1985/009

Institute of Hydrology

Natural Environment Research Council

THE EFFECTS OF LAND IMPROVEMENT
ON THE DISCHARGE FROM UPLAND PASTURES.

AN INTERIM REPORT ON A JOINT
ID/ADAS STUDY AT PLYNLIMON, mid-Wales

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A report on a joint IH/ADAS study at Plynlimon, mid-Wales

Introduction

A great deal of concern has been expressed recently about the levels of nitrogen, especially nitrate-nitrogen, in the sources of domestic drinking supplies. The process of reducing these levels to the World Health Organisation limit of 11 mg/litre of nitrate-nitrogen is both difficult and expensive. Much research is currently being carried out in tracing the origins of this nitrogen and to determine ways of reducing its input into streams, rivers and ground water.

One source of nitrogen in natural waters is that lost from agricultural land. This may occur by leaching through the soil profile, usually in the most mobile and soluble form of nitrate, or by soil erosion and losses of mineralised nitrogen in surface runoff following land cultivation. In general, losses of nitrogen are greatest in the intensively cultivated parts of the country and particularly in those areas where very high rates of highly soluble inorganic fertilizers are applied. Whilst nitrate concentrations in streams from upland high rainfall areas are low, the possible effects of land improvement in these areas is a source of concern since any increase in headwater concentrations would reduce the dilution effect on the downstream inputs. The amount of land improvement being carried out has increased rapidly following the publication of the Government's white paper on "Food from our own resources" (1975) where the desirability of producing more home-grown foodstuffs was pointed out.

This land improvement is generally carried out according to recommendations by the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF). For upland areas it consists of drainage (where necessary), liming at the appropriate rate, rotavation and reseeding, and an annual application of inorganic fertilizer. The main constituent of the inorganic fertilizer is nitrogen in the form of nitrate which is essential to plant and animal growth. Fertilizer applications are necessary because the supply of "natural" nitrogen, i.e. nitrogen fixation by bacterial action, nitrogen in rainfall, and nitrogen returned to the soil in animal manures, is inadequate to satisfy the needs of modern grass species.

Another aspect of land improvement which may affect water supplies is whether or not improved pasture uses more water than rough pasture. This is particularly important in upland areas as the water supplies of many industrial towns and cities are drawn from reservoirs built in these areas.

Objectives of the study

Following discussions between MAFF and IH concerning methods of studying the effects of land improvement a project proposal was drawn up in Spring 1977. The proposed objectives were:-

(i) to quantify any increase in nutrient, particularly nitrogen, levels in streams from upland pastures which can be attributed to land improvement and fertilizer applications,

(ii) to study surface and sub-surface water and solute movement, and

(iii) to measure and compare the water use of improved and rough pasture.

In order to achieve these objectives it was proposed to compare the discharges from two adjacent sub-catchments in the Wye catchment at Plynlimon before, during, and after the improvement of as much of one of the sub-catchments as possible. This Wye catchment of 1055 ha covers an altitude range of 320 to 740 m on the south east slopes of the Plynlimon range of hills in mid-Wales. It is part of an existing IH catchment study and is fully instrumented to measure rainfall, runoff, and the meteorological variables from which evaporation rates may be estimated. It has a mean annual rainfall of 2500 mm. The soils and the rough pasture vegetation are typical of upland grazing in much of Wales.

For the more detailed water and solute movement study, two "natural" lysimeters were to be used; one in rough pasture, and the other in an improved area.

However, a survey by ADAS representatives showed that only 30% of the proposed sub-catchment could be improved and that the cost of building access roads to carry out the improvement was prohibitive.

It was therefore decided to carry out a lysimeter study only. This meant a change in the objectives of the study, these now being:

(i) to quantify the increase, if any, in nutrient and particularly nitrate concentrations in the discharge from a small plot attributable to pasture improvement and regular fertilizer applications,

(ii) to determine the extent to which any increase is directly attributable to the fertilizer application and to study the mechanisms whereby the fertilizer is transported from the plot, and

(iii) to measure and compare the water use of improved and of rough pasture.

Method

The experimental design involved the construction of two "natural" lysimeters and the monitoring of both surface and sub-surface discharges from them prior to and following the improvement of 0.7 ha of pasture including and surrounding one lysimeter. At the same time a land management scheme would be carried out by ADAS and the landowner to ensure the correct grazing density in the improved pasture. The design was accepted for partial funding by MAFF and work started on the experiment in close cooperation with ADAS, Wales in Spring 1977.

The plot chosen for the experiment was an area of land approximately 1.5 ha at an altitude of 400 metres in the Nant Iago sub-catchment. The site was on an average slope of 1 in 10 and consisted of rough pasture on peat overlaying an impermeable boulder clay layer. The average depth of peat was 1.5 metres. Before any improvement could be carried out, it was found that it was necessary to drain the plot. This was carried out during the summer 1977. The area was split into two roughly equal sections and a main drain dug in each. Lateral drains were dug at a spacing of 10 metres in each section, tile drains inserted and the trenches back filled. Outflows were constructed for each of the main drains. At the same time, two 10 metre by 10 metre "natural" lysimeters were constructed, one in each section (fig 1).

