Institute of Hydrology

Natural Environment Research Council

THE EFFECTS OF AGRICULTURAL PRACTISES ON NITROGEN LOSSES FROM A SMALL RURAL CATCHMENT IN BUCKINGHAMSHIRE

GARETH ROBERTS 1986

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A report on a joint ADAS/IH study

by

Gareth Roberts
Institute of Hydrology

INTRODUCTION

This report describes the results obtained during a study carried out by the Institute of Hydrology (IH), with financial support from the Ministry of Agriculture, Fisheries and Food (MAFF) with the assistance of the Agricultural Development and Advisory Service (ADAS) into nitrogen inputs and outputs in a small agricultural catchment in Buckinghamshire. The main purpose of the study was to measure the nitrogen concentrations and losses in a stream draining land under mixed agriculture, and to examine what were the effects of various agricultural practices on these concentrations and losses. In particular, the interaction of climatological and hydrological influences on the agricultural practices are examined in some detail. A catchment nitrogen balance is attempted by determining inputs in rainfall and outputs in streamflow. Estimates are made of inputs in fertilizers, slurries and manures and outputs in agricultural produce.

This study is being conducted within the context of increasing nitrogen, specifically nitrate-N, concentrations in sources of domestic water supply. The presence of nitrate has been blamed for the occurrance of algal blooms in lakes and rivers and, when consumed in domestic water, for methaemoglobinaemia in young babies and more recently as a possible cause of gastric cancer. Evidence for the latter is conflicting though a few instances of fatalities of infants due to methaemoglobinaemia have been reported in the UK, the last being in 1972. Currently, the water authorities adopt the WHO standards laid down in 1970 which for nitrate, recommends concentrations less than 11.3 mg/ℓ as nitrogen for drinking water, with concentrations up to 22.6 mg/ℓ being acceptable. More recently, however, the UK adopted new EEC guidelines which effectively halve the WHO limit. There have been several reports, particularly from the Eastern part of the UK, of nitrate concentrations exceeding 11.3 mg/ℓ for part or the whole of the year and many sources of domestic water supply have had to be abandoned. The fear is that, should concentrations continue to increase, then a massive investment may be required to treat the water. A number of options are currently being considered including blending high and low nitrate water, removal by ion exchange and biological denitrification and the provision of low-nitrate bottled water when deemed necessary.

There are several possible reasons for the increasing nitrate concentrations. The general rise in industrial activity may well have caused an increase in pollution from point sources, both into water courses and the atmosphere as dry deposition, which returns dissolved in rainfall. Also, the intensification of agricultural practices in recent years, particularly the massive increase in the use of inorganic fertilizers and the move from grassland to arable land, may be causing the leaching of excess nitrate-N into groundwaters and streams draining agricultural land. This is relevant since the highest nitrate-N concentrations have been found in Eastern England, an area associated with the most intensive agriculture.

CATCHMENT DESCRIPTION

The area chosen for the study is a small (170 ha) clay catchment at Shenley Brook End, near Milton Keynes new town, Buckinghamshire (Fig.1). The catchment consists of gently undulating agricultural land with about 11% deciduous woodland, 23% arable land and 66% grassland (Fig.2). The woodland consists of mature deciduous trees, mostly in one large block, Howe Park Wood. Part of the grassland is grazed by dairy cows but the greater part is used for sheep grazing and for the production of hay and silage. The dairy farm grassland is fairly intensively managed but much of the other grassland receives relatively small amounts of fertilizers. The pattern of land use has remained virtually constant since 1977.

The soils of the catchment were mapped by the Soil Survey in the spring of 1979. Seven soil series were recognized and these are listed below, with an indication of their relative abundance (Fig.3).

Soil Series	Parent Material	% Area
Hanslope	Chalky Boulderclay	25
Ragdale	Chalky Boulderclay (decalcified in the soil profile)	50
Beccles	Chalky Boulderclay	5
Ashley	Chalky Boulderclay	2
Rowsham	Valley bottom head	3
Lawford	Valley bottom head	2
Horseley	Fluvioglacial drift	13

