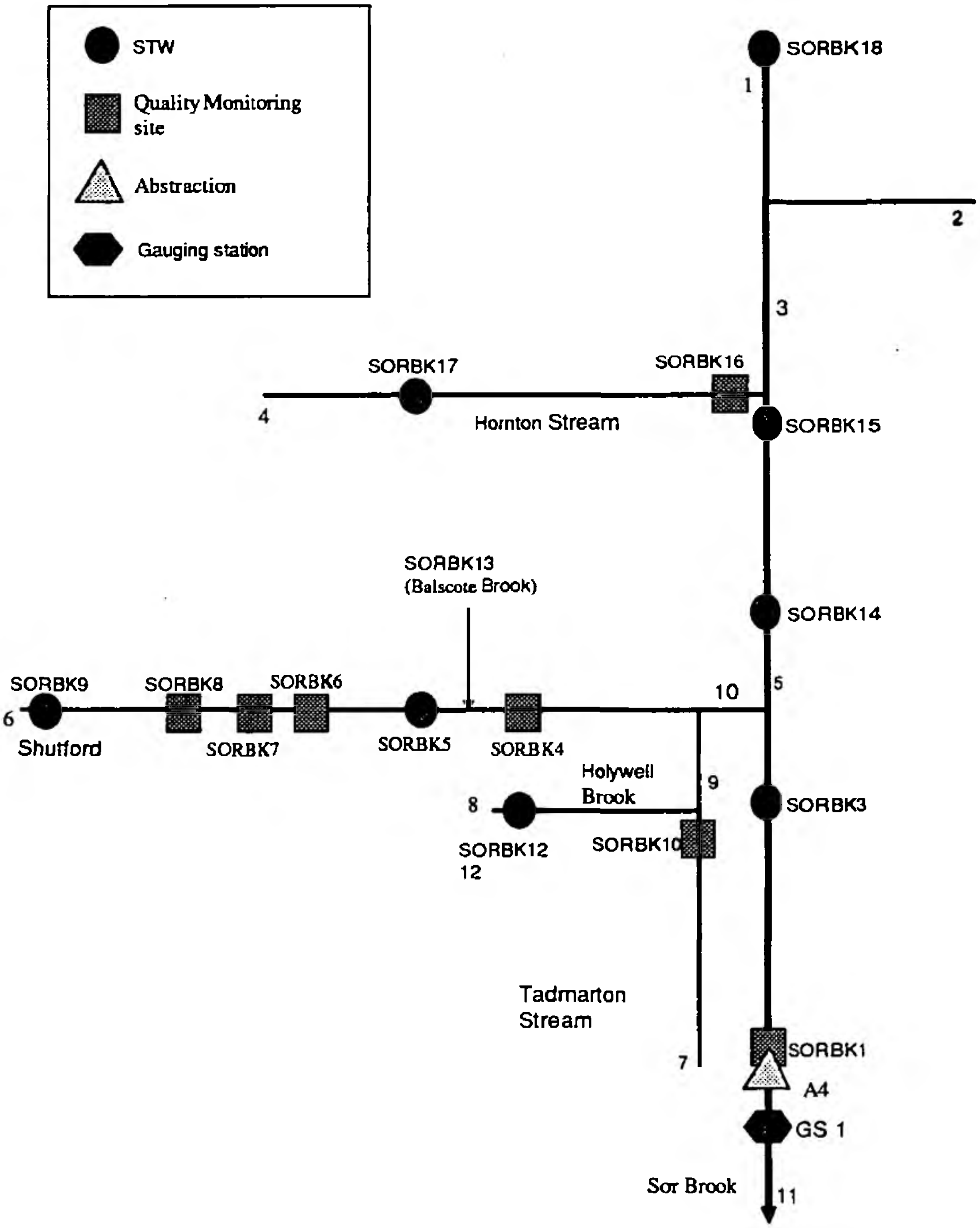


Figure 3.1 SIMCAT model schematic for the Sor Brook Catchment

Table 3.3 Monthly average volume abstracted by Bodicote pumping station, 1992-1996

Month	Volume abstracted (Ml/d)
May	34.19
June	21.75
July	0.72

The mean temperature of the river water defined in each of the models is given in Table 3.4. The same catchment conceptualisation was used for each of the models, only the input data differed.

Table 3.4 Mean river water temperatures used in the seasonal SIMCAT models

Model	Mean river water temperature (°C)
Annual	12
Summer	17
Winter	7

3.2 Flow Calibration

Flow data for the period March 1995 to December 1996 were available for Bodicote Gauging Station. This was the only point in the catchment where flow data were available. Since the abstraction at Bodicote pumping station is situated upstream of the gauging station, the average monthly abstraction was added back into the data. The data were then partitioned into summer and winter periods and then the summary statistics were calculated. The mean flow and standard deviation of these data appeared to be low compared to the next downstream gauging station at Adderbury and estimated flow statistics at Bodicote produced by the Environment Agency using Micro Low Flows. These estimated flow statistics could not be used as it was not possible to identify summer and winter period values. Therefore, a long term estimate was made for the flow at Bodicote. River flow data for the period 1967-1988 were available for Adderbury Gauging Station, situated further downstream. The Adderbury flow data were partitioned into the specified summer and winter periods. Summary statistics for annual, summer and winter were then calculated. Estimates of the flow at Bodicote were made from the Adderbury data on a pro-rata basis using the catchment areas above each of the gauging stations as shown in Table 3.5. The observed and estimated flow data at Adderbury and

Bodicote are summarised in Table 3.6. The values used in the SIMCAT models were the estimates of Bodicote flow from Table 3.6.

Table 3.5 Catchment areas above Bodicote and Adderbury gauging stations

	Above Bodicote gauging station	Above Adderbury gauging station
Catchment Area (km^2)	91.25	107

Table 3.6 Observed and estimated flow data at Bodicote and Adderbury

		Adderbury observed data (1967-1988)	Bodicote observed data (1995-1996)	Bodicote Micro Low Flows estimate	Bodicote estimate based on Adderbury observed data
ANNUAL	Mean (Ml/d)	73.4	31.2	62.5	62.6
	Q95	15.9	10.28	16.0	13.6
	Min	10.63	8.99	5.0	9.07
SUMMER	Mean (Ml/d)	51.2	19.41		43.7
	Q95	14.8	10.11		12.6
	Min	10.63	8.99		9.07
WINTER	Mean (Ml/d)	116.9	64.44		99.7
	Q95	22.4	15.02		19.1
	Min	16.59	7.1		14.15

Note: Q95 = 5 percentile low flow

No data were available for the headwaters, therefore, these were estimated. Chloride concentration data could have been used to apportion flow throughout the catchment to improve the flow balance and calibration. However, the available chloride data were insufficient to do this. Therefore, headwater flows for all reaches were set the same . The flows were manually calibrated by adjusting the headwater flows until a good fit was achieved between the calculated and estimated flow at Bodicote. The head water flows used in the SIMCAT models are summarised in Table 3.7.