Each lysimeter was constructed (fig 2) by digging a trench into the impermeable layer around the lysimeter "block" and then sealing it by cementing rigid plastic sheeting, extending about 9 inches above ground level, into the trench. Tile drains were placed in the trench both inside and outside the plastic sheeting and covered with a layer of gravel. The trench was back-filled and the turves replaces The turves on the inside of the plastic sheeting were angled in such a way that any surface runoff would be led into a collector at the lowest corner of the lysimeter. An exit for the sub-surface flow was constructed through the plastic sheeting at the peat/clay interface (fig 3). Both the surface and sub-surface discharges were led, through 4" plastic pipes, into an instrumentation hut.

The land improvement was carried out during May 1978 under the supervision of ADAS representatives. It consisted of liming at the rate of 8682 kg/ha (determined from a lime deficiency analysis of peat samples taken on 8.3.78), followed by rotavation, reseeding and fertilizer application. This was at a rate of 191 kg/ha of slag, 65 kg/ha of compound (15-15-15) fertilizer and 58 kg/ha of a nitrogen (34.5%N) fertilizer. This improvement was carried out on one half of the plot and on the lysimeter within. At the same time this part of the plot was fenced so that a land management scheme could be carried out once the new grass was established to ensure the correct grazing density.

Inspection of the new pasture during September 1978 revealed that the seed had taken well but that clover growth was patchy. It was felt that more intensive grazing would encourage clover growth. It was also decided that, should the experiment continue, a decision on the rate of fertilizer application in subsequent years would depend on the state of the pasture and on the land management scheme being carried out.

Instrumentation

The surface and sub-surface flows from both lysimeters are led into the instrumentation hut and then through a flow measuring system and a proportional water sampler (see fig 4). The primary means of measuring flow is by tipping bucket connected to a logging device. The number of tips of the bucket (approx capacity 1.5L) in a five minute period is recorded on magnetic tape for subsequent translation and processing. There is also a back-up measuring device whereby the water level in a stilling well connected to a V-notch box is recorded every five minutes on Fischer and Porter paper tape. Both instruments have been calibrated separately at the Hydraulics Research Station, Wallingford and the amount of flow in five minute periods may be calculated.

A small proportion of water from every other tip of the bucket is fed into a proportional water sampler. Each sample of water flows into a funnel along a hollow rigid tube connected to the shaft of a stepping motor and then into one of a series of bottles. The sampler is connected to the tipping bucket logger and after a preset number of tips of the bucket, the stepping motor is activated, the shaft rotated and the water samples led into a new bottle. By this means an integrated 1 litre sample is taken from each of the sub-surface flows every 800 litres of flow (equivalent discharge of 8 mm over the area) and from each of the surface flows every 100 litres of flow (equivalent discharge of 1 mm over the area). The water samples are taken to MAFF, Trawscoed for chemical analysis.

The site is equipped with two raingauges recording at 5 min. intervals and also two period gauges which are read every week and also act as rainfall sample collectors.

The discharge from the main drain on the improved pasture passes through a V-notch fitted with a Fischer and Porter stage recorder. Water levels are recorded at 15 min. intervals and converted into flows. Water samples are taken by means of two North Hants samplers, one taking a sample every eight hours and the other every half-hour during period of high flow. A water sample is taken manually every week from the drain outfall on the unimproved plot for comparison purposes.

Both lysimeters are fitted with three neutron access tubes for measuring the water content of the peat profile and a series of tubes for collecting water samples at different levels in the peat. Water content data are collected every week and water samples collected monthly.

One of the automatic weather stations used in the catchment network is located within the site. This records solar radiation, net radiation, wet bulb depression, dry bulb temperature, wind run, wind direction and rainfall on a five-minute time basis. These data are processed at Wallingford to give estimates of daily evaporation losses.

Data Processing

Data recorded on the cassette tape from the four tipping buckets and one recording raingauge, are translated at Wallingford to give 5 min discharges from both the surface and sub-surface collectors of each lysimeter, and 5 min rainfall totals. Any gaps or errors in the data due to instrument or logger malfunction are infilled. Infilling in the case of the discharges is by data from the V-notch boxes and in the case of rainfall, by data from a rainfall recorder connected to the automatic weather station logger.

The water samples collected by the proportional samplers are analysed at MAFF, Trawscoed for ammonium-N, nitrate-N, total organic N, total phosphorus, and potassium. The time period for which each sample is relevant is determined using the data from the tipping buckets. This means that not only are nutrient concentrations available but also nutrient losses may be calculated as the product of the discharges and the concentrations pertaining to the time period.

Similar data exist for the discharge from the main drain of the improved plot but, in this case, sampling occurs at pre-set time intervals starting from the time of triggering the first sample. Discharge values may again be calculated but care must be taken with these discharge and concentration values because the catchment area of this main drain cannot be accurately defined as is the case of the lysimeters. There is no doubt that there will be some gains to and losses from the drainage patterns of both the improved and unimproved plots. The gains will be from upslope of the plots especially during wet conditions and will effectively dilute the effects of the drainage and of the improvement. The losses will be from those areas within the plots below the bottom drain; these will effectively reduce the flows from the plots. Bearing these points in mind, the nutrient concentrations in both drains are presented merely to indicate the effects of the improvement on a drained area as opposed to an enclosed block. No attempt will be made to calculate nutrient losses in the drains in terms of kg/ha.

Rainfall samples are collected every week and taken to Trawscoed for analysis. The concentrations obtained are combined with the rainfall totals to give nutrient inputs to the plots.