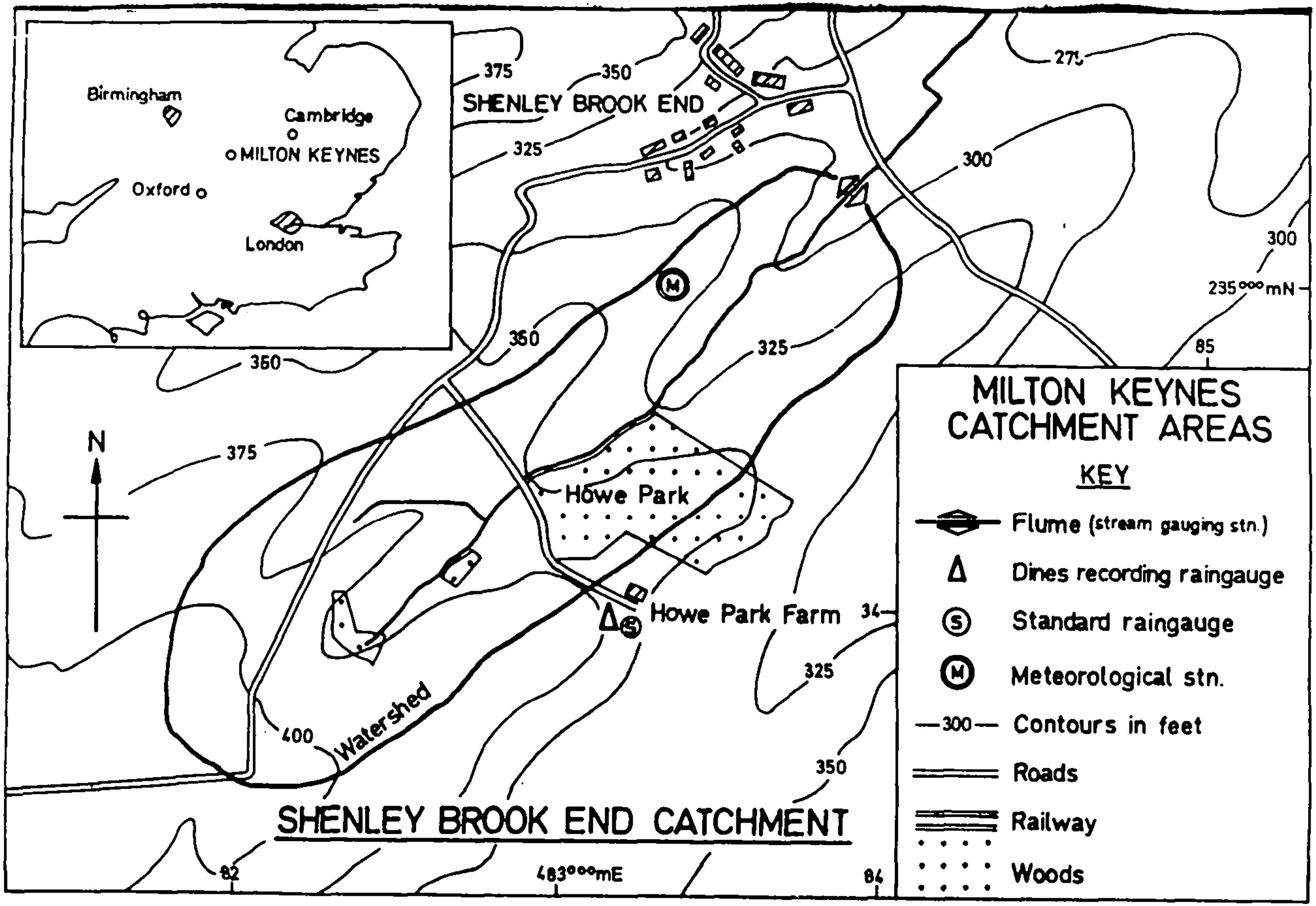

FIG. 1 THE STUDY AREA

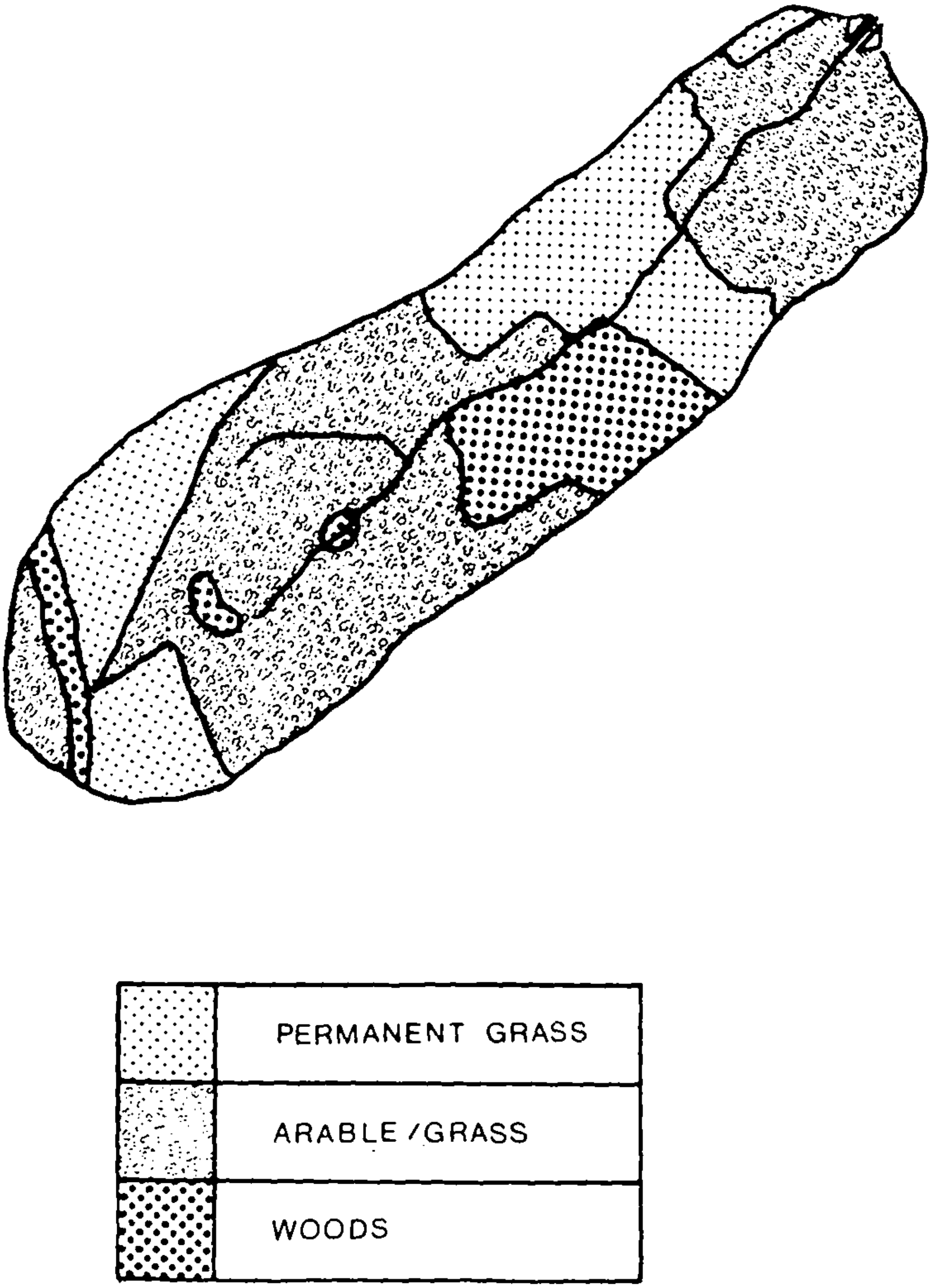

FIG. 2 LAND USE IN THE SHENLEY BROOK CATCHMENT

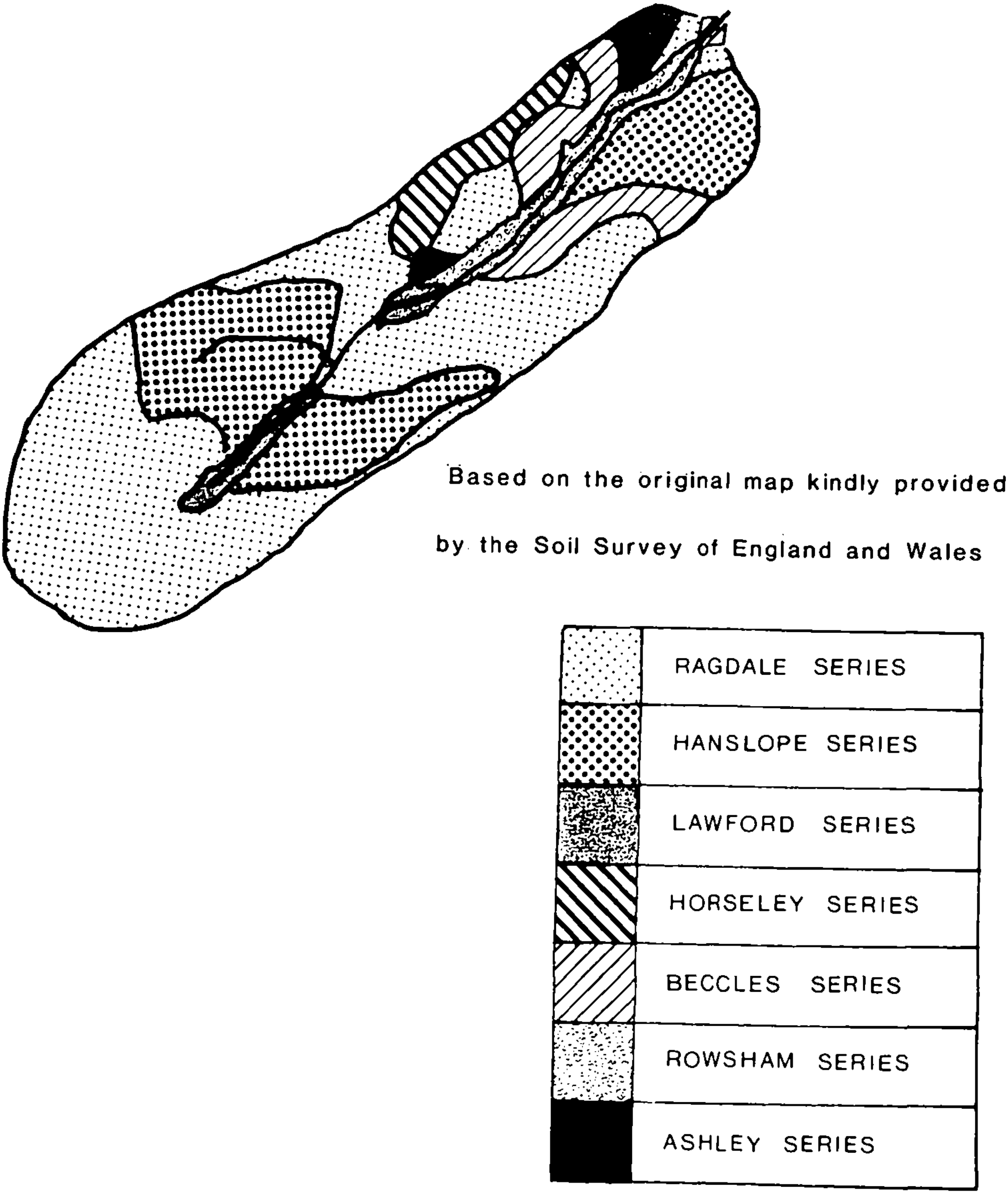

FIG. 3 SOILS OF THE SHENLEY BROOK END CATCHMENT

The catchment has been instrumented to measure rainfall, runoff and the meteorological variables required to calculate evaporation, and data since March 1972 are available. These show eleven year (1973-1983 inc.) annual average totals of 659 mm precipitation, 220 mm discharge (33% of precipitation) and 548 mm potential evapotranspiration. On average streamflow ceases for 5 months each summer.

DATA COLLECTION

The instruments required for streamflow sampling were installed in late 1977 and those for rainfall sampling in late 1978. It was arranged that ADAS would ascertain from farmers with land on the catchment the agricultural practices being carried out. From this it was hoped to estimate nitrogen inputs in fertilizers, slurries and manures and outputs in agricultural produce. It was hoped to correlate streamflow nitrate-N concentrations with the timing of the farming operations with due regard to the hydrological conditions prevailing. Data collection began in January, 1978.

(1) Hydrological Data

The runoff from the catchment was measured as the head or level of water in a stilling well connected to a trapezoidal flume. Two recorders were used:-

(a) A Leupold and Stevens recorder which produces a continuous recording on a strip chart. This is regarded as the primary recorder. The charts were digitized using a D-mac pencil follower to produce ultimately, water levels at 15 min intervals. These were converted into flows in cubic metres per second (cumecs) using a standard equation (British Standards, 1965) and then to mm of flow over the catchment at 15 min intervals. These values were stored on the Institute's data archive system and used in any subsequent calculations.

(b) A Fischer-Porter recorder which produces water levels at 15 min intervals on a punched paper tape. The data recorded on this instrument were used as back-up in case of malfunction of the Leupold and Stevens chart recorder, in which case the water levels were simply abstracted manually and converted to flow in mm over the catchment as described above.

Rainfall over the catchment was measured by means of a daily-read gauge at the meteorological station site and a weekly-read gauge at Howe Park Farm (Fig.1). Each gauge was assumed to represent a certain percentage of the catchment and was given a weighting. The rainfall totals were time distributed using a Dines recording raingauge situated at Howe Park Farm. The data were stored on the Institute's archive system and used subsequently in any calculations as hourly totals in mm over the catchment.

Daily estimates of potential evaporation and evapotranspiration (Penman, 1948) in mm over the catchment were made using the meteorological variables measured, on a daily basis, at the meteorological station. These variables, measured at 0900 GMT, are maximum and minimum temperature, wet and dry bulb temperature, wind run, number of sunshine hours and solar radiation. In addition, soil temperatures were measured at 5, 10 and 20 cm and, in a tube, at 30, 50 and 100 cm below ground level, again at 0900 GMT.

(2) Chemical Sampling

Streamflow samples were extracted just above the flume at the outfall of the catchment (Fig.1) at eight-hourly intervals using a vacuum-operated automatic sampler. During the first three years of the study, streamflow samples were also abstracted automatically at half-hourly intervals during selected storm events. All the samples were collected in brown glass bottles which were enclosed by an opaque cover. They were taken at weekly intervals to MAFF, Reading where they were analysed for nitrate-N using an Orion nitrate-selective electrode. For a small part of the study (up to the end of the 1979/80 flow period), a weekly bulked sample was analysed for ammonium-N, phosphorus, potassium and calcium. The results obtained were inspected to determine whether any changes were evident between sample collection dates. The absence of any definite pattern of nitrate-N loss or gain during any one week suggested that transformations in nitrogen species were insignificant and it was unnecessary to preserve the samples chemically. Some stream water samples were also analysed for nitrate-N, fresh and after storage for a week. The results were found to be similar.

No organic nitrogen determinations were done on the samples and, for the purpose of a nitrogen balance, it is assumed that all the nitrogen losses in streamflow are in the nitrate form. Similar studies have shown that this is generally the case (Dowdell, 1982; Wilkinson and Greene, 1982) and certainly the results of the ammonium-N analyses supports this observation. However, it is inevitable that some underestimate of total nitrogen losses in streamflow will have resulted from neglecting organic nitrogen. This will be discussed in greater detail later.

Rainfall samples were collected on a weekly basis at the outfall of the catchment in a brown glass bottle enclosed by an opaque plastic tube fitted with a plastic funnel having a coarse nylon mesh. Initially, the samples were analysed at MAFF, Trawscoed for ammonium-N, nitrate-N, phosphorus, potassium and pH using standard procedures (DOE, 1972). After 1981, the samples were analysed at the Institute of Hydrology for nitrate-N, using a colorimetric autoanalyser method, and for pH.

(3) Land management data

Land use and nitrogen application rates in fertilizers and slurries were assessed by interviewing the various farmers holding land on the catchment. The results obtained are shown in Table 1. The agricultural land is partly permanent grass, partly temporary grass (2-year or 3-year leys) and partly arable land (Fig.2). Most of the arable land is cropped with cereals (winter wheat, winter barley, winter oats and spring barley). In 1983, one field was cropped with winter oil seed rape and in the calculations in section 4, this crop is grouped with the cereals. The only other crop grown is turnips which are grazed by sheep in the autumn. This crop is followed by winter cereals. Most of the fields have fairly old tile drainage systems.

The amount of nitrogen removed permanently from the catchment in crops and livestock products was estimated as indicated below, bearing in mind the percentage of catchment under different land uses. Offtake of nitrogen by winter wheat was calculated by assuming a yield of 7t/ha of grain and 4t/ha of straw and a nitrogen content of 1.5% in grain and 0.5% in straw, giving an annual nitrogen offtake of 125 kg/ha. Similarly, for spring barley, an assumed yield of 4t/ha of grain and 3t/ha of straw gives an

TABLE 1

CROPPING AND NITROGEN USE 1977-84

	PERMANENT GRASS			TEMPORARY GRASS			CEREALS			TURNIPS			TOTAL AGRIC. LAND		
YEAR	AREA (ha)	TOTAL N USAGE (kg)	MEAN N RATE (kg/ha)	AREA (ha)	TOTAL N USAGE (kg)	MEAN N RATE (kg/ha)	AREA (ha)	TOTAL N USAGE (kg)	MEAN N RATE (kg/ha)	AREA (ha)	TOTAL N USAGE (kg)	MEAN N RATE (kg/ha)	AREA (ha)	TOTAL N USAGE (kg)	MEAN N RATE (kg/ha)
1977	70.9	8,955	126	6.5	486	75	66.8	6,668	100	0	0	0	144.2	16,109	112
1978	70.9	8,572	121	17.7	1,501	85	43.9	4,374	100	11.8	1,470	125	144.2	15,917	110
1979	70.9	8,837	125	40.2	7,431	185	24.7	2,507	101	8.4	898	107	144.2	19,673	136
1980	56.0	4,655	83	32.7	4,450	136	55.5	6,590	119	0	0	0	144.2	15,695	109
1981	56.0	4,609	82	23.5	3,118	133	64.7	7,413	114	0	0	0	144.2	15,140	105
1982	56.0	3,815	68	25.7	2,358	92	55.7	6.022	108	6.9	768	112	144.2	12,963	90
1983	56.0	3,779	68	22.6	3,950	175	50.2	7,210	144	15.5	1,480	95	144.2	16,419	114
1984	56.0	2,374	42	22.6	940	42	56.1	7,987	142	9.5	1,069	112	144.2	12,370	86

NOTE Nitrogen usage includes the total amount of nitrogen in both fertilizers and manures annual offtake figure of 75 kg/ha. A similar calculation for grass cut twice a year gives an offtake of 120 kg/ha. It is reasonable to assume that for grass grazed by dairy cows at normal stocking density, the nitrogen offtake is also 120 kg/ha, as the removal of nitrogen from the system (in milk sold) is considerable. Grass grazed by sheep and lambs gives a much smaller nitrogen offtake (as most of the nitrogen is returned as dung and urine) and an approximate calculation suggests that 25 kg/ha is removed. Beef cattle occupy an intermediate position and it has been assumed that nitrogen offtake by beef cattle grazing at the normal stocking density is 60 kg/ha. This figure could probably be estimated more accurately, but this has not been done as the area of catchment grazed by beef cattle is only 11.2 ha. Where grassland has been cut and then grazed, it has been assumed that offtake is 100 kg/ha. It has also been assumed that where sheep graze turnips, the nitrogen offtake is the same as where they graze grass. This is a reasonable assumption as the output is similar although the production is at a different time of the year. A final assumption is that the nitrogen offtake from rough grazing which receives no fertilizer is nil, as the grazing is only light and output usually very small.

