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N. FAWTHROP

YIELD CALCULATIONS AND NITRATE PREDICTIONS FOR GRAFHAM WATER

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September 1989

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SUMMARY

This report includes the Yield Calculations and documentation that was part of the draft report of April 1989[1]. It incorporates subsequent work which was undertaken on nitrate modelling for Grafham Reservoir. The reason for including these is to provide a final definitive report on work undertaken on nitrate prediction at Grafham.

Yields of Grafham Water are calculated using the current Anglian Water level of service criteria. For 2011 the forecast demand on Grafham was taken as 207 tcmd and compares with a yield of 278 tcmd for the same year.

Further discussions with scientific staff (NRA and PLC) and MAFF concluded that future river nitrate trends are either likely to hold steady or increase slightly (see appendix 7). In addition it was obvious that the historical period chosen for the nitrate regression prediction equation was critical and could be chosen so as to influence the trend.

It was reported in the draft report of April 1989[1] that the multiple regression equation for river nitrate prediction based on the historic period '76 to '87 had indicated a 'negative trend' (-0.326 mg/l NO3 per annum). It was concluded that this was not a satisfactory outcome and not likely to be representative. The period '72 to '88 was chosen for further multiple regression analysis as this included the '76 drought and an adequate lead in period, this resulted in a 'positive trend' (+0.04 mg/l NO3 per annum). From this analysis two equations were produced, one with a trend component the other without.

Table 2 Section 4.3 shows a comparison of the results for the simulation of nitrates in Grafham using different multiple regression equations. The periods of non-compliance with the 45 mg/l limits occurs during the drought periods (namely 1933, 1944 and 1976) of the historical dataset. The percentage frequency of exceedence of this limit varies between 1.5 and 2.4% of the time for 1991 conditions (with Demand=Yield) and between 0.1 and 2.4% of the time for 2011 conditions. The percentage frequency of exceedence of the 20mg/l limit (mixing) varies between 60.4 and 64.4% of the time for 1991 conditions and between 51.7 and 71.1% of the time for 2011 conditions.

1.0 INTRODUCTION

For the purpose of this report the following definitions of Yield and Demand have been applied.

Demand - Actual take (abstraction) from the reservoir

Yield - The quantity of water which could be abstracted and comply with the levels of service criteria. Since the yield is a factor of effluent return upstream of the intake it is dependent on the demand and hence varies with time. Therefore yield is quoted for a particular year which relates to a particular abstraction and effluent return pattern.

eg	1991	Yield	= 247 tcmd
		Effluent Return	= 113 tcmd
		Demand	= 186 tcmd

An earlier report [2] to the Nitrate Steering Group predicted nitrate concentrations in Rutland Water for different reservoir yields. This showed that increased output leads to greater drawdown, reduced dilution for the pumped inflows and reduced retention times, hence higher nitrate concentrations in output water. Following consideration of the Rutland Water report the Nitrate Steering Group requested a similar model for Grafham Water. This brief was subsequently extended to the other major Anglian Water reservoirs.

The objectives for the Grafham Water work were defined as follows:-

a) Agree the method of reservoir yield analysis with the NRA and update Grafham Water yield.

b) Develop a multiple regression equation to predict nitrate concentration upstream of the intake to Grafham Water.

c) Incorporate reservoir operational rules, a river nitrate prediction equation and the reservoir denitrification and mass balance into the existing Grafham simulation program and use this to predict nitrate concentration in Grafham Water.

A schematic of the main features of the Grafham system is shown in Figure 1.

The general approach to the simulation modelling is summarised in Figure 2.

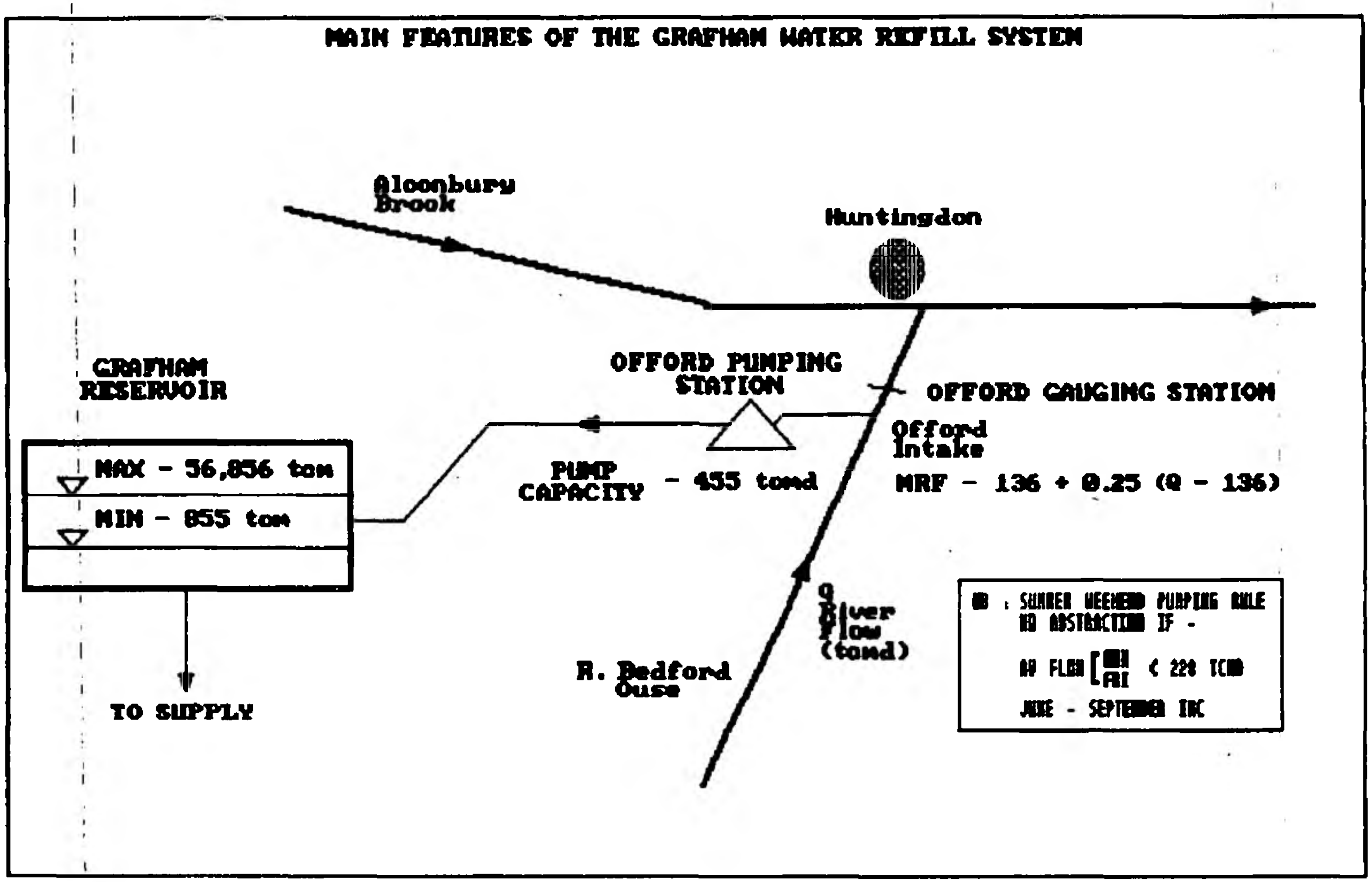

MAIN FEATURES OF THE GRAFHAM WATER REFILL SYSTEM
Alconbury Brook
Huntingdon
GRAFHAM RESERVOIR
MAX - 56,856 tcm
MIN - 855 tcm
TO SUPPLY
OFFORD PUMPING STATION
PUMP CAPACITY - 455 tcmd
OFFORD GAUGING STATION
Offord Intake
MRF - 136 + 0.25 (Q - 136)
Q River Flow (tcmd)
R. Bedford Ouse
SUMMER WEEKEND PUMPING RULE
NO ABSTRACTION IF -
< 228 TCMD
JUNE - SEPTEMBER INC

FIGURE 1

GENERAL APPROACH TO THE SIMULATION MODELLING

	MAIN FUNCTIONS OF EACH PROGRAM
PREPARATION PROGRAM	Produces monthly volumes of inflow to Grafham for use in OSAY program
OSAY PROGRAM	Derives reservoir yield and control curves for introducing conservation measures appropriate to different levels of service (hosepipe ban, MRF reduction, standpipes)
SIMULATION PROGRAM	Simulates daily reservoir storage and nitrate concentration for hydrological conditions observed during the period 1933-84 for user specified demands.

2.0 CALCULATION OF GRAFHAM WATER YIELD

The yield of Grafham Water was previously evaluated during 1985[3] for 1986, 1991, 2001 and 2011 conditions (based on 1984 series demand forecasts) and updated in December 1988[4] for the revised level of service criteria. These criteria are that a hosepipe ban should not be required more than 1 in 10 years, MRF (Minimum Residual Flow in River) reduction or publicity campaign for saving water 1 in 20 years and stand-pipes 1 in 100 years. In this report yield is revised using 1988 demand forecasts updated to December 1988[5]. Yield analysis is carried out using a program called OSAY (Operating Strategy Assessment of Yield), which incorporates reductions in demand when conservation measures are introduced in line with the above criteria.

2.1 PREPARATION OF RESERVOIR INFLOWS FOR YIELD ANALYSIS

The OSAY program requires as input 2 sets of monthly reservoir inflows. Both sets are derived from a combination of naturalised river flow at Offord (the point of abstraction) with abstractions and effluents in the Bedford Ouse above Offord. This first set is constrained by an MRF at Offord of 136 tcmd + .25 excess [7] and the second set is constrained by an MRF at Offord of 77 tcmd (the latter figure is the MRF which would come into operation under the second level of service criterion with a return probability of not more than 1:20 years). A preparation program is used to prepare the inflows. The details are described more fully in Appendix 1. The abstraction and effluents used as input to the preparation program are based upon demand forecasts and therefore vary through time. To take these forecasts into account sets of data are prepared for 1986, 1991, 2001 and 2011. An additional set of inflows has been prepared for 2011 because Lee Valley Water Company (LVWCo) had no prediction of demand on Grafham for 2011 at the time the model runs were undertaken. The first 2011 run includes an estimated 2011 LVWCo demand and the second ('2011 Alt' in subsequent text) the LVWCo Reserved quantity.

2.2 RESULTS OF YIELD ANALYSIS USING OSAY

OSAY is a program for assessing the yield of a reservoir by taking into account the reductions in demand which occur due to the introduction of conservation measures, eg. hosepipe ban, MRF reduction/publicity campaign, use of stand-pipes. In this report there are 2 outputs from OSAY which are used in the nitrate simulation model:-

(i) Reservoir yield

(ii) Control curves for conservation measures - 12 monthly values of reservoir storage for each of hosepipe ban, MRF reduction/publicity campaign and stand-pipes.

The major controlling factors within OSAY for deriving the above outputs are the yield itself and the 'plan' months for introduction of conservation measures. The program uses inflow set 1 (MRF = 136 tcmd + .25 excess, abstraction coefficient = 0.75, spray irrigation demand zero) and set 3 (MRF = 77 tcmd, abstraction coefficient = 1.0, spray irrigation demand zero). The method of deriving the outputs is iterative and is described in Appendix 2.

Five reservoir yields and sets of control curves are derived, corresponding to 1986, 1991, 2001, 2011 and 2011(alt) conditions.

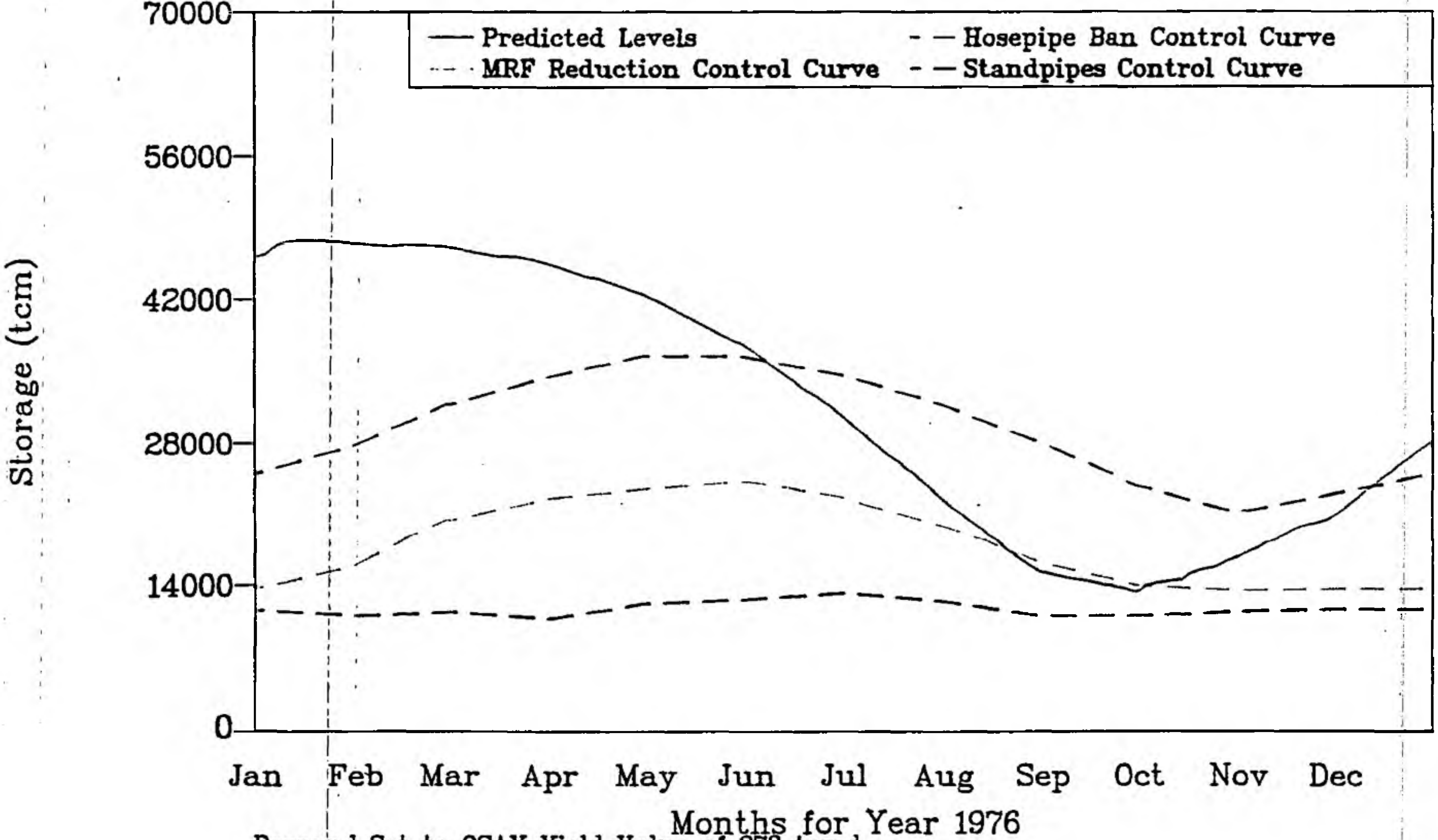
The yields are as follows:-

YEAR	YIELD	DEMAND*	EFFLUENT#
1986:	235 tcmd	137 tcmd	107 tcmd
1991:	247 tcmd	155 tcmd	123 tcmd
2001:	264 tcmd	193 tcmd	154 tcmd
2011:	278 tcmd	234 tcmd	186 tcmd
2011(alt):	345 tcmd	340 tcmd	282 tcmd

An example of the control curves is given in Figure 3. This also shows how the rate of storage decline reduces after the MRF reduction/publicity campaign curve is reached.

* Total Demand on Grafham Reservoir.
\# Effluent returned from Grafham Water Abstraction to the R.Ouse Upstream of Offord.

Storage Curves for the Introduction of Conservation Measures



Demand Set to OSAY Yield Value of 278 tcmd
Forecast for Year 2011

FIGURE 3

3.0 GRAFHAM SIMULATION - RESOURCES

Modelling of the operation of Grafham is an intermediate stage between yield/control curve calculation and nitrate prediction.

3.1 MODIFICATION OF EXISTING PROGRAM

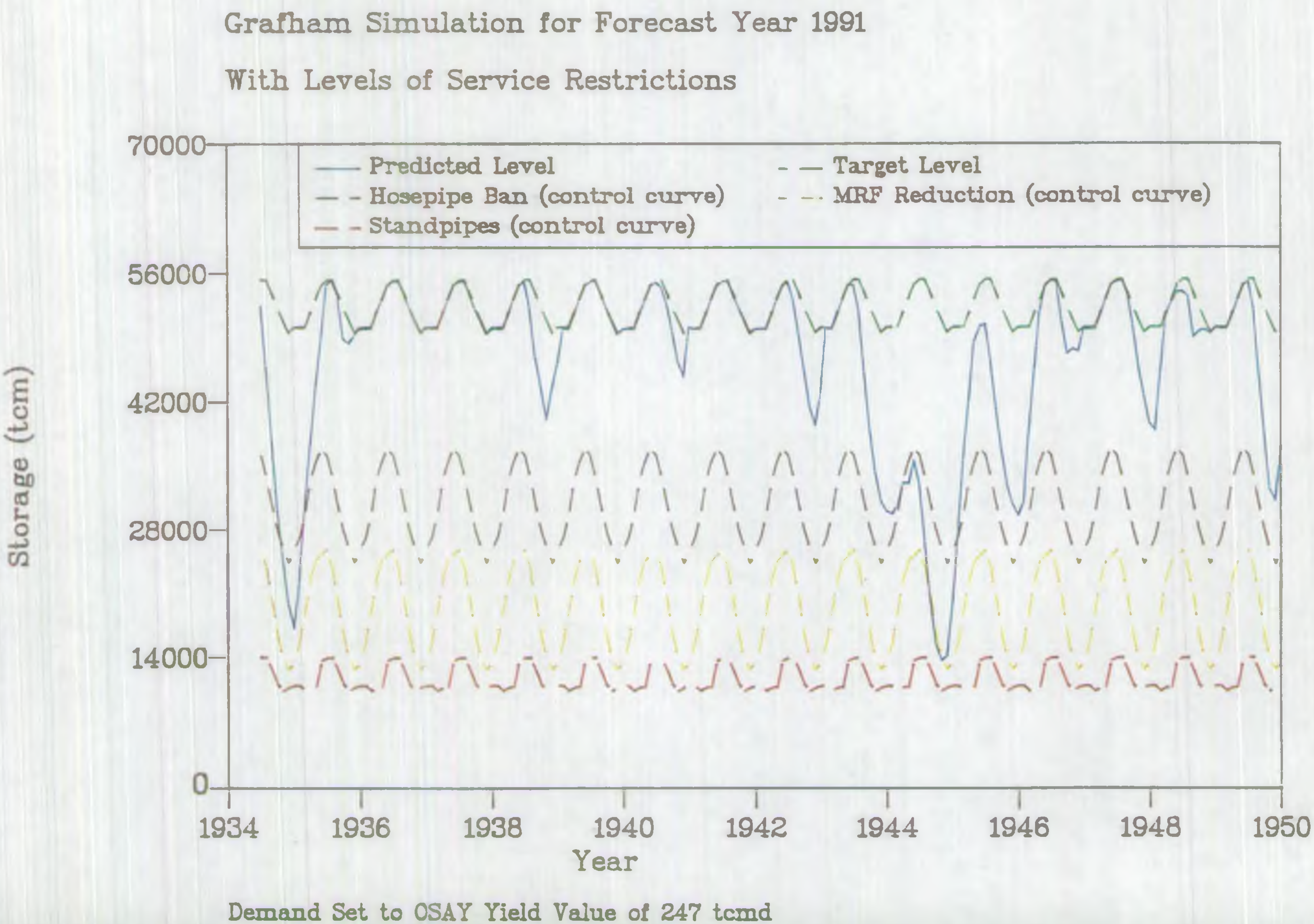
Details of the existing program are given in Appendix 3. Two modifications were made to improve the simulation:-

(i) Incorporation of the levels of service control curves derived from OSAY.