Data Analysis

In March 1978 samples collected at various points in the two plots were analysed to determine the status of the soil prior to the improvement. These analyses indicated an acid peat of pH 4.6, with total N content ranging from 2.3% in the upper 30 cm layer to 0.4% at 1 metre. The peat was found to be deficient in phosphorus, potassium and magnesium; analysis of peat water showed ammonium-N and nitrate-N in the ranges 2.7 → 0.8 mg/L and 1.5 → 0.3 mg/L respectively down the profile.

Data collection began in October 1977 and the improvement was effected during May 1978. This meant that there was a period of seven months during which an intercalibration of the two plots could be carried out.

Initial inspection of the data collected up to June 1979 show:-

(i) Very few occurrences of flow on the surface of the lysimeters. On these occasions, the percentage of flow is extremely low compared with the sub-surface discharge. The concentrations of the various nutrients in the surface flow from both lysimeters are in the range: NH_4^+-N 0 → 3.5 mg/L, NO_3^-N 0 → 5.2 mg/L, N 0 → 2.3 mg/L, P 0 → 1.4 mg/L, K 0 → 3.7 mg/L. Nearly all of the higher concentrations are found in samples taken from the improved lysimeter after the improvement had taken place. The higher values are well in excess of the concentrations found in the rainfall so it is clear that some nutrients are being lost by being dissolved in surface runoff. However, because of the small amount of surface runoff that occurs, the losses in terms of kg/ha are negligible.

(ii) Very high concentrations of NO_3^--N (up to 17 mg/L) in the sub-surface discharges from both lysimeters in the period before the improvement was carried out, (see figs. 5a and 5b). These high concentrations were generally obtained during storm events and are thought to be due to mineralisation and subsequent leaching of the organic nitrogen present in the peat used as backfill in the trenches on the inside of the lysimeters. However, these concentrations decreased during the winter 1977/78 and were found to be approximately 3 mg/L prior to the improvement in May 1978 (indicated by a vertical dotted line on fig. 5b). The effects of the improvement and the fertilizer application on the quality of the discharge from the improved lysimeter was not apparent until the end of June. The reason for this was a long period of relatively dry weather in May and June. Following the rain towards the end of June it became obvious that the concentration of nitrate-N in the discharge from the improved lysimeter was consistently higher than that in the discharge from the unimproved lysimeter. (see figs. 5b and 5c). No significant increases in the concentrations of the other nutrients were apparent.

(iii) Similar results were obtained (see figs 6a, 6b, 6c) for the nutrient concentrations in the drain discharges but, in this case, increases were found in the concentrations of all the nutrients. However, two points must be borne in mind: (a) the contributing areas to the discharges from the drains cannot be accurately defined, and (b) weekly water samples only are taken from the drain on the unimproved plot.

Discussion

It is obvious, therefore, in spite of the reservations about the water quality data from the main drains, that there has been a substantial increase in the nutrient, especially nitrate, concentrations in the discharge from both the lysimeter and the drain on the improved plot following the improvement in May 1978. This is true of both the surface and sub-surface runoff but, because of the relatively small amounts of surface runoff, the loss in terms of kg/ha from the surface is negligible. One point which rather clouds the issue in the case of the sub-surface discharges is the fact that the nutrient concentrations were high even before the improvement was carried out. This was presumably due to the soil disturbance during the construction of the lysimeters resulting in mineralization and subsequent leaching. However, the concentrations from the two lysimeters were similar and apparently diminishing before the improvement occurred. Whilst it may cast some doubt on the absolute values of the losses in the first year, it should not have had any effect on the difference between improved and unimproved. Another point that must be borne in mind is the fact that the increases due to the improvement could be as a result of the cultivation and/or the fertilizer application. The cultivation is a once only phenomenon whilst the fertilizer application will probably be an annual event. It will be interesting to see what increases, if any, will occur in the concentrations in the discharges from the improved plot in subsequent years due to fertilizer applications only.

Future work

The improved grass is now well established and the seasonal fertilizer application was carried out in late May 1979. Data from the period following this application are still being analysed. It is proposed that the study be taken through at least one more annual cycle with sheep and cattle grazing at the full recommended density/frequency to establish firmly the pattern of N inputs and losses. During this the accumulating data will be fully analysed to quantify the trends in nutrient status of the soil profile as well as the input, output and offtake stages of the nitrogen cycle.

Because of the continuing drainage from both lysimeter blocks during the first year of operation it was not possible to carry out accurate water balance determinations of water use. With the profiles now in a more stable condition work on this aspect will be intensified during this and the following cycle.

The initial results indicate that the major transport process for nitrate loss from the lysimeter is by leaching through the profile. However, the lysimeter represents the 'hilltop' situation only. The cumulative effects of overland flow on a complete slope should be studied. Typically also the soils are thin and variable in composition on these upland hillsides and movement of water between surface and subsurface flow is not uncommon. Ideally therefore the next step in the study should be from the lysimeter to the sub-catchment scale.