Table 3.7 Estimated headwater flow data (Ml/day)

	Mean (Ml/d)	Q95	Shift
Annual	3.17	0.13	0.09
Summer	2.06	0.01	0.005
Winter	5.42	1.1	0.3

Shifted Lognormal distributions were used to represent the river and headwater flow data.

The agricultural flow data provided from the ADAS model were partitioned into similar summer and winter periods and summary statistics were calculated. The flows are summarised in Table 3.8 for the whole catchment and as a diffuse input per km river length. Total modelled river length was 50 km. Figure 3.2 shows the flow distributions for the annual, summer and winter periods. For SIMCAT input, these were assumed to have shifted lognormal distributions. A "year on year" plot of the agricultural flow data is shown in Figure 3.3.

Table 3.8 Agricultural flow data from ADAS model

	Whole Catchment		Flow rate per km	
	Mean (Ml/d)	Q95	Mean (Ml/d)	Q95
Annual	38.90	11.51	0.78	0.23
Summer	28.22	11.56	0.57	0.23
Winter	60.37	10.43	1.21	0.21

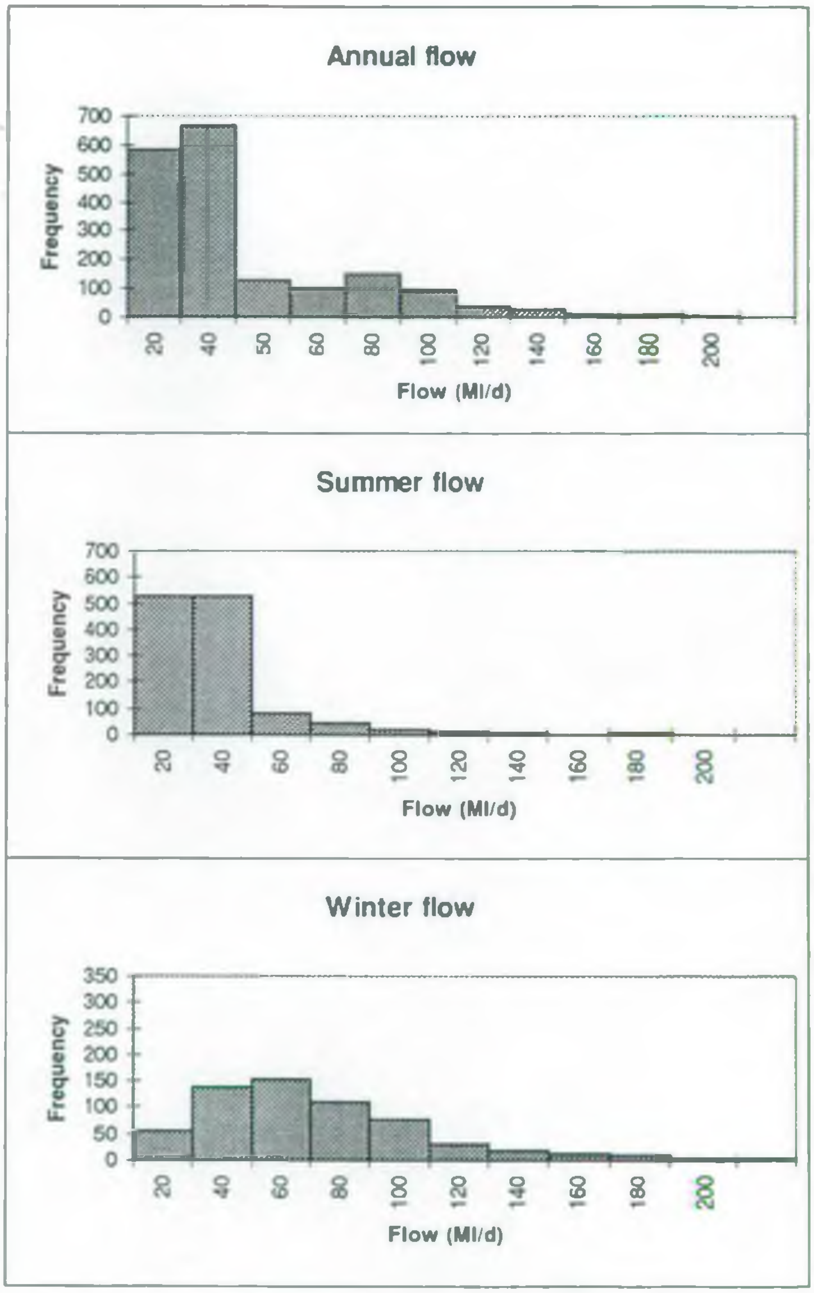


Figure 3.2 Frequency distributions of agricultural flow estimates

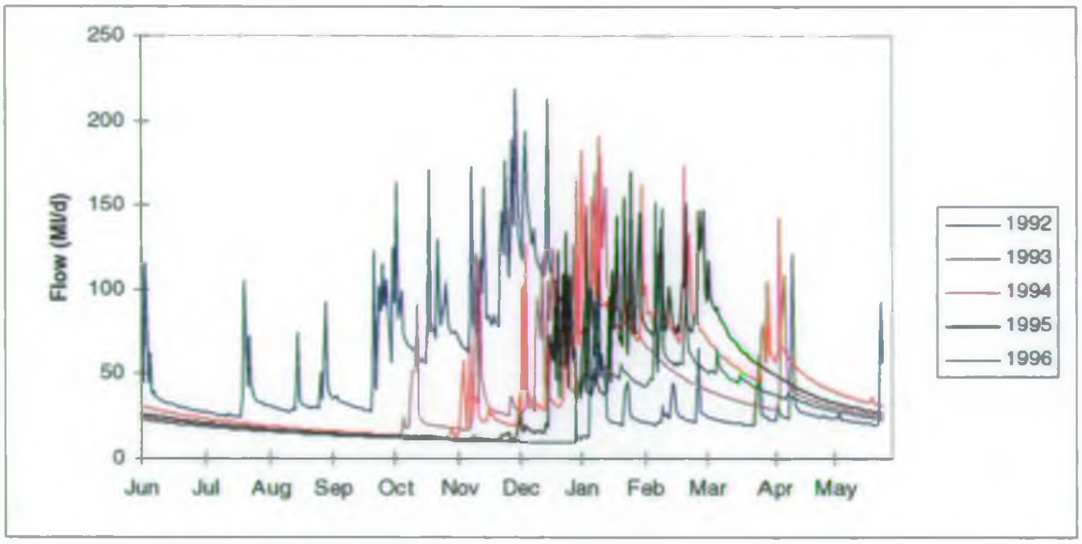


Figure 3.3 Year-on-year plot of flow data at Bodicote - Agricultural inputs

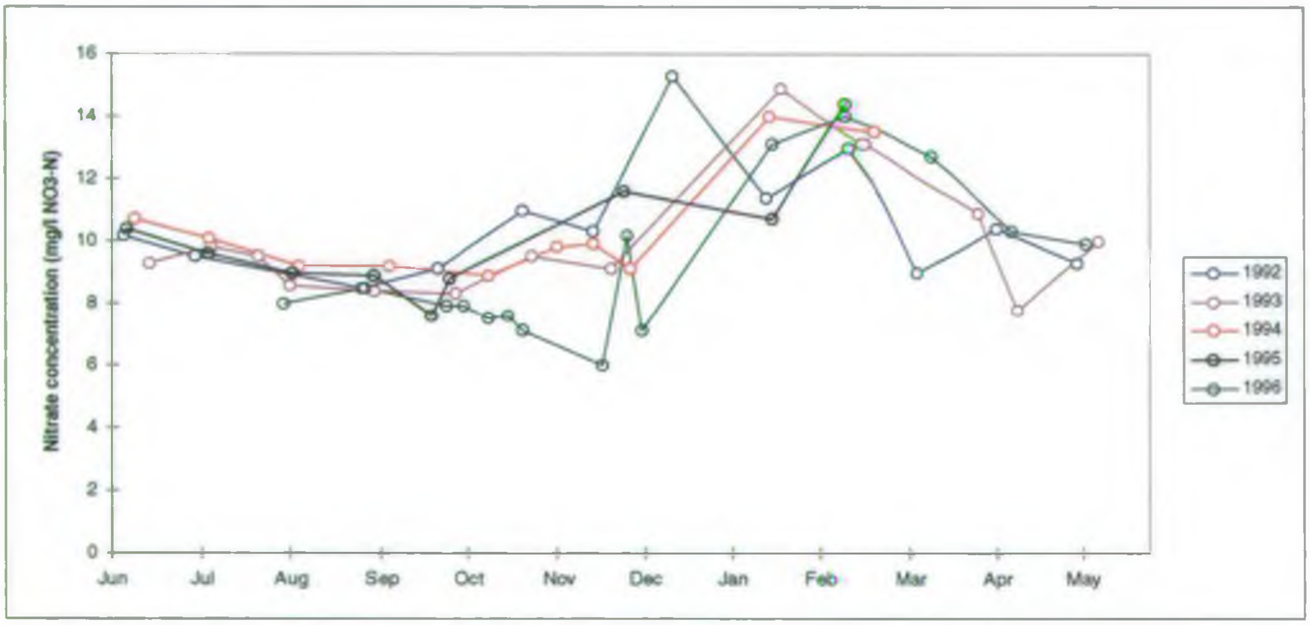


Figure 3.4 Year-on-year plot of observed nitrate concentration data at Bodicote

Maximum consented flow data were available for the STWs. Flow statistics were estimated based on the following standard assumptions for modelling STW flows:

Maximum consented flow = 3 × DWF
Mean Flow = 1.3 × DWF
Standard deviation = mean flow/3
Minimum flow = DWF/2

