INSTITUTE of HYDROLOGY

Effects of Upland Land Use
on Water Quality

Progress Reports on the
Institute of Hydrology
Catchment Scale Studies at
Llanbrynmair (initial afforestation)
Nant-y-Moch (grassland improvement)
Severn (clear-felling)
by

G. Roberts, J.A. Hudson
and J.R. Blackie

Introduction

This report describes the progress made and the initial results obtained during the first three years in a series of studies conducted by the Institute of Hydrology into the effects of land use change on water quality in streams draining upland areas. These studies are part funded by the Department of the Environment, Welsh Office, Forestry Commission and, until 1983, by the Water Research Centre.

All of the investigations are being conducted in the Plynlimon region in mid-Wales. The land use changes studied are initial afforestation of land previously under upland grassland, clear felling of plantation forestry and upland grassland improvement. Also included in the original programme was the aerial application of remedial fertilizer to established forestry. This is being studied independently at Glen Orchy in central Scotland by the Water Research Centre.

The water quality parameters of major concern in these investigations are nitrogen (in its various forms), phosphorus (as ortho-phosphate) and potassium, though other determinands have been analysed also and are reported on here. These elements are important in that, not only are they widely regarded as being the three most important nutrients limiting plant growth but also high losses to watercourses are a potential problem to the water supply industry. Nitrogen, in its most mobile form nitrate N, is causing growing concern in lowland areas where its concentration in water supply areas is already higher than the World Health Organisation limit and is steadily increasing. The problem will be accentuated in 1985 when the UK will adopt the more stringent EEC guidelines on water supply which effectively halves the WHO recommended limit for nitrate. Also, the eutrophication of lakes and reservoirs, caused by the growth and subsequent decay of algal blooms, is steadily increasing. This results in discoloration, reduced levels of oxygen and nasty odours. As well as being an additional burden on the water industry, this can also have a detrimental effect on aquatic life in general. It is generally agreed that the nutrient limiting the growth of algal blooms in natural conditions is phosphorus, as ortho-phosphate.

Runoff from undisturbed upland areas is of very high quality requiring minimal treatment. For this reason, many reservoirs have been installed in these areas, particularly in Wales and northern England, to supply the water demands of lowland conurbations. Of particular importance also is the role of upland streams in diluting waters polluted by intensive agriculture and industrial and sewage effluents in densely populated areas downstream. Any deterioration in the water quality which limits this role of upland runoff may have serious financial implications for the water industry. These studies, therefore, are an attempt to quantify the increases, if any, in nutrient concentrations and losses from upland areas as a result of the land use changes outlined above.

Each of the studies adopts a twin catchment approach—one catchment being undisturbed and acting as a control whilst the other is subjected to the land use change following a suitable period of catchment comparison. Often management strategies mean that little or no time is available for comparison prior to the land use change. In this case, it has to be assumed that both catchments behave similarly under undisturbed conditions. In any case, the nutrient concentrations in these undisturbed areas are so low that the appreciable enhancement likely to be of concern to the water industry will be very obvious.

In each of the studies, the land use changes are "normal" in the sense that they would have happened irrespective of whether they were being monitored. A possible exception to this is the clear-felling study where part of the tree harvesting has been brought forward to accommodate the funding schedule. In all other respects, the practices, areas involved and rates of change are what would have happened in due course. The maps in the succeeding sections showing the areas of land use change can only be taken as approximate at present. It is hoped that, in due course, an aerial survey can be made of each of the study areas and more accurate maps produced.

As a minimum requirement to calculate nutrient concentrations and losses, it is necessary to collect streamflow samples and to measure the flow from each of the catchments under study. The type of flow measuring structure required at the outfall of each catchment has been chosen with due regard to the topography of the stream bed at that point and the size of the catchment which, in turn, governs the range of flows expected. Each flow measuring structure is equipped with a stilling well where the head of water or stage is measured by means of a float and then stored on a cassette tape. These tapes are normally changed at fortnightly intervals. Conversion of stage to flow is done using theoretical stage/discharge relationships derived for the type of flow measuring structure of given dimensions. These relationships for each of the structures are being checked using a dilution gauging technique and, if necessary, modifications will be made to the theoretical ratings.

Streamflow sampling has been restricted to weekly or fortnightly intervals. Each sample (approx. 1.5L) is composed of a number of 2 ml sub-samples eg for a weekly sampling interval, sub-samples are taken at 15 min. intervals. It was felt that these composite samples would give better average concentrations, and hence more accurate losses, than spot samples. On the other hand, the use of these composite samplers has precluded the use of preservatives because of possible problems associated with changing sample/preservative ratios. This has been counteracted to a certain extent for nitrogen by analysing for mineral nitrogen (ammonium-N and nitrate-N) and Kjeldahl nitrogen, thereby giving the organic N component. In any case, a comparison of the results obtained by analysing untreated, filtered and filtered and preserved spot samples during the control period of the clear felling study showed that, at the low nutrient concentrations experienced in these situations, no consistent differences were found between preserved and non-preserved samples. The results obtained are shown in Appendix 1. The composite samplers have been used on a time basis to date but work is being done to convert them to a flow-proportional basis. The samples collected at the outfalls of the experimental catchments have been supplemented by additional ones taken at various points within the catchments, so that the effects of different contributing areas may be assessed. This is particularly important bearing in mind that the land use change will be implemented only on part of the catchment. In the case of the clear-felling study, it was also found necessary to install an additional flow measuring structure within the experimental catchment to measure separately flows from the felled and unfelled portions of the catchment. Inputs of nutrients in rainfall have been assessed using a rainfall collector and a network of raingauges for each study.

The rainfall and flow data have been processed within the Institute of Hydrology's data processing system to produce totals concurrent with the rainfall and streamflow sampling schedule so that nutrient inputs and outputs (in kg/ha) may be calculated. The water samples are analysed at two laboratories - the Institute of Hydrology, Wallingford and the Severn-Trent Water Authority, Shelton. Although no formal quality control of the results obtained from the two laboratories has yet been possible, the results obtained during the change over of laboratories for analysing the samples taken from the clear-felling study suggest that there are no inherently large differences between the results obtained from the two laboratories.

Past studies of nutrient losses from upland areas of Britain have been scarce and, in general, it has been necessary to rely on studies conducted overseas, particularly in the United States of America. As a precursor to the catchment studies reported on here and those being carried out under the same funding arrangements by the Freshwater Biological Association (FBA) and the Institute of Terrestrial Ecology (ITE), a bibliography of the environmental effects of the various forestry practices - afforestation, fertilizer applications and clear-felling - was produced (Blackie et al., 1980). No such bibliography of the effects of upland pasture improvement is available though Roberts et al (in press) describe the results of a small plot experiment and also quote findings obtained from similar agricultural practices. Baseline data from undisturbed catchments in upland Britain have been presented by Roberts et al., 1983 and by Reid et al., 1981.

In the following sections, details are given of the progress to date on the three catchment studies being undertaken.

Hore catchment clear-felling study

This study is being carried out in the forested headwaters of the river Severn at Plynlimon. Here, the Institute of Hydrology has been studying the effects of upland forestry plantations on water resources (IH, 1976). As part of these investigations three sub-catchments within the main Severn catchment have been fully instrumented to measure rainfall, runoff and the meteorological variables. Two of these sub-catchments, the Hore and the Hafren, are being used for this particular study. Details of the sub-catchments are shown in Fig. 1 and in the table below.

Hore and Hafren sub-catchments of IH Severn catchment

Sub-catchment	Area (ha)	Alt. Range (m)	Land Use (% Area) Agric/other	1937/38 Planting	1945/50 Planting	1963/64 Planting
HORE	335	375	22.7	26.8	20.0	30.5
HAFREN	347	295	50.2	1.4	39.8	8.6

Areal rainfall inputs are measured by means of a network of canopy and ground-level raingauges and flows estimated by means of steep stream structures, specially designed for use in this terrain. Mean annual runoff totals (mm) were found to be 1956 and 1961 for the Hore and Hafren, respectively, during the period 1976-1982 (inc). These totals represent 77% and 79% of the incoming rainfall.