(ii) Incorporation of a target hydrograph for use when refilling the reservoir. This was obtained from the Ruthamford Manager and is the one used at present in the model.

3.2 DISCUSSION OF SIMULATION RESULTS

The simulation was carried out with yields derived from OSAY for 1986, 1991, 2001, 2011 and 2011(alt) conditions, but with effluents returned upstream of Offord calculated at 90% of the predicted demand for these years. These predicted demands and effluents are those shown in Table A1.1 (Appendix 1). Figure 4 shows as an example the results of this simulation for 1991 conditions with a reservoir yield of 247 tcmd. Levels of service restrictions would have been required during the droughts of 1934, 1944 and 1976, involving hosepipe bans and MRF reductions/publicity campaigns.

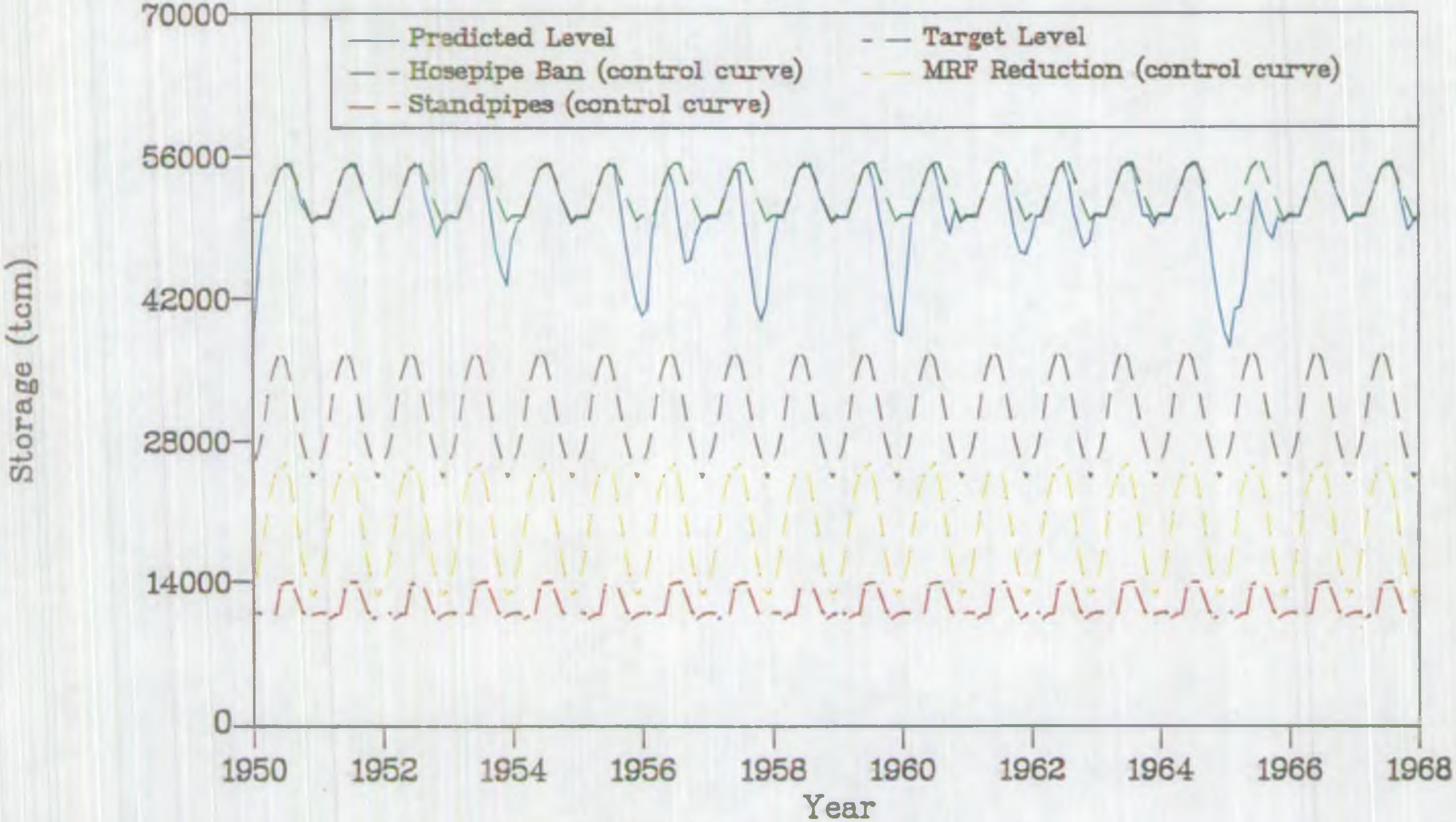


Grafham Simulation for Forecast Year 1991
With Levels of Service Restrictions
Predicted Level
Target Level
Hosepipe Ban (control curve)
MRF Reduction (control curve)
Standpipes (control curve)
Storage (tcm)
70000
56000
42000
28000
14000
0
1934
1936
1938
1940
1942
1944
1946
1948
1950
Year
Demand Set to OSAY Yield Value of 247 tcmd

FIGURE 4

Grafham Simulation for Forecast Year 1991

With Levels of Service Restrictions

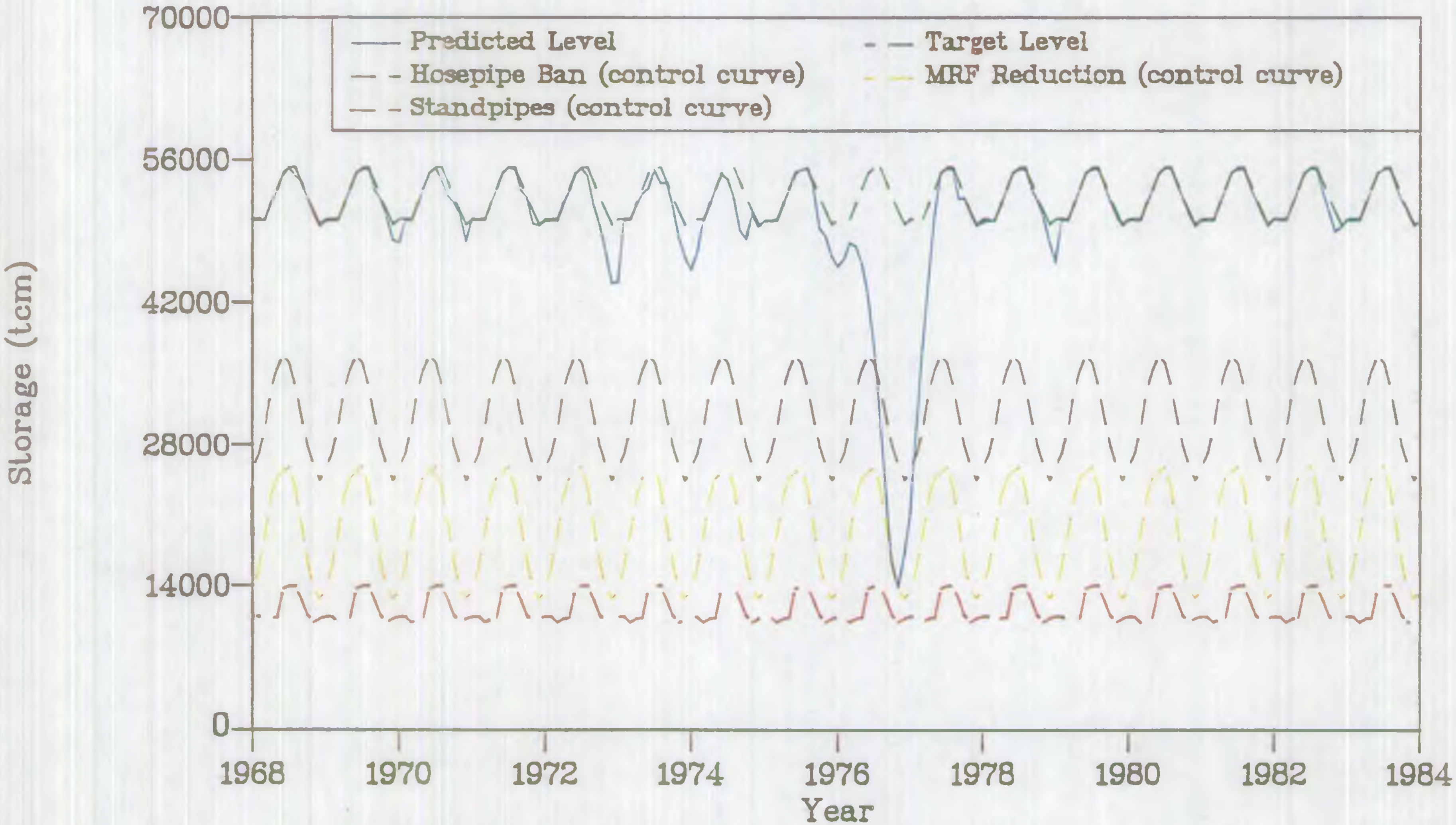


Demand Set to OSAY Yield Value of 247 tcmd

FIGURE 4
cont.

Grafham Simulation for Forecast Year 1991

With Levels of Service Restrictions



Demand Set to OSAY Yield Value of 247 tcmd

FIGURE 4
cont.

4.0 GRAFHAM SIMULATION - NITRATE

Future nitrate trends in Graham Water were investigated by incorporating the river nitrate prediction equation, reservoir denitrification and mass balance in the simulation model.

4.1 MULTIPLE REGRESSION ANALYSIS

Multiple regression analysis was carried out relating nitrates to river flow for the R. Ouse at Offord. The method used was the same as for previous work on Rutland Water [2]. Details are given in Appendix 4.

Following the work outlined in the draft report of April 1989[1], which indicated that nitrates were decreasing at a rate of 0.326 mg/l nitrate p.a., further regression analysis was undertaken using historical data for the period 1972 to 1988. This period was chosen because it included a lead in period to the high nitrate levels experienced during the 1976 drought. This produced a positive trend of 0.04 mg/l nitrate p.a. indicating that there indeed was a degree of bias in the '76 to '88 dataset used in the earlier work.

Table 1 compares the trend term obtained from nitrate data for different periods and catchments.

Table 1 - Trend terms obtained from regression analysis

Catchment	Regression Period	Trend Term mg/l p.a.
R.Ouse	1976 - 1987	-0.33
R.Ouse	1972 - 1988	+0.04
R.Welland	1968 - 1988	+0.90
R.Nene	1968 - 1988	+0.60

4.2 ADAPTION OF THE SIMULATION PROGRAM FOR NITRATE PREDICTION

Three main routines were added to the simulation program used in section 3.

(i) Multiple regression equation for predicting nitrate concentration in the R. Ouse at Offord.

(ii) Nitrate mixing and mass balance calculations for Grafham Water.

(iii) Calculation of denitrification in Grafham Water.

4.3 DISCUSSION OF SIMULATION RESULTS - NITRATES

Actual nitrate data for Grafham from 1981-84 was used to validate the models (Figures 5, 6 and 7). Actual demands and effluent returns for that period were not readily available, so 1986 values were used. Taking this into consideration the results of the simulation of nitrate for 1981-84 is reasonable.

One set of prediction runs was undertaken for each regression equation. This compares to the two shown in the draft report of April 1989[1] (ie with Demand=Forecast and Demand=Yield).

With demand on Grafham set to the yield value calculated from OSAY and conditions as follows :-

Year	Effluent Return U/S Offord (Table A1.1)	Grafham Yield (tcmd)
1991 Conditions	119	247
2011 Conditions	176	278

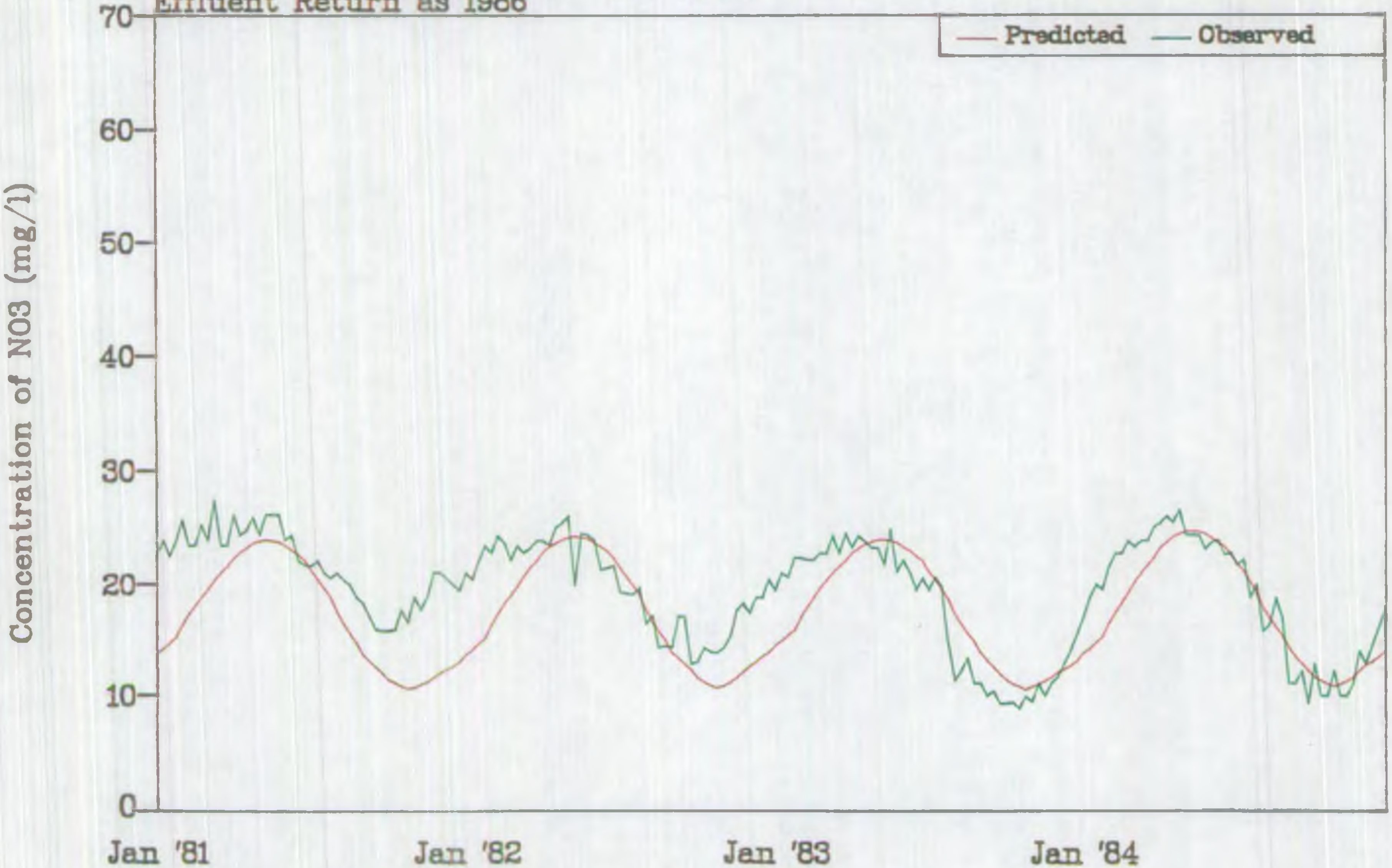
Figures 8 to 10 show the results of the prediction runs for each of the models incorporating the different regression equations. These are only shown for the year 2011 conditions. It can be seen that the periods of non-compliance occur during the drought periods of 1935, 1945 and 1976.

The nitrate concentration exceedance frequency curves are shown in figures 11 to 12. These are shown for both 1991 and 2011 conditions. From these it can be seen that there is no significant difference between the small 'positive' trend and the 'zero' trend regression equations. Although they are significantly different to those forecast with the 'negative' trend equation. A summary of values interpolated from these curves can be seen in table 2 .

Table 2 summary of simulation results

Multiple Regression		For 1991 Effluent returned conditions Demand=247 tcmd			For 2011 Effluent returned conditions Demand=278 tcmd		
Data Set	Trend	% exceed of 20mg/l	%exceed of 45mg/l	max NO3	%exceed of 20mg/l	%exceed of 45mg/l	max NO3
76-87	-ve	60.4	1.5	52	51.7	0.1	45
72-88	zero	63.1	2.3	59	68.1	2.0	56
72-88	+ve	64.4	2.4	60	71.1	2.4	57

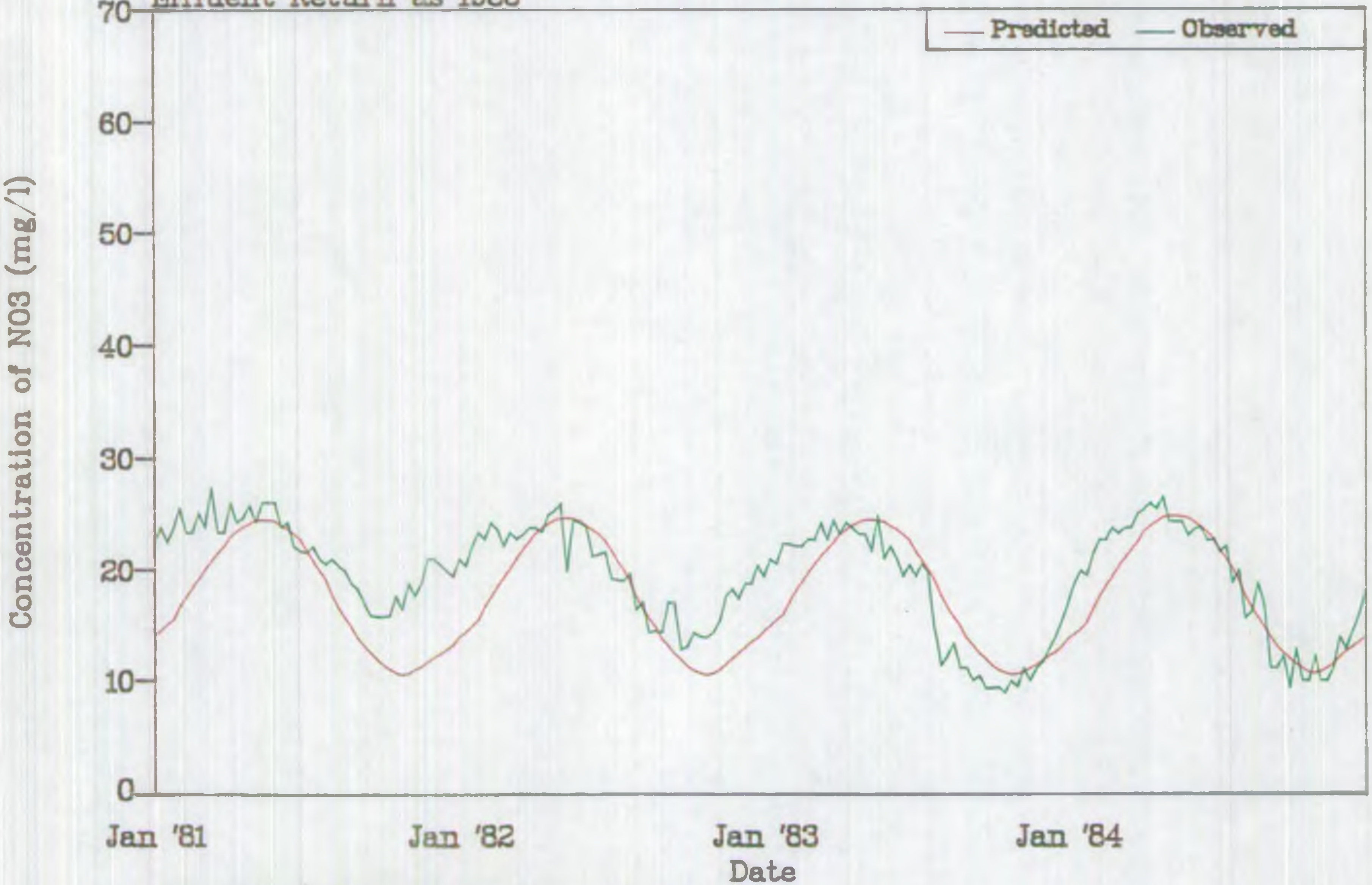
Observed and Simulated Nitrates (NO3) in Grafham Reservoir
For Regression Equation Based on 76-87 Data (-ve Trend)
Demand Set to 1986 Value = 168 tcmd
Effluent Return as 1986