The estimated flow statistics are summarised in Table 3.9. These are likely to be higher than actual flows.

Table 3.9 Estimated STW flow data

STW	max consented flow (Ml/d)	DWF (Ml/d)	Mean (Ml/d)	Standard deviation	Minimum (Ml/d)
Wykham mill STW	0.01	0.003	0.0043	0.001	0.002
Shutford STW	0.927	0.309	0.4	0.134	0.15
Home farm STW	0.005	0.0017	0.002	0.001	0.001
Tadmarton Heath Golf Club STW	0.02	0.0067	0.009	0.003	0.003
Broughton STW	1.37	0.455	0.59	0.2	0.23
Horley STW	0.195	0.065	0.085	0.028	0.033
Horton STW	0.186	0.062	0.081	0.027	0.031
Ratley STW	0.093	0.031	0.04	0.013	0.016

Once the models had been manually calibrated, SIMCAT was run in modes 1 and 2 to auto-calibrate the three models. The flow balance results for Bodicote, prior to auto-calibration, given in Table 3.10, demonstrate a close match between calculated and observed flows.

Table 3.10 Flow balance results for Bodicote

	Calculated Flow Data		Observed Flow Data	
	Mean	95 %ile	Mean	95 %ile
Annual	62.52	13.56	62.6	13.6
Summer	43.62	12.59	43.7	12.6
Winter	99.45	18.83	99.7	19.1

The models were then auto-calibrated to match the estimated flow at Bodicote.

3.3 Quality Calibration

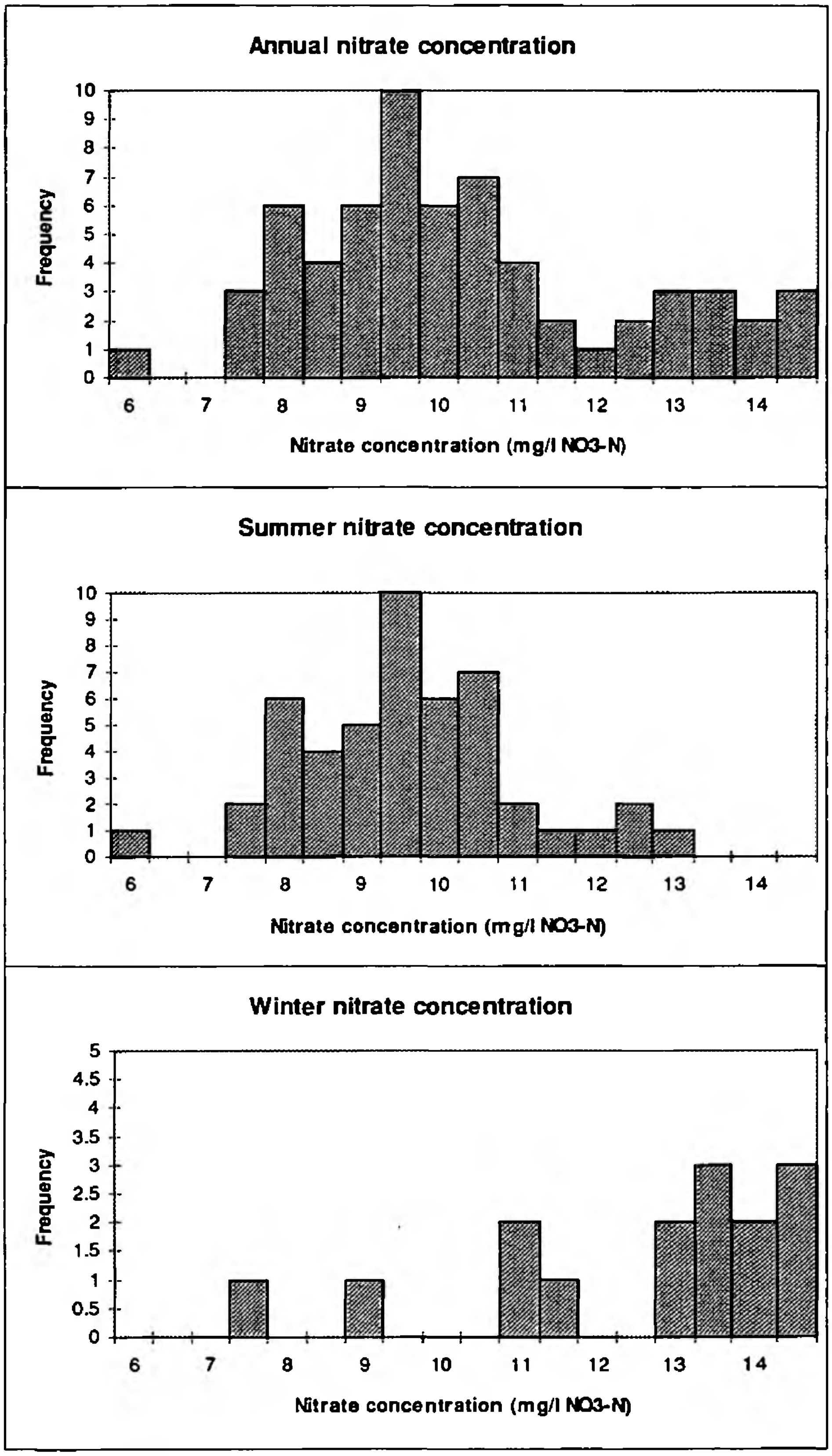
Nitrate quality data were available for each of the river quality monitoring sites and sewage treatment works in the Sor Brook catchment. These data covered the period 1992-1996. The data were partitioned into annual, summer and winter periods and the summary statistics were calculated. A Lognormal distribution was assumed for those sites where the number of samples was greater than 10. A normal distribution was used for those sites where the number of samples was less than 10.