Spot streamflow samples were collected on a monthly basis at the outfalls of the Hore and Hafren sub-catchments and at a point mid-way up the Hore sub-catchment (immediately above the area to be clear-felled) mainly during 1980. The samples were analysed for ammonium-N, nitrate-N, Kjeldahl-N, phosphorus, potassium and pH. The results obtained are shown in Table 1. These figures, together with the runoff totals quoted above, suggest that nutrient losses from the undisturbed sub-catchments are very similar.

Negotiations began with the Forestry Commission in the summer of 1982 on the possibility of clear-felling part of the Hore sub-catchment in order to assess its impact on the nutrient concentrations and losses in the runoff, using the Hafren sub-catchment as the control. Although much of the timber within the Hore sub-catchment was not considered to be ready for harvesting, particularly in view of the depressed timber market in this country, agreement was reached with FC on a felling schedule beginning during the spring of 1985 and to continue for 2 years. At the same time, FC agreed to suspend any thinning activity within the Hore and Hafren as soon as reasonably possible so as to allow a long period of undisturbed control.

The timetable of operations for this particular study is:-

(i) A control period of two years from April 1983 to March 1985.

(ii) Clear-felling part of the Hore sub-catchment during April 1985 until September 1987.

(iii) Continue monitoring until the effects of the clear-felling have subsided. It is difficult to predict the duration and magnitude of the effects though studies in the USA do suggest that the greatest effect is found in the second year following felling.

This schedule may be subject to changes in Forestry Commission plans.

Rainfall and flow measurements and evaporation estimates have continued to be made for the two sub-catchments as part of the main Plynlimon experiment. In order to provide an additional control, it was decided to construct a flow measuring structure in the upper Hore, above the area to be felled (Fig. 1). The steepness of the stream-bed at this point dictated that the most suitable was a steep stream structure, as existing at the outfalls of all the sub-catchments at Plynlimon. It was hoped that this could be constructed during the autumn of 1984 so that some comparisons could be made between the flows from the upper Hore and from the whole sub-catchment. Unfortunately, this could not be done and the construction has been postponed until the spring of 1985.

Streamflow sampling at the outfalls of the Hore and Hafren and in the upper Hore (Fig. 1) began during April 1983. These were supplemented by rainfall samples collected at Carreg Wen in the unforested part at the head of the Hore sub-catchment. Originally, spot streamflow samples were collected on a weekly basis but the sampling frequency was changed to two weekly during March 1984. Composite samplers were installed at the outfalls of the Hore and Hafren in June 1984, replacing the manually-collected spot samples. Between April and November 1983, the samples were analysed at the Institute of Hydrology. Following this, the chemical analysis has been done at the Severn-Trent laboratories in Shelton. The results of the chemical analyses obtained to date are shown in Fig. 2. Although it has not been possible to carry out a formal comparison between the results obtained from the two laboratories, it is gratifying to note that no obvious divergences in the results for nitrogen, phosphorus, potassium or pH occurred at the change-over point. Also, there are no large consistent differences between the results from the three sampling points, thus confirming the results of the 1980 sampling survey (Table 1).

It is proposed that two areas within the Hore sub-catchment be felled during 1985 to 1987 (Fig. 1). The first consists of 90 ha of Norway and Sitka spruce planted in 1937/38 and the other of 67 ha containing mainly Sitka spruce but also Japanese Larch, Norway Spruce and Lodgepole pine planted in 1948-50. The total area involved is approximately 47% of the area of the sub-catchment. No indication regarding the actual felling practices has been given but it is assumed that practices appropriate to the area and to the local terrain will be employed.

Nant-y-Moch grassland improvement study

This study is being carried out on two small (approx. 80 ha) catchments draining into the Nant-y-Moch reservoir on the western slopes of Plynlimon (Fig. 3).

Here, the Crown Estate Commissioners, who own the grazing rights to 1090 ha of common land, proposed a hill improvement project in December 1981. This involved improving 120 ha of grassland on the lower slopes to increase the stock carrying capacity of the area and the planting of approximately 80 ha of shelter belts. The scheme also involved fencing some of the common land. A considerable delay ensued whilst permission for the scheme was sought from the Secretary of State for Wales. This was compounded by the fact that part of the area (to the east of the dotted line in Fig. 3) was specified as a site of special scientific interest (SSSI) by the Nature Conservancy Council. However, permission was granted in December 1983 and the implementation of the scheme began almost immediately (Fig. 4).

The two catchments, the Maesnant Fach (experimental) and the Maesnant (control), were identified in 1982 as being suitable for monitoring the effects of the grassland improvement. Unfortunately, because of the uncertain fate of the Crown Estate's proposals, it was not possible to begin instrumenting the catchments until the spring of 1984. This meant that a control period prior to the implementation of the improvement scheme was not possible.

Originally, the drainage area of the experimental catchment was unclear because of some boggy ground immediately upstream of the proposed shelter belt in the north of the catchment. To resolve the problem a cut-off drain was dug from this boggy area to the outfall of the catchment. This drain now effectively forms part of the catchment boundary.

The size of the two catchments dictated that the most suitable structures for measuring the outflows were compound sharp-crested weirs. These are rectangular in shape and have a 90° V-notch to give precision at low flows. The one on the experimental catchment was constructed during the spring of 1984 and became operational in the middle of May. Because of other commitments, it was not possible to complete the weir on the control catchment until September 1984. Insufficient data have been obtained to date from the two weirs for comparison. Rainfall is measured by means of one ground-level period gauge in each catchment. The data from these are time distributed by means of a recording gauge situated in the experimental catchment.

Streamflow sampling at the outfalls of the two catchments and at two further points within the experimental catchment began at two weekly intervals in January 1984 (Fig. 3). Sampling is by means of composite samplers at the outflows from the two catchments and mid-way up the experimental catchment above the areas to be improved whilst spot samples are taken from the cut-off drain where it enters the main stream. A rainfall sampler was installed on site during July 1984. All the samples are analysed at the Institute of Hydrology. The results obtained to date for the streamflow samples are shown in Figure 5 for nitrate-N, Kjeldahl-N, potassium and pH. The concentrations of ammonium-N and phosphorus were more often than not below the limit of detection and have not been included. Obvious differences do exist in the concentrations of nitrate-N and Kjeldahl N in the samples from the three collection points. These differences will be analysed closely particularly bearing in mind the short period of control that was available for this particular study.

The schedule for the implementation of the pasture improvement scheme within the confines of the Maesnant Fach catchment is given in Fig. 4. The planting of the shelter belts within the catchment was completed in Feb/March 1984. This was done by ditching and planting the young saplings in the upturned ridges. No fertilizers were applied. A number of species of trees were planted though no indications have been given of the types or percentages. As a rough estimate, it has been calculated that 4.7 ha of shelter belt, representing 6% of the catchment area, has been planted.

The improvement of one of the designated areas within the catchment (Fig. 3) was implemented in April 1984. This is an area of approximately 4 ha (5% of catchment area) on the North side of the stream. The agricultural practices involved were burning existing vegetation, light rotavation by spiking and seeding from an attached broadcastor, liming and a fertilizer application. The rates of liming and fertilizer application are given in Appendix 2. The rates per unit area have not been worked out because of the uncertainty in the areas involved. This will be done later when an aerial survey of the catchment has been done. The other area for improvement is scheduled for the spring of 1985.

Llanbrynmair Afforestation Study

This study is being conducted on Llanbrynmair Moor a few miles north of the Plynlimon catchments. Approximately 1500 ha of the moor was purchased by the Economic Forestry Group for forestry plantation starting in 1983. Later, approximately 200 ha was purchased by the Fountain Forestry Group for planting beginning in 1984.

Two catchments for monitoring the afforestation were identified in 1981. The experimental catchment, the Cwm, is 300 ha in area (Fig. 6) whilst the control, the Delyn, is about 100 ha. Both catchments are used as a local water supply by the Severn-Trent Water Authority, the Delyn on a permanent basis and the Cwm during periods of low flow.