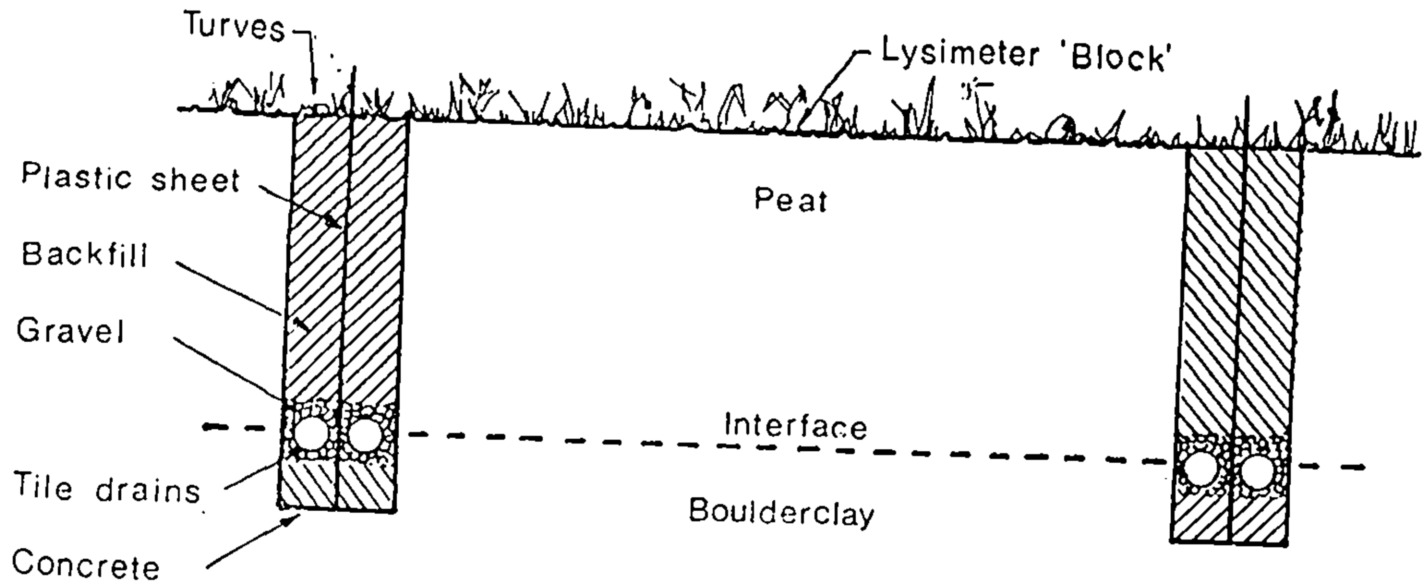

FIG. 2. CROSS-SECTION OF LYSIMETER SHOWING DETAILS OF CONSTRUCTION

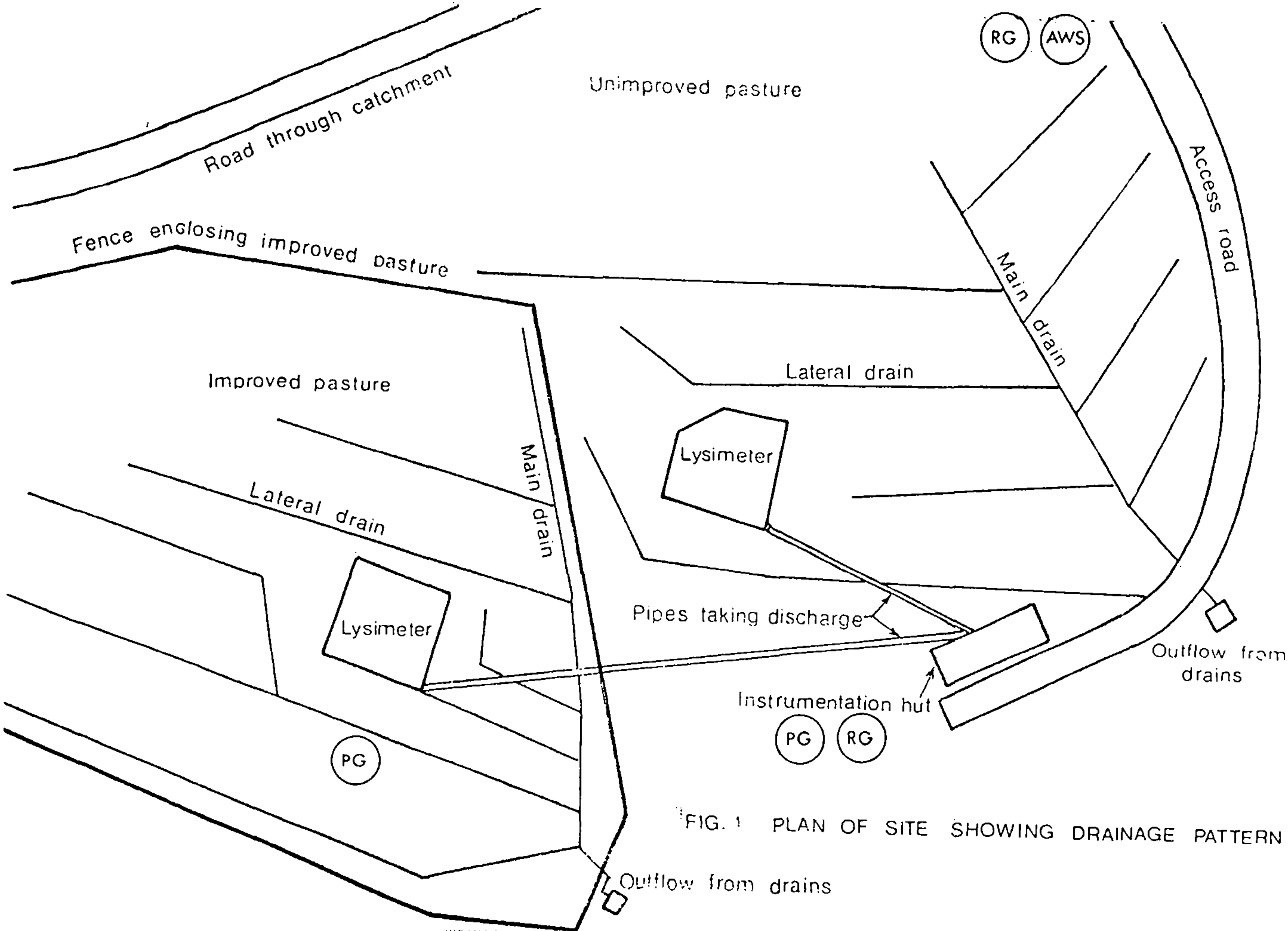