Table 3.11 summarises the river nitrate quality data. A "year on year" plot of nitrate quality data is shown in Figure 3.4. Figure 3.5 shows the nitrate distributions for the annual and seasonal models.

Table 3.11 River nitrate quality data (mg/l NO_3-N)

	ANNUAL				SUMMER				WINTER				
	Dist	Mean	SD	n	Dist	Mean	SD	n	Dist	Mean	SD	Shift	n
SORBK16	2	9.72	2.6	57	1	8.6	1.6	35	1	11.4	2.5	-	22
SORBK8	1	13.7	5.72	6	2	11.9	5.96	4	2	17.4	4.2	-	2
SORBK7	1	14.8	2.67	6	2	13.9	2.3	4	2	16.7	3.2	-	2
SORBK6	1	11.8	5.13	6	2	10.1	5	4	2	15.2	4.7	-	2
SORBK13	1	13.1	1.3	5	2	13.1	1.8	5	2	13.1	0.8	-	2
SORBK4	1	13.2	2.5	47	1	12	1.9	30	1	15.3	1.9	-	17
SORBK10	2	11.8	2.9	39	2	11.1	1.5	26	3	13.2	4.4	6.4	13
SORBK1	2	10.1	2.1	63	1	9.4	1.4	48	1	12.5	2.3	-	15

Note: n - number of samples
Dist = assumed distribution shape; 1 = normal, 2 = lognormal, 3 = shifted lognormal



Annual nitrate concentration

Summer nitrate concentration

Winter nitrate concentration

Figure 3.5 Frequency distributions of observed nitrate concentrations at Bodicote for the annual, summer and winter periods

No effluent quality data were available for Tudor Hall School STW (SORBK2) or Swalcliffe Mill STW (SORBK11). Therefore, these were not included in the model.

The STW nitrate data are summarised in Table 3.12.

Table 3.12 STW nitrate concentration data (mg/l NO_3-N)

	ANNUAL				SUMMER				WINTER				
	Dist	Mean	SD	n	Dist	Mean	SD	n	Dist	Mean	SD	Shift	n
SORBK18	1	29.7	7.6	61	1	29.8	6.8	43	2	29.6	9.9	-	18
SORBK17	1	16.7	5.8	61	1	18.1	6.2	42	2	13.7	3.4	-	19
SORBK15	1	17.6	6.2	37	1	17.6	6.9	26	2	17.6	4.5	-	11
SORBK14	2	19.3	5.5	56	1	19.3	5.5	34	3	19.1	5.5	10	22
SORBK9	2	14.6	14.5	4	2	14.6	14.5	4	2	14.6	14.5	-	4
SORBK5	1	19.1	3.6	62	2	19.9	3.2	40	2	17.7	3.9	-	22
SORBK3	2	57.5	23.6	15	2	57.5	23.6	15	2	57.5	23.6	-	15
SORBK12	1	12.8	8.5	17	1	10.1	5.5	13	2	22	11	-	4

Note: n - number of samples
Dist = assumed distribution shape; 1 = normal, 2 = lognormal, 3 = shifted lognormal

Since the number of samples at SORBK3 and SORBK9 were so small, it was decided that the annual concentration would be used in the summer and winter models.

Nitrate concentration data for the diffuse agricultural inputs were provided by the ADAS model. These data were partitioned and analysed, as previously described, and used as the nitrate concentration of diffuse agricultural flows in the SIMCAT models. These are summarised in Table 3.13. Figure 3.6 shows a "year on year" plot of daily nitrate concentration data from the ADAS model results. Frequency distributions of the annual and seasonal nitrate concentration data are shown in Figure 3.7. Agricultural nitrate concentrations were assumed to have a Lognormal distribution.

Table 3.13 Nitrate quality data - Agricultural inputs (mg/l NO_3-N)

	Mean	Standard Deviation
Annual	14.90	0.93
Summer	14.96	0.87
Winter	14.79	1.04

Figure 3.8 shows the frequency distribution of agricultural nitrate loads and Figure 3.9 shows the monthly variation in total nitrate loads. The average agricultural nitrate input is 1029 tonnes per year. Of this, 51% occurred in the winter period of 4 months from December to March.