Work began on the installation of a flow measuring structure on the Cwm catchment during the spring 1982. Because of the size of the catchment, it was decided that the most appropriate structure was a Crump weir. Although not very sensitive at low flows, this type of weir can comfortably cope with the range of flows expected from a 300 ha catchment. The installation was completed at the end of June. A compound (rectangular with a 90° V-notch) sharp-crested weir was installed at the outfall of the Delyn catchment during the autumn 1982. This was inoperative between the beginning of February 1983 and the middle of April 1983 due to silting up following a severe thunderstorm accompanied by snowmelt on the 31st January. No clearance work was possible during this period because of risk of contamination of water supplies during the water workers strike. Although the Crump weir was similarly affected by the storm, its ability to provide sensible water levels was unimpaired and no data were lost. Since then the return of data from the two structures has been good although some gaps do exist because of instrument malfunction. Rainfall records are available since the beginning of the study from two sites belonging to the Welsh Water Authority at Llanbrynmair and from the automatic rain gauge installed at the head of the experimental catchment. These have been supplemented by a further two period gauges positioned at the outfalls of the two catchments.

The rainfall and runoff data processed to date are summarised in Fig. 7 as cumulative weekly or, more recently, two weekly totals in mm over the catchment. During those periods when one of the flow measuring structures was inoperative, the data from the other is substituted. Analysis of the flow records suggests that this is feasible on a weekly (or longer period) basis but, as more data become available, it should be possible to devise more sophisticated ways of infilling such gaps in the data. For those periods when data are available from both weirs, the agreement is very good, despite the need to extrapolate below the British standard limit on the Crump weir in the Cwm catchment during low flow conditions. Investigations of the stage/discharge relationships at low flows are in hand using both dilution gauging and volumetric methods. Initial results suggest that the rating in use is not significantly in error. A comparison of the data from the experimental and control catchments for the first eighteen months of the study gives streamflow losses of 84% and 85%, respectively, of the incoming rainfall, figures which are similar to those obtained from the long term grassland catchment at Plynlimon.

Streamflow sampling at the outfalls of the two catchments began in June 1982. Initially, spot samples were collected manually at weekly intervals. These were replaced in January 1983 after the installation of a composite sampler at each of the outfalls. More recently (since February 1984) the sampling frequency was changed to two weekly and the composite samples collected at the outfalls of the two catchments supplemented by spot samples collected at two points further up the Cwm catchment (Fig. 6). Rainfall sampling, at the same frequency as the flow sampling, began in September 1982. All of the samples are analysed at the Severn-Trent Water Authority laboratories at Shelton. A time series graph of the results obtained to date from the samples extracted from the outfalls of the two catchments is shown in Fig. 8.

Although exceptions do occur, these data suggest that the concentrations of free ions are higher in the flow from the control catchment whilst the reverse is true for organically bound elements. This is to be expected, since the control catchment is much steeper than the experimental and has a higher percentage of mineral soil whilst the experimental catchment is flatter and covered for part of its area with blanket peat. Also, there is evidence of some agricultural activity in the control catchment manifest in high concentrations, up to 1.3 mg/L, of potassium in streamflow samples during June 1983. These differences are also reflected in the pH values, those in the flow from the control catchment being invariably higher than those in the flow from the experimental catchment. More data analysis has to be done before it can be determined whether the planting carried out in 1983 and 1984 had any effect on the chemistry of the streamflow from the experimental catchment.

The Economic Forestry Group completed the bulk of their planting within the Cwm catchment early in 1983 (Fig. 6), with only a small area in the north-east corner remaining to be done in the planting year 1984/85. Tree-planting practice included the burning of existing vegetation, surface drainage and the application of phosphate at an average rate of 181 kg/ha of P_2O_5. Fountain forestry planted part of their area with a mixture of Douglas Fir, Japanese Larch, Sitka Spruce and Noble Fir during 1984 (Fig. 6). This was done by screef planting with ground disturbance reduced to a minimum. The rest of their area is to be planted with Sitka spruce in 1985 and 1986. All of these areas, apart from steep banks and adjacent to streams, are to be ploughed prior to planting. Groups of broad leaves are to be planted in strips adjacent to the stream beds during 1986. On completion, approximately 90% of the catchment will have been afforested.

As part of their planting schedule, Fountain forestry are also constructing a number of access roads within the catchment. Although no formal agreement regarding access has yet been received, it is envisaged that these newly constructed roads will greatly aid data collection. Negotiations are also proceeding regarding the installation of a sediment trap within the stream. This is designed to protect the abstraction point of the Severn-Trent Water Authority and will also provide IH with valuable data on sediment losses.

Future Work

Future plans are to continue measuring and sampling the rainfall and runoff in each of the catchments through the control period, the land use change and until such time when conditions revert to what they were prior to the implementation of the various practices. Meantime, much data analysis remains to be done on the resuls already obtained so that meaningful relationships can be derived between the results obtained from the experimental and control catchments. These relationships can then be used to compare with data collected from the experimental catchments following the various land use changes.

Although it is not planned to extend the instrument networks or data collection within the confines of the studies described in this report, other related studies are being actively encouraged particularly at Llanbrynmair. Here, the transition from grassland to 90% afforestation provides a unique opportunity to study the long-term effects on stream acidification, aquatic biota, sediment dynamics and water use. This study, together with those on established forestry and clear-felling at Plynlimon, will provide valuable information concerning these stream water characteristics throughout the forestry cycle.

Also, development work is continuing to convert the composite streamflow samplers from a time to a flow proportional basis so that more accurate assessments of chemical and sediment losses may be made from these catchments where flow rates change so quickly.

References

Blackie, J.R., Ford, E.D., Horne, J.E.M., Kinsman, D.J.J., Last, F.T. and Moorhouse, P., 1980. Environmental effects of deforestation. An annotated bibliography. Freshwater Biological Association Occasional publication no.10.

IH Report no.33, 1976. Water balance of the headwater catchments of the Wye and Severn. Inst. Hydrol., Wallingford, Report no.33.

Reid, J.M., Macleod, D.A. and Cresser, M.S., 1981. Factors affecting the chemistry of precipitation and river water in an upland catchment. J. Hydrol., 50, 129-145.

Roberts, G., Hudson, J.A. and Blackie, J.R., 1983. Nutrient cycling in the Wye and Severn at Plynlimon. Inst. Hydrol., Wallingford, Report no. 86.

Roberts, G., Hudson, J.A. and Blackie, J.R., (in press). Effects of grassland improvement on nutrient losses from upland areas. Inst. Hydrol., Wallingford.