Also

Crop	Offtake (kg/ha)
Spring wheat	75
Winter barley	100
Winter oats	100
Winter o.s. rape	100
Spring re-seed	60

RESULTS

(1) Hydrological Data

A summary of the annual totals (mm over the catchment) of rainfall, runoff and potential evapotranspiration from Shenley Brook for the years

1973 to 1983 (inc.) is shown in Table 2. The results obtained from the Grendon catchment, a nearby larger clay catchment in Buckinghamshire (Mandeville et al., 1970) are shown for comparison.

The results show that the years covering this study period (1978-1983) were unexceptional, in terms of rainfall, runoff and evaporation, compared with previous years. They also show a very good agreement between the rainfall and runoff totals at Shenley with those at Grendon particularly during the period 1972-1977. During the study period, however, rainfall inputs at Shenley were consistently higher than those at Grendon. This resulted in a higher runoff from Shenley so that, in terms of water use (rainfall-runoff), the two catchments behaved very similarly throughout 1973-1983. This suggests that, on an annual basis at least, the hydrological conditions experienced at Shenley Brook may be typical of a substantial area of Southern England.

Potential evaporation, as calculated from the data collected manually once a day at the meteorological station (Penman, 1948), is generally higher at Shenley than at Grendon. This is attributed to the fact that the meteorological site at Shenley is more exposed than that at Grendon and consequently wind speeds are greater.

(2) Streamflow nitrate-N concentrations

The nitrate-N concentrations found in the streamflow samples are shown in Fig.4. The concentrations varied a great deal particularly during high flows. Therefore, in order to demonstrate trends in concentration, they are shown as weekly mean values (not flow weighted) in mg/ℓ. The horizontal dotted line indicates the World Health Organisation recommended limit for nitrate-N concentrations in drinking water, 11.3 mg/ℓ. Mean weekly soil moisture deficits (mm) obtained from the Meteorological Office (MORECS, 1981) and weekly runoff totals (mm) are also shown. Daily values of the three variables are plotted, on an annual basis, in the appendix.

The annual patterns in stream nitrate-N concentrations are remarkably similar showing high concentrations in the autumn or winter when flow resumes. These concentrations gradually decrease during the winter months

	SHENLEY BROOK			GRENDON		
YEAR	RAINFALL	RUNOFF	EVAPORATION	RAINFALL	RUNOFF	EVAPORATION
1973	468.0	34.8	572.1	464.8	29.9	492.8
1974	806.0	270.6	519.5	784.7	246.0	461.4
1975	540.6	198.6	620.6	517.9	152.0	518.2
1976	505.7	63.4	660.9	485.3	66.4	545.1
1977	692.7	232.5	507.8	701.7	240.0	444.0
1978	608.8	180.8	489.3	541.5	152.0	550.6
1979	788.8	328.7	494.6	746.4	250.5	431.6
1980	693.7	295.9	523.8	636.5	147.6	433.9
1981	754.7	346.9	515.5	653.2	212.9	405.7
1982	721.7	263.3	557.9	650.2	198.8	485.2
1983	637.8	206.0	586.1	562.9	141.4	473.3

TABLE 2. ANNUAL RAINFALL, RUNOFF AND POTENTIAL EVAPORATION (MM) FROM SHENLEY AND GRENDON.

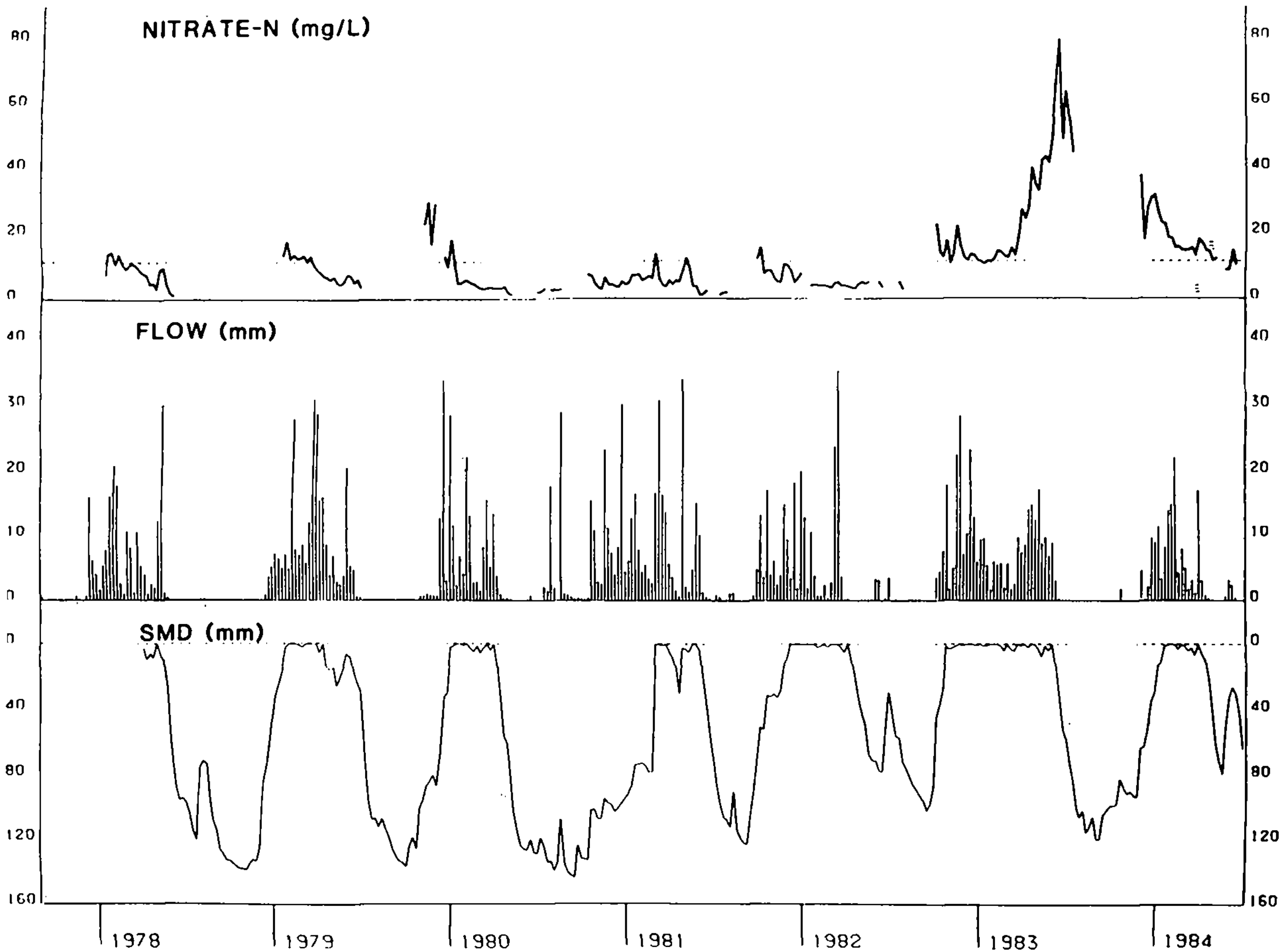

FIG. 4 WEEKLY FLOW,SOIL MOISTURE DEFICIT AND NITRATE-N CONCENTRATIONS AT SHENLEY BROOK

followed by an increase and a peak concentration in the spring. This spring peak is particularly evident during 1983 when nitrate-N concentrations exceeded 80 mg/ℓ for six days during May with a peak value of 110 mg/ℓ. One exception to the general autumn to spring concentration pattern is 1980/81 when the concentrations remained fairly constant throughout. The significance of these patterns in terms of agricultural practices and climatological conditions will be discussed later.

Within the general pattern of stream nitrate-N concentrations, there is a great deal of scatter. An increase in flow is generally, but not always, accompanied by an increase in concentration. On the other hand, peak concentrations often occur in the absence of an increase in flow. Similar patterns have been found in other catchments though, in general, an increase in streamflow in the summer months will cause an increase in nitrate concentration whilst an increase in the winter will cause a dilution (Webb & Walling, 1985). This suggests that these nitrate-N concentrations depend, not only on rainfall inputs to leach the soil, but also on the availability of leachable nitrogen within the soil profile.

(3) Rainfall nitrogen concentrations

Unlike the streamflow samples, where it has been assumed that a good estimation of nitrogen loss can be obtained by analysing only for nitrate-N, the results obtained from analysing the rainfall samples for ammonium-N, nitrate-N and organic N at MAFF, Trawscoed during the early part of the study showed conclusively that nitrate-N is only a relatively small part of the nitrogen content of rainfall. This is demonstrated in Fig.5 where total N (NH4-N, NO3-N and organic N) concentrations are plotted against nitrate-N for the results obtained. The dotted line shows the least squares regression. For those periods (1982 onwards) when only nitrate-N analysis was done on the rainfall samples, this regression (TOTAL N=1.23 + 1.75 NITRATE-N) was used to calculate total N concentrations.

The data shown in Fig.5 suggest that this regression overestimates total N as it is influenced by the results from two samples collected in the summer months of 1980 having high concentrations of ammonium-N and organic N, probably as a result of windblown organic debris being trapped