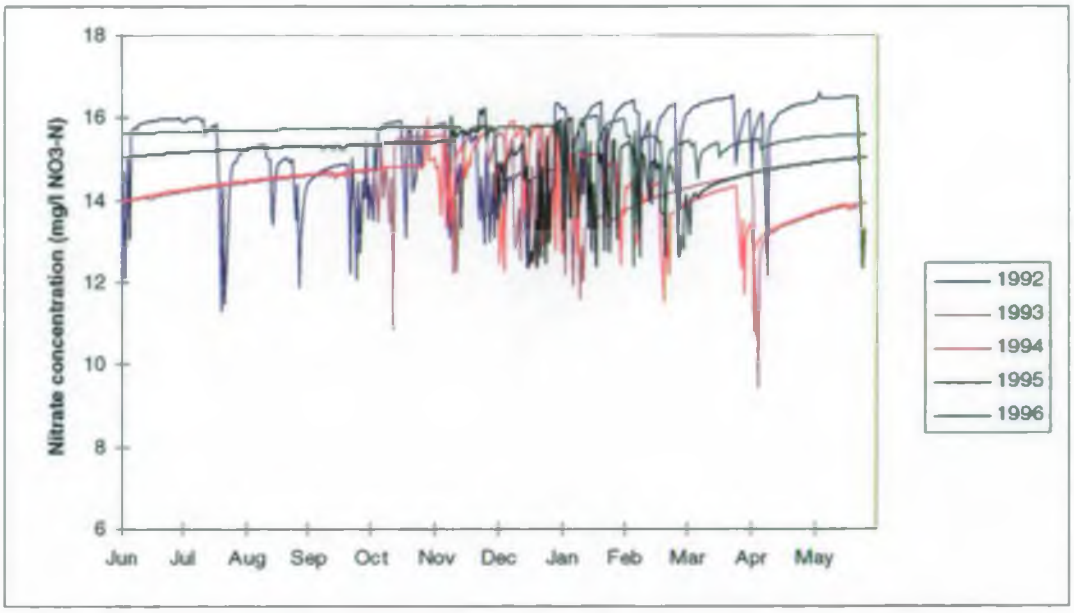


Figure 3.6 **Year-on-year plot of nitrate concentrations at Bodicote for agricultural inputs**

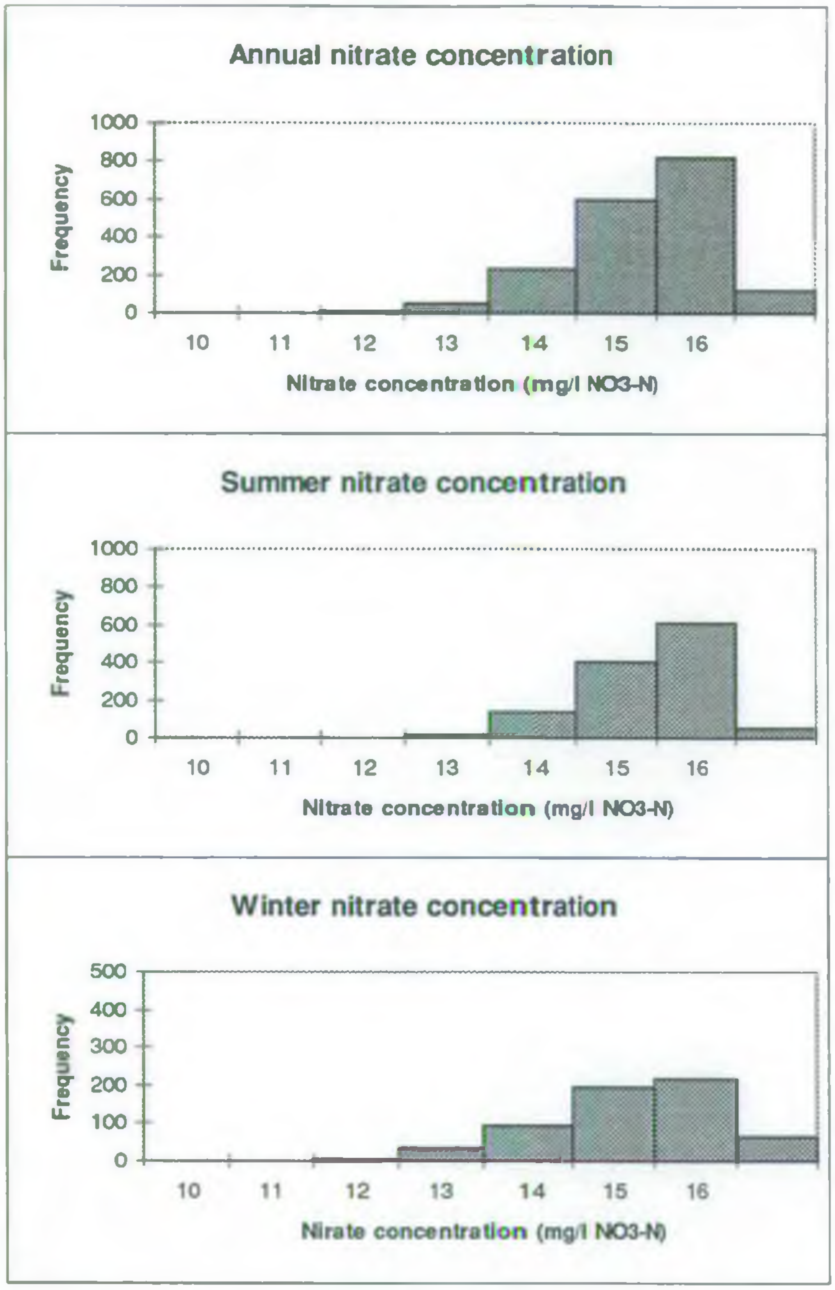


Figure 3.7 **Frequency distributions of nitrate concentration data for agricultural inputs**