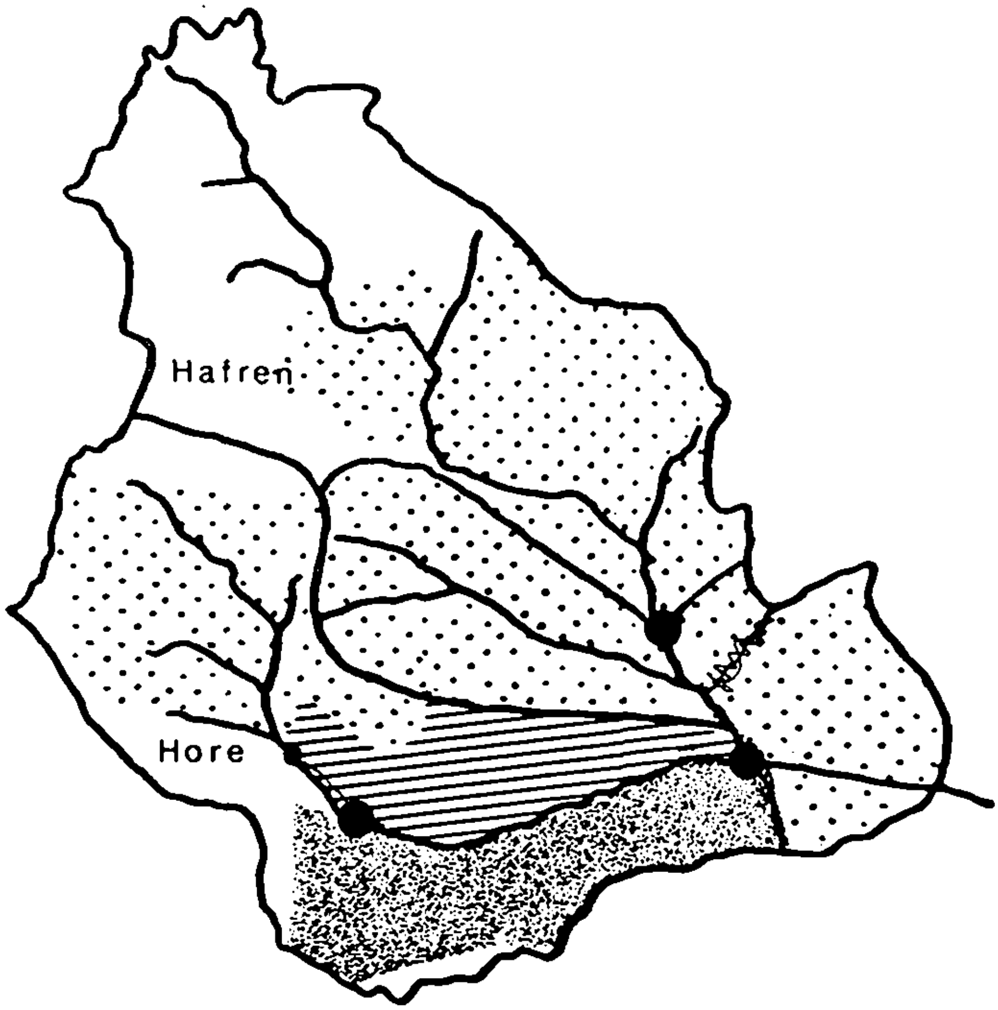

FIG. 1 SEVERN SUB-CATCHMENTS SHOWING PROPOSED AREAS OF CLEAR-FELLING IN THE HORE

1937/38 NORWAY AND SITKA SPRUCE

1948/49/50 MAINLY SITKA SPRUCE

OTHER FORESTED AREAS

STREAM SAMPLING AND MEASUREMENT POINTS

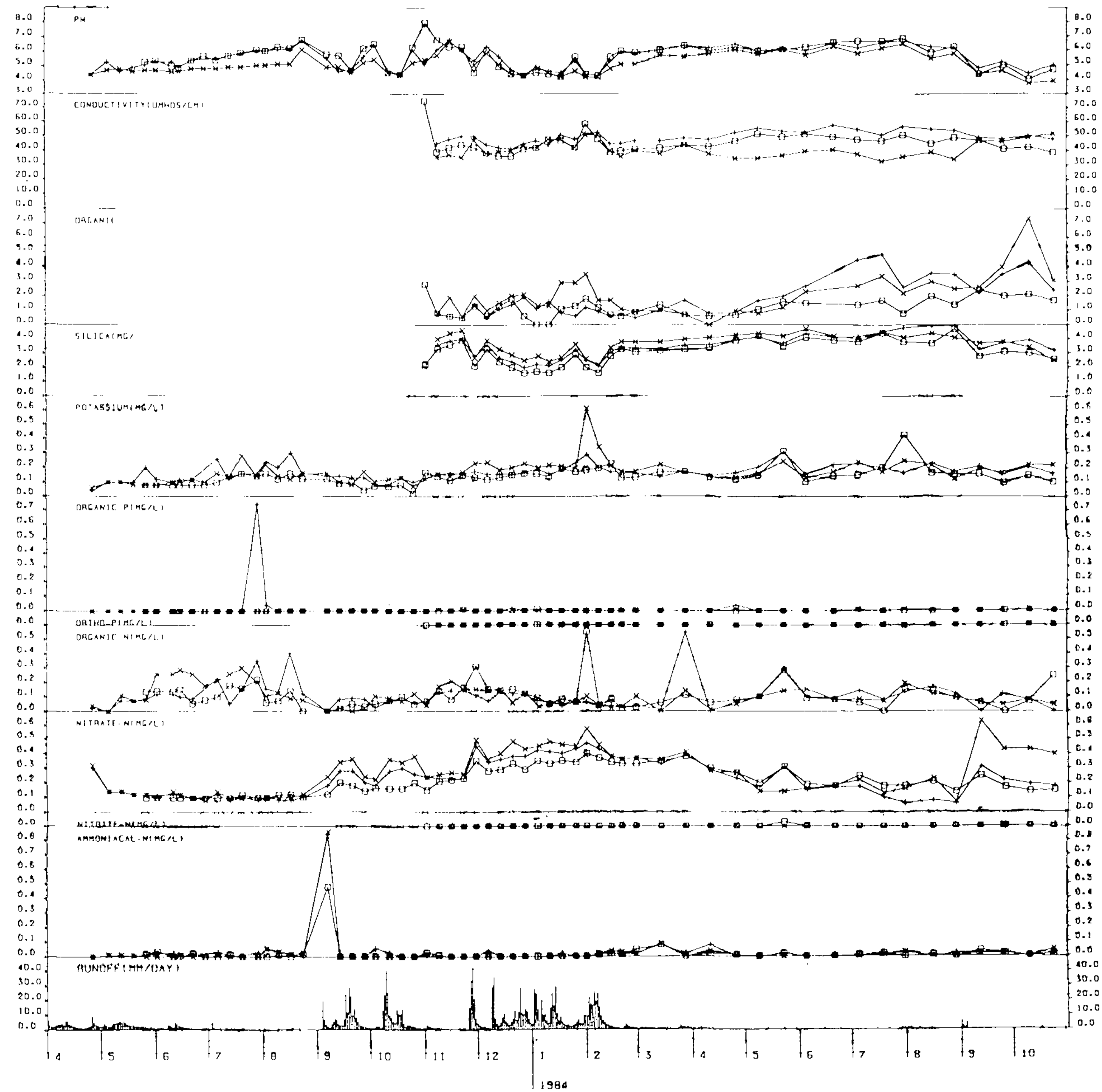

FIG 2