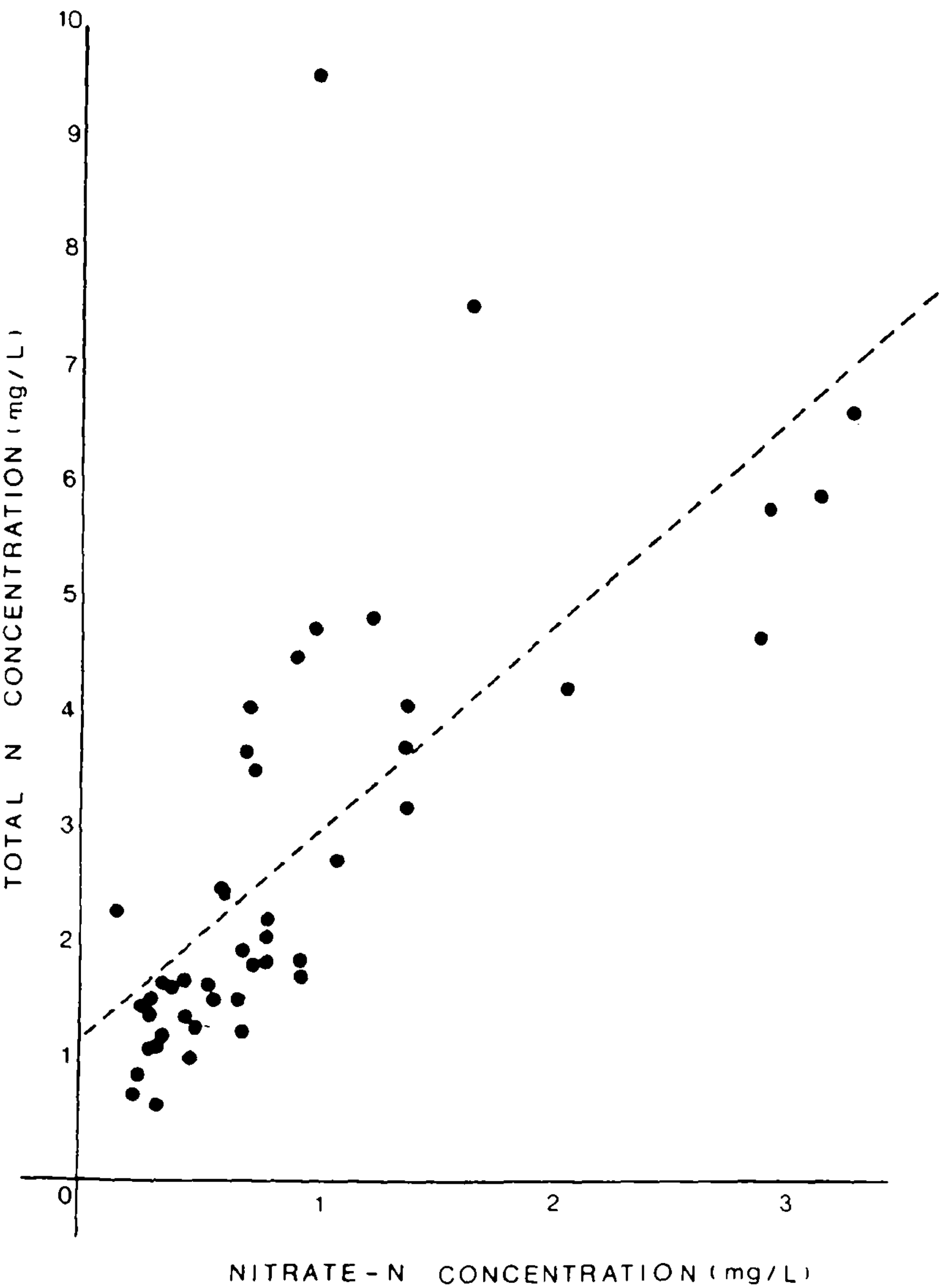

FIG.5 TOTAL NITROGEN AND NITRATE-N CONCENTRATIONS IN RAINFALL SAMPLES AT SHENLEY BROOK END

in the collector. Other studies suggest an average total N concentration in rainfall for England and Wales of about 1 mg/ℓ (Wilkinson and Greene, 1982) though no indication is given whether this includes dry deposition. This compares with an average value of 2.82 mg/ℓ for this study (2.91 mg/ℓ from the results of actual total N analyses and 2.77 mg/ℓ from the regression). The concentrations varied from 0.68 to 15.74 mg/ℓ, the higher values generally occurring during the summer months, again probably as a result of the leaching of organic debris. Since the rainfall samples are a combination of wet and dry deposition they can be regarded as referring to 'bulk deposition' as defined by Whitehead and Feth, 1964.

NITROGEN INPUTS AND OUTPUTS

Nitrogen inputs in rainfall are calculated as the product of the rainfall total and the total nitrogen concentration in the sample applicable to that period as indicated below:-

$$\text{TOTAL N INPUT} = \frac{\text{RAINFALL TOTAL} * \text{TOTAL N conc.}}{100} \quad \text{(kg/ha)}$$

When the rainfall samples were analysed at Trawscoed, total N concentration was expressed as the sum of nitrate-N and Kjeldahl N whereas the regression described in the previous section was used during those periods when only a nitrate-N analysis was performed. Rainfall sampling began in January 1979 so no input data for 1978 are available.

In the case of nitrogen outputs in streamflow, the results of the chemical analyses carried out on all of the samples collected, both eight-hourly and half-hourly during storm events, are used together with the appropriate streamflow totals. Also, as indicated previously it is assumed that all nitrogen streamflow losses are in the nitrate form.

Monthly nitrogen inputs in rainfall and outputs in streamflow together with net inputs (input - output) are given in Table 3 and Fig.6. Annual total nitrogen inputs in rainfall during the study period are in the range 13-25 kg/ha. This compares with the widely accepted value of 10 kg/ha for England and Wales (Wilkinson and Greene, 1982) though the values quoted in

TABLE 3. MONTHLY NITROGEN INPUTS IN RAINFALL, OUTPUTS IN STREAMFLOW AND NET INPUTS (INPUT-OUTPUT), kg/ha AT SHENLEY BROOK END

MONTH	INPUT	OUTPUT	NET INPUT
1978			
JAN		5.59	
FEB		4.01	
MARCH		2.69	
APRIL		0.72	
MAY		4.61	
JUNE			
JULY			
AUG		0.02	
SEPT			
OCT			
NOV			
DEC		3.29	
		20.93	
1979			
JAN	0.89	3.96	-3.07
FEB	0.72	6.92	-6.20
MARCH	2.69	8.66	-5.97
APRIL	1.31	2.66	-1.35
MAY	1.50	2.37	-0.87
JUNE	0.45	0.52	-0.07
JULY	0.32		+0.32
AUG	1.06		+1.06
SEPT	0.27		+0.27
OCT	0.89	0.12	+0.77
NOV	0.38	0.74	-0.36
DEC	2.56	10.00	-7.44
	13.04	35.95	-22.91
1980			
JAN	0.91	2.48	-1.57
FEB	1.09	2.03	-0.94
MARCH	1.81	1.33	+0.48
APRIL	0.78	0.45	+0.33
MAY	1.42		+1.42
JUNE	7.55	0.02	+7.53
JULY	3.04	0.85	+2.19
AUG	1.61	1.34	+0.27
SEPT	0.39	0.19	+0.20
OCT	1.56	1.73	-0.17
NOV	3.04	2.70	+0.34
DEC	0.71	2.23	-1.52
	23.91	15.35	+8.56
1981			
JAN	0.59	3.00	-2.41
FEB	0.51	1.31	-0.80
MARCH	3.65	5.65	-2.00
APRIL	2.16	2.72	-0.56
MAY	2.51	1.48	+1.03
JUNE	1.03	0.13	+0.90
JULY	2.36	0.03	+2.33
AUG	1.45	0.12	+1.33
SEPT	3.31	0.44	+2.87
OCT	3.33	5.90	-2.57
NOV	1.90	3.17	-1.27
DEC	1.84	2.40	-0.56
	24.64	26.35	-1.71
1982			
JAN	1.65	1.02	+0.63
FEB	1.09	0.20	+0.89
MARCH	3.48	3.47	+0.01
APRIL	0.71	0.02	+0.69
MAY	2.04	0.01	+2.03
JUNE	4.36	0.58	+3.78
JULY	1.27	0.01	+1.26
AUG	1.25		+1.25
SEPT	0.77		+0.77
OCT	1.61	5.96	-4.35
NOV	1.70	10.73	-9.03
DEC	0.79	6.44	-5.65
	20.72	28.44	-7.72
1983			
JAN	1.15	3.20	-2.05
FEB	0.63	2.71	-2.08
MARCH	2.79	5.14	-2.35
APRIL	2.35	16.91	-14.56
MAY	3.12	16.30	-13.18
JUNE	1.69	6.52	-4.83
JULY	2.01	0.10	+1.91
AUG	0.31		+0.31
SEPT	0.97	0.08	+0.89
OCT	0.74	0.89	-0.15
NOV	0.65	2.08	-1.43
DEC	0.72	7.11	-6.39
	17.13	61.04	-43.91
1984			
JAN	1.04	10.46	-9.42
FEB	0.99	6.12	-5.13
MARCH	1.10	4.80	-3.70
APRIL	0.27	0.47	-0.20
MAY	1.99	0.56	+0.43
JUNE	1.02	0.55	+0.47

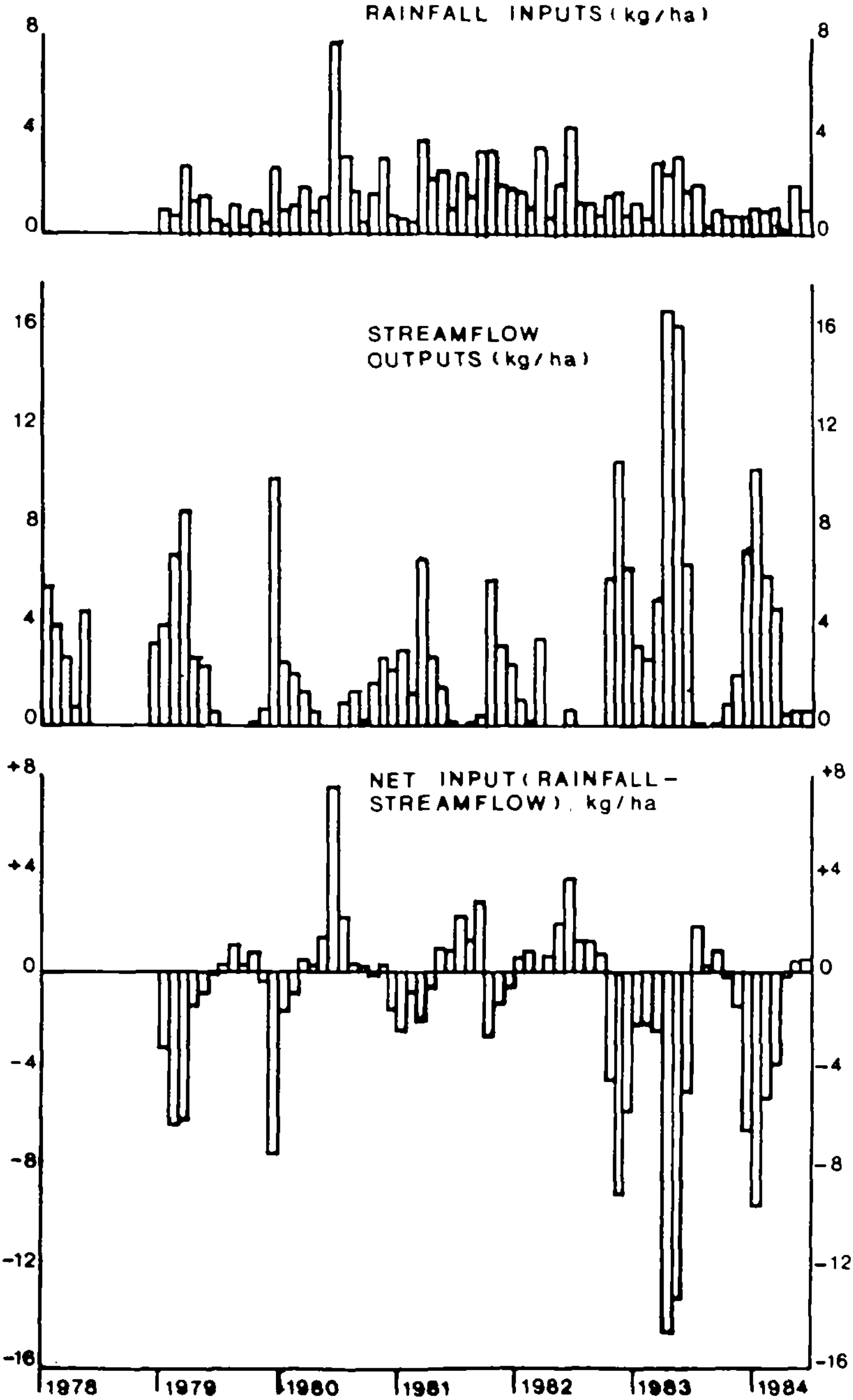

FIG. 6 MONTHLY NITROGEN RAINFALL INPUTS, STREAMFLOW OUTPUTS AND NET INPUTS.

the literature for eastern England can be as low as 5 and as high as 16 kg/ha (Edwards, 1973,b). In general, they are well correlated with rainfall totals ie. there is no indication of either an increasing or decreasing trend in nitrogen concentration in rainfall over the study period. However, such generalizations are difficult because these estimated inputs are often influenced to a great extent by one value, particularly during the summer months when one sample, often containing a great deal of organic debris, will represent several weeks' rainfall. This is especially so in June 1980 when by far the largest N monthly input calculated was dominated by one sample containing 3.4 mg/ℓ of ammonium-N, 1.0 mg/ℓ of nitrate-N and 5.2 mg/ℓ of organic N. Whether such samples are a good representation of inputs to the catchment as a whole is unlikely.

Annual total nitrogen outputs in streamflow are higher than inputs in rainfall and are much more variable. Also, they are not highly correlated with streamflow totals or with inputs in rainfall. The high variability in these losses in streamflow are a reflection of the variability in the stream nitrogen concentrations illustrated in Fig.4 and the appendix. This is particularly so during the spring of 1983. In this case, this was not due to any one particular sample but was as a result of high stream nitrogen concentrations extending over a considerable period of time.