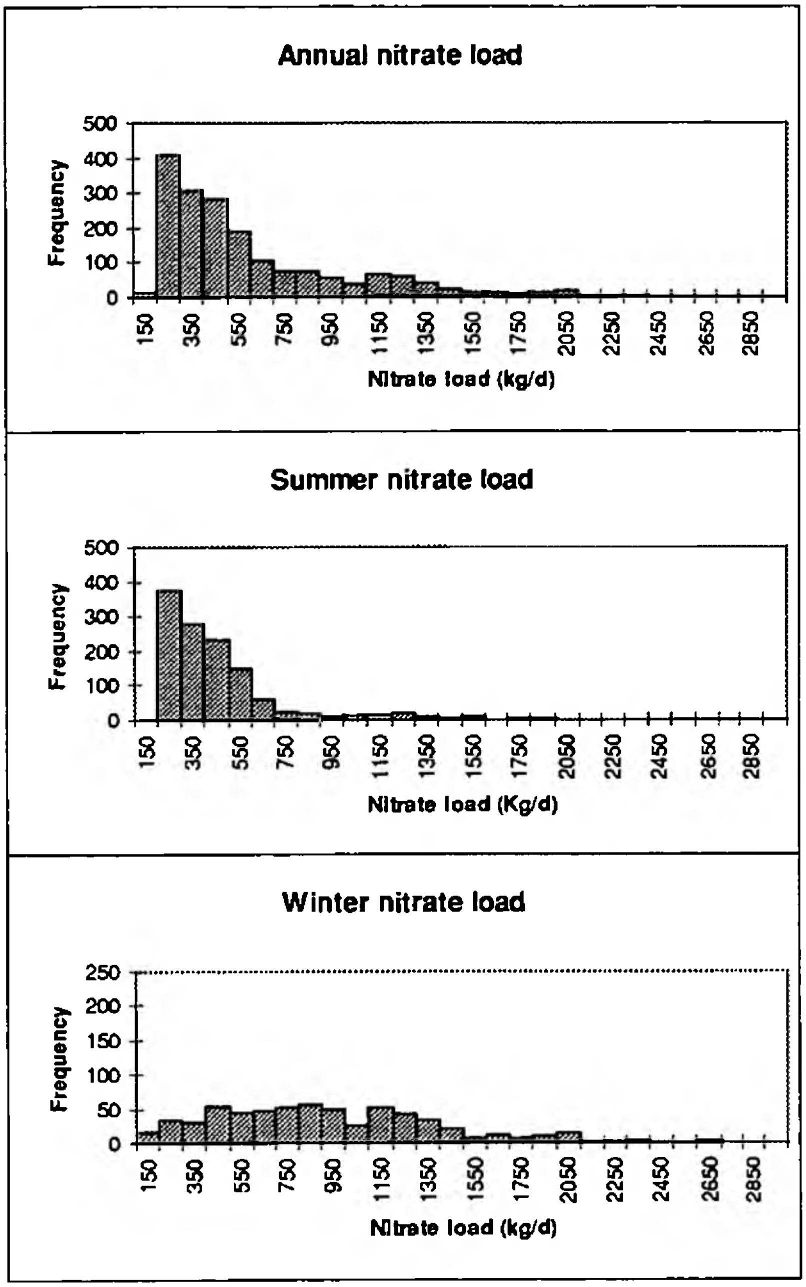


Figure 3.8 Histograms of nitrate load at Bodicote - Agricultural inputs

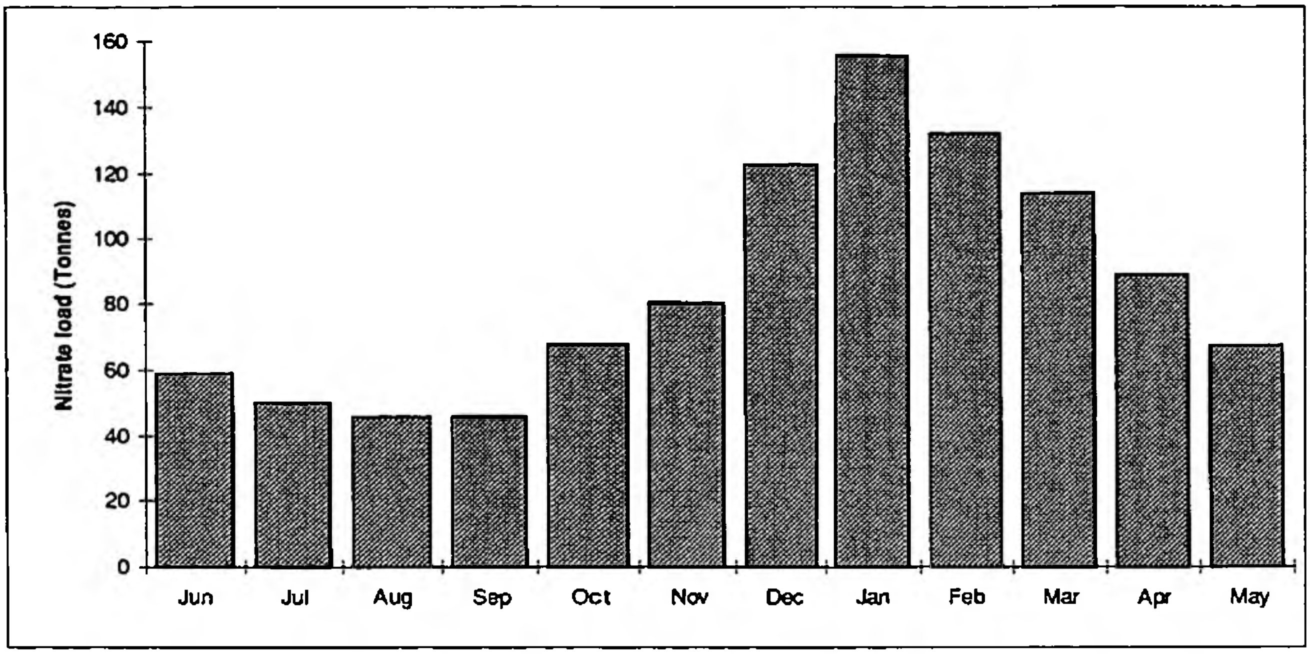


Figure 3.9 Mean monthly loads at Bodicote for agricultural inputs (1992-1996)

As no headwater information was available, the nitrate quality was manually calibrated by adjusting the headwater quality until a good fit was achieved compared to observed river data. SIMCAT was then run in modes 3 and 4 to auto-calibrate the nitrate quality. The load results showed that nitrate load was being removed for the annual and summer models. To prevent this, a decay rate was used in these models. A number of decay rates were tested, the final decay rates are summarised in Table 3.14 and the final headwater quality used in the SIMCAT models is summarised in Table 3.15. The derived headwater quality nitrate concentrations were smaller than observed river and estimated agricultural input concentrations.

Table 3.14 Nitrate decay rates used in annual and summer models

	Annual model	Summer Model
Average Temperature (°C)	12	17
Decay Rate (reciprocal days)	0.95	0.9
Average half life for nitrate decay (hours)	23	19.5

Table 3.15 Estimated headwater quality data (mg/l NO_3-N)

	Annual		Winter		Summer	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Headwater Sor Brook 1	5.0	2.0	8.0	2.5	5.0	1.0
Headwater Sor Brook 2	5.0	2.0	8.0	2.5	5.0	1.0
Headwater Hornton Stream	3.0	2.0	8.0	2.5	2.0	0.3
Headwater Shutford Stream	4.0	2.0	8.5	3.5	2.0	0.4
Headwater Tadmarton Stream	4.0	3.6	8.0	4.4	1.0	0.2
Headwater Holywell Brook	5.0	2.0	8.0	2.5	5.0	1.0

The headwater quality and nitrate decay rate were used to achieve the nitrate load balance at Bodicote, based on the flows and loads from the observed STW inputs and the ADAS model estimates for agricultural inputs. The headwater inputs represent river and non-agricultural inputs, plus any unknown inputs and uncertainties in the data.