HAFREN FOREST CLEAR FELLING STUDY

+ HORE
× HAFREN
□ UPPER HORE

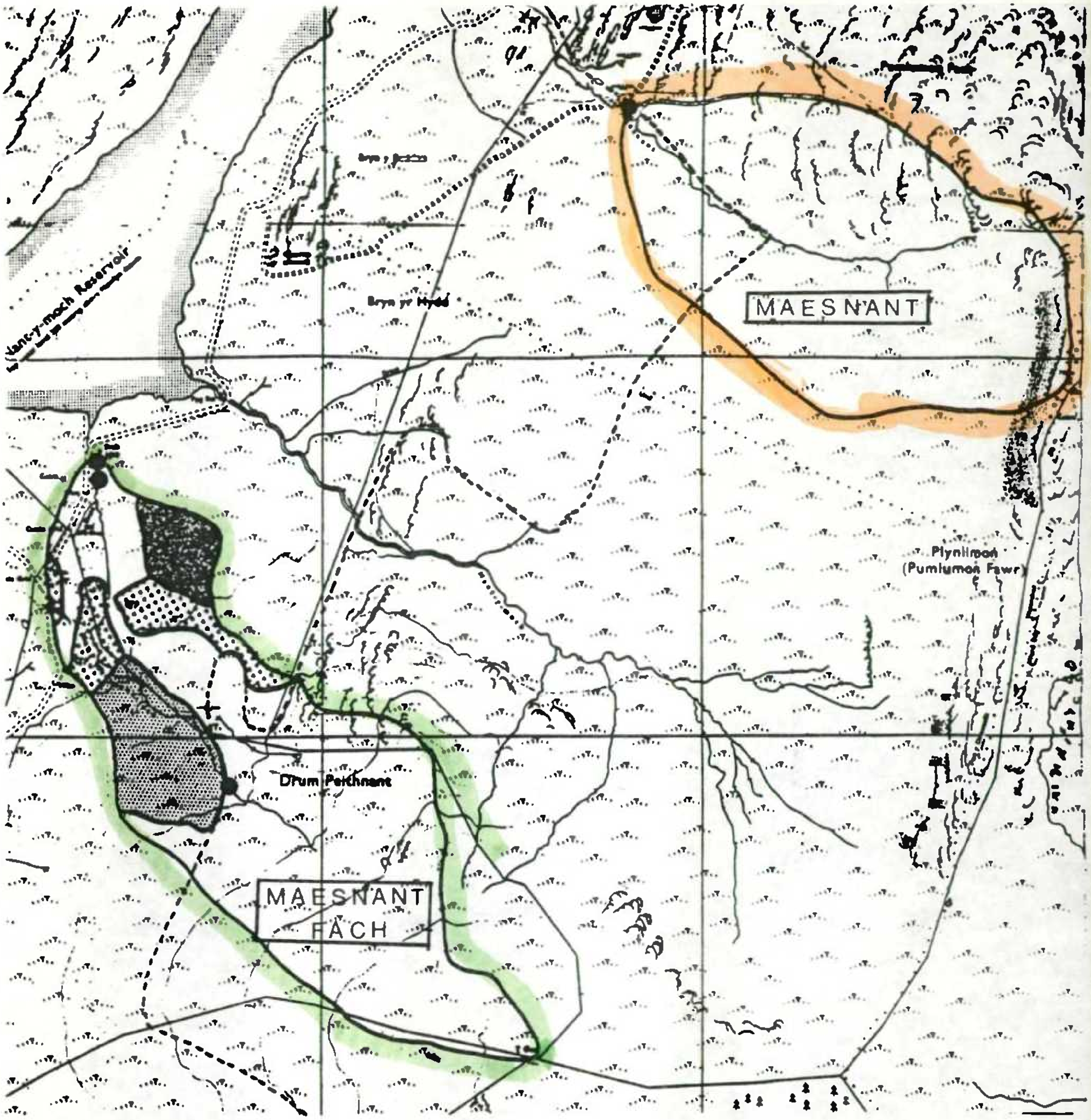

FIG 3. THE NANT-Y-MOCH CATCHMENTS

PASTURE IMPROVEMENT APRIL 1984

PASTURE IMPROVEMENT SPRING 1985

SHELTER BELTS MARCH 1984

----- BOUNDARY OF SSSI ● STREAM SAMPLING

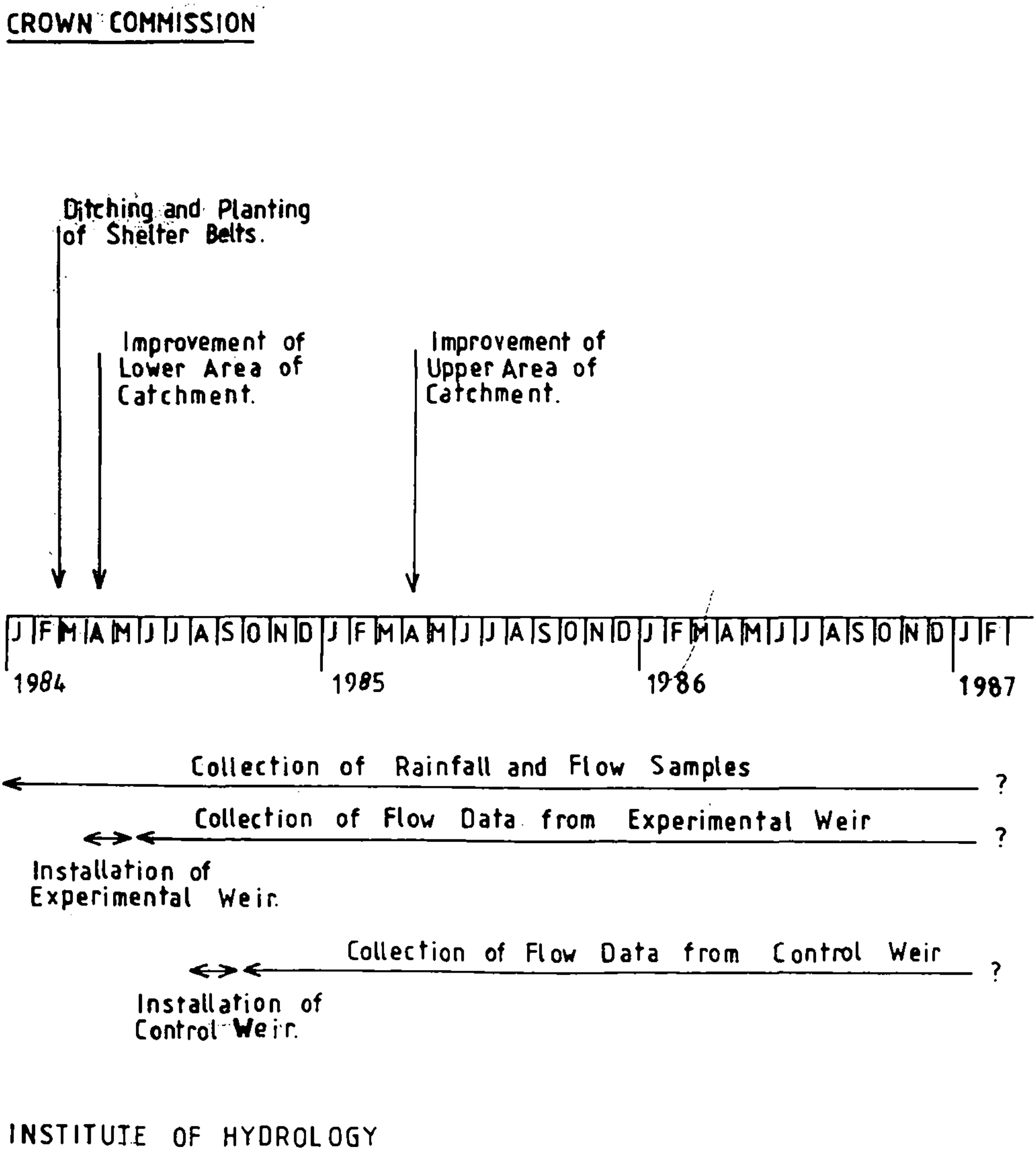