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

FIGURE 5

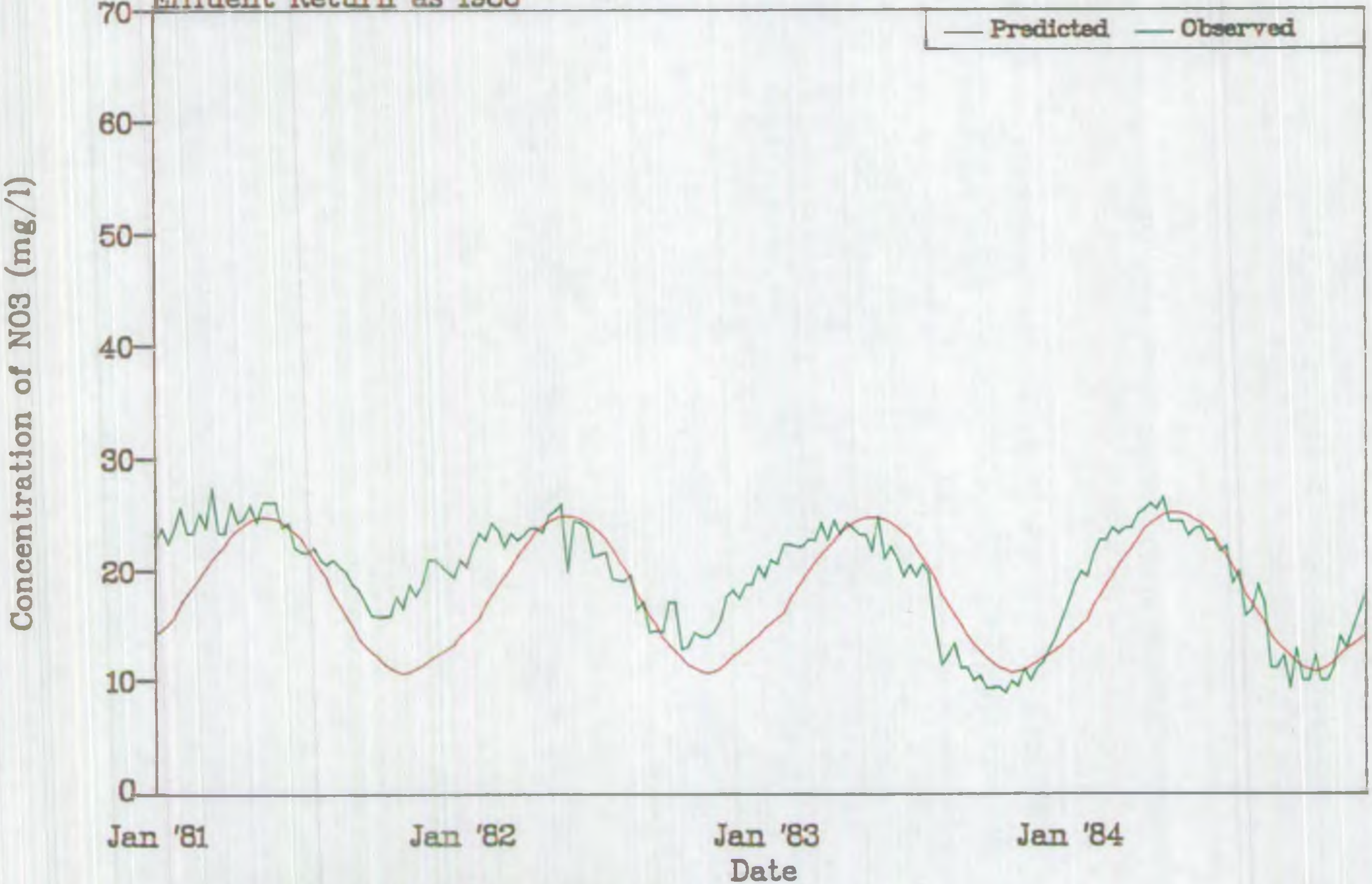
Observed and Simulated Nitrates (NO3) in Grafham Reservoir
For Regression Equation Based on 72–88 Data (Zero Trend)
Demand Set to 1986 Value = 168 tcmd
Effluent Return as 1986



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

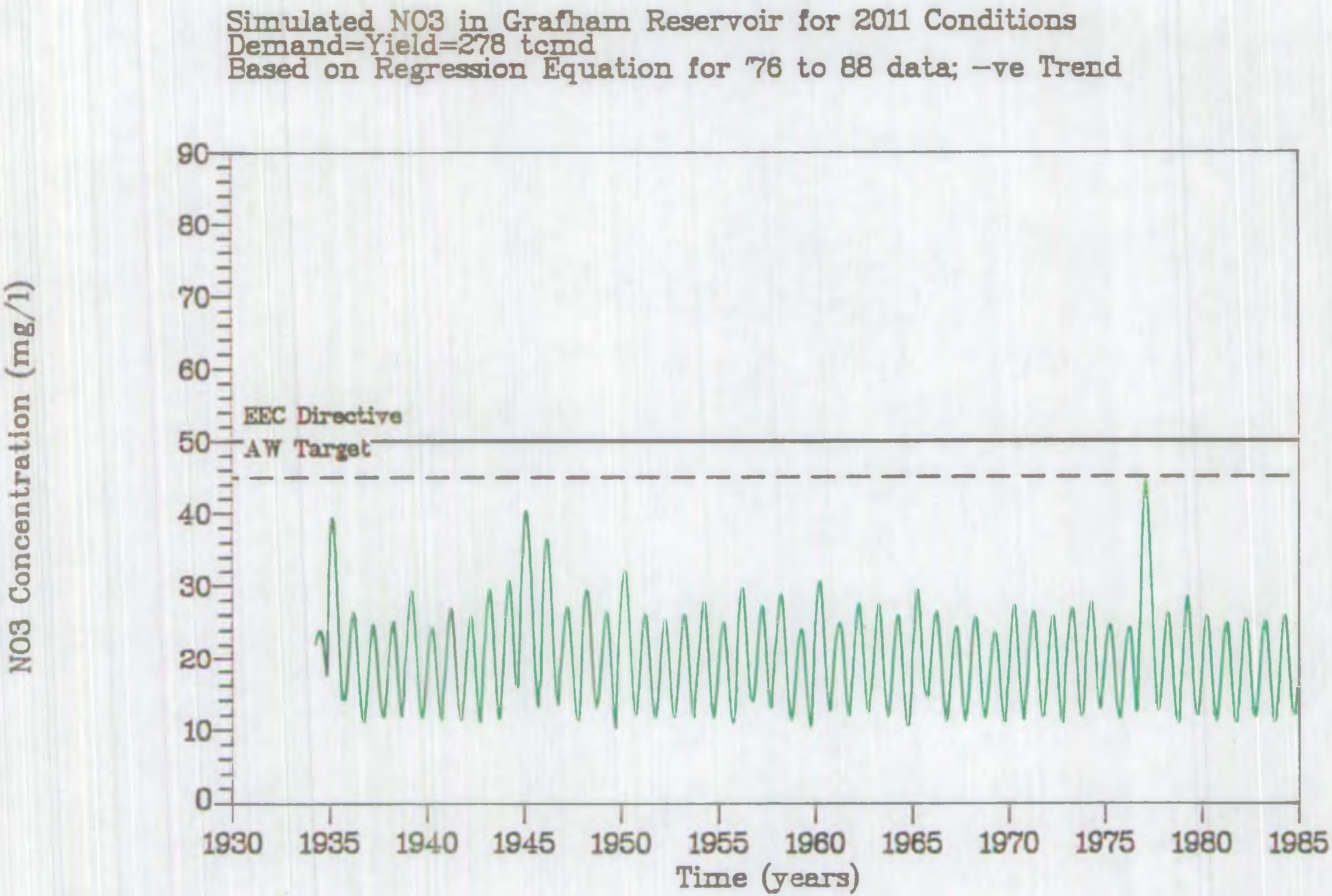
FIGURE 6

Observed and Simulated Nitrates (NO3) in Grafham Reservoir
For Regression Equation Based on 72–88 Data (+ve Trend)
Demand Set to 1986 Value = 168 tcmd
Effluent Return as 1986



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

FIGURE 7



Simulated NO3 in Grafham Reservoir for 2011 Conditions
Demand=Yield=278 tcmd
Based on Regression Equation for '76 to 88 data; -ve Trend
NO3 Concentration (mg/l)
EEC Directive
AW Target
0
10
20
30
40
50
60
70
80
90
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
Time (years)

FIGURE 8

Simulated NO3 in Grafham Reservoir for 2011 Conditions
Demand=Yield=278 tcmd
Based on Regression Equation for '72 to 88 data; Zero Trend

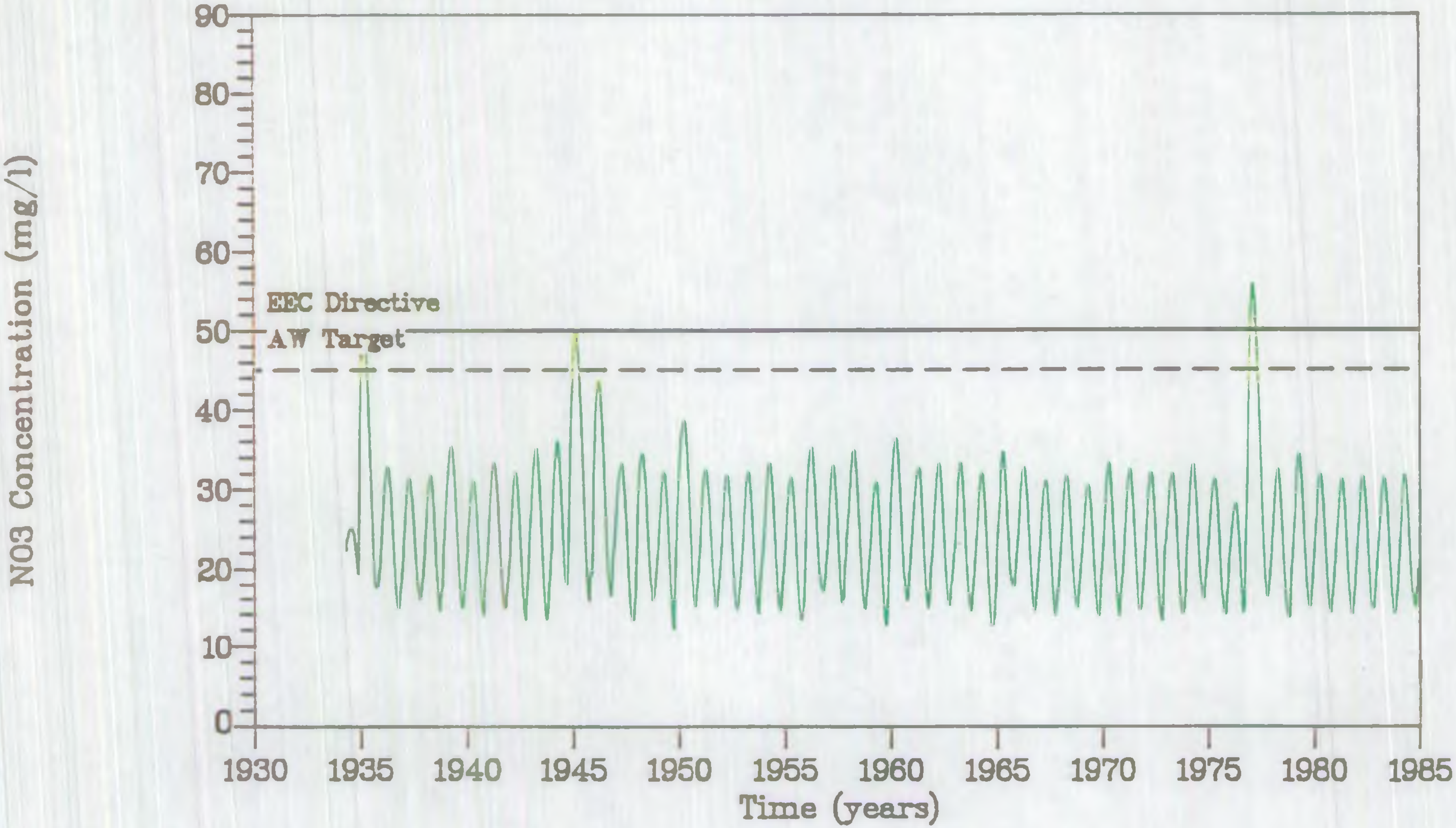


FIGURE 9

Simulated NO3 in Grafham Reservoir for 2011 Conditions
Demand=Yield=278 tcmd
Based on Regression Equation for '72 to 88 data; +ve Trend

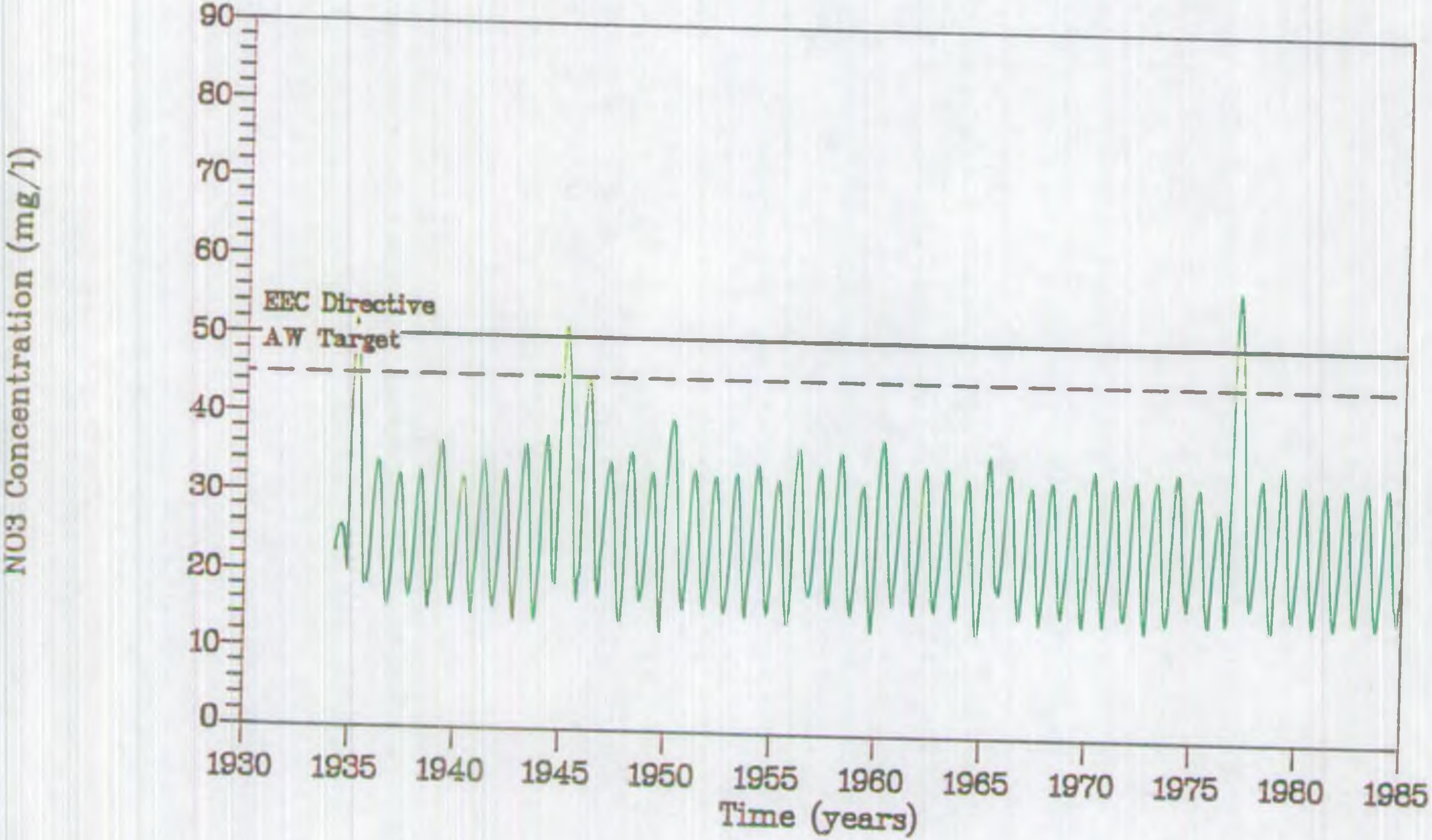


FIGURE 10

NO3 Exceedance Frequency for Grafham Reservoir
for 1991 with Demand = Yield = 247 tcmd

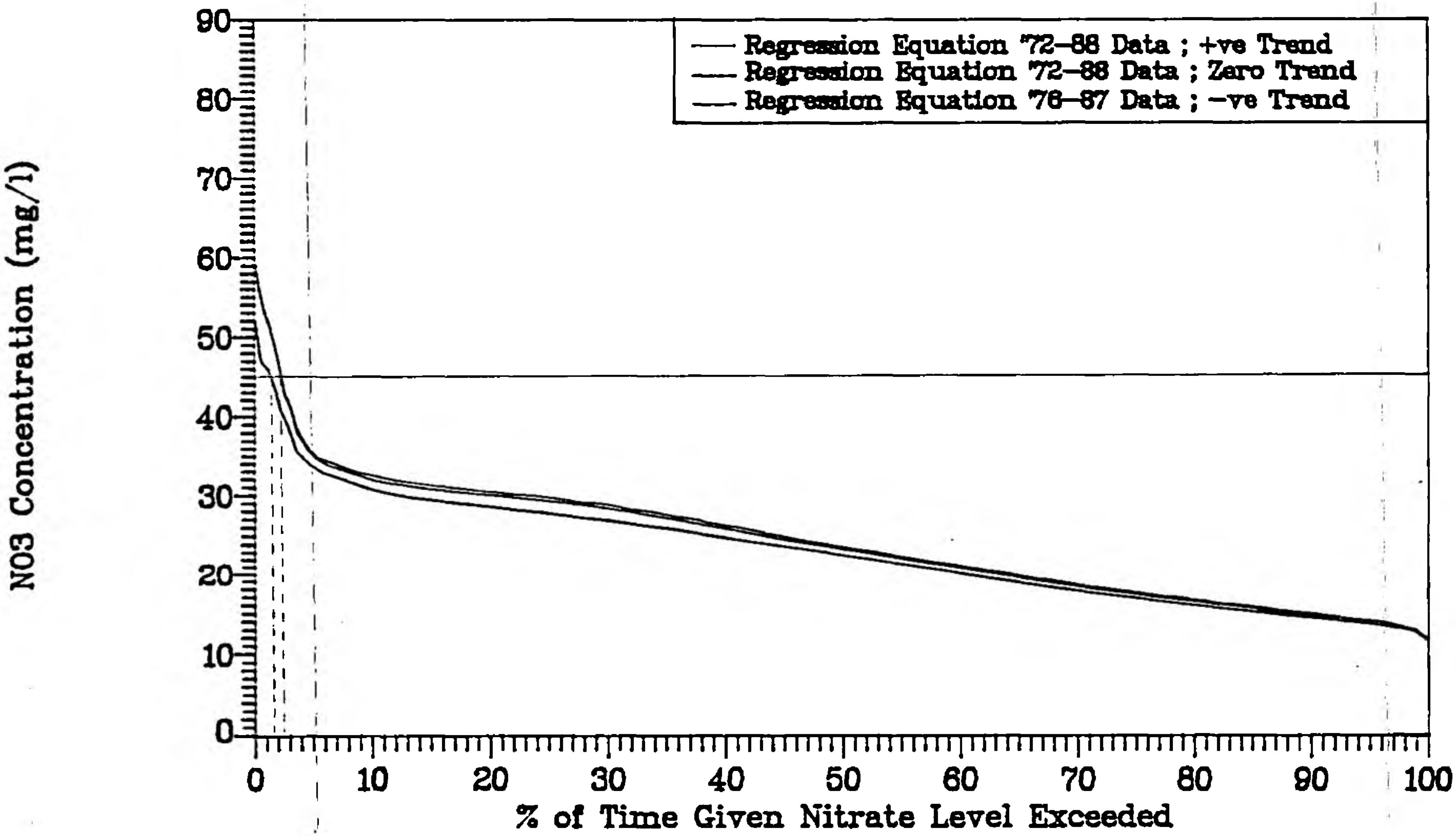


FIGURE 11

NO3 Exceedance Frequency for Grafham Reservoir
for 2011 with Demand = Yield = 278 tcmd