The quality calibration results, prior to auto-calibration of quality, are given in Table 3.16. Only four sites were used as quality calibration sites. These were SORBK16, SORBK4, SORBK10 and SORBK1. SORBK6, SORBK7 and SORBK8 were not used due to the very low sample numbers at these sites. The calibration results following auto-calibration to the calibration sites are summarised in Table 3.17.

Table 3.16 Nitrate quality manual calibration results (mg/l NO_3-N)

		Calculated Values		Observed Values	
	STATION	Mean	95%ile	Mean	95%ile
ANNUAL	SORBK16	10.1	12.9	9.7	14.6
	SORBK8	8.2	11.6	13.7	25.8
	SORBK7	9.3	12.6	14.8	20.0
	SORBK6	10.1	13.1	11.8	22.7
	SORBK4	11.9	14.1	13.2	17.8
	SORBK10	10.3	12.5	11.8	17.2
	SORBK1	9.6	11.5	10.1	13.9
SUMMER	SORBK16	11.3	14.3	8.6	11.5
	SORBK8	9.6	14.3	11.9	24.7
	SORBK7	10.6	14.4	13.9	18.4
	SORBK6	11.1	14.4	10.1	20.9
	SORBK4	12.6	15.1	12.0	15.5
	SORBK10	10.6	13.0	11.1	13.8
	SORBK1	9.7	11.4	9.4	11.9
WINTER	SORBK16	11.3	13.7	11.4	16.2
	SORBK8	10.0	14.9	17.4	25.8
	SORBK7	10.7	15.0	16.7	23.0
	SORBK6	11.3	15.0	15.2	24.9
	SORBK4	12.6	14.4	15.3	18.8
	SORBK10	12.2	15.4	13.2	22.3
	SORBK1	12.4	13.7	12.5	16.9

Table 3.17 Nitrate quality calibration results following auto-calibration (mg/l NO_3-N)

		Calculated Values		Observed Values	
	STATION	Mean	95%ile	Mean	95%ile
ANNUAL	SORBK16*	9.7	14.6	9.7	14.6
	SORBK8	9.4	15.3	13.7	25.8
	SORBK7	10.7	16.5	14.8	20.0
	SORBK6	11.6	17.3	11.8	22.7
	SORBK4*	13.2	17.8	13.2	17.8
	SORBK10*	11.8	17.2	11.8	17.2
	SORBK1*	10.1	13.9	10.1	13.9
SUMMER	SORBK16*	8.6	11.5	8.6	11.5
	SORBK8	9.6	13.5	11.9	24.7
	SORBK7	10.5	13.4	13.9	18.4
	SORBK6	10.9	13.0	10.1	20.9
	SORBK4*	12.0	15.5	12.0	15.5
	SORBK10*	11.1	13.8	11.1	13.8
	SORBK1*	9.4	11.9	9.4	11.9
WINTER	SORBK16*	11.4	16.2	11.4	16.2
	SORBK8	11.7	15.7	17.4	25.8
	SORBK7	13.0	16.1	16.7	23.0
	SORBK6	14.3	16.9	15.2	24.9
	SORBK4*	15.3	18.8	15.3	18.8
	SORBK10*	13.2	22.3	13.2	22.3
	SORBK1*	12.5	16.9	12.5	16.9

* auto-calibration sites

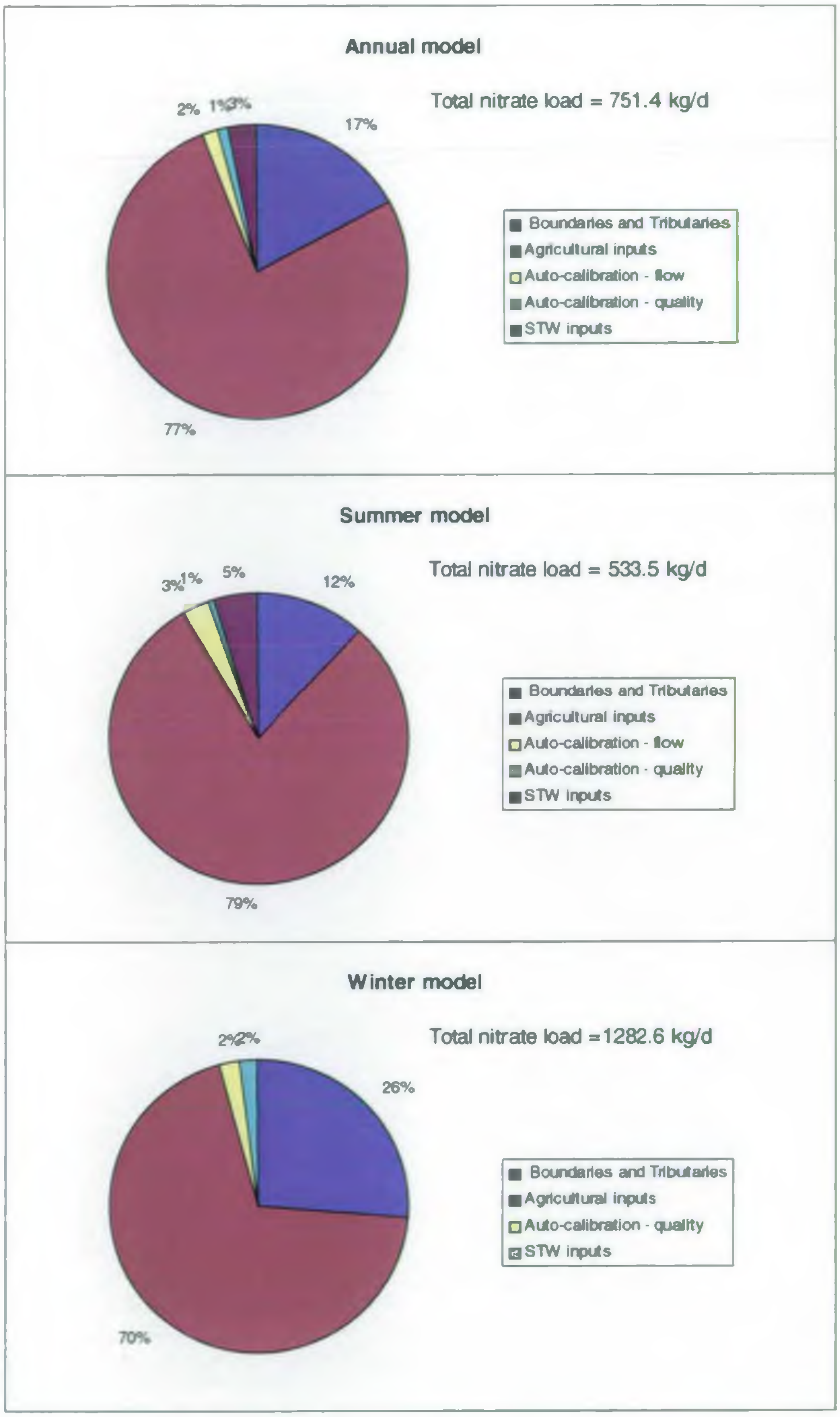


Figure 4.1 Scenario A - Proportion of nitrate load inputs for whole catchment

4.1.2 Scenario B - What is the contribution of all STWs to the 95%ile nitrate concentration at the abstraction point during the period when it fails?