FIG. 4 SCHEDULE FOR THE GRASSLAND IMPROVEMENE STUDY

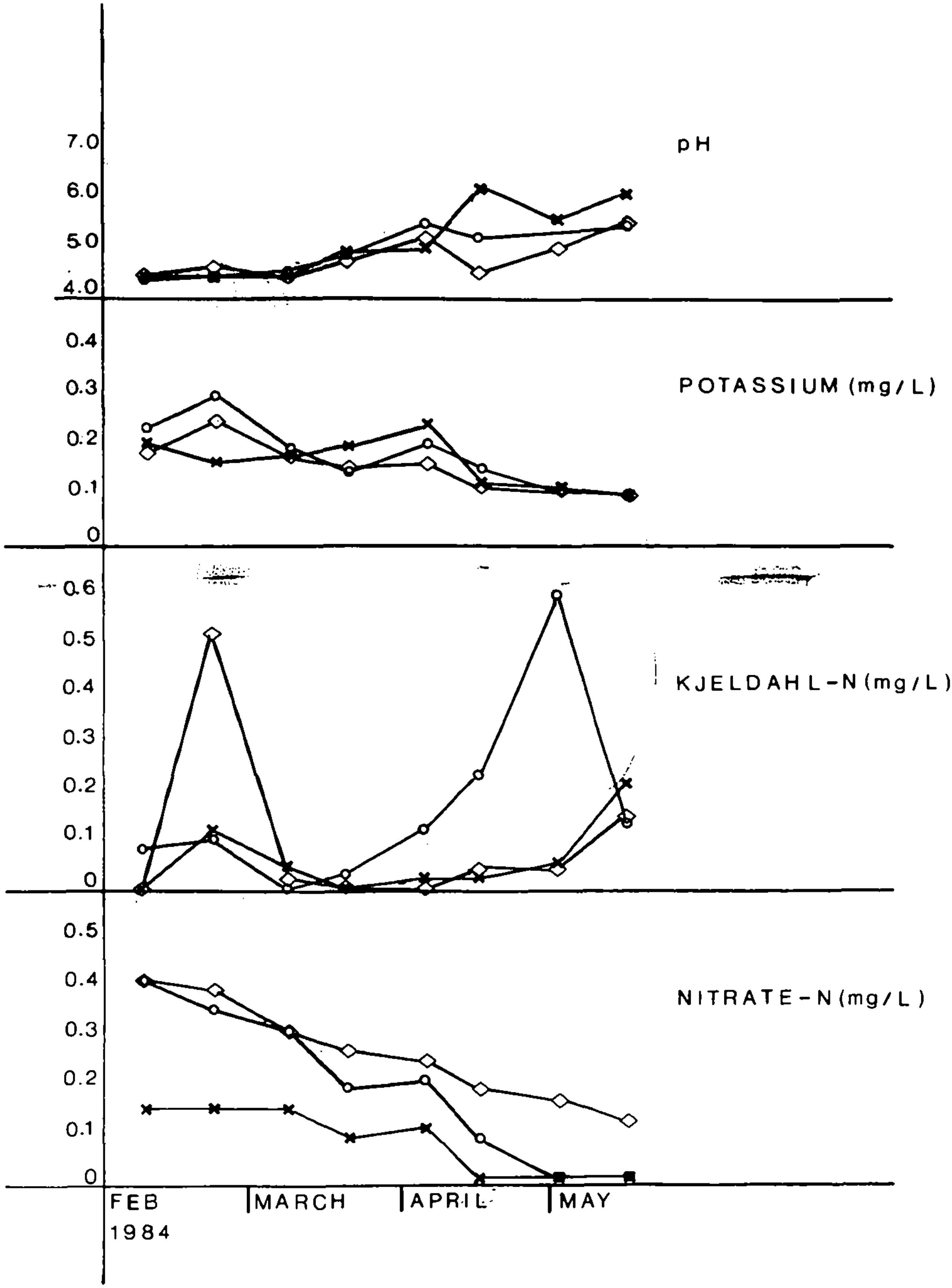

FIG. 5 NUTRIENT CONCENTRATIONS AT NANT-Y-MOCH

× MAESNANT FACH ○ MAESNANT

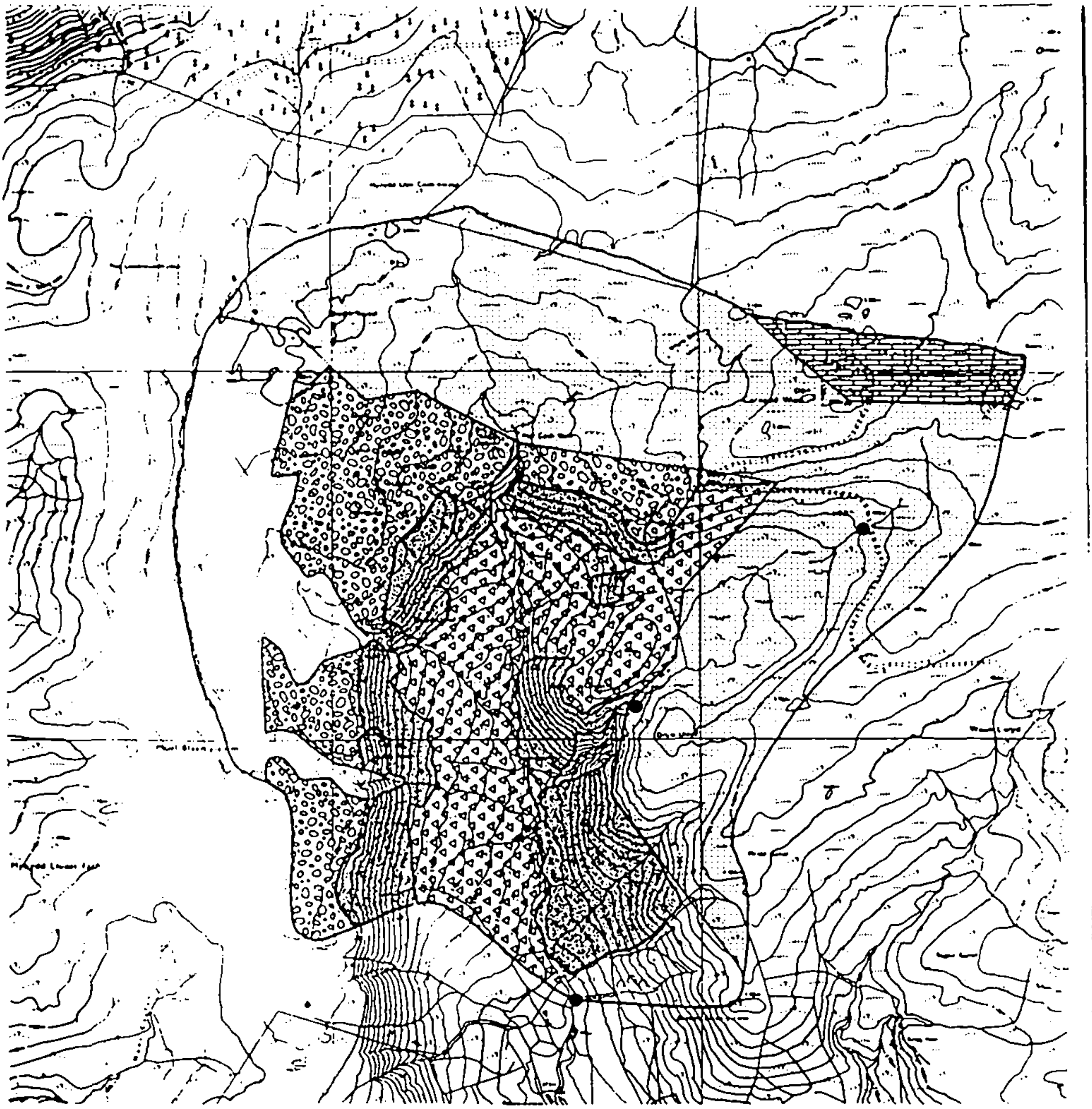

FIG 6 LLANBRYNMAIR EXPERIMENTAL CATCHMENT (Cwm).

UNCHANGED (ROUGH PASTURE)