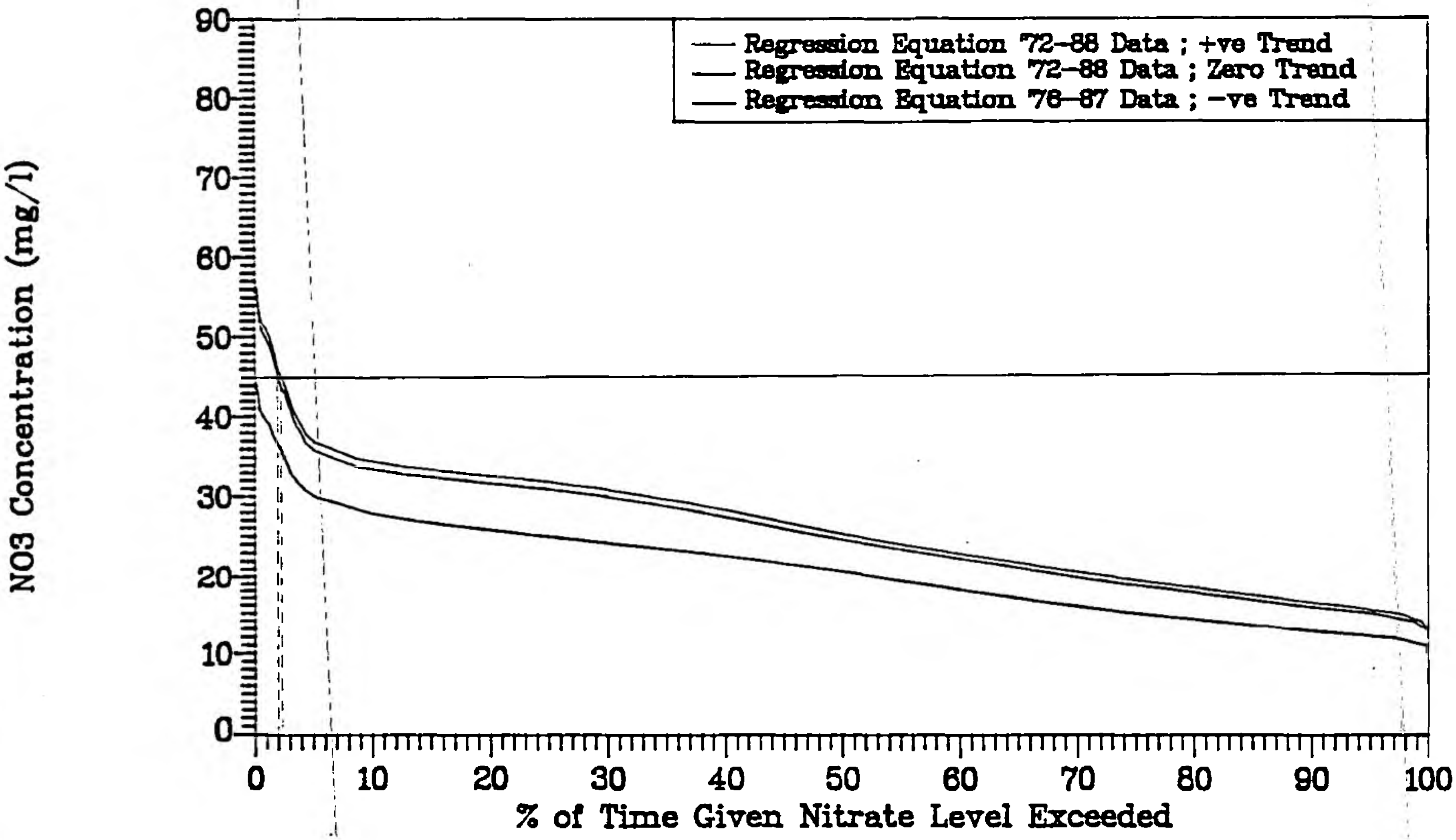


FIGURE 12

5.0 <u>FURTHER WORK</u>

The following further work is required :-

5.1 <u>LONG TERM</u>

(i) Update results as new demand forecasts become available. This applies to PWS demand (PLC forecasts) and spray irrigation and industrial demand (NRA forecasts).

(ii) Revise the naturalised flow record at Offord and extend from 1984 to 1988 after the NRA have revised the Bedford flow record (used to reconstruct the early part of the Offord record).

(iii) Liaise with the NRA to assess how their Management Catchment Model could be used to improve modelling of river abstraction and effluent return upstream of Offord.

(iv) Use the model to investigate reservoir control rule optimisation.

5.2 <u>SHORT TERM</u>

(i) Investigate whether there are better models for nitrate and flow simulation of the River Ouse catchment which would take into account the quality of effluent returned, baseflow concentrations etc.

(ii) Investigate the impact of using the nitrate/phosphate ratio in Grafham to control abstraction at Offord.

REFERENCES

(1) Draft Report - Yield Calculations and Nitrate Predictions for Grafham Water, Plc & NRA units 4/1989.

(2) Water Supplies for Lincolnshire, Anglian Water, NRA Unit, 12/1988.

(3) Yields of Grafham and Rutland, Water Steering Group 2, CJT, 1/5/1985.

(4) Brief Note on Grafham Yield, CJT, 12/12/1988.

(5) Asset Management Plan, Water Resources; Plc Unit, 12/1988.

(6) OSAY Yield Analysis - A Users Manual, Anglian Water, 9/1979.

(7) The Great Ouse Water Authority Order, DOE, 1971.

(8) Modelling Nitrate Concentrations in some United Kingdom Reservoirs, D.Johnson and J.Davis, Canadian Water Resources Journal Vol. 7, No. 1,pp. 319-336, 1982.

APPENDIX 1 - PREPARATION OF INFLOWS FOR YIELD ANALYSIS

A1.1 COMPUTER PROGRAM

All files for the work have been transferred from the Honeywell mainframe to an IBM PS/2. They are as follows:-

GRAFDP1.EXE - the preparation program, FORTRAN. This also contains the following DATA :-
- abstraction coefficients : 2*0.75,4*1.0
- MRF : 136,136,77,77,39,39 (tcmd)
- pump capacity at Offord : 455 tcmd
- spray irrigation factor : 0,1,0,1,0,1
- 12 monthly factors for converting average to to peak SI demand
- start and finish year and month : 1/1933, 12/1984
- net PWS/effluent, direct demand, spray irrigation (SI) demand upstream Offord, and SI demand upstream Brownshill respectively (tcmd):-

1986	: 97,12,5,4
1991	: 113,15,5,5
2001	: 144,25,6,8
2011	: 176,37,6,11
2011Alt	: 272,37,6,11

(See Table A1.1)

QOF84-3.DAT - input - naturalised daily river flows at Offord, 1/1933-12/1984, tcmd

MLDEM.DAT - input - annual Middle Level SI demand, 1933-1984, tcmd

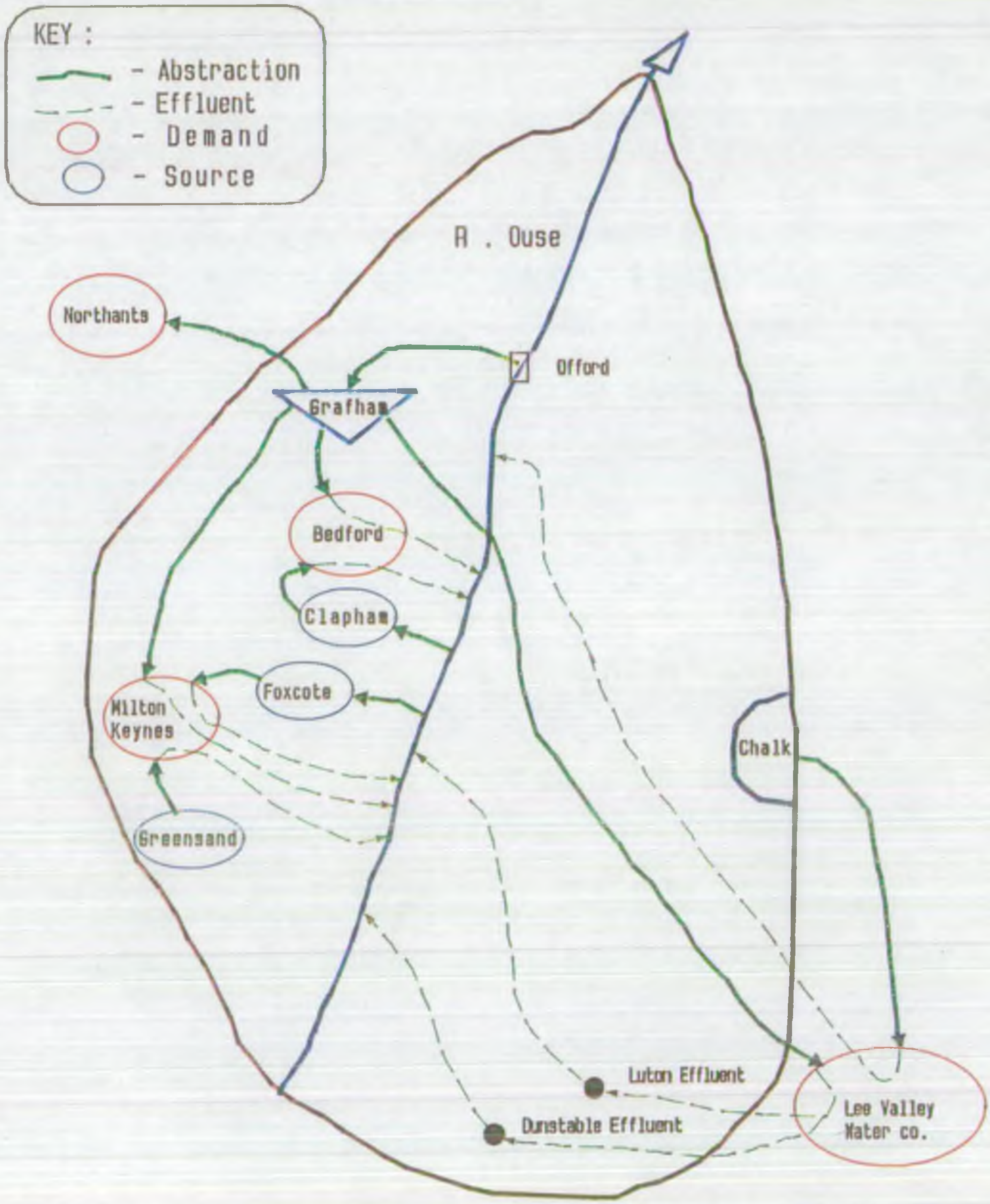
FL-86.DAT)
FL-91.DAT)
FL-01.DAT)
FL-11.DAT)
FL-11A.DAT) - 2 sets of monthly inflows to Grafham, 1933-1984, tcmd, for each forecast year

A1.2 CALCULATION OF FUTURE CONDITIONS IN THE BEDFORD OUSE CATCHMENT UPSTREAM OF OFFORD

The net PWS/effluent, direct demands and spray irrigation demand for 1986-2011 given above are calculated as shown in Table A1.1.

The assumptions embodied in this table are shown in Figure A1.1.

Figure A.1.1 - Schematic of the Abstractions and Effluent Return Upstream of Offord on the River Ouse.



PREDICTED FUTURE CONDITIONS IN THE BEDFORD OUSE CATCHMENT UPSTREAM OF OFFORD

(Figures in tcmd)

(Revision of Table 1 in C Thomas paper, 1/5/85)

	1988		1991	2001	2011	2011 Alt.
PWS from Grafham :-						
Bedford	25	)				
Milton Keynes	62 (1)	)	105 (1)	148 (1)	117 (1)	177
Lee Valley W Co	32 (1)		32 (1)	23 (1)	30 (1)	136 (2)
Total	119		137	171	207	313
(a) 90% effluent return	107		123	154	186	282
PWS abstraction (3) u/s Offord (Greensand+Foxcote+ Clapham+Lee Valley Chalk (4)	95		100	100	100	100
(b) 10% of above not returned as effluent	10		10	10	10	10
Net PWS/Effluent (a-b)	97		113	144	176	272
Industrial direct abstraction (5)	12		15	25	37	37
Spray irrigation (6)	5		5	6	6	6

Effluent (from imported water)

net Abstraction (from internal sources)

Eff − abs (+ve ⇒ net gain)

NOTES:-

(1) These data have been used in the Asset Plan (Dec 1988).

(2) The alternative scenario for 2011 uses LVWCo reserved abstraction from Grafham.

(3) All this PWS abstraction is abstracted and returned upstream of Offord, less 10%.

(4) Lee Valley Chalk abstraction is returned within the catchment (conversation with J Simpson of LVWCo, 17/2/89)

(5) As used in 1988 work on Grafham. Assume 5% pa nett increase from base of 12 tcmd.

(6) As used in 1988 work on Grafham. Assume 1% pa nett increase from base of 5 tcmd.

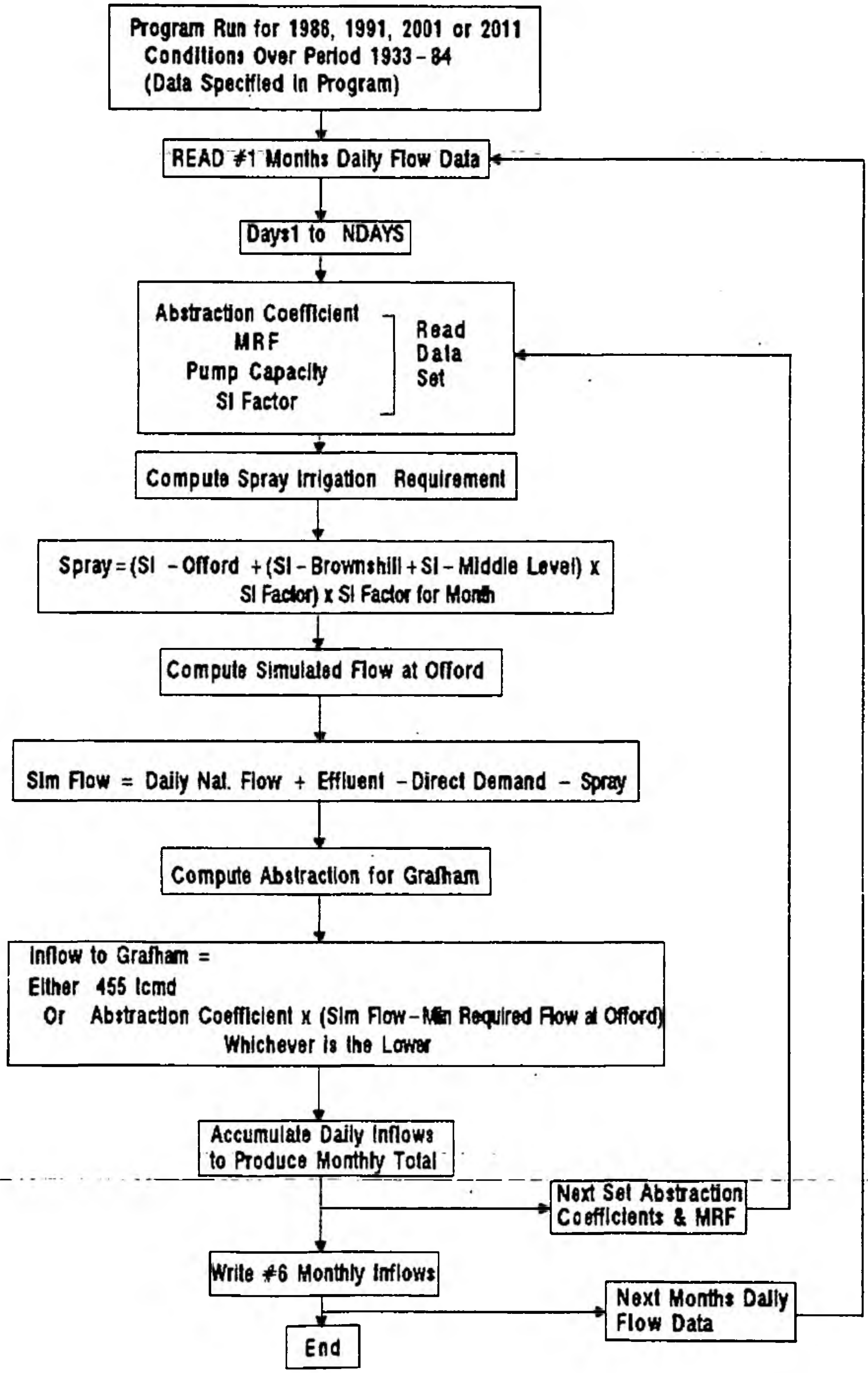
TABLE A1.1

A1.3 PROGRAM OPERATION

The basic logic for the inflow preparation is relatively simple and is shown in Figure A1.2.

The output is in the form of monthly inflows to Grafham (tcm); 6 values per month corresponding to the 6 sets of conditions specified as data within the program (A1.1, GRAFDP1.EXE, above).

Figure A1.2 – Preparation Program – Basic Logic



APPENDIX 2 - DERIVATION OF YIELD AND LEVELS OF SERVICE CONTROL CURVES USING OSAY

A2.1 COMPUTER PROGRAM

OSAY analysis is carried out on the IBM PS/2 using the following files:-

OSAY1.EXE - OSAY program, FORTRAN
This also contains the DATA for demand reduction at the 3 levels of service:-

	J	F	M	A	M	J	J	A	S	O	N	D
LOS1	.03	.03	.04	.07	.10	.12	.12	.10	.09	.07	.04	.03
LOS2	.14	.14	.16	.22	.28	.32	.32	.28	.26	.22	.16	.14
LOS3	.34	.34	.36	.42	.48	.52	.52	.48	.46	.42	.36	.34

GRUN.IN - input - control parameters as follows :-

```
1,1933,12,1984 : start month & year; finish month & year
56,5,56 : capacity,bottom level & start level
60,100 : 'risk' level; probability standpipes
24 : maximum drought length
2 : number of augmentation levels
8,3,5 : no. inflow columns & required columns
13 : 'plan' for augmentation (in months)
4 : no. restriction levels
7,14,23 : 'plan' for restrictions (in months)
200 : yield
1.00 : factor
1 : fudge
0 : noprep (=0 for create data, =1 for read data)
.97,.97,.97,.98,1.0,1.06,1.05,1.01,1.07,1.0,1.0,.97 :-
demand factors                    1.02 ?
```

FL-86.DAT)
FL-91.DAT)
FL-01.DAT)
FL-11.DAT)
FL-11A.DAT) - input - monthly inflows to Grafham, 1933-84, tcmd, for each forecast year, of which columns 3 & 5 are read in

FL-86.OUT) ditto.OUT)	-	output	- yield - summary table giving the number of months and years affected by the three conservation measures - number of occurrences of stand-pipes - histogram of reservoir contents, MCM - augmentation (ie MRF reduction) and restriction (ie hosepipe bans, stand-pipes) events during simulation - reservoir levels during simulation, MCM - control rule curve table
FL-86.CSV) ditto.CSV)	-	output	- monthly control curve data for plotting

A2.2 PROGRAM EXECUTION

The original OSAY program was written in 1979 and described in a report by J Brew [5]*. Subsequently the program was simplified and rewritten by C Page but no revised manual is available. For the present work the program has been amended to run interactively.