The trend in the net nitrogen input (rainfall - runoff) is very similar over the six years studied though a large variation in magnitude occurs. There is generally a net input of nitrogen during the summer months when flows cease and high nitrogen concentrations occur in the rainfall. This is more than counterbalanced by net losses during the winter when the nitrogen concentrations in the streamflow are much higher than those in the rainfall.

When attempting to calculate a complete nitrogen balance for the catchment, a decision has to be made on the time interval over which such a balance is to be calculated. A calendar year is not suitable, as this would split the period during which streamflow occurs. It is much more sensible to ensure that the start of the balance year coincides with the beginning of flow in the autumn and the end coincides with the cessation of flow in the following summer. Such an approach has been adopted in other nutrient balance studies (see, for example Barraclough et al., 1984). Accordingly, the fertilizer used and crop offtake for 1978 are compared with rainfall inputs and streamflow losses in the winter 1978/79. This is also done in the following years.

The components of the nitrogen balance which can be measured or estimated are as follows:-

(1) Inputs in fertilizers and manures brought into the catchment, and rain falling on it.
(2) Offtakes in crops and livestock products from the catchment.
(3) Losses in streamflow.

Components of the nitrogen cycle for which no values have been attributed include changes in the amount held in the soil, gains in nitrogen fixation and losses in denitrification. Typical values for these will be discussed later.

Inputs in rainfall and outputs in streamflow have been measured reasonably accurately but, for reasons mentioned earlier, it is quite likely that an overestimation of inputs and an underestimation of outputs has been made. Their relevance to the nitrogen balance as a whole will be discussed later.

Nitrogen removal from the catchment has been measured as described previously, but this estimate is subject to very considerable uncertainty and is the least accurate of the figures entering into the nitrogen balance. On the other hand, the estimation of the nitrogen inputs in fertilizers and manures was straightforward. It is calculated from the know fertilizer dressings on each field and the field area (Table 1). By dividing this by the area of the whole catchment including the woodland, a fertilizer input figure per hectare of catchment was obtained for each cropping year. Similarly a nitrogen input from manures was calculated by adding the amounts of total nitrogen from manures spread on fields in the catchment, using figures for the total nitrogen content of manures (ADAS, 1983). The total nitrogen content of manures was used rather than the available nitrogen as the latter is rather arbitrary. Manure dropped by grazing livestock was not considered as it is not a net input into the catchment.

Nitrogen balances based on all these estimates, expressed in kg/ha, are given in Table 4.

DISCUSSION

The data presented in this report highlight two major points:-

(1) The trends in the streamflow nitrate-N concentrations and possible factors affecting these trends. In this respect, the very high concentrations experienced during the spring of 1983 will be particularly relevant.

(2) The nitrogen balance or, to be more precise, the lack of balance found for most of the years under study.

High nitrogen, particularly nitrate-N, concentrations in streamflows in the autumn months are a common and well-documented occurrence from many parts of the country (White et al., 1983; Edwards, 1973,a; Foster and Walling, 1978). This so-called 'autumn flush' has been attributed to the leaching, by the first autumn rains, of readily soluble material accumulated within the soil profile during the preceding dry summer months. It has generally been found that, the drier the summer, the greater the autumn flush. This was especially apparent during 1976 when nitrate-N concentrations increased by up to 50-fold in a 9.3 sq km catchment in East Devon (Foster and Walling, 1978).

At Shenley, the biggest agricultural change that occurred during the study period was in 1979/80 when there was a conversion of some 20% of the permanent grassland to temporary grassland and arable land. Even so, the overall annual fertilizer application rate to the catchment remained fairly constant at about 108 kg/ha with a slight trend of reduced rates in the latter half of the study period. Also, there is no evidence of increasing or decreasing nitrogen concentrations in the incoming rainfall. This suggests that the year to year variations in the autumn flush experienced at Shenley are likely to be a function of the climatological and hydrological conditions rather than to any specific agricultural practices. This is also true for the spring peak nitrate-N concentrations experienced during some years. However, the agricultural practices cannot

TABLE 4. NITROGEN BALANCES FOR THE SHENLEY BROOK END CATCHMENT

	INPUTS		OUTPUTS	
1978/79	FERTILIZERS, MANURES	= 110 kg/ha	CROP OFFTAKE	= 82 kg/ha
	RAINFALL	= 11 (estimated)	STREAMFLOW	= 28 "
	EXCESS OF GAIN OVER LOSS = 11 kg/ha			
1979/80	FERTILIZERS, MANURES	= 136 kg/ha	CROP OFFTAKE	= 79 kg/ha
	RAINFALL	= 10	STREAMFLOW	= 17 "
	EXCESS OF GAIN OVER LOSS = 50 kg/ha			
1980/81	FERTILIZERS, MANURES	= 109 kg/ha	CROP OFFTAKE	= 72 kg/ha
	RAINFALL	= 30	STREAMFLOW	= 23 "
	EXCESS OF GAIN OVER LOSS = 44 kg/ha			
1981/82	FERTILIZERS, MANURES	= 105 kg/ha	CROP OFFTAKE	= 83 kg/ha
	RAINFALL	= 29	STREAMFLOW	= 17 "
	EXCESS OF GAIN OVER LOSS = 34 kg/ha			
1982/83	FERTILIZERS, MANURES	= 90 kg/ha	CROP OFFTAKE	= 74 kg/ha
	RAINFALL	= 19	STREAMFLOW	= 74 "
	EXCESS OF GAIN OVER LOSS = -39 kg/ha			
1983/84	FERTILIZERS, MANURES	= 114 kg/ha	CROP OFFTAKE	= 68 kg/ha
	RAINFALL	= 9	STREAMFLOW	= 33 "
	EXCESS OF GAIN OVER LOSS = 22 kg/ha			

be disregarded because it is the interaction of the hydrological conditions with these practices which is likely to control nitrate release. In particular, the climatological conditions immediately following fertilizer applications are crucial in determining how much of this applied nitrogen is retained by the system.

The bulk of the fertilizer used at Shenley Brook is applied in the spring, usually during late March or early April depending on the conditions. The stream nitrate-N concentrations shown in Fig.4 and in the appendix show that, where increases in concentration occur during the spring, they are generally short-lived and very little of the applied fertilizer is lost by being leached into the stream. An obvious exception to this is 1983 when a massive increase in concentration occurred during June culminating in a peak concentration of 110 mg/ℓ. Similar spring peaks have been reported elsewhere. For example, nitrate-N concentrations of over 10 mg/ℓ, with a maximum of 26 mg/ℓ, were obtained in April 1973 at the Great House Experimental Husbandry Farm. This was caused by 66 mm of rainfall in 72 hours following a long dry period during which an application of pig slurry and farmyard manure had been applied to the land (Webber and Wadsworth, 1976). An examination of the soil moisture deficits (Fig.4 and appendix) suggests a reason for the occurrence at Shenley. During the winter of 1982/83 no soil moisture deficit existed from the beginning of November 1982 to the end of May 1983, a much longer period than any of the other years studied. This means that the pathways for leaching excess nitrate from the soil remained open throughout this period and, more importantly, were still open in the period immediately following the fertilizer application in the spring. The spring of 1983 was one of the wettest experienced during the course of the study, resulting in sustained flows throughout the spring until the middle of July.

Similar, though much smaller, peaks were evident for those years (1978, 1979, 1981) when field capacity (zero soil moisture deficit) was maintained beyond the time when fertilizer applications were made (appendix). It seems therefore that spring peak nitrate-N concentrations are as a result of a combination of zero soil moisture deficit and rainfall following the fertilizer application. The results from 1983 also suggest that, the longer the soil has been at field capacity, the higher the spring peak stream nitrate-N concentration will be, though this latter observation is based only on the one year.

Average winter streamflow nitrate-N concentrations are highly dependent on the hydrological conditions during the previous summer. Fig.7 shows the winter mean nitrate-N concentrations (January-March) plotted against the number of days in the preceding summer having a soil moisture deficit. The data exhibit a great deal of scatter suggesting that other factors influence these concentrations. These include summer soil temperature, whether any runoff occurred during the summer months and the timing and intensity of the first autumn storms. Similar observations have been made by other workers eg. Burt et al., 1984; Foster and Walling, 1978. Such a relationship has been termed the "catchment's memory" by Burt et al., 1984 and reflects the build up of mineralized nitrogen in the soil during the warm dry months whereas, during a wetter summer, any excess nitrogen will be leached into the stream. Why such high winter nitrate-N concentrations should occur in 1982/83 and 1983/84 is unclear but the latter may well be associated with the massive losses that occurred during the spring of 1983. Some of the applied fertilizer may have been leached beyond the rooting zone in the spring to be further leached into the stream in the following winter.

Although many studies of nitrogen losses from British catchments have been reported in the literature, most are from much larger catchments than Shenley Brook. These generally contain significant urban areas where nitrogen from sewage effluent is a large proportion of the total N load. Studies from small catchments where virtually all the nitrogen load in the streamflow can be attributed to an agricultural origin are less numerous. Streamflow nitrogen losses, together with catchment size, land use and fertilizer application rates where available from this and other studies are shown in Table 5. The results given show large year to year variations and also differences in nitrogen losses for site to site. For the River Dart at Devon (Webb and Walling, 1985), the lowest value, 8.3 kg/ha, was obtained during the drought year 1975/76, whilst the highest value, 51.4 kg/ha, was obtained in the following year and was mainly due to a huge flushing effect in the autumn of 1976. If these two years are disregarded, then the range of annual losses, 18-27 kg/ha, is much narrower. Similarly, if the 1982/83 year for the Shenley Brook Study is disregarded, then the range is 17-33 kg/ha. Clearly by ignoring these 'untypical' years, the

FIG 7 MEAN WINTER STREAMFLOW NITRATE-N CONCENTRATION vs NUMBER OF DAYS IN PREVIOUS SUMMER SHOWING A SOIL MOISTURE DEFICIT