FIG. 1 PLAN OF SITE SHOWING DRAINAGE PATTERN

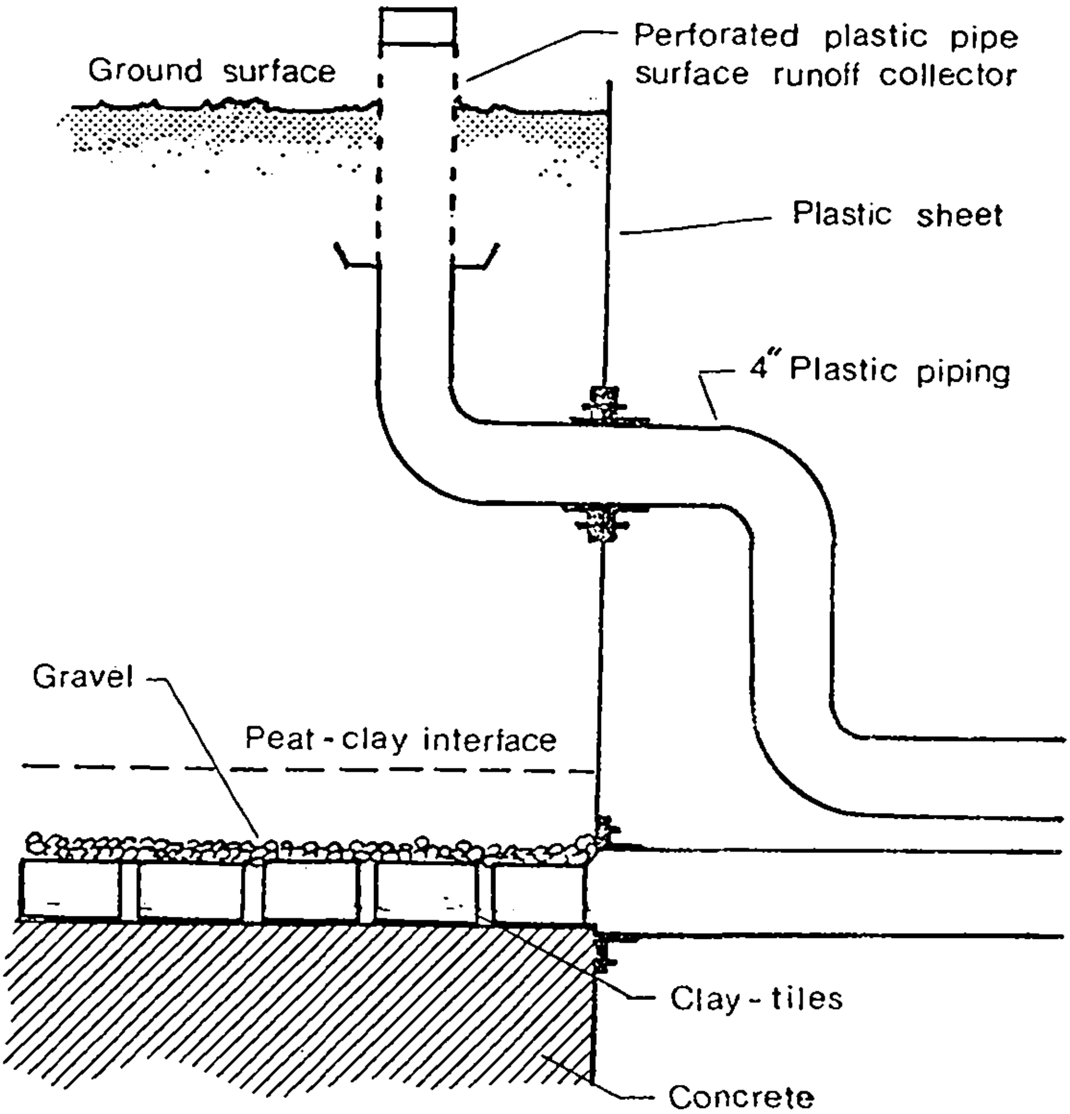

FIG. 3.
SURFACE AND SUB-SURFACE DISCHARGE COLLECTORS