The yield and 'plan' months are specified initially. The 'plan' month fixes the position of the OSAY control curve in time within the 24 month test drought. This test drought is based upon the cumulative worst inflows derived from the historic inflow data. For the more extreme probability of stand-pipes occurring (1:100) the OSAY control curve can be assumed fixed at a 'plan' month of 23. The number of parameters to alter is thus reduced to that of varying yield and the 'plan' months for hosepipe bans and MRF reduction/publicity campaign. The 'plan' month for augmentation of river flow by MRF reduction and restriction of demand by publicity campaign is set equal because the target probabilities are the same. The program outputs to the screen the actual probabilities for each level of service during the run, derived from the number of years in which restriction and augmentation occurred. These are then compared with the target probabilities (1:10, 1:20, 1:100), the 'plan' months and/or the yield adjusted and the program re-run. This iterative process continues until the target probabilities are achieved, while maximising the yield value. Tables A2.1 to A2.5 show how this was achieved for 1986,1991,2001,2011 and 2011 Alt conditions.

* Reference Section 7.0

OSAY RUNS

Flow Input Filename - FL-86.DAT
OSAY Control Filename - GRRUN.IN

DEMAND (tcmd)	PLAN RESTRICTIONS (Months ; Cat 1,2,3)	OUTPUT FILENAMES	ACTUAL PROBABILITIES (TARGET - 1:10,1:20,<1:52)	TOT NO. OF MNTHS RESTRICT IMPOSED (Cat 1,2)
225	7, 8, 23		1:52,<1:52, <1:52	
230	7, 8, 23		1:17,<1:52, <1:52	
235	7, 8, 23		1:12, 1:17, <1:52	
237	7, 8, 23		1:12, 1:17, <1:52	
237	7, 9, 23		1:12, 1:17, <1:52	
237	7,10, 23		1:12, 1:17, <1:52	
237	6,10, 23		1:10, 1:17, <1:52	25, 3
238	7, 9, 23		1:12, 1:17, <1:52	
235 *	6,10, 23	FL-86.OUT FL-86.CSV	1:10, 1:25, <1:52	26, 2
236	7,10, 23		1:12, 1:17, <1:52	
240	7, 9, 23		1:12, 1:17, <1:52	
240	6, 9, 23		1:12, 1:17, <1:52	
240	6,10, 23		1: 8, 1:17, <1:52	
240	7,10, 23		1:12, 1:17, <1:52	
240	7,11, 23		1: 6, 1:17, <1:52	
236	6,10, 23		1:10, 1:17, <1:52	25, 3
240	4, 7, 23		1:12, 1:17, <1:52	
240	4, 8, 23		1: 6, 1:17, <1:52	
240	3, 7, 23		1: 6, 1:17, <1:52	

TARGET PROBABILITIES - Hosepipe Ban 1:10 (Cat 1)
MRF Reduction & Publicity Campaign 1:20 (Cat 2)
Stand-Pipes 1:100 (Cat 3)

[NB Plan Augmentation = Plan Restriction Cat 2]

TABLE A2.2

OSAY RUNS

Flow Input Filename - FL-91C.DAT
OSAY Control Filename - GRRUN.IN

DEMAND (tcmd)	'PLAN' RESTRICTIONS (Months ; Cat 1,2,3)	OUTPUT FILENAMES	ACTUAL PROBABILITIES (TARGET - 1:10,1:20,<1:52)	TOT NO. OF MNTHS RESTRICT IMPOSED (Cat 1,2)
226	6,10,23		1:25, <1:52, <1:52	
250	6,10,23		1:8, 1:17, <1:52	
248	6,10,23		1:7, 1:51, <1:52	
245	6,9,23		1:10, <1:52, <1:52	
246	6,9,23		1:12, 1:52, <1:52	
247*	6,9,23	FL-91C.OUT FL-91C.CSV	1:10, 1:25, <1:52	
248	6,9,23		1:12, 1:17, <1:52	

TARGET PROBABILITIES - Hosepipe Ban 1:10 (Cat 1)
MRF Reduction &
Publicity Campaign 1:20 (Cat 2)
Stand-Pipes 1:100 (Cat 3)

[NB Plan Augmentation = Plan Restriction Cat 2]

OSAY RUNS

Flow Input Filename - FL-01C.DAT
OSAY Control Filename - GRRUN.IN

DEMAND (tcmd)	'PLAN' RESTRICTIONS (Months ; Cat 1,2,3)	OUTPUT FILENAMES	ACTUAL PROBABILITIES (TARGET - 1:10,1:20,<1:52)	TOT NO. OF MNTHS RESTRCT IMPOSED (Cat 1,2)
241	6,9,23		1:25, <1.52, <1.52	
291	6,9,23		1:5, 1:17, <1:52	
281	6,9,23		1:6, 1:17, <1:52	
271	6,9,23		1:7, 1:25, 1:52	
261	6,9,23		1:12, 1:25, <1:52	
263	6,9,23		1:12, 1:25, <1:52	
264 *	6,9,23	FL-01C.OUT FL-01C.CSV	1:12, 1:17, <1:52	
265	6,9,23		1: 6, 1:17, <1:52	
262	4,7,23		1:12, 1:25, <1:52	
262	6,10,23		1:7, 1:51 <1:52	
263	7,10,23		1:12, 1:25, <1:0	
264	7,11,23		1:8, 1:25, <1:0	
264	8,12,23		1:8, 1:25, <1:0	
264	12,15,23		1:12, 1:17, <1:0	
264	12,16,23		1:8, 1:25, <1:0	
260	6,10,23		1:7, <1:0, <1:0	
260	2,6,23		1:7, <1:0, <1:0	
264.5	6,9,23		1:12, 1:17, <1:52	
266	6,9,23		1:8, 1:12, <1:52	

TARGET PROBABILITIES - Hosepipe Ban 1:10 (Cat 1)
MRF Reduction &
Publicity Campaign 1:20 (Cat 2)
Stand-Pipes 1:100 (Cat 3)

[NB Plan Augmentation - Plan Restriction Cat 2]

OSAY RUNS

Flow Input Filename - FL-11.DAT
OSAY Control Filename - GRRUN.IN

DEMAND (tcmd)	PLAN RESTRICTIONS (Months ; Cat 1,2,3)	OUTPUT FILENAMES	ACTUAL PROBABILITIES (TARGET - 1:10,1:20,<1:52)	TOT NO. OF MNTHS RESTRICT IMPOSED (Cat 1,2)
250	6, 9, 23		<1:52,<1:52, <1:52	
260	6, 9, 23		1:25,<1:52, <1:52	
260	6,10, 23		1:17,<1:52, <1:52	
265	6,10, 23		1:12, 1:17, <1:52	
267	6, 9, 23		1:12,<1:52, <1:52	
270	6, 9, 23		1:12,<1:52, <1:52	
275	6, 9, 23		1:12,<1:52, <1:52	
280	6, 9, 23		1: 8, 1:17, <1:52	
277	7,10, 23		1:12, 1:25, <1:52	
278	6,10, 23		1: 8, 1:25, <1:52	
278	6, 9, 23	FL-11.OUT FL-11.CSV	1:10, 1:17, <1:52	19, 3
278	7,10, 23		1:10, 1:17, <1:52	19, 3
278	10,13, 23		1:10, 1:17, <1:52	19, 3
278	10,14, 23		1: 8, 1:25, <1:52	
278	11,14, 23		1:10, 1:17, <1:52	
279	10,14, 23		1: 8, 1:17, <1:52	
279	11,14, 23		1:10, 1:17, <1:52	19, 3

TARGET PROBABILITIES - Hosepipe Ban 1:10 (Cat 1)
MRF Reduction &
Publicity Campaign 1:20 (Cat 2)
Stand-Pipes 1:100 (Cat 3)

[NB Plan Augmentation = Plan Restriction Cat 2]

OSAY RUNS

Flow Input Filename - FL-11C.DAT (LVWCo Alt)

OSAY Control Filename - GRRUN.IN

DEMAND (tcmd)	'PLAN' RESTRICTIONS (Months ; Cat 1,2,3)	OUTPUT FILENAMES	ACTUAL PROBABILITIES (TARGET - 1:10,1:20,<1:52)	TOT NO. OF MNTHS RESTRICT IMPOSED (Cat 1,2)
278	6,9,23		<1:52, <1:52, <1:52	
310	6,9,23		<1:52, <1:52, <1:52	
320	6,9,23		1:52, <1:52, <1:52	
330	6,9,23		1:25, <1:52, <1:52	
335	6,9,23		1:12, <1:52, <1:52	
338	6,9,23		1:12, 1:52, <1:52	
340	6,9,23		1:12, 1:52, <1:52	
345 *	6,9,23	FL-11C.OUT FL-11C.CSV	1:10, 1:17, <1:52	
344	6,9,23		1:12, 1:17, <1:52	
338	6,10,23		1:8, <1:52, <1:52	
344	2,5,23		1:12, 1:17, <1:52	
345	2,5,23		1:10, 1:17, <1:52	
345	10,13,23		1:10, 1:17, <1:52	
345	13,16,23		1:10, 1:17, <1:52	

TARGET PROBABILITIES - Hosepipe Ban 1:10 (Cat 1)
MRF Reduction &
Publicity Campaign 1:20 (Cat 2)
Stand-Pipes 1:100 (Cat 3)

[NB Plan Augmentation - Plan Restriction Cat 2]

APPENDIX 3 - DEVELOPMENT AND USE OF GRAFHAM SIMULATION PROGRAM.

A3.1 COMPUTER PROGRAM

The simulation program was run on the IBM PS/2 using the following files :-

SIMB8.EXE - FORTRAN simulation program this contains the following DATA :-

- direct demand and SI for 1986,1991,2001,2011 (tcmd)
- 12 monthly factors for converting from average to peak SI demand
- 12 monthly factors for converting from average to peak PWS demand
- Grafham yields and the quantities finishing upstream and downstream of Offord (used in effluent calculation) for 1986,1991,2001 and 2011 (tcmd)
- LVWCo Chalk, Greensand, Foxcote and Clapham demands for 1986,1991,2001 and 2011 (tcmd)
- 12 monthly reservoir targets (tcm)
- 12 monthly reservoir storages for level of service control curves, for 1986,1991,2001, 2011 (tcm)
- 12 monthly demand reduction factors for the 3 levels of service
- 12 monthly effluent reduction factors for the 3 levels of service
- abstraction coefficients : 0.75 (for MRF of 136 tcmd) and 1.0 (for MRF of 77tcmd)
- MRF : 136 and 77 tcmd
- pump capacity at Offord : 455 tcmd

QOF84-3.DAT - input - naturalised daily river flows at Offord, 1/1933-12/1984, tcmd

MNTHOUT.PRN - monthly storage, control curves and target levels for plotting

A3.2 PROGRAM OPERATION

The program is similar in concept to the OSAY preparation program, and the logic is shown in Figure A3.1.

Problems with the levels of service restrictions alternating from day to day only occurs between the hosepipe ban/MRF reduction boundary. Since this 'hunting' only occurs for a short period of time a minimum duration for each level of service was not used.

Figure A3.1 Simulation Program – Basic Logic

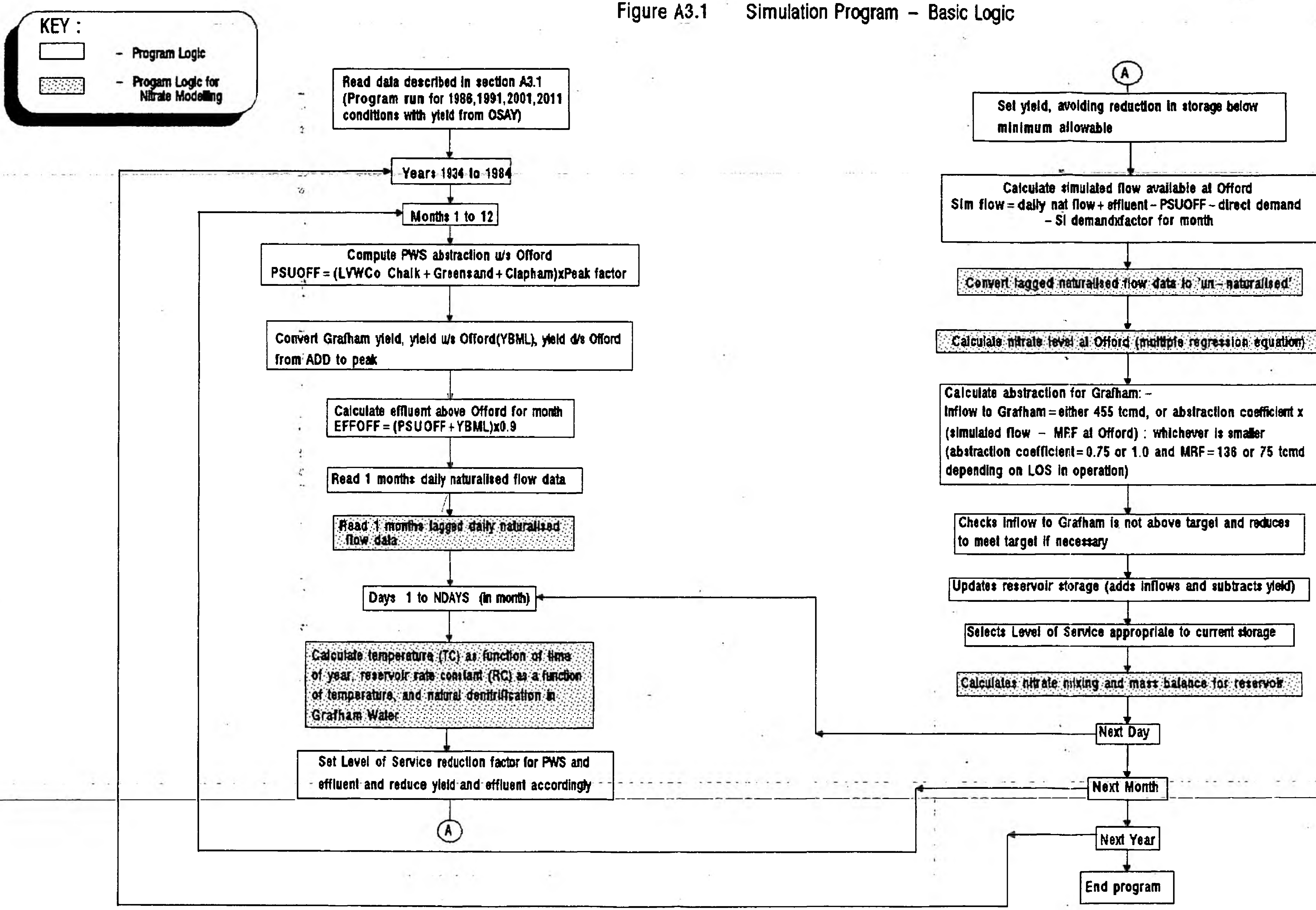
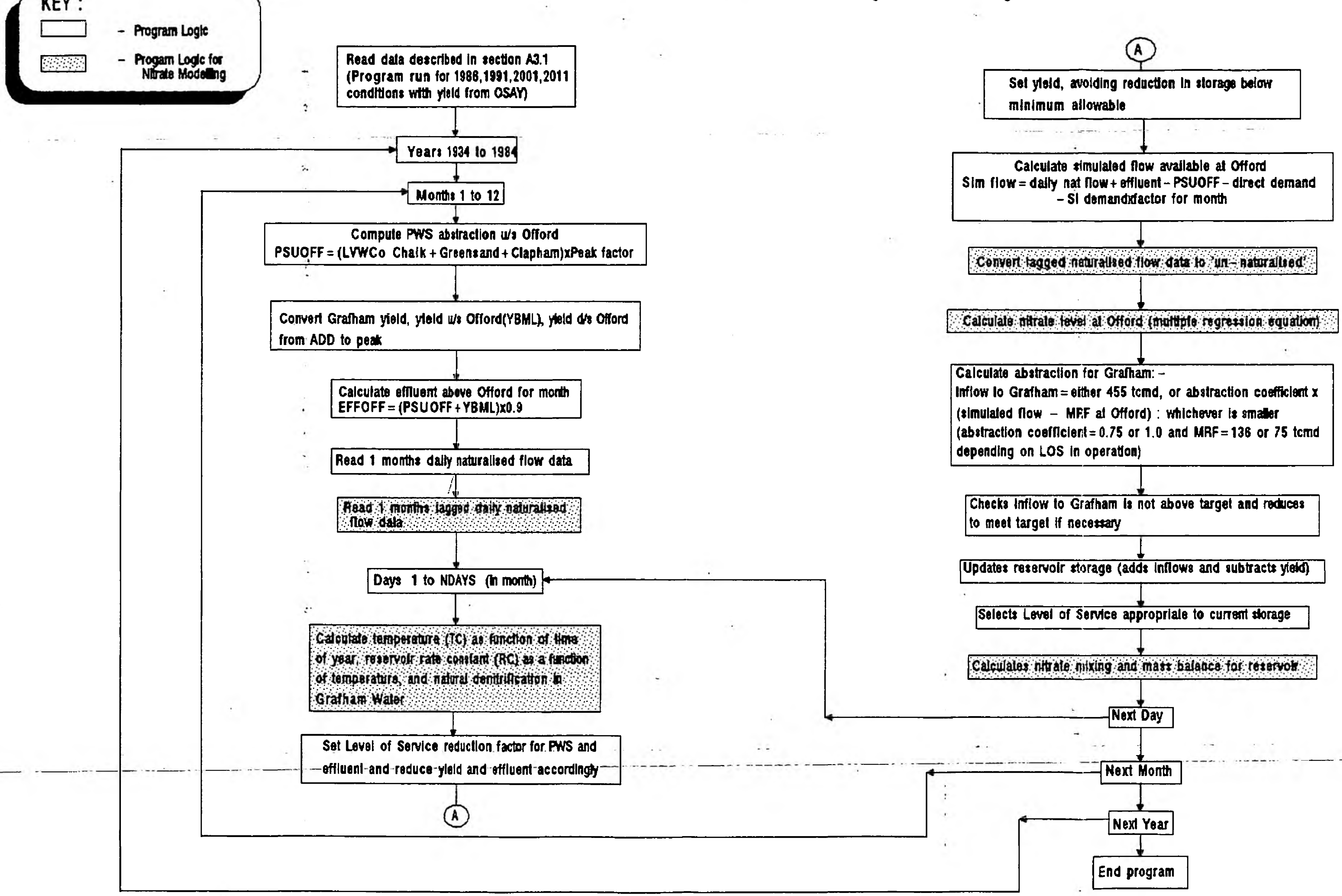


Figure A3.1 Simulation Program - Basic Logic



The demand reduction factors are the same as those used in the OSAY program. Use of the same factors for effluent may give effluent returns to the river which are too high under summer conditions. This is because during the summer, garden irrigation is likely to be evapo-transpired while in the winter a greater proportion of supplied water will be returned to the river.