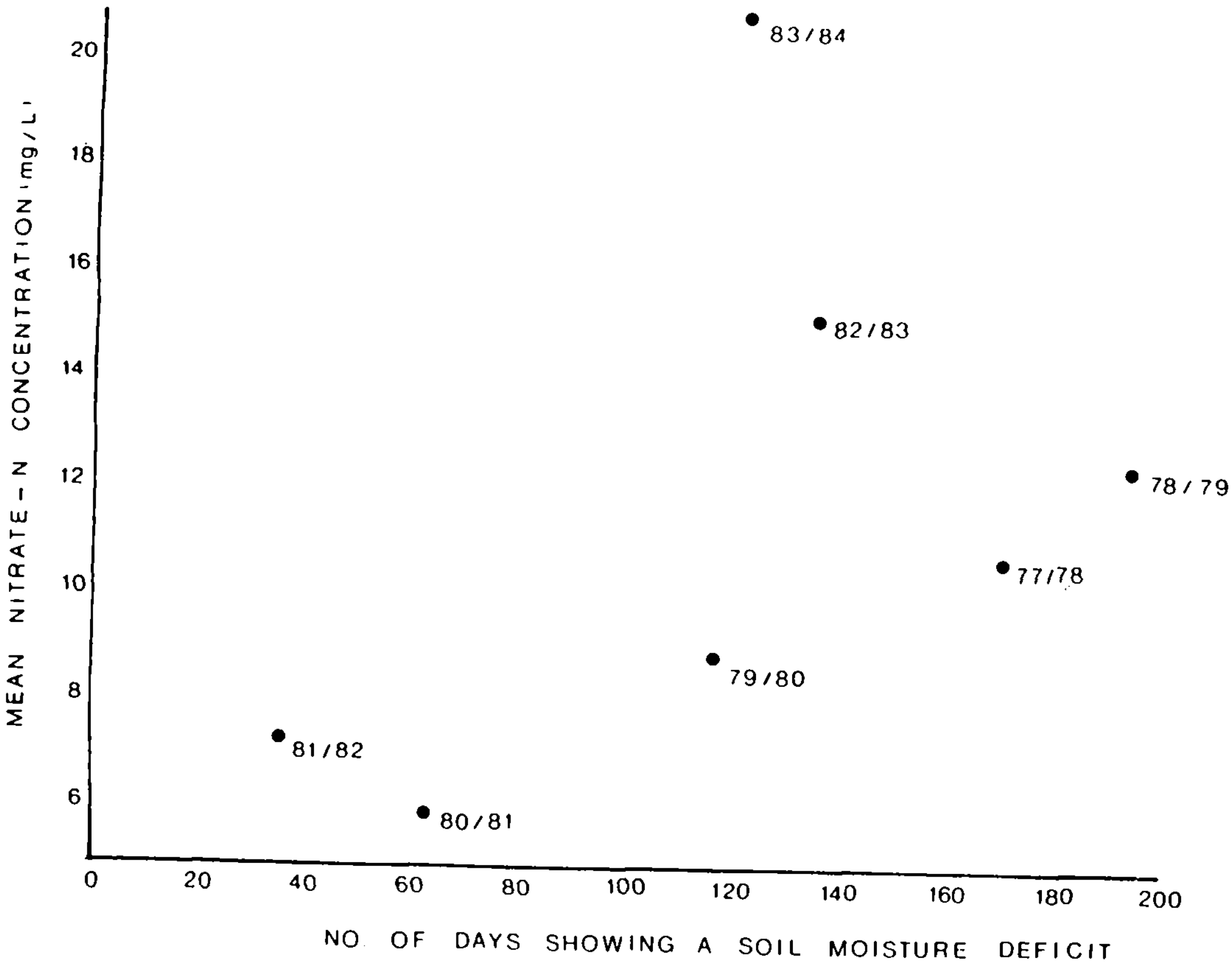

TABLE 5 STREAMFLOW NITROGEN LOSSES FROM SHENLEY BROOK AND OTHER AGRICULTURAL CATCHMENTS

CATCHMENT	AREA (sq.km)	ARABLE	PASTURE	WOODLAND	URBAN	FERTILIZER RATE (kg/ha)	N LOSSES (kg/ha/yr)
SHENLEY BROOK (this study)	1.7	23%	66%	11%		~120	17-74 (MEAN 32)
DART, DEVON (Webb and Walling, 1985)	46	~5%	~89%	~5.5%			8.3-51.4 (MEAN 24)
FROME) WYE Valley	144	35%	59.5%	5.1%	1.3%	~105	MEAN 8.9
TROTHY)	142	14%	82.8%	2.3%	1.0%	~105	MEAN 10.2
(Houston and Brooker, 1980)							
YARE) NORFOLK	232	MAINLY AGRICULTURAL WITH MUCH ARABLE LAND				~65	MEAN 14
TUD)	73					~65	MEAN 10
(Edwards, 1973b)							
SLAPTON WOOD) SOUTH	0.94	27%	59.5%	13.5%		48	MEAN 27
STOKELEY BARTON) DEVON	1.50	(				99	MEAN 29
SLAPTON STREAM)	10.8	(~26%	~73%	~0.7%			27
RIVER GARA)	23.6	(					34
(Troake et al., 1976)							
GREAT HOUSE EHF (Webber and Wadsworth, 1976)	0.41		100%			288	40
WYE (upland)	27.2	(					2.7
LUGG	1030	(20%	66%	9%			27.2
RIVER WYE	4010	(					16.7
(Oborne et al., 1980)							

range of losses from the various catchments become remarkably similar considering the variations in climate, topography, soil types, geology, agricultural practices etc. An obvious exception to this is the upper Wye (Oborne et al., 1980). However, the agricultural practices employed in this upland catchment are likely to be much less intensive than in the others.

Many studies have been conducted over the years to assess nitrogen leaching losses under different land uses. Most of these studies have been carried out in small plots or lysimeters and the results obtained have varied a great deal between studies and between years. For example, Colbourn, 1985 found leaching losses of 35 kg N ha^{-1} annually from intensive winter cereal production when conventional tillage methods were employed whilst Dowdell et al., 1984, found losses of 65-83 kg N ha^{-1} annually from spring barley receiving 120 kg N ha^{-1}. Other studies reflect the wide variation in the results obtained with quoted losses varying between 27 and 85 kg N ha^{-1}. Leaching losses from permanent pasture, on the other hand, are much lower, generally less than 5% of the applied fertilizer (Hood, 1976). If the figure of 1.5% found by Barraclough et al., 1983 is assumed for the grassland areas of Shenley Brook, then the highest annual nitrogen leaching losses for the study period from these areas will only be of the order of 1.5 kg ha^{-1}. If this is the case, and assuming similar small losses from the wooded areas, then the losses from the arable areas were very high ranging from 69-317 kg/ha. Although such losses have been experienced from the ploughing of old pasture (Young et al., 1976), this cannot be the sole reason for the high losses observed during 1982/83. In the first place, the conversion from grassland to arable land at Shenley occurred in 1979/80 and the percentage of catchment involved was much smaller than the 23% that would have been required to produce such large losses. Secondly, the high losses in 1982/83 were due mainly to the high streamflow nitrate-N concentrations during the spring of 1983, whereas ploughing is only carried out in the autumn. Also, it is unlikely that the leaching of the arable land only in the spring of 1983 would have produced such losses. It can only be assumed, therefore, that there was a general loss of applied fertilizer, from both arable land and grassland during this period and that the leaching losses from the grassland areas in 1982/83 were substantially higher than 1.5 kg/ha. During the more "normal" years, when the leaching losses from the grassland and wooded areas would be expected to be in the region of 1.5 kg/ha, those from the arable areas would have to have been approximately 98 kg/ha to produce an average catchment output of 23.6 kg N/ha. This figure is slightly on the high side of those from the lysimeter and small plot studies quoted earlier and may be as a result of a certain amount of ploughing that is done each year.

Differences in the annual total nitrogen inputs and outputs for the Shenley Brook catchment (Table 4) show net inputs for each of the years studied except 1982/83. These net inputs are generally quite large in the region of 11-50 kg/ha. An exception to this is 1982/83 where streamflow nitrate-N concentrations were much higher than in previous years. Similar net inputs have been observed for other systems (Frizzel, 1977). These net inputs are either immobilized in roots and soil organic matter or lost by ammonia volatilization and denitrification. All of these processes are difficult to measure because of spatial variability and reliable field data are scarce. The data quoted in the literature vary a great deal depending on crop type, climatological and hydrological conditions and fertilizer applications. A typical figure for gaseous loss from ploughed soil is 5 kg N ha^{-1} (Colbourn, 1985) whereas denitrification from grassland receiving 250 kg N ha^{-1} is 11.1 kg/ha (Ryden, 1983) with ammonia volatolization from faeces and urine being approximately 5 kg/ha (Frizzel, 1977). Denitrification losses from woodland are considered insignificant. If these figures are applied to Shenley Brook catchment, it would give annual gaseous losses of approximately 12 kg/ha.

It has already been established that nitrogen inputs in rainfall are likely to be overestimated and outputs in stream flow underestimated. No data exist to give an estimate of by how much streamflow losses are underestimated but if the figure of 10 kg/ha/an for rainfall inputs is adopted (Wilkinson and Greene, 1982) instead of the ones measured and an annual gaseous loss of 12 kg/ha assumed, then the balance of the nitrogen inputs and outputs over the study period is very close indeed, at a net input of only 2 kg/ha.

It is likely then that the soil content at Shenley increased during the first few years of the study and then decreased when conditions were conducive for leaching as in the spring of 1983. It is not possible to ascertain whether the high concentrations of nitrate-N in the streamflow during this period originated from the applied fertilizer or from the mineralized nitrogen in the soil profile. However, approximately 40 kg/ha of N was lost in the streamflow during April to June 1983. This compares with an application of about 90 kg/ha. Interestingly, the lowest crop offtake value was calculated for 1983/84, though not by a significant margin compared with some of the previous years.

SUMMARY

Streamflow and rainfall samples were collected from a small agricultural catchment in Buckinghamshire. The samples were analysed for nitrate-N and the results obtained combined with rainfall and runoff totals to calculate nitrogen loads. These loads were used, together with agricultural nitrogen inputs and outputs, to calculate annual nitrogen balances for the catchment. The major findings of the study were:-

(1) Similar annual trends in the streamflow nitrate-N concentrations for all the years studied. This trend consisted of high concentrations in the autumn/winter on the resumption of flow gradually decaying with, in some years, a spring peak concentration. It was found that the level of stream winter nitrate-N concentration was dependent on the hydrological conditions in the previous summer. Similarly, the occurrence and magnitude of the spring peak depended on the hydrological conditions during and following the application of fertilizers in the spring.

(2) The nitrogen balances indicated a substantial net input during most of the years studied though this is subject to some errors in the calculation of inputs and outputs.

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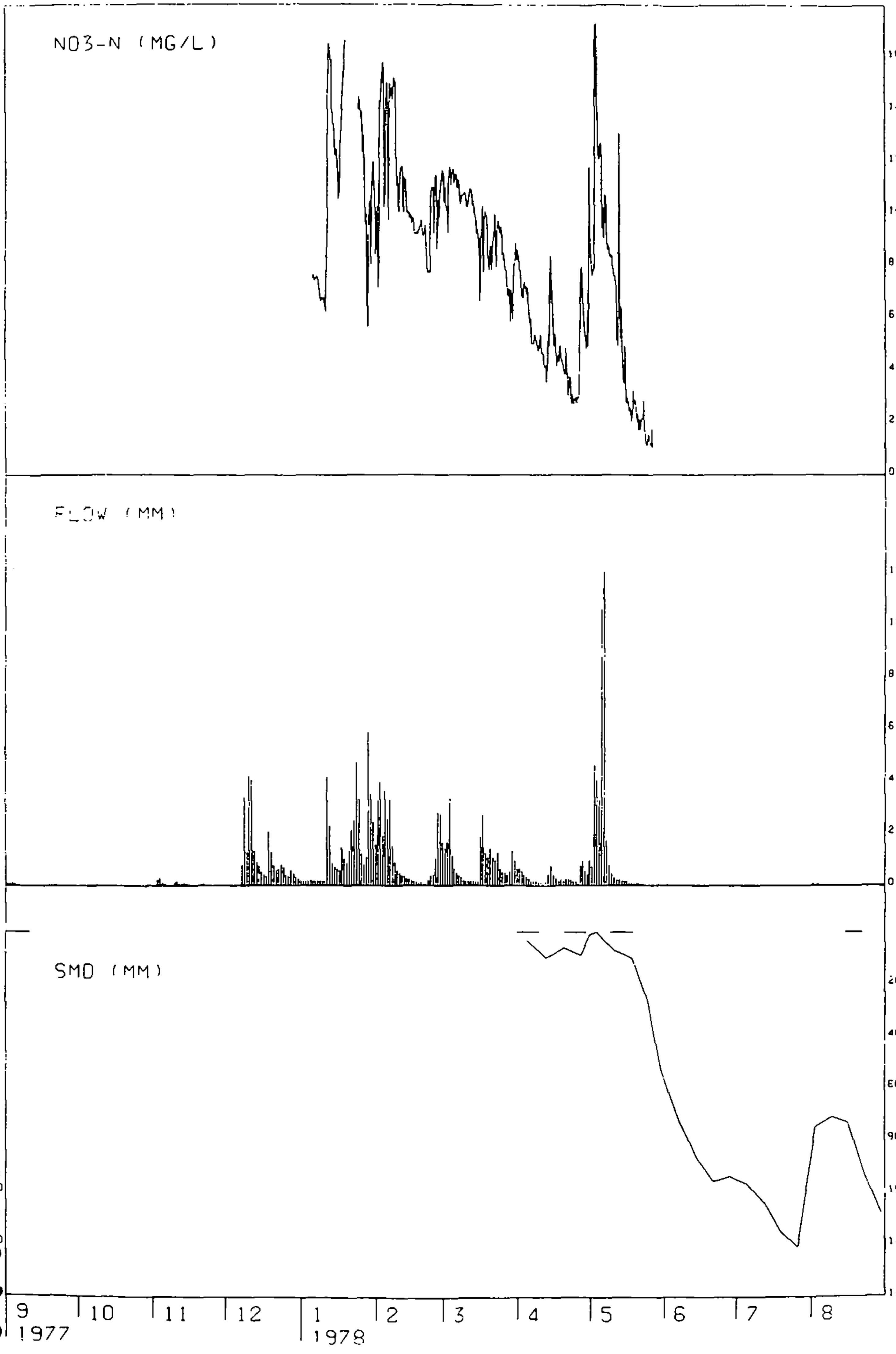
ACKNOWLEDGEMENTS

The author wishes to acknowledge the work done by the staff of the catchment section of the Institute of Hydrology in collecting and processing the hydrological data contained in this report. Many thanks are also given to Colin Chumbley, soil scientist at MAFF, Reading, for providing the data on agricultural nitrogen inputs and outputs, and to the analytical chemists at MAFF Reading, MAFF Trawscoed and at IH for analysing the considerable number of water samples collected.