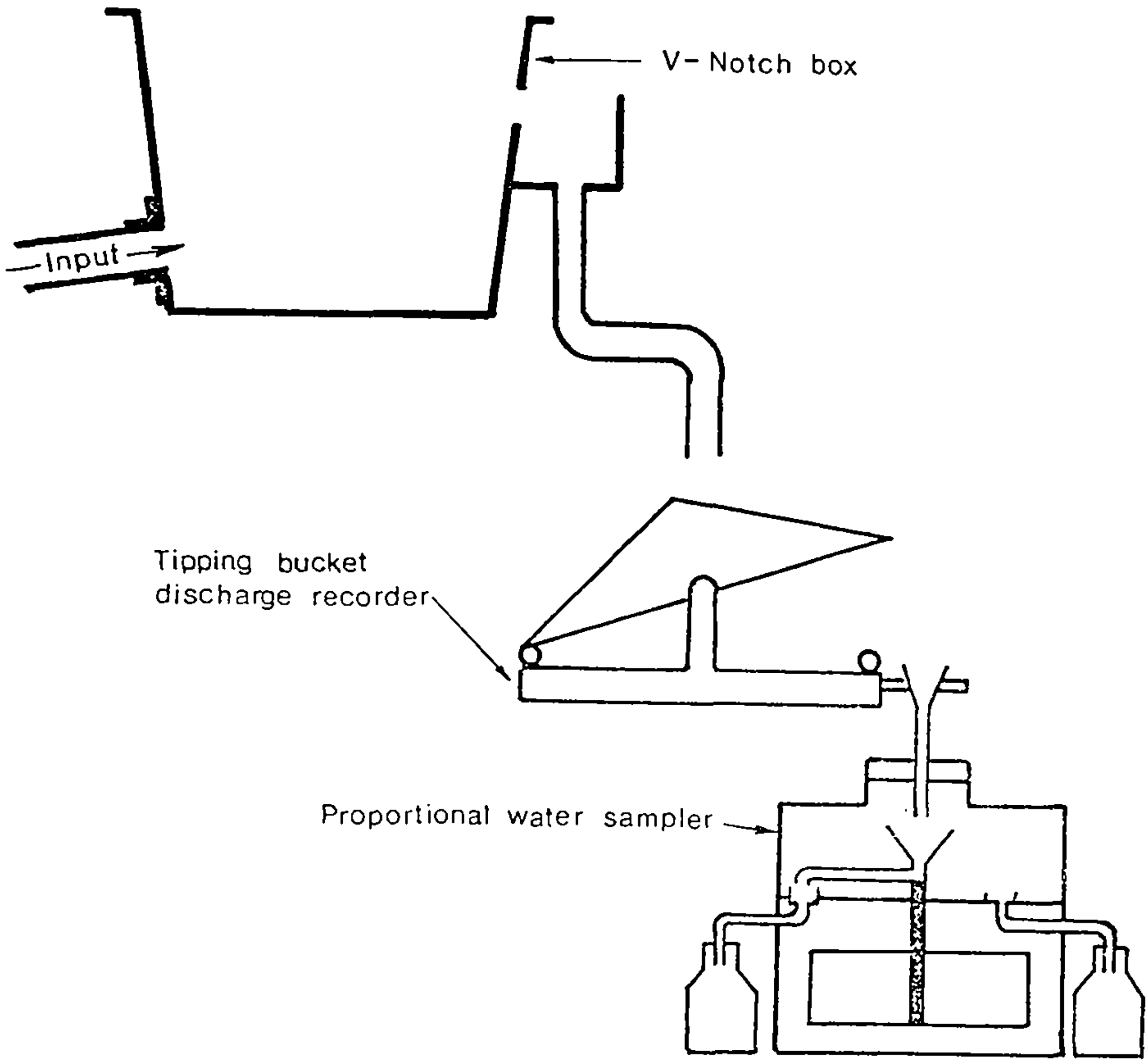

FIG. 4. FLOW MEASURING DEVICES AND PROPORTIONAL WATER SAMPLER

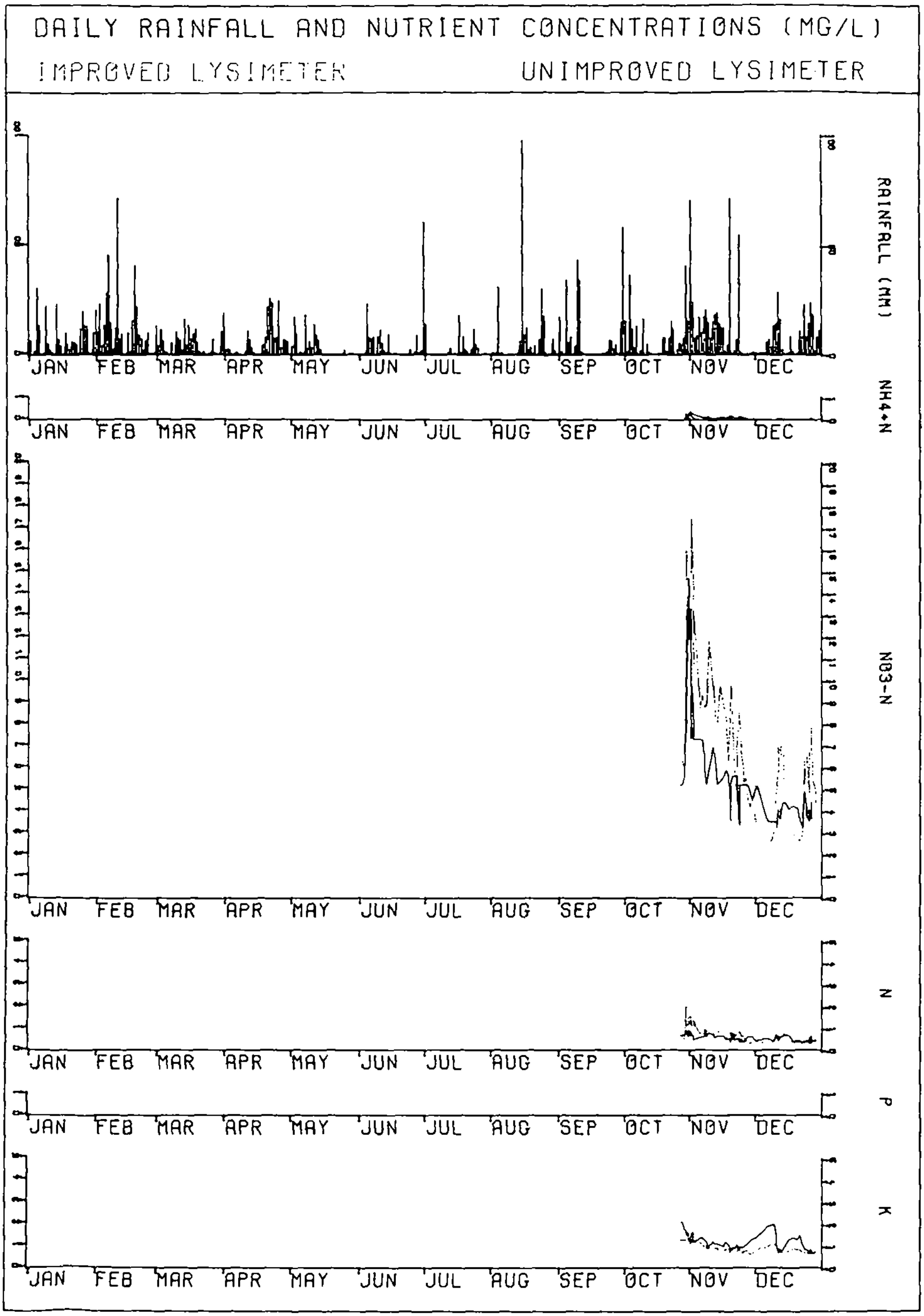