FOREST PLANTING

ECONOMIC FORESTRY GROUP 1983

ECONOMIC FORESTRY GROUP 1985

FOUNTAIN FORESTRY 1984

FOUNTAIN FORESTRY 1985

FOUNTAIN FORESTRY 1986

● STREAM SAMPLING POINTS

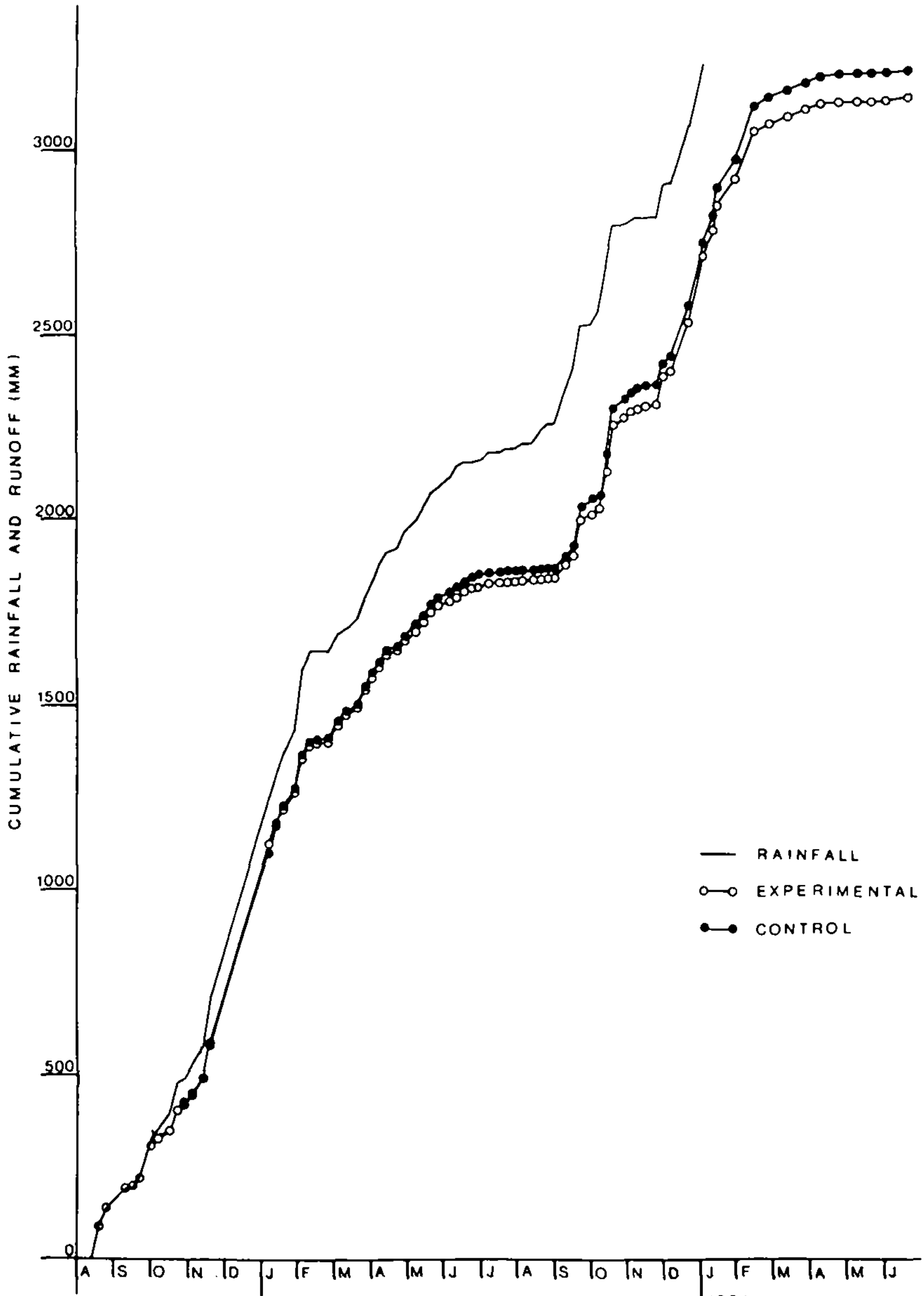

FIG. 7 CUMULATIVE RAINFALL AND RUNOFF FROM THE LLANBRYNMAIR CATCHMENTS

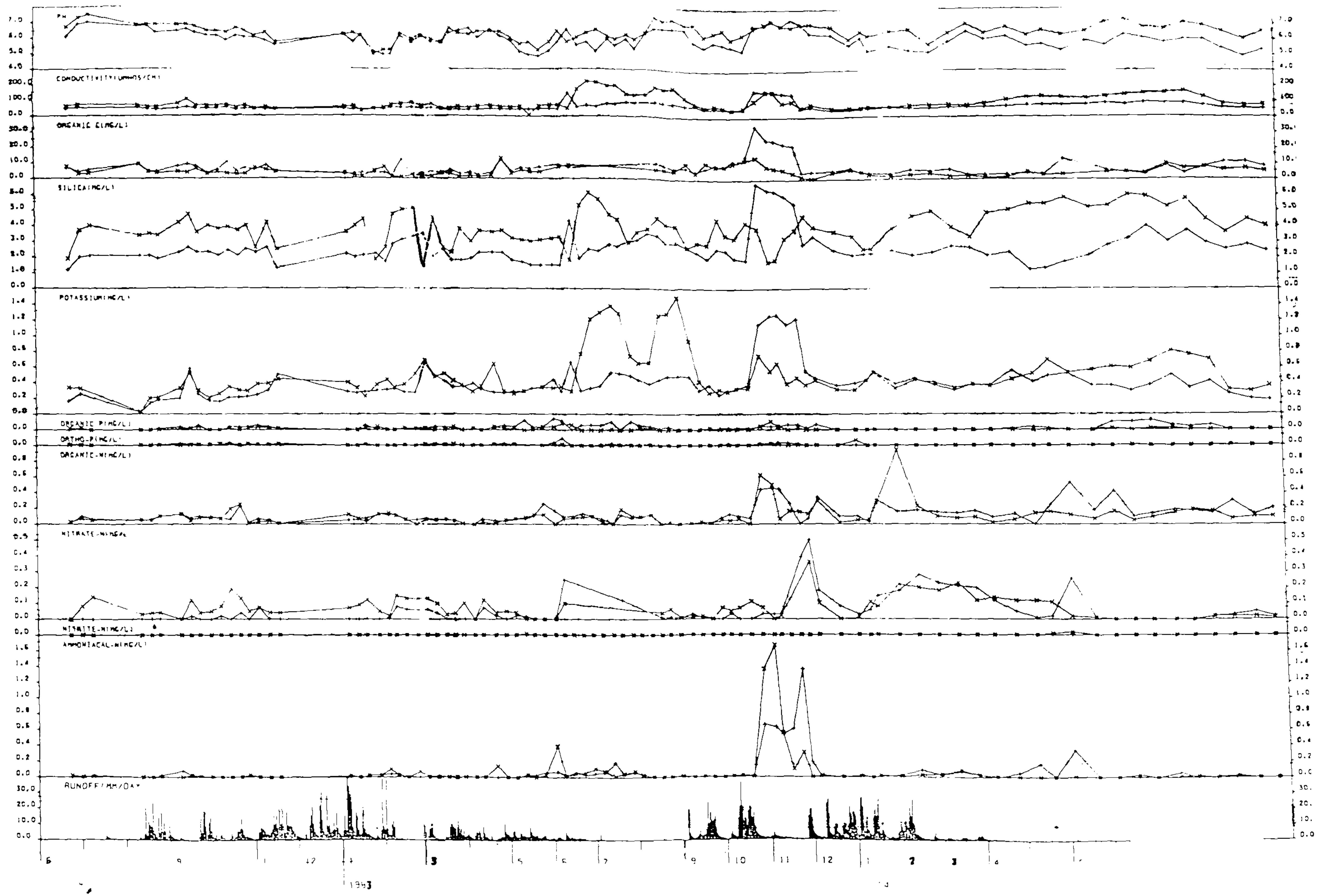

FIG 8

LLANBRYNMAIR AFFORESTATION STUDY

+ LLANBRYNMAIR EXPERIMENTAL

× LLANBRYNMAIR CONTROL

TABLE 1. NUTRIENT CONCENTRATIONS (MG/L) AT THE OUTFALLS OF THE HORE AND HAFREN SUB-CATCHMENTS AND IN THE UPPER HORE.