The results from Scenario A can be compared with those from Scenario Di (see 4.1.3) to indicate the effect of STW inputs on the winter failure period 95 percentile nitrate concentration, as shown in Table 4.3.

Table 4.3 95 percentile failure period nitrate concentrations with and without STW nitrate inputs

	95 percentile nitrate concentration mg/l NO_3-N
With STW nitrate inputs (Scenario A)	16.9
Without STW nitrate inputs	16.2

Removal of STW flows and loads changes the 95 percentile to 16.8 mg/l. Hence, STW inputs have little impact on the failure period 95 percentile concentration.

4.1.3 Scenario C - Does the abstraction point still fail if the agricultural nitrate load from the STWs is excluded by:

(i) removing all effluent nitrate but retaining effluent flow?

Modifications were made to the winter SIMCAT model to remove the effluent nitrate by setting these values to zero in the data file. The models was then run in mode 4. The results are presented in Tables 4.4 and 4.5 for comparison with Tables 4.1 and 4.2.

Table 4.4 Scenario Ci - Load results

	Winter Nitrate load (kg/d)
Headwaters	337
Agricultural inputs	891.4
Decay	0
Auto-calibration inputs - Flow	-9.1
Auto-calibration inputs - Quality	33
STW inputs	0
TOTAL	1252.3

Table 4.5 Scenario Ci - Calculated nitrate concentration at Bodicote

	Winter nitrate concentration (mg/l NO_3-N)
Mean	12.2
95%ile	16.2
Threshold Exceedance (%)	62.6

These results show that there is a dilution effect by removing the effluent nitrate but retaining the flow. However, the abstraction point would still fail.

(ii) removing all effluent nitrate and flow

For this scenario, the STW flow was set to a very small constant value (0.001) in all three models. It was necessary to set the flow at SORBK3 to 0.1 to maintain model stability.

The results are shown in Tables 4.6 and 4.7. There was a smaller improvement in nitrate concentrations compared to Scenario Ci due to the reduction in dilution produced by reducing the STW effluent flows.

Table 4.6 Scenario Cii - Load results

	Winter Nitrate load (kg/d)
Headwaters	337
Agricultural inputs	891.4
Decay	0
Auto-calibration inputs - Flow	-9.4
Auto-calibration inputs - Quality	33
STW inputs	0
TOTAL	1252.1

Table 4.7 Scenario Cii - Calculated nitrate concentration at Bodicote

	Winter nitrate concentration (mg/l NO_3-N)
Mean	12.4
95%ile	16.7
Threshold Exceedance (%)	65.7

It can be seen through comparison of the results for this scenario with the results obtained in Scenario A, that the STWs contribute very little to the nitrate concentration at Bodicote.

4.1.4 Scenario D - Does the abstraction point still fail if the agricultural load is removed (but the flow retained)?

For this scenario, the STW effluent data were included in the winter model, but the diffuse agricultural input concentration was set to zero.

The results, shown in Table 4.8, indicate that the abstraction point would not fail with a predicted 95 percentile concentration of 7.8 mg/l NO_3-N.

Table 4.8 Scenario D - Calculated nitrate concentration at Bodicote

	Winter nitrate concentration (mg/l NO_3-N)
Mean	5.0
95%ile	7.8
Threshold Exceedance (%)	0.2

4.2 Summary of Results and Conclusions

The SIMCAT results, based on historic data and ADAS model estimates of agricultural inputs clearly indicate the relatively small contribution of STW inputs to nitrate loads and concentrations at the Bodicote abstraction point. Nitrate concentrations at Bodicote would still fail the Directive threshold if all STW inputs of flow and load were removed. The abstraction point would not fail if estimated agricultural nitrate loads were removed.

These results demonstrate the viability of the methodology used, although lack of flow data within the catchment restricted the separation of headwater and non-agricultural diffuse flows and loads. The results support the proposed designation of the Sor Brook as a surface water NVZ. Further SIMCAT modelling could be used to identify the load reductions required to ensure compliance with the Directive standard at the Bodicote abstraction point.

APPENDIX ESTIMATION OF DIFFUSE AGRICULTURAL NITROGEN INPUTS

Estimation of Diffuse Agricultural Nitrogen Inputs

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The ADAS Environment Modelling and GIS Group were required to provide WRc with daily best estimates of the nitrate concentrations in drainage from agricultural land within the study catchments. This was done by first establishing the mass of the soil nitrogen that was available or *vulnerable* to leaching by autumn / winter drainage. And secondly by calculating the volume of soil drainage and proportion of the available nitrate leached on a daily basis. The resulting 'packets' of leachate were routed through the river system at a rate that was dependent upon the state of a catchment soil water reservoir or store. The greater the volume of water in the store, the wetter the catchment and the higher the soil water table, having the effect of increasing the effective soil transmissivity and the rate at which water moved through the system.

Estimates of the soil nitrogen available for leaching in each drainage season were calculated for each unique combination of land use and soil texture. Land use and soil texture information were derived from the National Environment Database developed by ADAS under the MAFF funded NT1701 project; the land use data were correct for 1995. The nitrogen estimates were based upon coefficients embedded in the Neap-N model, which had themselves been derived from multiple runs of the NitCat (Lord, 1992) and N-Cycle (Scholefield *et al.*, 1991) models, supported by empirical evidence from the monitoring of nitrate leaching, land use and drainage relationships within the Nitrate Sensitive Areas

Daily drainage from each land use type was calculated using the MORECS model for soils of medium plant available water (AWC 2), using weather data recorded at or near the centroid of the study catchments (Thompson *et al.*, 1981). Drainage time series and estimates of vulnerable autumn nitrogen were combined as input to the Slimmer model (Anthony *et al.*, 1981) to derive time series of leachate volume and nitrate concentrations. The Slimmer model is embedded in the EvenFlow model, under development, that routed the leachate through the river system at rates dependent upon catchment wetness and the Low Flow Host Group (LFHG) that the catchment soils had previously been assigned to by Boorman *et al.* (1995). The contributions of each land use to river flow and nitrate concentrations were area-weighted.

The results of this were time series of river flow and nitrate concentrations at the mouth of each study catchment, on the basis that there had been no in-river removal of nitrate (by plant up-take or chemical denitrification), nor any further inputs of water and nitrate from non-agricultural land and / or from point sources such as sewage effluent discharges. The quantification of the non-agricultural inputs to the river systems, including diffuse input from non-agricultural land, was the responsibility of WRc.

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