FIG. 5a NUTRIENT CONCENTRATION IN THE LYSIMETER DISCHARGES FOR 1977

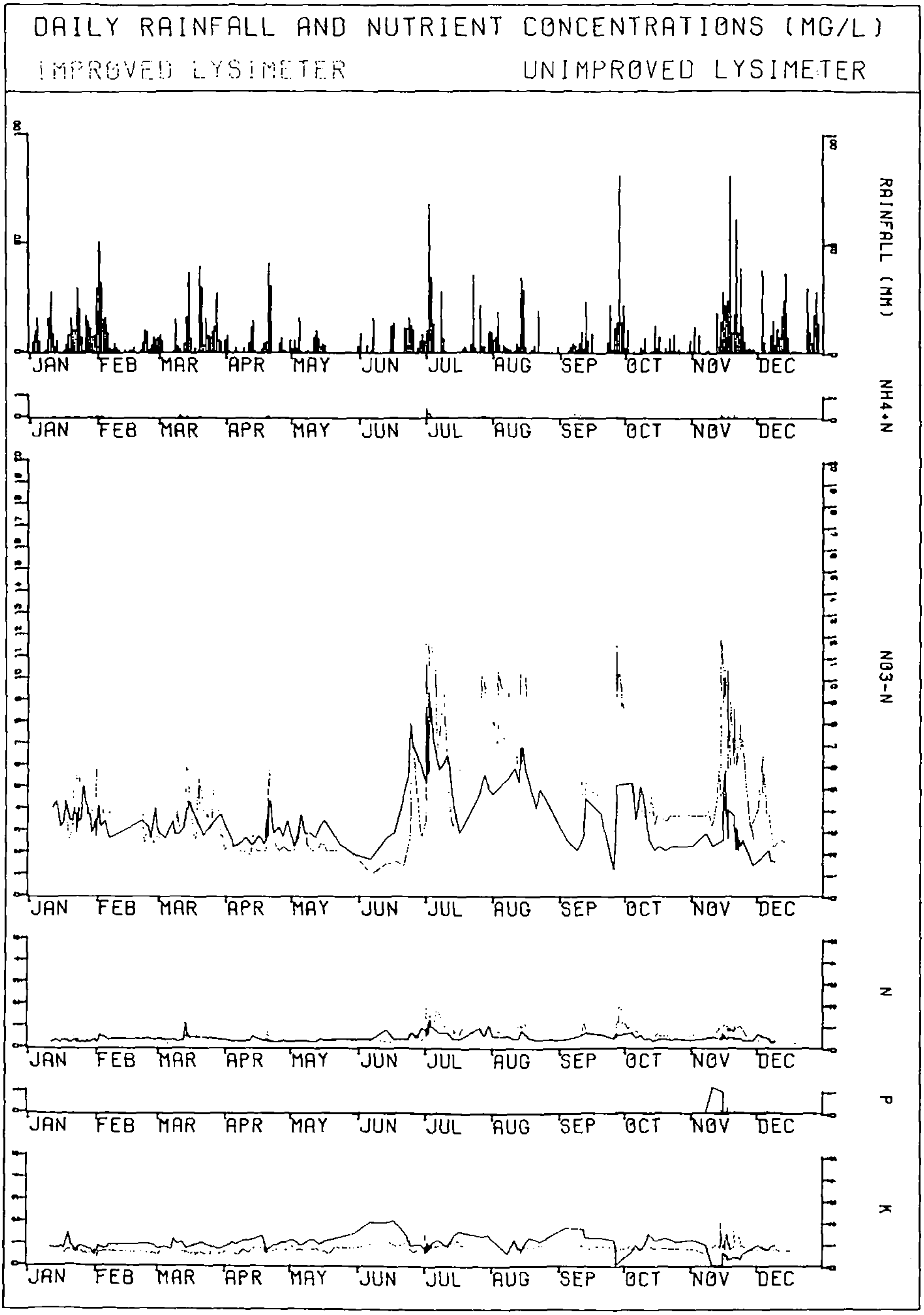

FIG. 5b NUTRIENT CONCENTRATION IN