HORE SUB-CATCHMENT

DATE	NH4+N	NO3-N	ORG N			PH
16.11.77	<0.02	0.32	0.07	<0.02	0.20	4.8
29.11.79	<0.02	0.32	0.05	<0.02	0.09	5.8
9.01.80	<0.02	0.29	0.08	<0.02	0.14	6.0
30.01.80	<0.02	0.45	0.10	<0.02	0.15	4.7
5.03.80	<0.02	0.27	0.06	<0.02	0.10	5.9
2.04.80	<0.02	0.25	0.05	<0.02	0.10	4.7
2.05.80	<0.02	0.16	0.07	<0.02	0.12	6.7
4.06.80	<0.02	0.18	0.06	<0.02	0.13	6.5
15.07.80	<0.02	0.13	0.07			6.7
6.08.80	<0.02	0.14	0.16			5.6
30.10.80	<0.02	0.29	0.07			4.9
9.12.80	<0.02	0.30	0.14			6.3
MEAN		0.24	0.08		0.13	5.7
STD.DEV.		0.09	0.04		0.04	0.8

HAFREN SUB-CATCHMENT

16.11.77	<0.02	0.29	0.07	0.02	0.20	5.0
29.11.77	<0.02	0.32	0.05	<0.02	0.12	6.1
9.01.80	<0.02	0.29	0.12	<0.02	0.24	5.3
30.01.80	<0.02	0.46	0.19	<0.02	0.20	4.6
5.03.80	<0.02	0.25	0.05	<0.02	0.09	5.8
2.04.80	<0.02	0.27	0.05	<0.02	0.08	4.7
2.05.80	<0.02	0.18	0.07	<0.02	0.11	6.3
4.06.80	<0.02	0.19	0.06	<0.02	0.15	6.2
15.07.80	<0.02	0.15	0.03			6.6
6.08.80	<0.02	0.15	0.21			5.3
30.10.80	<0.02	0.26	0.13			4.7
9.12.80	<0.02	0.33	0.24			5.7
MEAN		0.26	0.10		0.15	5.5
STD.DEV.		0.09	0.06		0.06	0.7

UPPER HORE

16.11.77	<0.02	0.34	0.10	<0.02	0.19	4.7
29.11.79	0.02	0.26	0.08	<0.02	0.10	6.3
9.01.80	<0.02	0.29	0.05	<0.02	0.09	6.3
30.01.80	<0.02	0.45	0.17	<0.02	0.15	4.6
5.03.80	<0.02	0.29	0.04	<0.02	0.08	5.9
2.04.80	<0.02	0.22	0.05	0.02	0.10	5.0
2.05.80	<0.02	0.19	0.07	<0.02	0.14	5.6
4.06.80	<0.02	0.18	0.05	<0.02	0.10	6.3
15.07.80	<0.02	0.15	0.09			6.6
6.08.80	<0.02	0.15	0.17			5.2
30.10.80	<0.02	0.23	0.03			4.8
9.12.80	<0.02	0.27	0.12			6.1
MEAN		0.25	0.09		0.12	5.7
STD.DEV.		0.09	0.04		0.03	0.8

APPENDIX 1. RESULTS OF THE CHEMICAL ANALYSES OF UNTREATED/FILTERED AND PRESERVED WATER SAMPLES AT PLYNLIMON.

WATER SAMPLES WERE EXTRACTED BY HAND FROM TWO FORESTED SUB-CATCHMENTS AT PLYNLIMON. THE SAMPLES WERE SPLIT INTO THREE AND TREATED AS FOLLOWS.

1. AS SAMPLED.
2. FILTERED.
3. FILTERED + ADDITION OF 2.5 MLS OF A 1% SOLUTION OF MERCURIC CHLORIDE PER 250 ML SAMPLE.

THE SAMPLES WERE REFRIDGERATED AND ANALYSED AT IH WALLINGFORD FOR

A. AMMONIUM-N(MG/L)
B. NITRATE-N(MG/L)
C. KJELDAHL-N(MG/L)
D. TOTAL PHOSPHORUS(MG/L)
E. POTASSIUM(MG/L)
F. PH

HORE SUB-CATCHMENT

DATE	TREATMENT	A	B	C	D	E	F
26.04.83	1	<0.004	0.28	0.01	<0.02	0.04	4.9
	2	<0.004	0.28	0.05	<0.02	0.05	4.9
	3	<0.004	0.30	0.02	<0.02	0.04	4.4
5.05.83	1	<0.004	0.14	<0.04	<0.02	0.10	6.1
	2	<0.004	0.14	<0.04	<0.02	0.10	6.0
	3	0.010	0.14	<0.04	<0.02	0.10	5.3
12.05.83	1	<0.004	0.14	<0.04	0.05	0.10	5.1
	2	<0.004	0.12	0.18	<0.02	0.10	5.2
	3	0.004	0.14	0.08	<0.02	0.10	4.6
19.05.83	1	<0.004	0.12	<0.04	<0.02	0.08	5.7
	2	<0.004	0.12	0.04	<0.02	0.10	5.9
	3	0.008	0.12	0.08	<0.02	0.10	4.9
26.05.83	1	0.052	0.12	0.20	<0.02	0.20	6.2
	2	0.034	0.12	0.14	<0.02	0.20	6.3
	3	0.010	0.12	0.10	<0.02	0.20	5.1
1.06.83	1	0.024	0.10	0.08	<0.02	0.10	6.5
	2	<0.004	0.12	0.36	0.16	0.24	6.4
	3	0.022	0.12	0.14	<0.02	0.12	5.3

HAFREN SUB-CATCHMENT

DATE	TREATMENT	A	B	C	D	E	F
26.04.83	1	<0.004	0.32	<0.01	<0.02	0.06	4.8
	2	<0.004	0.32	0.03	<0.02	0.06	4.8
	3	<0.004	0.32	0.04	<0.02	0.06	4.4
5.05.83	1	<0.004	0.12	0.04	<0.02	0.10	5.4
	2	<0.004	0.12	<0.04	<0.02	0.10	5.3
	3	0.010	0.14	<0.04	<0.02	0.10	4.7
12.05.83	1	<0.004	0.14	0.06	<0.02	0.08	4.8
	2	0.014	0.14	0.12	<0.02	0.08	4.4
	3	0.010	0.14	0.12	<0.02	0.10	4.8
19.05.83	1	<0.004	0.12	0.04	<0.02	0.08	5.3
	2	<0.004	0.12	0.08	<0.02	0.08	5.0
	3	0.006	0.12	0.08	<0.02	0.08	4.6
26.05.83	1	<0.004	0.10	0.06	<0.02	0.08	5.2
	2	<0.004	0.12	0.14	<0.02	0.10	5.6
	3	<0.004	0.12	0.08	<0.02	0.08	4.7
1.06.83	1	<0.004	0.10	0.10	<0.02	0.08	5.6
	2	<0.004	0.10	0.08	<0.02	0.10	5.7
	3	<0.004	0.10	0.26	<0.02	0.08	4.7

UPPER HORE

DATE	TREATMENT	A	B	C	D	E	F
26.05.83	1	<0.004	0.10	0.06	<0.02	0.06	6.3
	2	0.016	0.10	0.14	<0.02	0.08	6.3
	3	0.020	0.10	0.16	<0.02	0.08	5.7
1.06.83	1	<0.004	0.08	0.28	<0.02	0.06	6.5
	2	0.014	0.10	0.26	<0.02	0.08	6.7
	3	0.038	0.10	0.18	<0.02	0.08	5.4

APPENDIX 2. LIME AND FERTILIZER APPLICATIONS TO THE MAESNANT FACH CATCHMENT APRIL 1984.

NOTE - THESE APPLICATIONS MADE TO A TOTAL AREA OF APPROX. 19HA OF WHICH APPROX. 4HA LIES WITHIN THE CATCHMENT.

80 TONNES OF LIME
4.5 TONNES OF TRIPLE SUPERPHOSPHATE
4.5 TONNES OF COMPOUND FERTILIZER

FERTILIZERS

1. TRIPLE SUPERPHOSPHATE - KAISER

P O SOLUBLE IN NEUTRAL AMMONIUM CITRATE & WATER
46% (20% P)
SOLUBLE IN WATER 44% (19% P)

2. COMPOUND FERTILIZER - ICI 2 22.11.11

TOTAL NITROGEN 22% - AMMONIUM-N 13%
NITRATE-N 9%

PHOSPHORUS P O SOLUBLE IN NEUTRAL AMMONIUM CITRATE WATER 11% (4.8% P)
SOLUBLE IN WATER 10% (4.5% P)

POTASSIUM K O SOLUBLE IN WATER 11% (9% K)

PLANT FOOD PER 50KG BAG

N = 11.0KG
P O = 5.5KG
K O = 5.5KG