APPENDIX 4 - DETAILS OF MULTIPLE REGRESSION ANALYSIS

Nitrate data at the Offord intake together with river flow data upstream of the intake, for the period 1976-87 was used for the multiple regression analysis. It was found that the use of antecedent flow averaged over 140 days, 95 days prior to the 'current' day gave the best results (cf. 140/75 for the R. Nene).

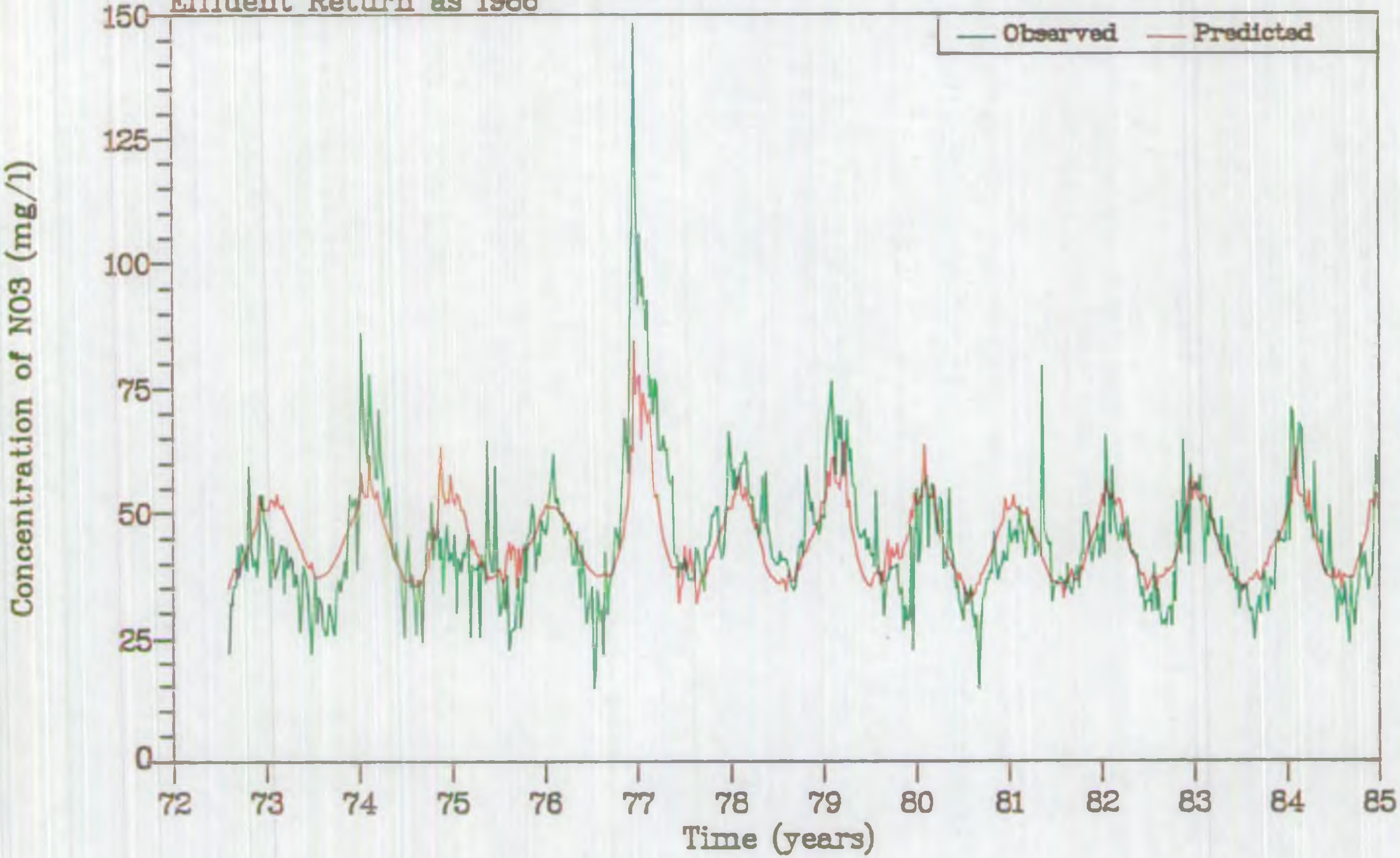
The flow and antecedent flow input to the regression analysis were derived from flows above Offord abstraction point, obtained from the NRA, Brampton.

Figures A4.1 to A4.3 compares the observed and predicted values of nitrate for the different regression equations. The 1976/77 values show a reasonable correlation which gives a degree of confidence in the application to extreme conditions.

A summary of the results of the multiple regression analysis is given in Tables A4.1 to A4.3, the percentage of total variance explained is higher for the '76 to '87 data regression at 73% than that for the '72 to '88 data regression of 66%.

Figures A4.2 & 3 show plots of the residuals against time and observed nitrate respectively for regression based on data of period '76 to '87 (-ve trend).

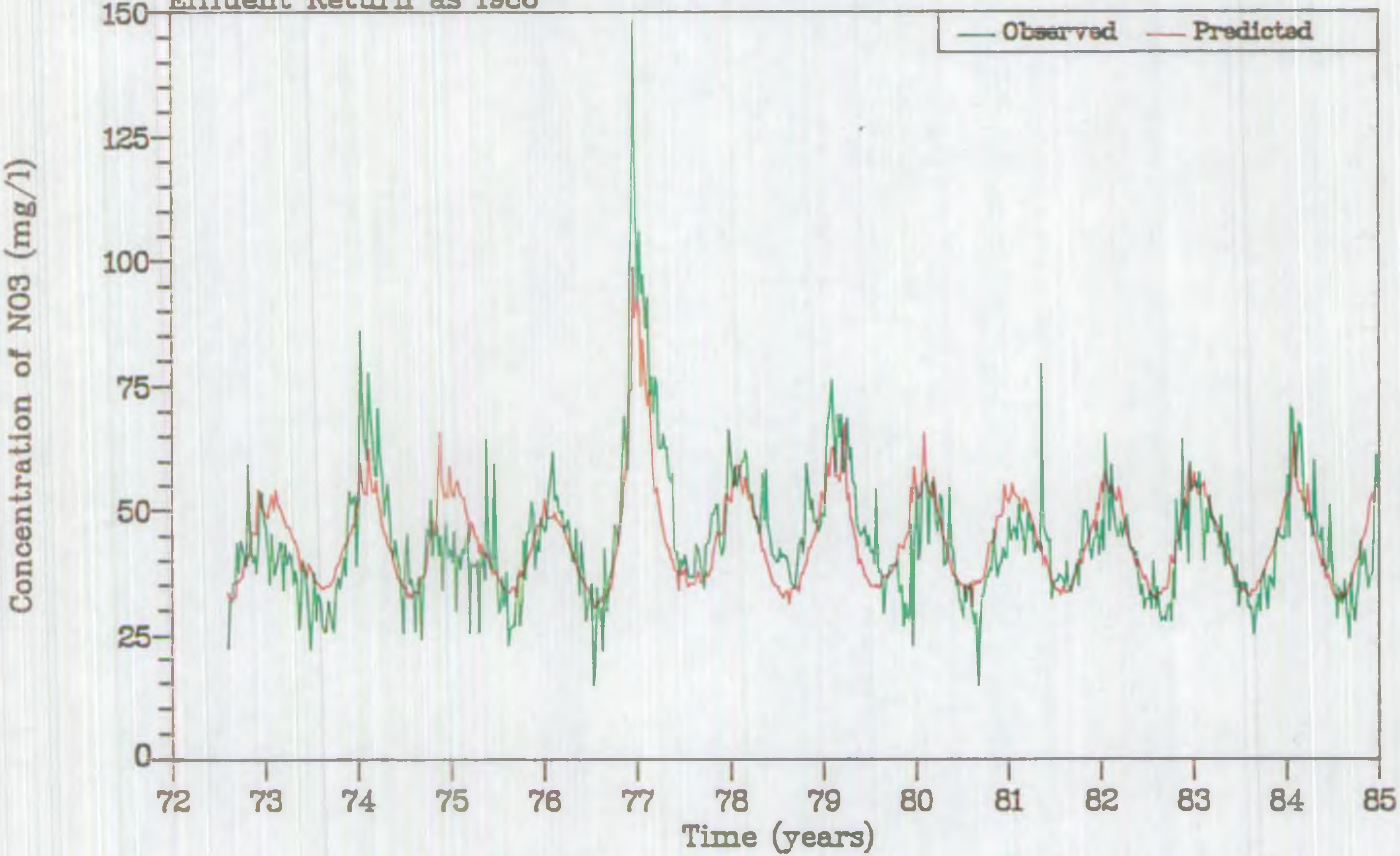
Observed and Simulated Nitrates (NO3) in the R.Ouse at Offord
For Regression Equation Based on 76–87 Data (–ve Trend)
Demand Set to 1986 Value = 168 tcmd
Effluent Return as 1986



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

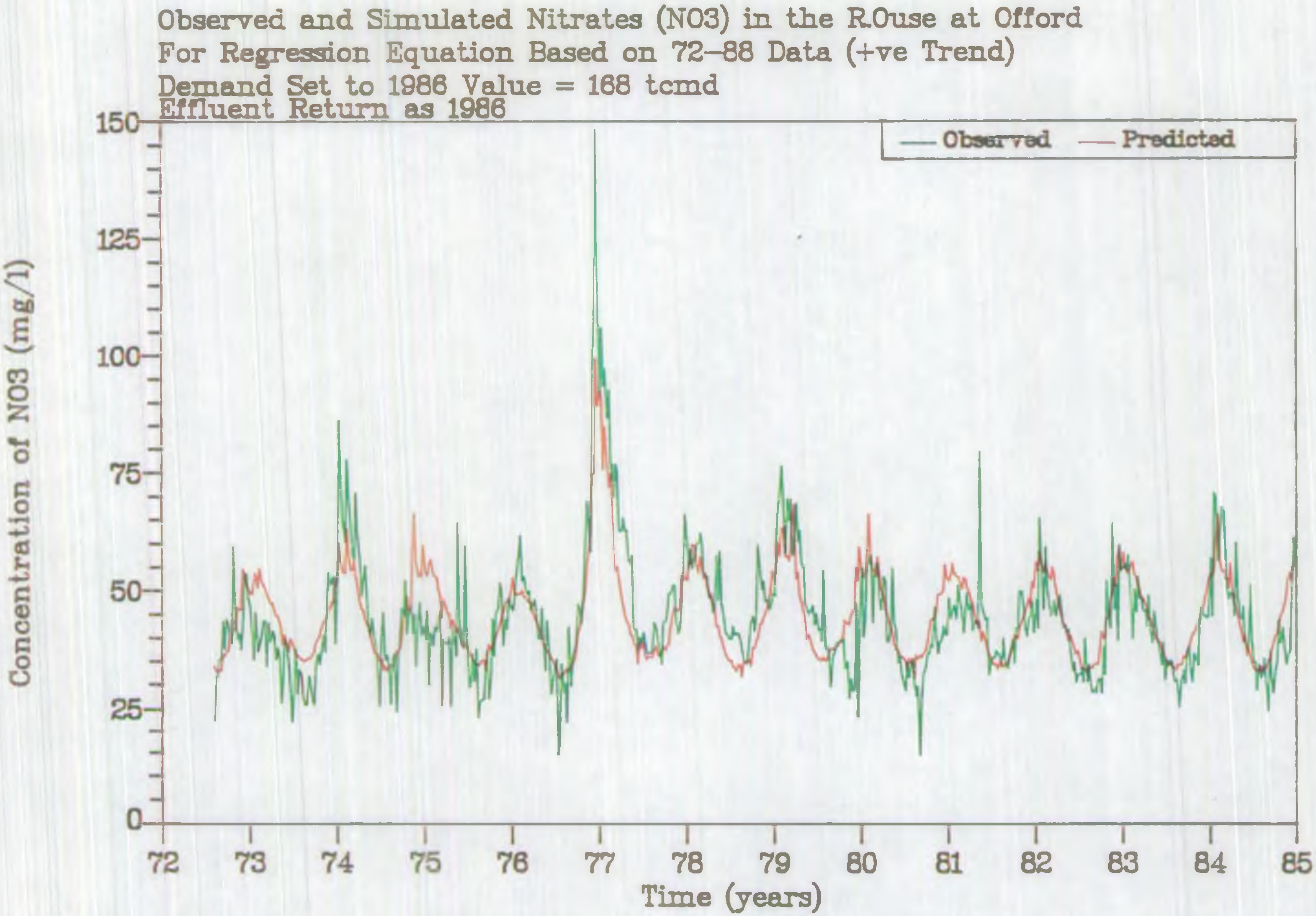
FIGURE A4.1

Observed and Simulated Nitrates (NO3) in the R.Ouse at Offord
For Regression Equation Based on 72–88 Data (Zero Trend)
Demand Set to 1986 Value = 168 tcmd
Effluent Return as 1986



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

FIGURE A4.2



Note : Simulated at 7,14,21,28 Day in Month
Actual at Every 7 Days

FIGURE A4.3

TABLE A4.1 - Regression on '76 to '87 data ('Negative' Trend)

Results of Multiple Regression Analysis for the

River Ouse at Offord

Equation derived by multiple regression of NO^3 against river flow.		Relative significance of variables used, in order of their selection by the multiple regression.		
NO^3 (mg/l) =		Order of Selection	Cumulative Explained Variance	Partial F-ratio
Coefficient	Variable			
- 0.3118	constant	N.A.	N.A.	N.A.
+ 2460.	1 / A	1	42.4	13.5
+ 15.01	$e^{-25/F}$	2	61.0	26.9
+ 1.347	$\cos(2\pi T)$	3	64.5	53.2
+ 0.3858	F / A	4	66.9	25.2
+ 0.8371	$\sin(2\pi T)$	5	68.5	31.2
+105700000.	$1 / A^3$	6	70.8	23.4
- 0.0049	F^2 / A^2	7	71.4	17.7
- 0.0737	T	8	71.9	8.2
+ 0.02118	A^2 / F^2	9	72.2	13.2
- 890100.	$1 / A^2$	10	72.6	14.6
- 0.3939	1 / F	11	73.1	11.8
- 0.000230	F	12	73.3	5.7

Where : T = The date expressed as a single figure, eg. 1/6/72 approximately = 72.5.

F = The flow on the current day.

A = Average flow over 140 days for the period ending 95 days prior to the current day.

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean of squares	F-statistic
Regression	12	4187	348.9	127.3
Residual	555	1521	2.741	

Square of multiple correlation coefficient = 0.7335

TABLE A4.2 - Regression on '72 to '88 data ('Zero' Trend)

Results of Multiple Regression Analysis for the

River Ouse at Offord

N.B. Significant variables only included.

Equation derived by multiple regression of NO_3 against river flow.		Relative significance of variables used, in order of their selection by the multiple regression.		
NO_3 (mg/1) =		Order of Selection	Cumulative Explained Variance	Partial F-ratio
Coefficient	Variable			
- 148.435251	constant	N.A.	N.A.	N.A.
+ 0.450428	F / A	1	36.3	53.1
+ 1.520315	cos $(2\pi T)$	2	51.1	108.6
+ 0.916807	sin $(2\pi T)$	3	56.5	53.9
+ 764901.0	$1 / A^2$	4	61.9	51.0
+ 219.881662	$e^{-25/F}$	5	63.4	8.3
- 7018.998352	1 / A	6	63.9	26.7
- 0.005927	F^2 / A^2	7	64.5	32.9
- 8.300788	$\log_e(A)$	8	64.8	16.2
+ 0.002577	A	9	65.4	11.6
- 1.327719	$\log_e(F/F^1)$	10	65.7	18.2
- 0.000339	F^1	11	66.2	19.0
+ 4974.437561	1 / F	12	66.2	7.9
-2072476.90625	$1 / F^3$	13	66.6	7.4

Where : T = The date expressed as a single figure, eg. 1/6/72 approximately = 72.5.

F = The flow on the current day.

F^1= The flow on the previous day.

A = Average flow over 140 days for the period ending 95 days prior to the current day.

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean of squares	F-statistic
Regression	13	4736	364.3	119.0
Residual	782	2394	3.062	

Square of multiple correlation coefficient = 0.6642

TABLE A4.3 - Regression on '72 to '88 data ('Positive' Trend)

Results of Multiple Regression Analysis for the

River Ouse at Offord

N.B. Significant variables plus 'T' term forced.

Equation derived by multiple regression of NO_3 against river flow.		Relative significance of variables used, in order of their selection by the multiple regression.		
NO_3 (mg/l) =		Order of Selection	Cumulative Explained Variance	Partial F-ratio
Coefficient	Variable			
- 139.609754	constant	N.A.	N.A.	N.A.
+ 0.44959	F / A	1	36.3	53.1
+ 1.516305	cos $(2\pi T)$	2	51.0	108.6
+ 0.92007	sin $(2\pi T)$	3	56.5	53.9
+ 767869.203	$1 / A^2$	4	61.9	51.0
+ 211.515085	$e^{-25/F}$	5	63.4	8.3
- 7080.141479	1 / A	6	63.9	26.7
- 0.005915	F^2 / A^2	7	64.5	32.9
- 8.481973	$\log_e(A)$	8	64.8	16.2
+ 0.002662	A	9	65.4	11.6
- 1.320533	$\log_e(F/F^1)$	10	65.7	18.2
- 0.000335	F^1	11	66.2	19.0
+ 0.00903	T	12	66.3	0.2
+ 4789.928039	1 / F	13	66.3	7.9
-2019317.04687	$1 / F^3$	14	66.6	7.4

Where : T = The date expressed as a single figure, eg. 1/6/72 approximately = 72.5.

F = The flow on the current day.

F^1 = The flow on the previous day.

A = Average flow over 140 days for the period ending 95 days prior to the current day.