NO3-N (MG/L)
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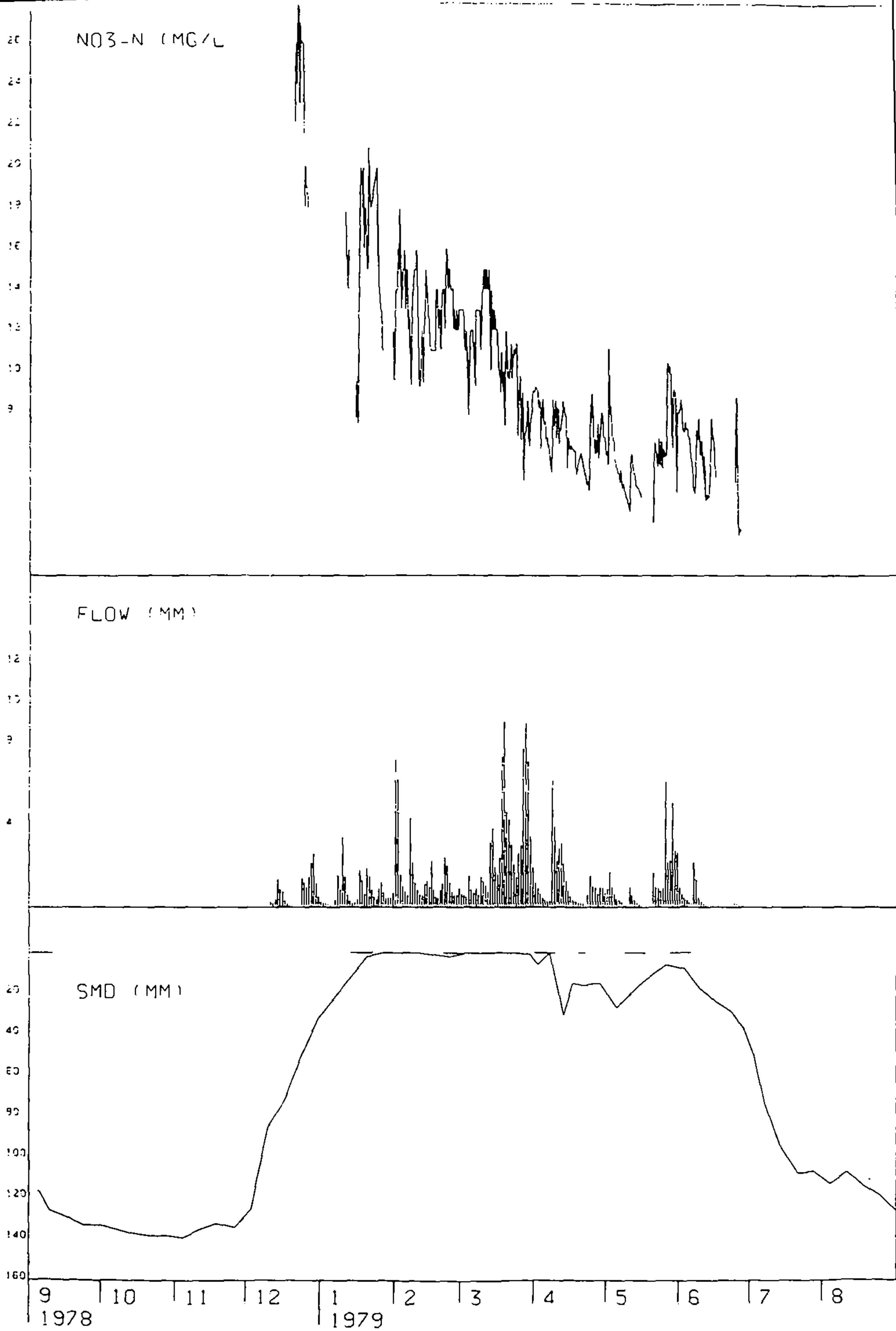

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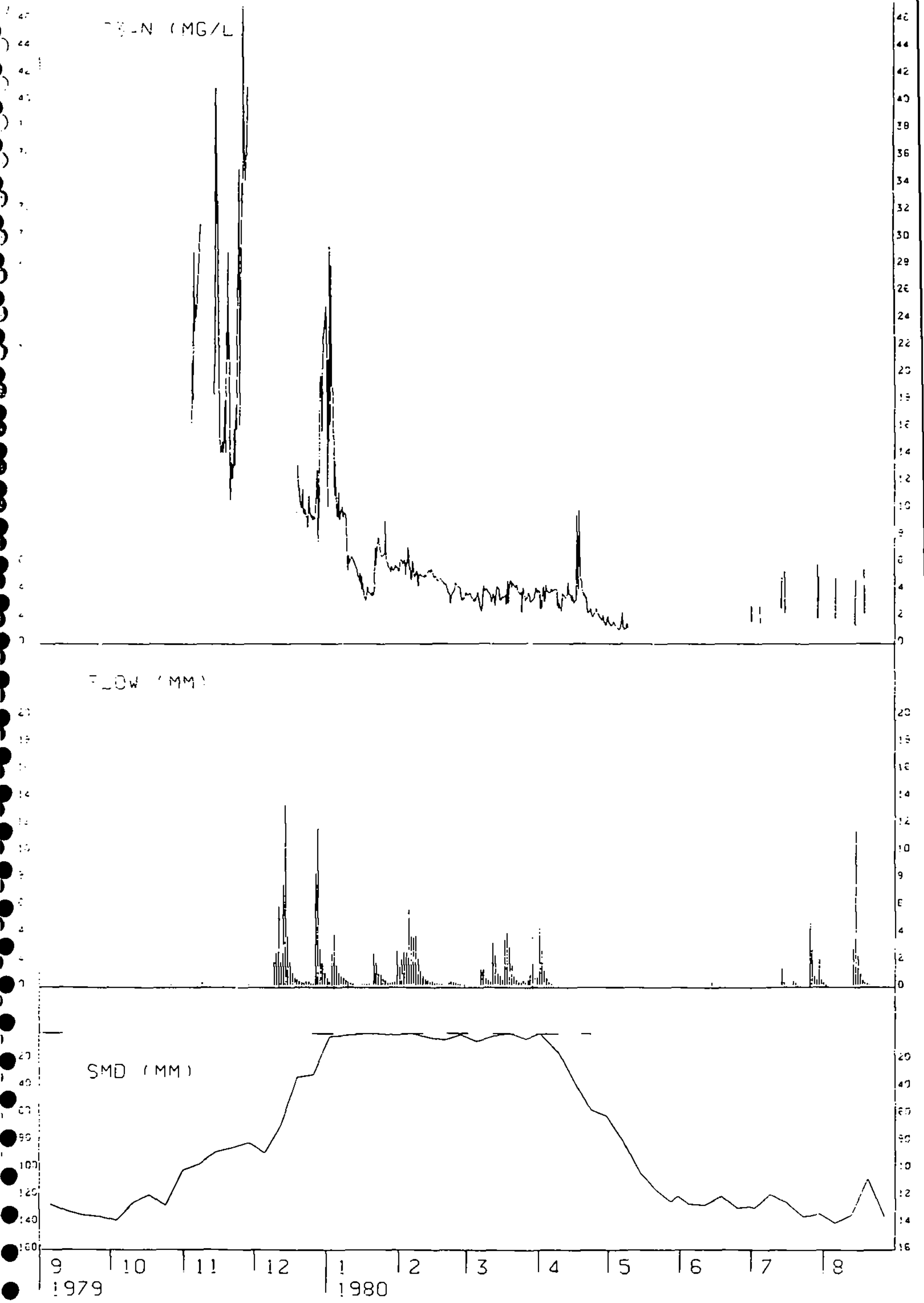

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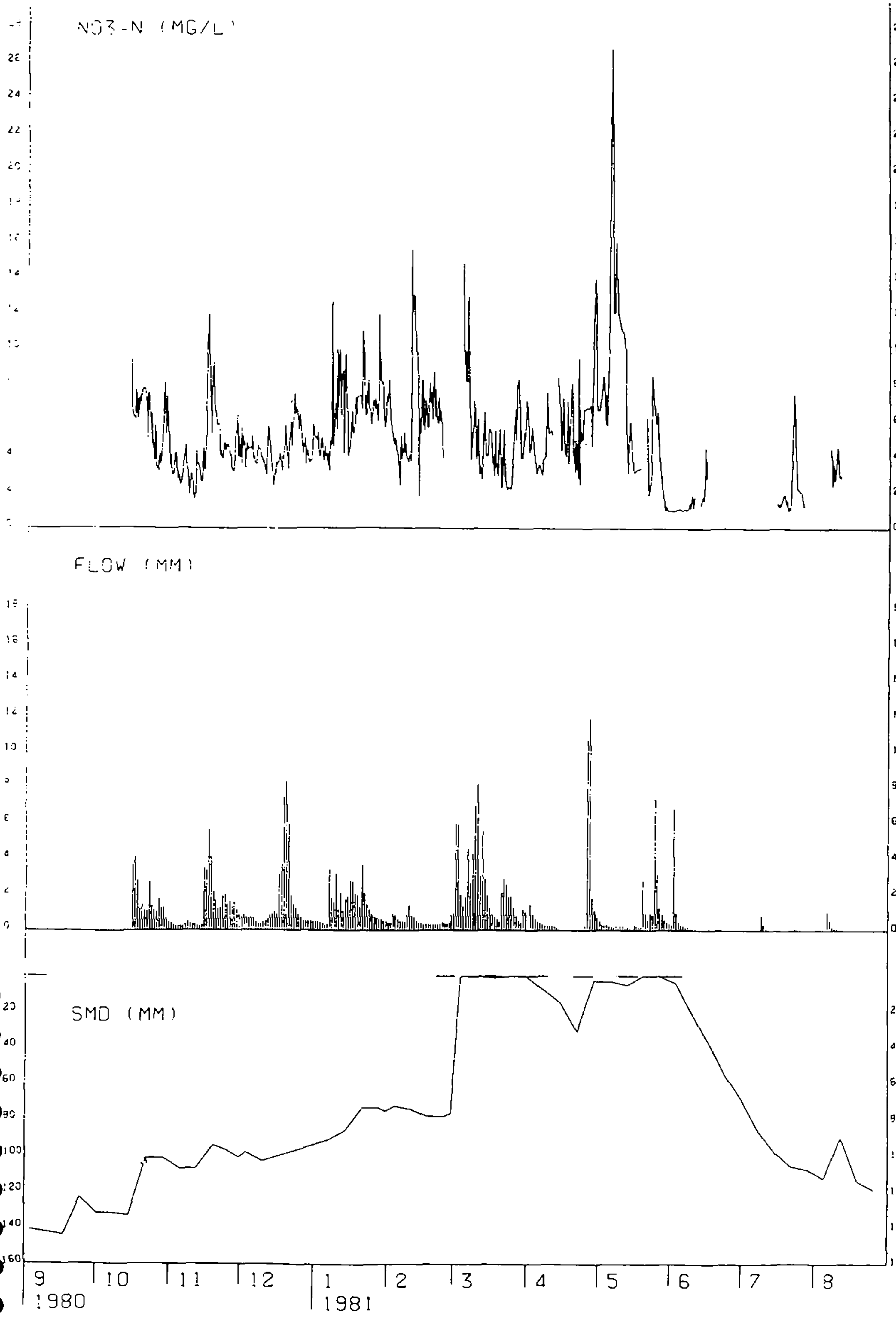