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean of squares	F-statistic
Regression	14	4738	338.4	110.4
Residual	781	2393	3.064	

Square of multiple correlation coefficient = 0.6644

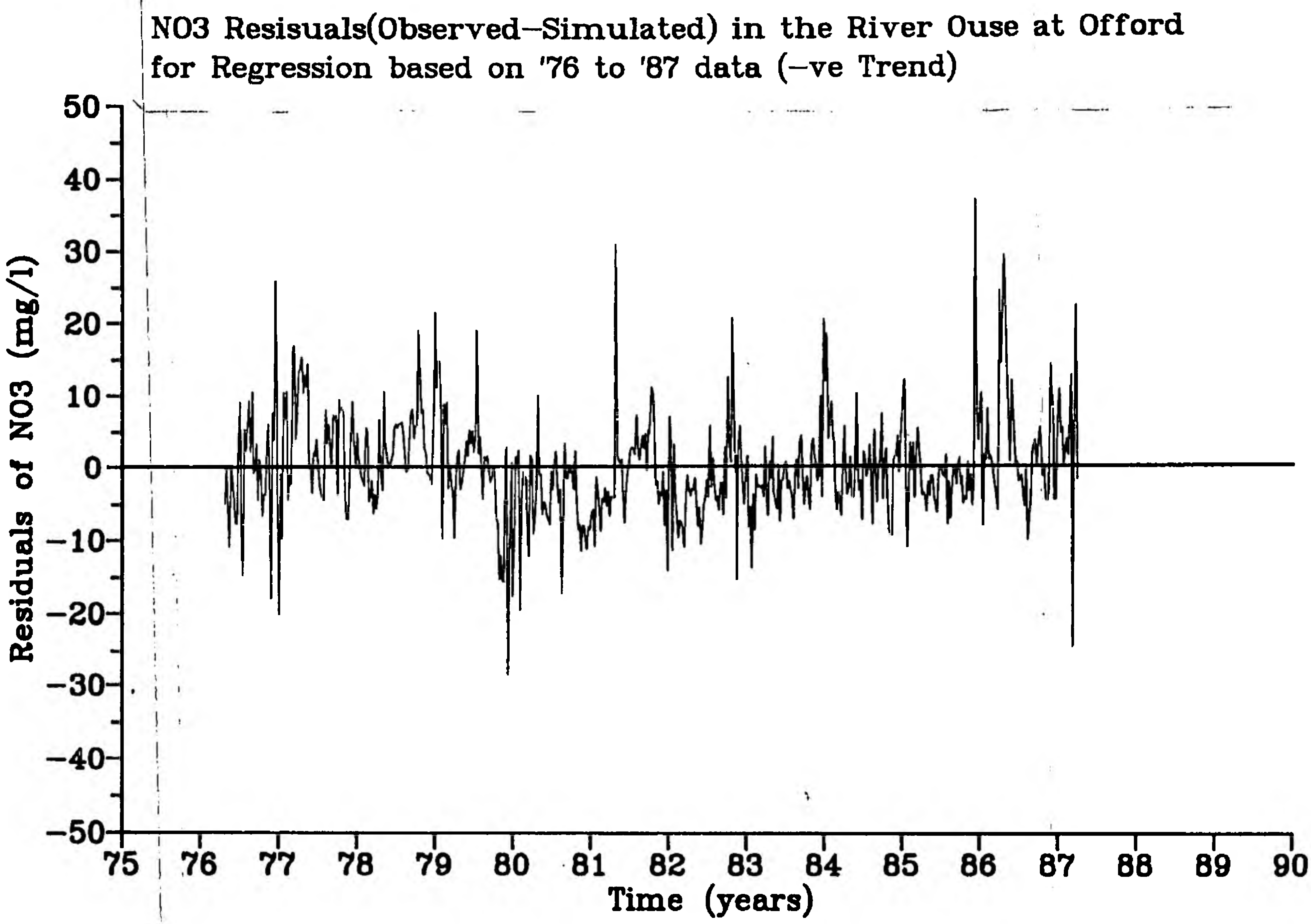

NO3 Resisuals(Observed-Simulated) in the River Ouse at Offord
for Regression based on '76 to '87 data (-ve Trend)
50
40
30
20
10
0
-10
-20
-30
-40
-50
Residuals of NO3 (mg/l)
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Time (years)

FIGURE A4.4

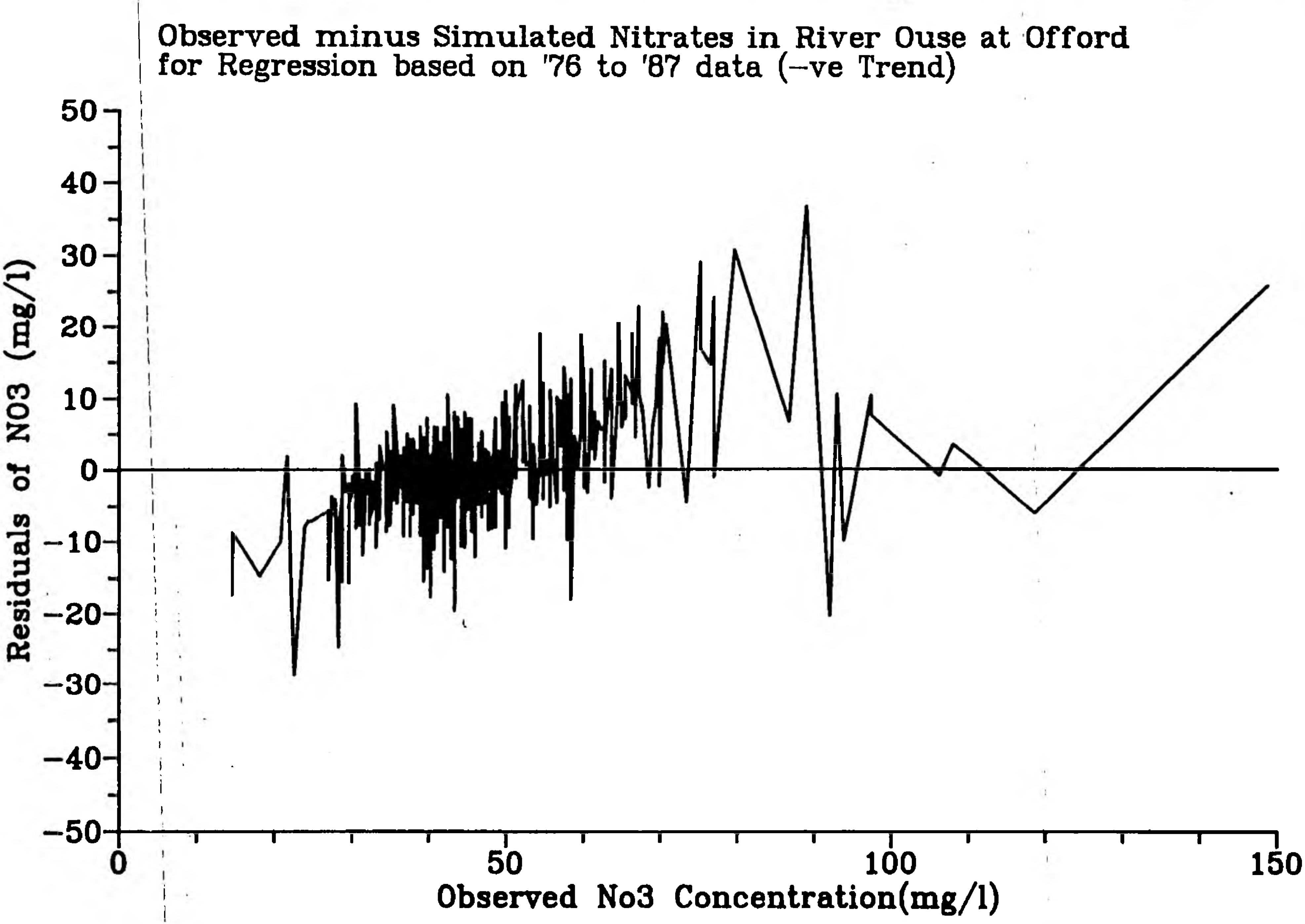

Observed minus Simulated Nitrates in River Ouse at Offord
for Regression based on '76 to '87 data (-ve Trend)
Residuals of NO3 (mg/l)
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
50
100
150
Observed No3 Concentration(mg/l)

FIGURE A4.5

APPENDIX 5 - DEVELOPMENT AND USE OF THE GRAFHAM SIMULATION PROGRAM FOR NITRATE PREDICTION.

A5.1 COMPUTER PROGRAM.

The following files were used for simulation:-

SIMB8A.EXE	-	FORTRAN program - adaption of SIMB8.EXE with no additional DATA statements
QOF84AL3.DAT	-	input - average naturalised flows at Offord over a period of 140 days ending 95 days prior to the current day, 5/1934-12/1984, tcmd
NPLOT.OUT	-	output - river and reservoir data for plotting

Other input/output files are the same as for SIMB8.EXE.

A5.2 PROGRAM OPERATION.

The program logic is shown in Figure A3.1, with the nitrate sections highlighted. These are as follows :-

(i) Lagged naturalised river flows are read in, 'de-naturalised' by adding effluent and subtracting abstraction, and used in the multiple regression equation to calculate nitrate concentration in the R.Ouse.

(ii) Reservoir temperature is calculated as a function of time of year,

TC = 11.144-6.56(SIN(TI)) - 2.52(COS(TI))

where TI = 6.2832(XY + NDP/NDY)

where XY = year for which nitrate conditions are to be simulated -1900

NDP = number of days in the current year to the current day

NDY = number of days in the current year

Natural denitrification in Grafham is calculated by,

NO3(C) = NO3(P)(EXP(-RC))

where RC = $0.0017(1.12^{TC}-1.0)$

NO3(C) = nitrate concentration in reservoir on current day, after denitrification

NO3(P) = nitrate concentration in reservoir on previous day

These equations are based on work presented in a paper on nitrate concentrations in some United Kingdom Reservoirs[(8)*].

(iii) Nitrate concentration of river flow at Offord is calculated using the multiple regression equation described in Appendix 4.

(iv) Nitrate mixing and mass balance in Grafham Water is calculated by,

NO3GRAF = ((NO3(P) x V1) + (NO3(F) x X1)) / (V1 + X1)

where NO3GRAF = Grafham nitrate concentration after inflow and mass balance

NO3(F) = nitrate concentration of river flow on current day

V1 = Grafham storage volume on previous day

X1 = Inflow to Grafham on current day

Nitrate in the above calculations is expressed as Nitrate-N and converted to nitrate before program output.

* Reference Section 7.0

APPENDIX 6 - R.OUSE NITRATE LOADING ANALYSIS

A6.1 AVAILABLE DATA

Nitrate Data -

(i) R.Ouse at Offord
Pre 1976 Data - Held at Bedford WTW as Paper Records
26-4-1976 to 30-11-1987 - 5¼ Disc. Filename OFF.NO3
Post 1987 data - Held on Chemical Dbase.

(ii) Grafham Reservoir
1-1-1981 to 12-12-1984 - 5¼ Disc.

(iii) Nitrate content of STW Discharge
contact Julie Maycock.

Flow Records -

(i) Gauged flow records at Offord
1-2-1970 to 1-12-86 - 5¼ Disc. Filename QOF.DAT
Post 1986 not on database

(ii) Naturalised flow records at Offord
1-1-1933 to 31-1-1970 - Synthesised } 5¼ Disc
1-2-1970 to 31-12-1984 - Naturalised } QOF84-3.DAT

(iii) Lagged naturalised flow records at Offord
1-5-1934 to 31-12-1984 - 5¼ Disc Filename QOF84AL3.DAT

A6.2 ANALYSIS

To provide an indication of possible trends in nitrate concentration in the River Ouse the raw data has been plotted and analysed.

The analysis takes the form of calculating an average loading based on the formula -

$$\text{Av loading} = \sum_{1}^{n} \frac{N*Flow}{n}$$

N : Nitrate Concentration (mg/l)
n : No. of discrete samples within a hydrological year.
Flow : Gauged flow.

These were then plotted with Mean daily concentration and mean flow in cumecs for each year in the period 1976 to 1986. See Figures A6.1 and A6.2.

A comparison of these different plots shows a slight decrease in nitrate loading since 1978. This statement must be tempered by the fact that within this period the hydrological conditions (ie distribution and intensity of rainfall) are not constant.

Nitrate Load Analysis for the R.Ouse at Offord for Hydrological Year (oct-sep)

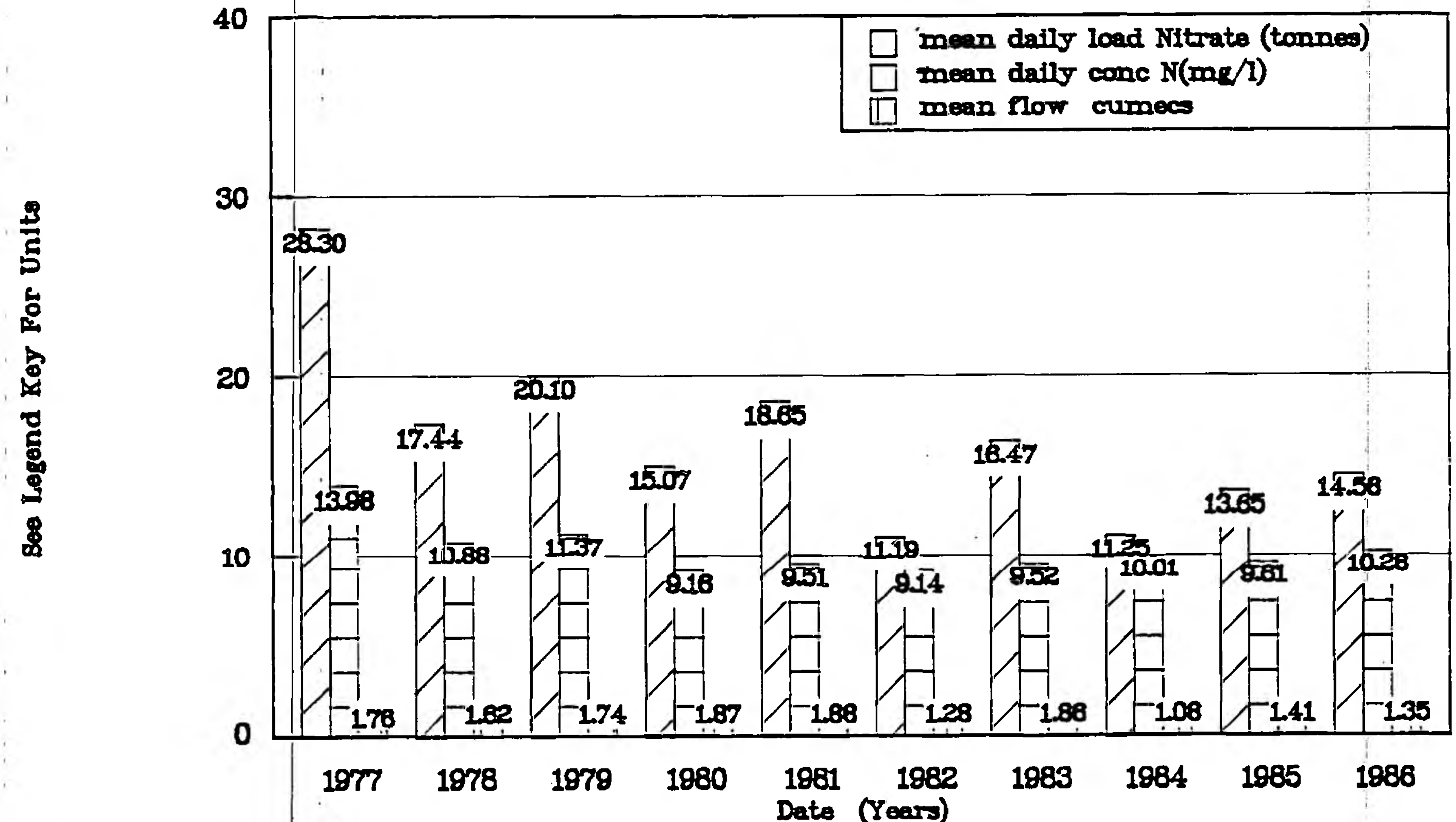


FIGURE A6.1

Nitrate Load Analysis for the R.Ouse at Offord for Calendar Year (Jan-Dec).

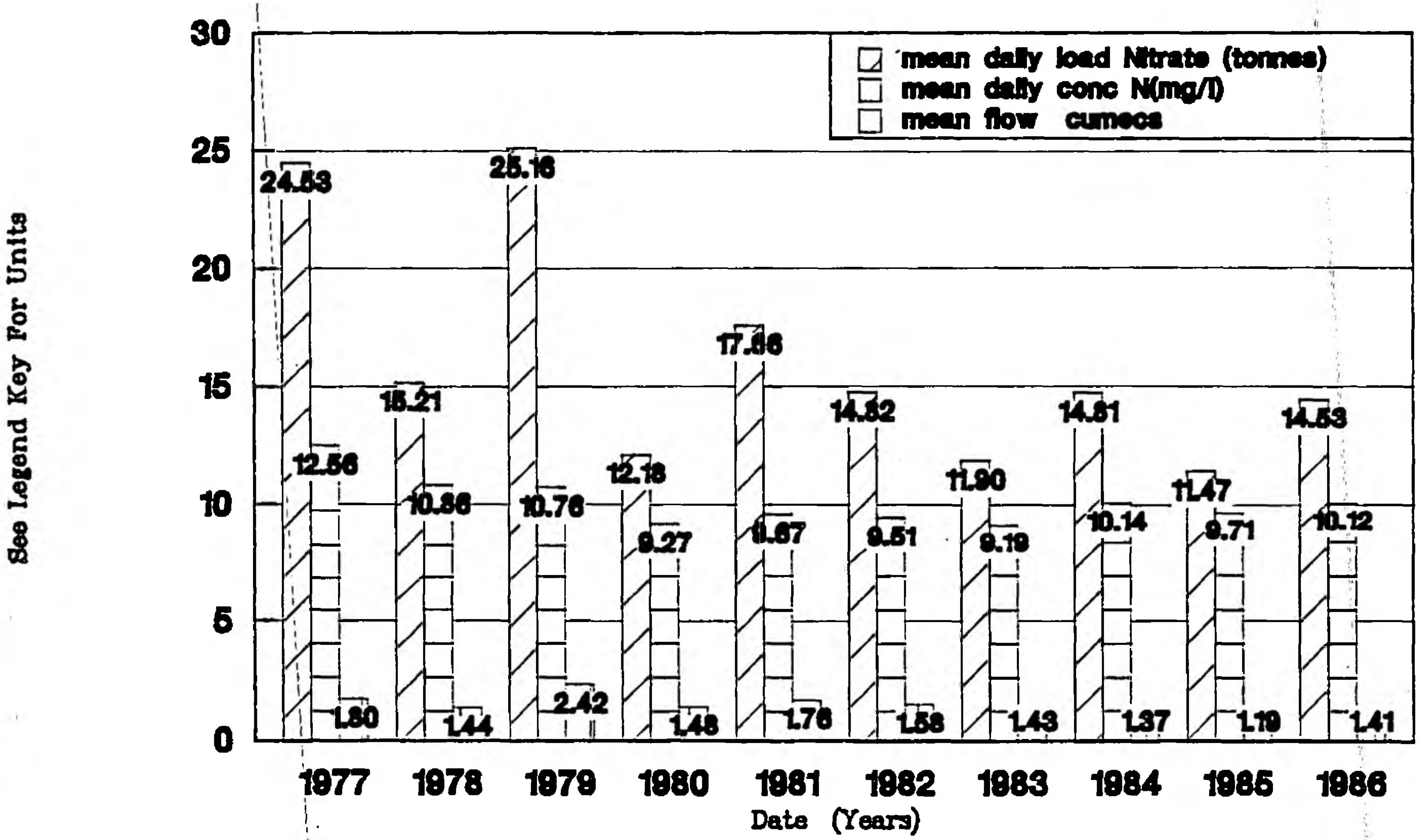


FIGURE A6.2

For a more realistic assesment of trends, comparison of nitrate levels for similar hydrological years should be undertaken. This was attempted by plotting River flows, of similar average yearly values, for different years on the same graph. The nitrate concentrations were also plotted for these years.

See the following Figures -

Fig A6.3	Nitrate Concentrations (mg/l)	1980, '81, '83
Fig A6.4	Gauged River Flow (cumecs)	ditto
Fig A6.5	Nitrate Concentrations (mg/l)	1982, '85, '86
Fig A6.6	Gauged River Flow (cumecs)	ditto

No obvious trends are apparent although concentrations in nitrate levels during the winter months does show an increase. This could be due to different cropping during Autumn and Winter months.

Nitrate Concentrations in the River Ouse at Offord

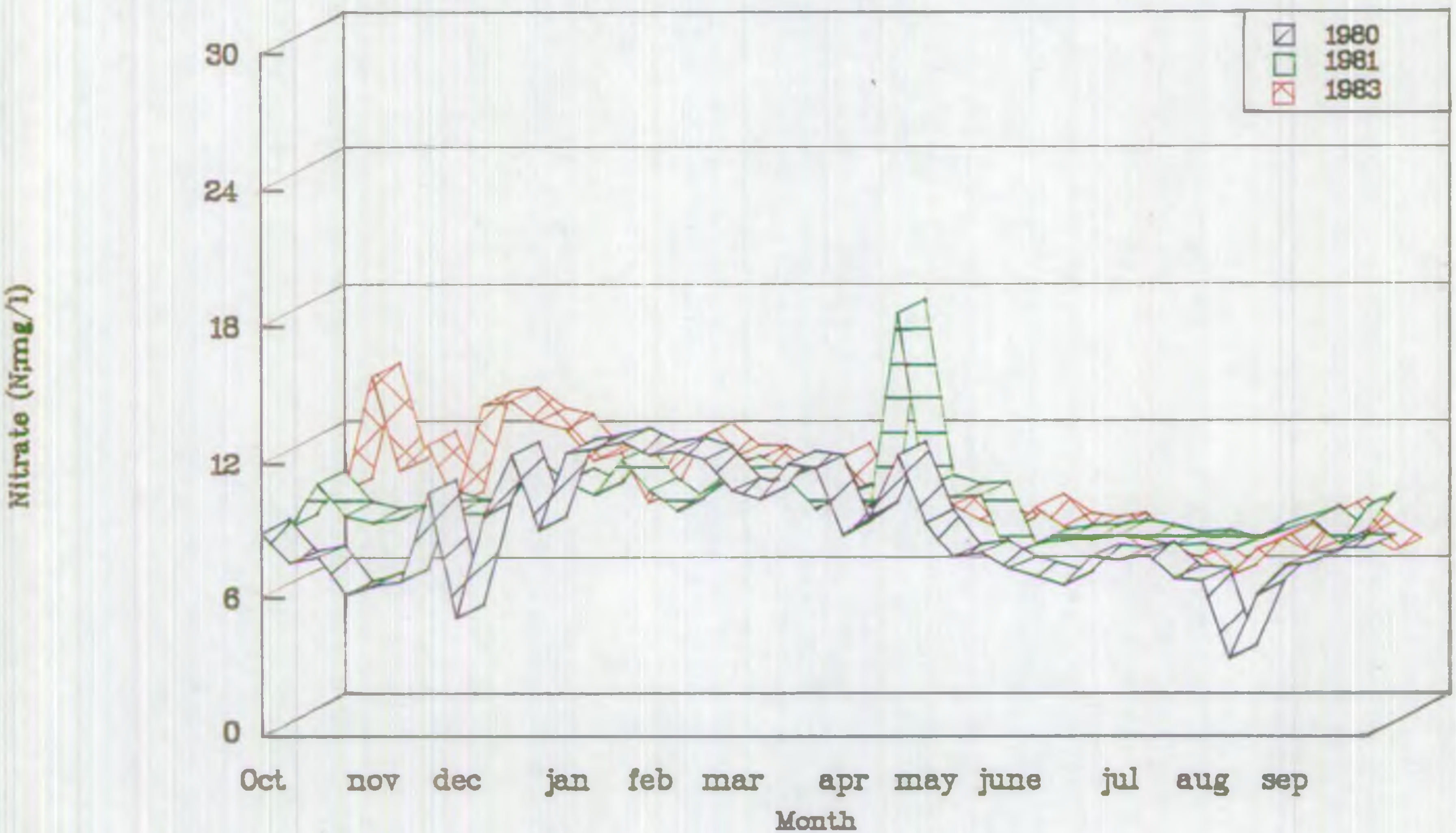


FIGURE A6.3

Flows in the River Ouse at Offord for Different Years

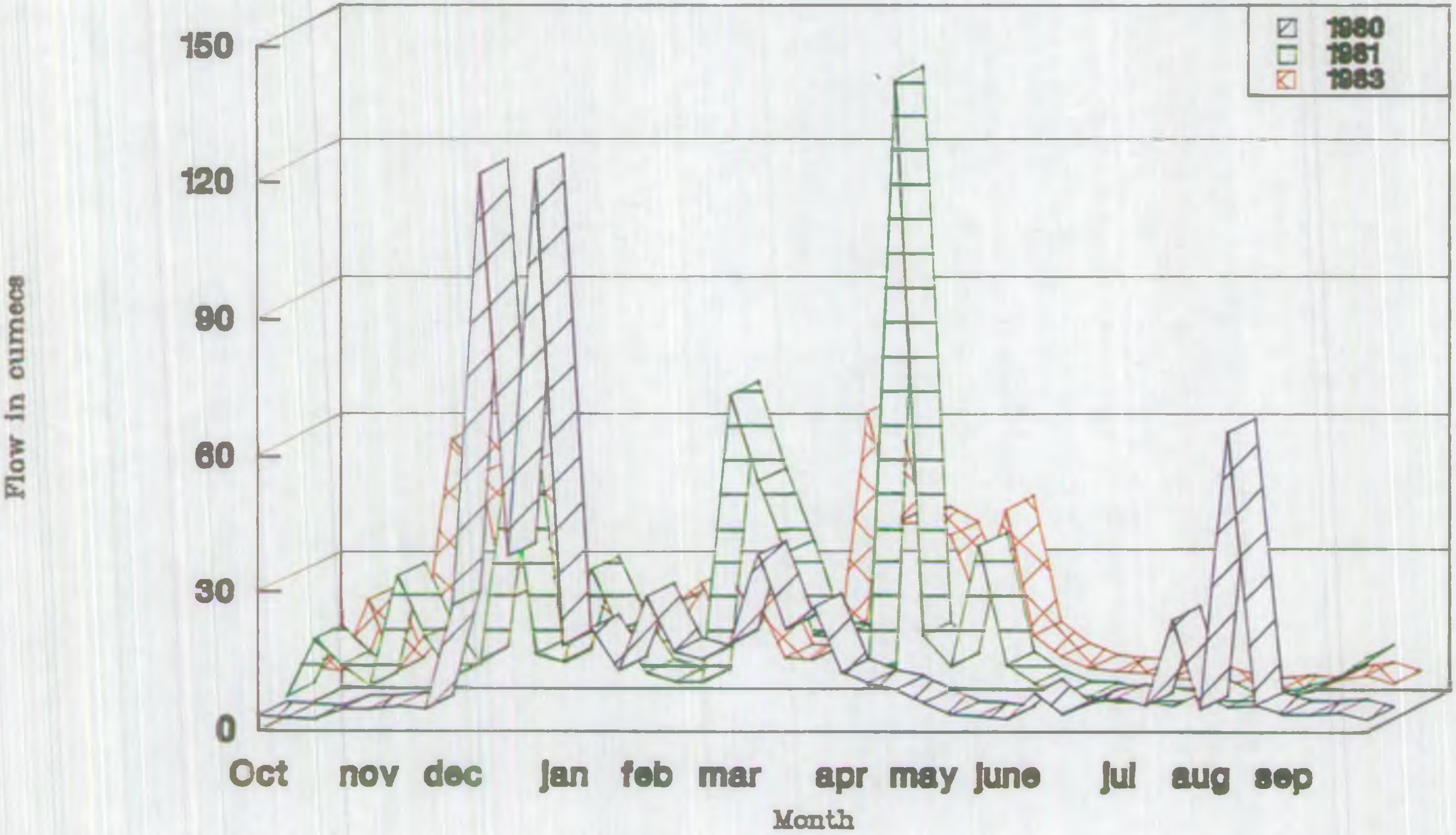


FIGURE A6.4

Nitrate Concentrations in the River Ouse at Offord

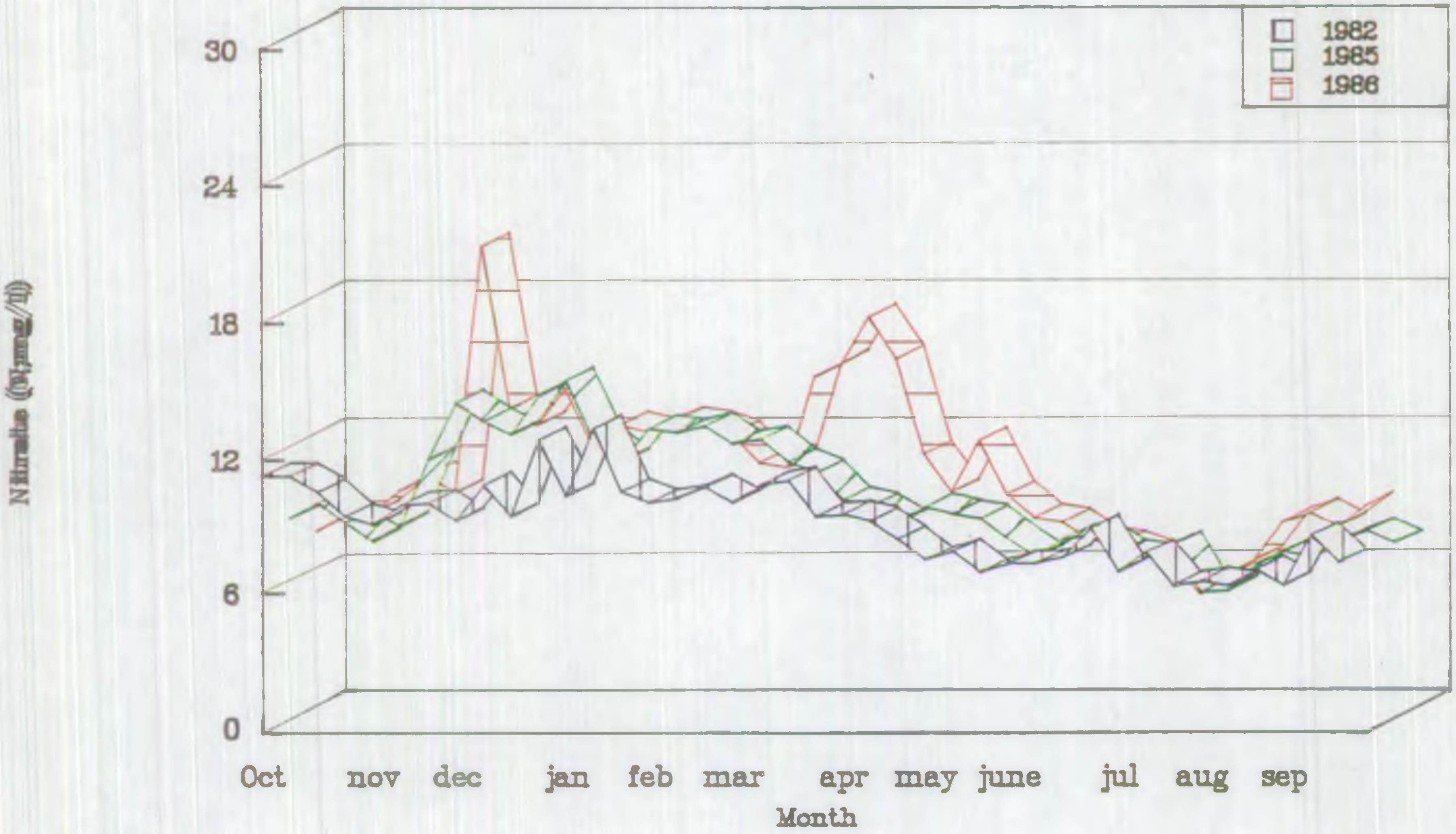


FIGURE A6.5

Flow in the River Ouse at Offord for Different Years

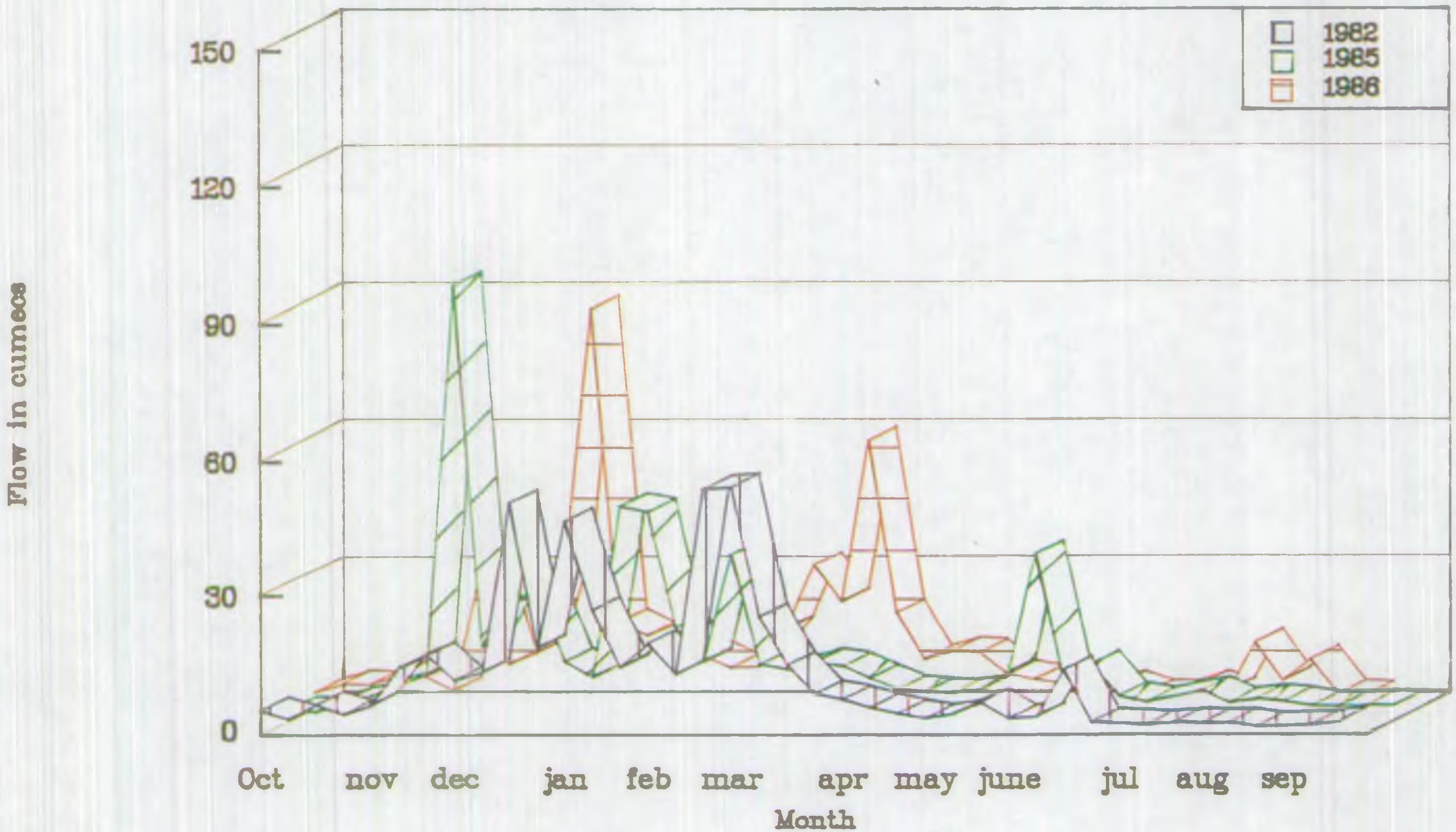


FIGURE A6.6

APPENDIX 7 - NOTES ON DISCUSSION WITH MAFF

There is evidence of an upward trend in the application of fertilisers since the early seventies, although a levelling-off has occured since 1984 (See Fig A7.1). There is also an upward trend in atmospheric nitrate load. This has been recently quoted at 41 Kg/ha p.a. as compared to the previously used value of 18 to 20 Kg/ha p.a. Figures are available from the air pollution monitoring department at Harnwell Laboratory.

Two primary sources of information need to be accessed to enable total loads of nitrates to be derived :-

(i) The Cropping Pattern Census. Obtainable from the MAFF offices at Guildford. Summaries available at Cambridge.

(ii) The Fertiliser Application Practise reports. Obtainable from MAFF offices Cambridge.

Nitrate uptake can be calculated via crop yield data. The efficiency of nitrate uptake is dependent on crop type, for example vegetables are relatively inefficient in their nitrate uptake as compared to cereals and grassland. Data is available on this. The Lower-Ouse Catchment has a large proportion of agricultural land being used for vegetable crops.

Different soil types and drainage would have an influence on the 'lag' time for the introduction of leached nitrates into the River.

The availability of this data could enable a more deterministic approach to be applied to the prediction of nitrate leaching from the soil into the rivers. This combined with a catchment model would provide a more sound basis for future prediction of nitrate levels in the river.

FIGURE A7.1 - Extract from Fertiliser Application Practice Report. Showing Levels of Nitrate (N) Applied from 1970 to 1988.

FIGURE 1(a): *Overall use of N on tillage and grass since 1970*

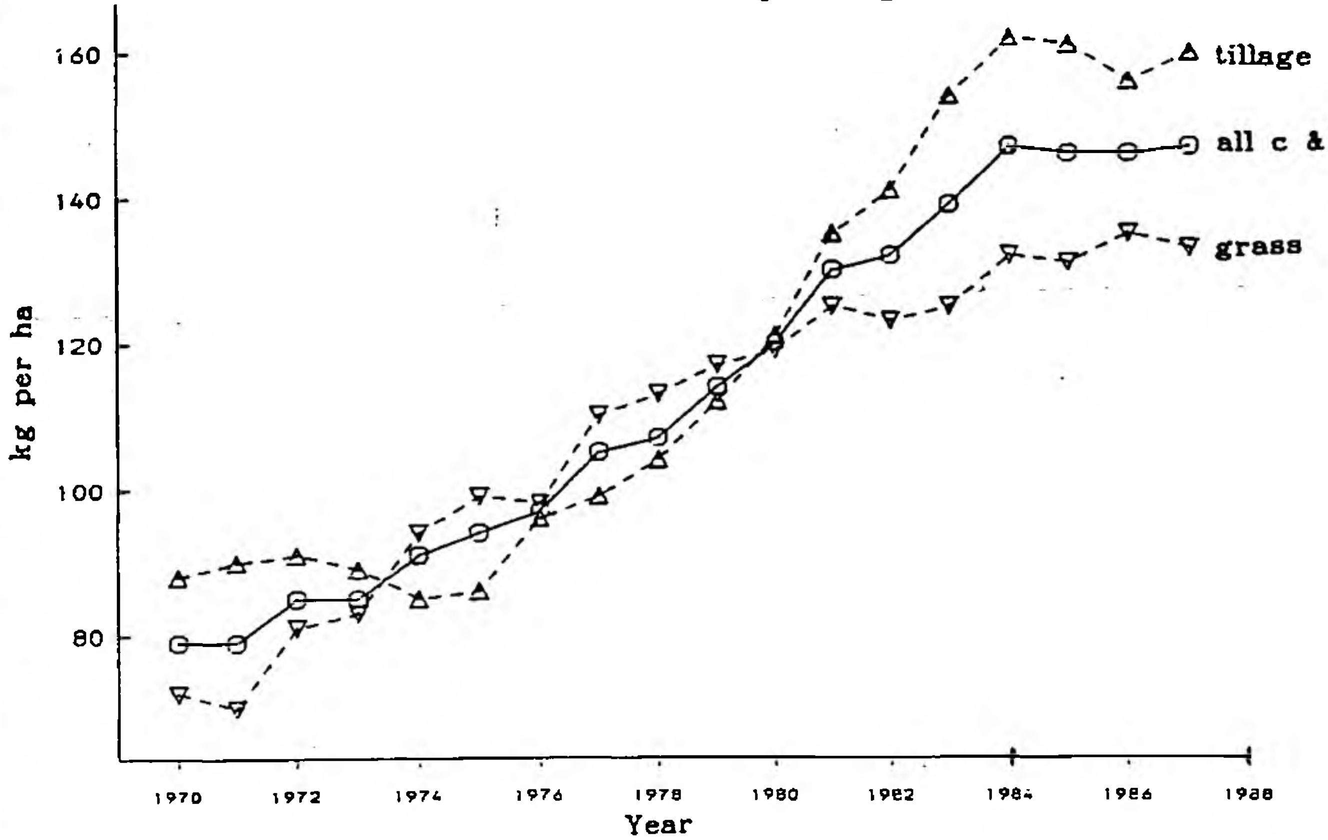


FIGURE 1(b): *Overall use of N on all crops and grass since 1970*