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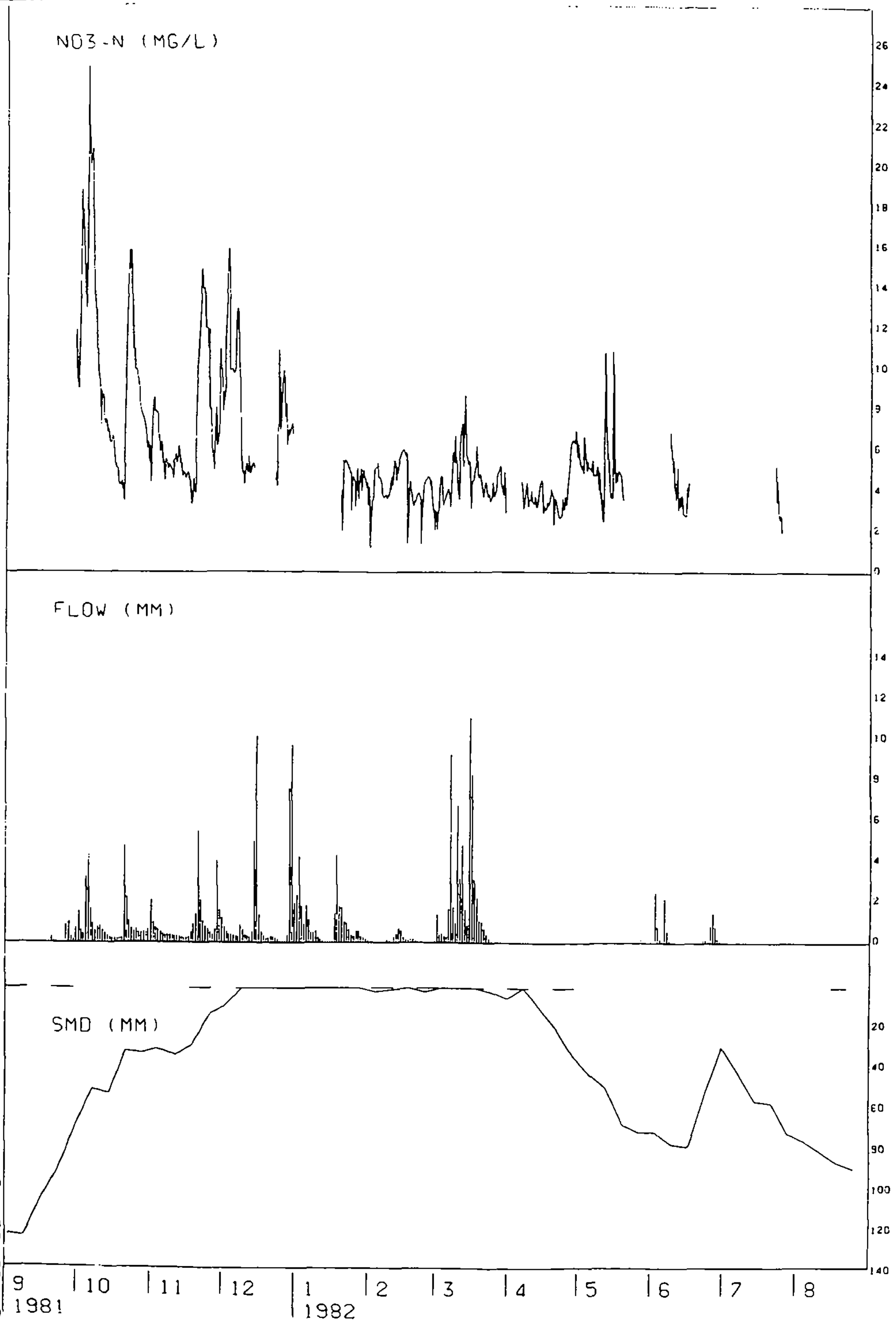
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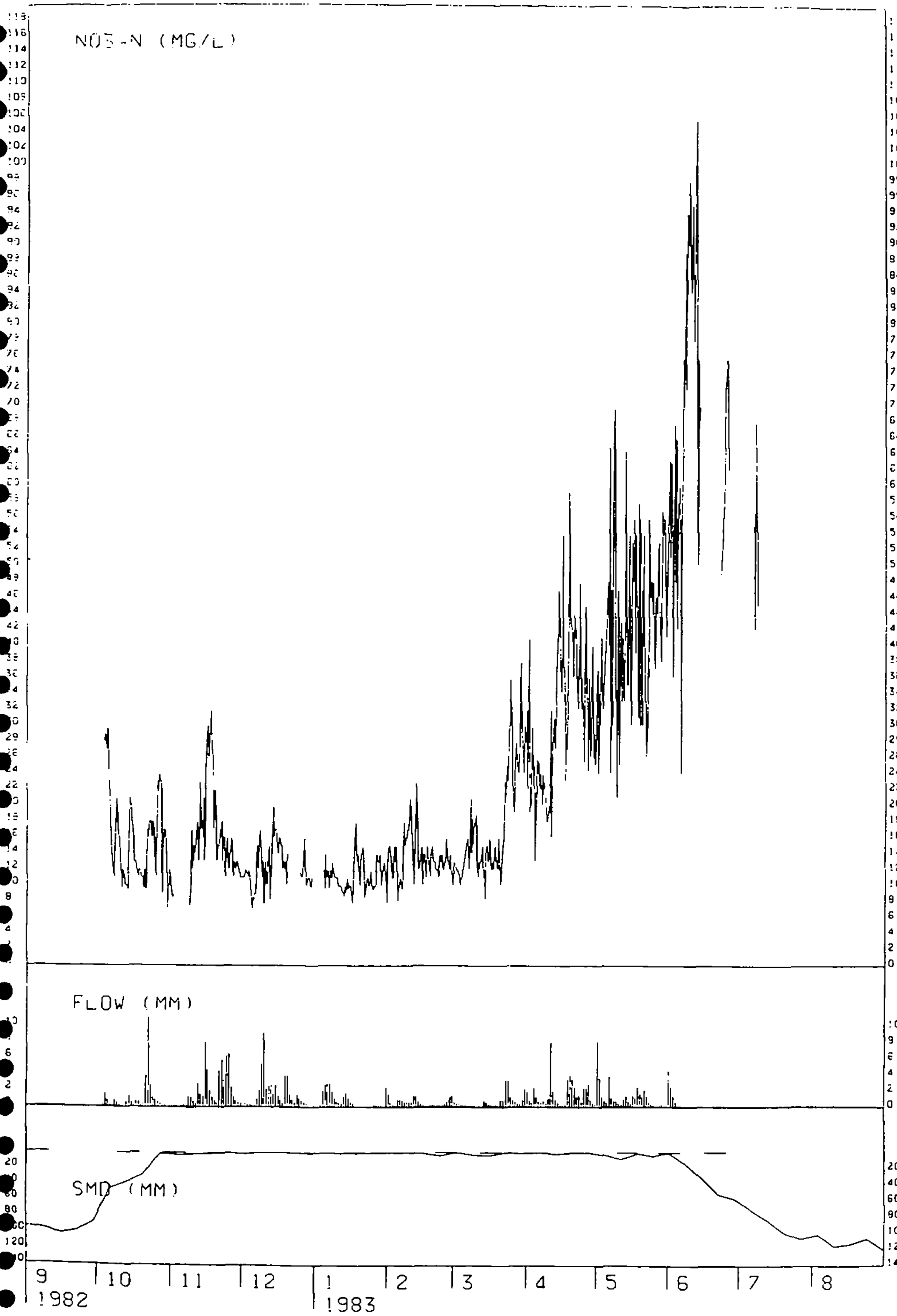

NO3-N (MG/L)
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SMD (MM)
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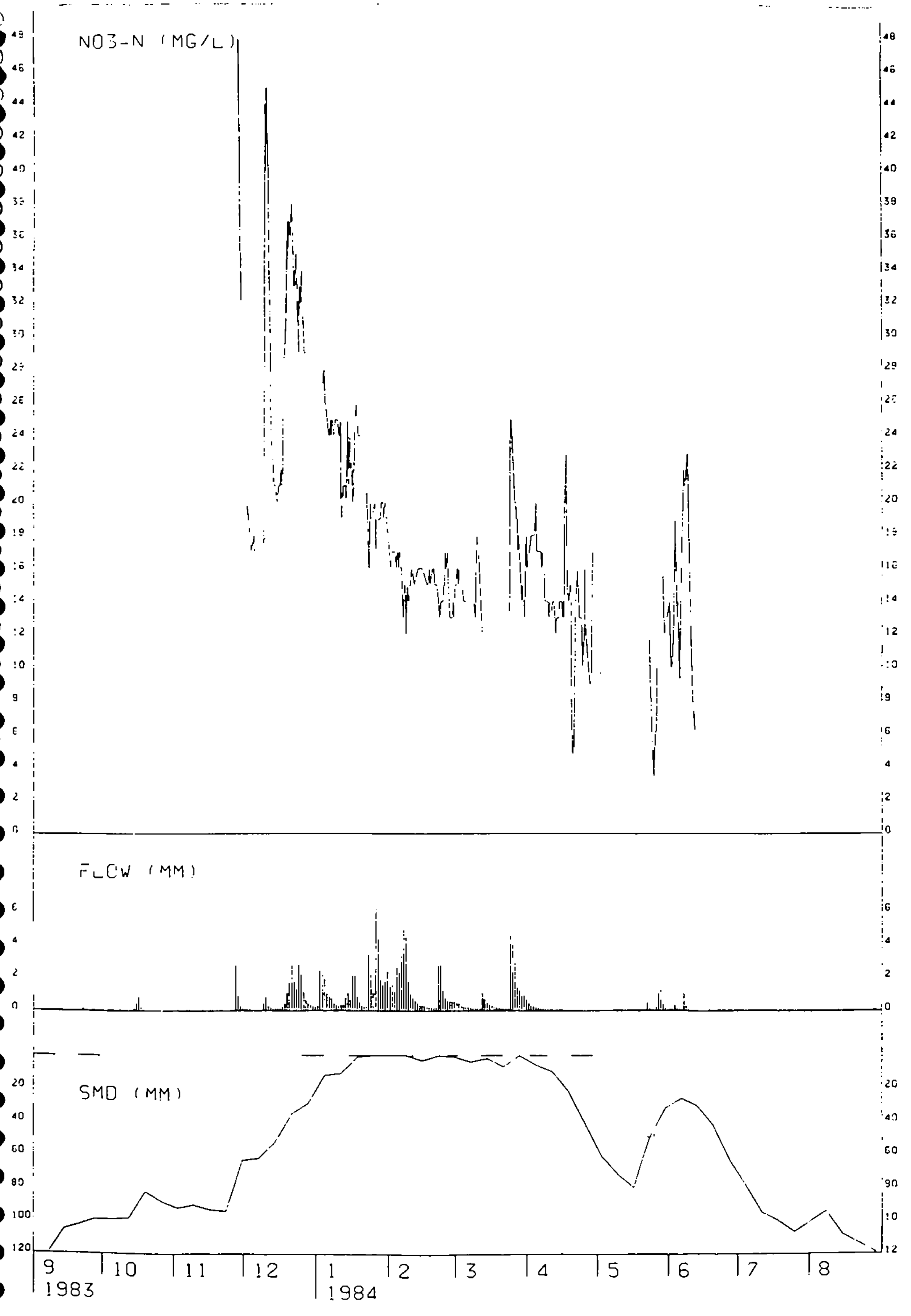

NO3-N (MG/L)
FLOW (MM)
SMD (MM)
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