THE LYSIMETER DISCHARGES FOR 1978

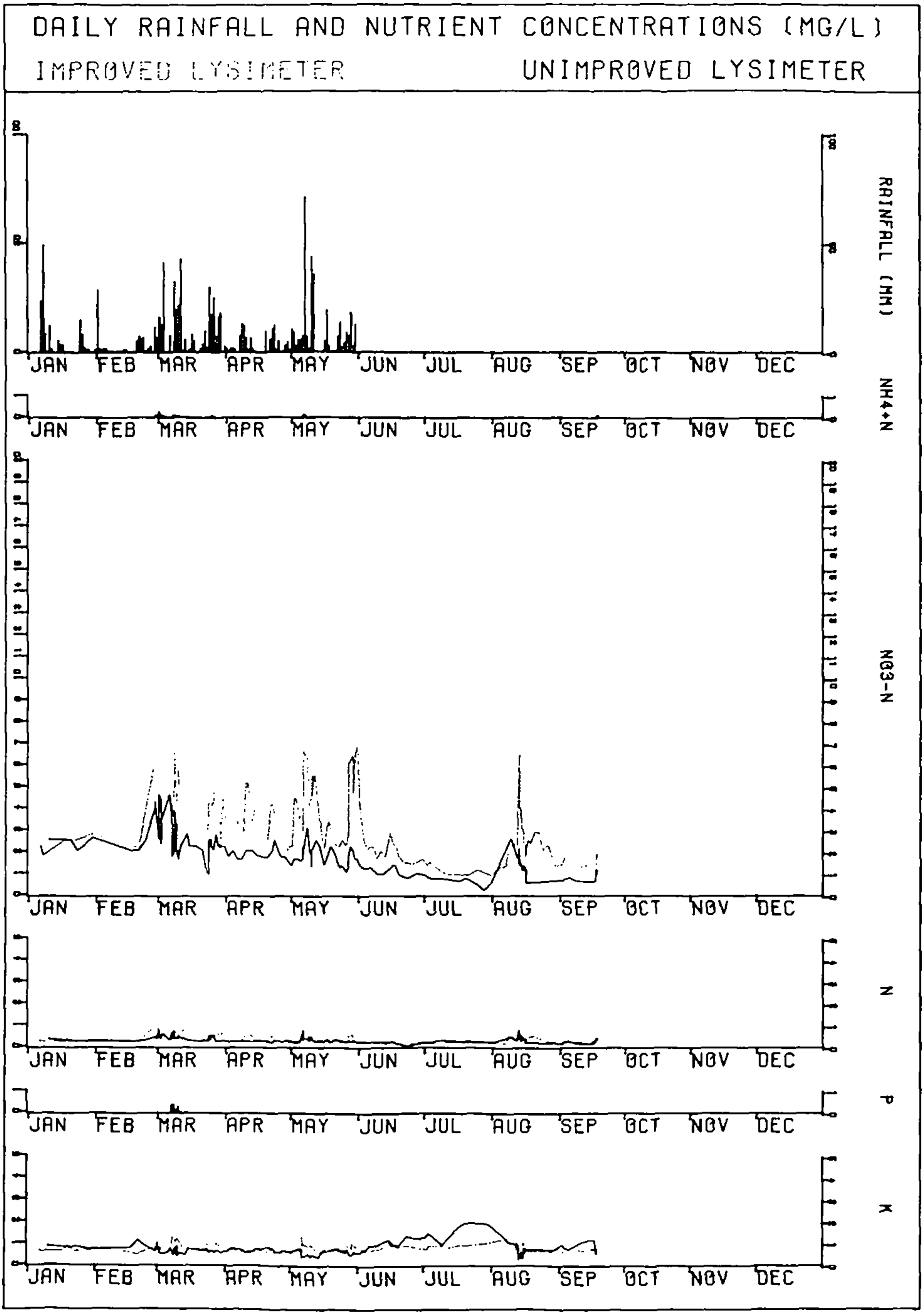

FIG. 6c NUTRIENT CONCENTRATION IN THE LYSIMETER DISCHARGES FOR 1979

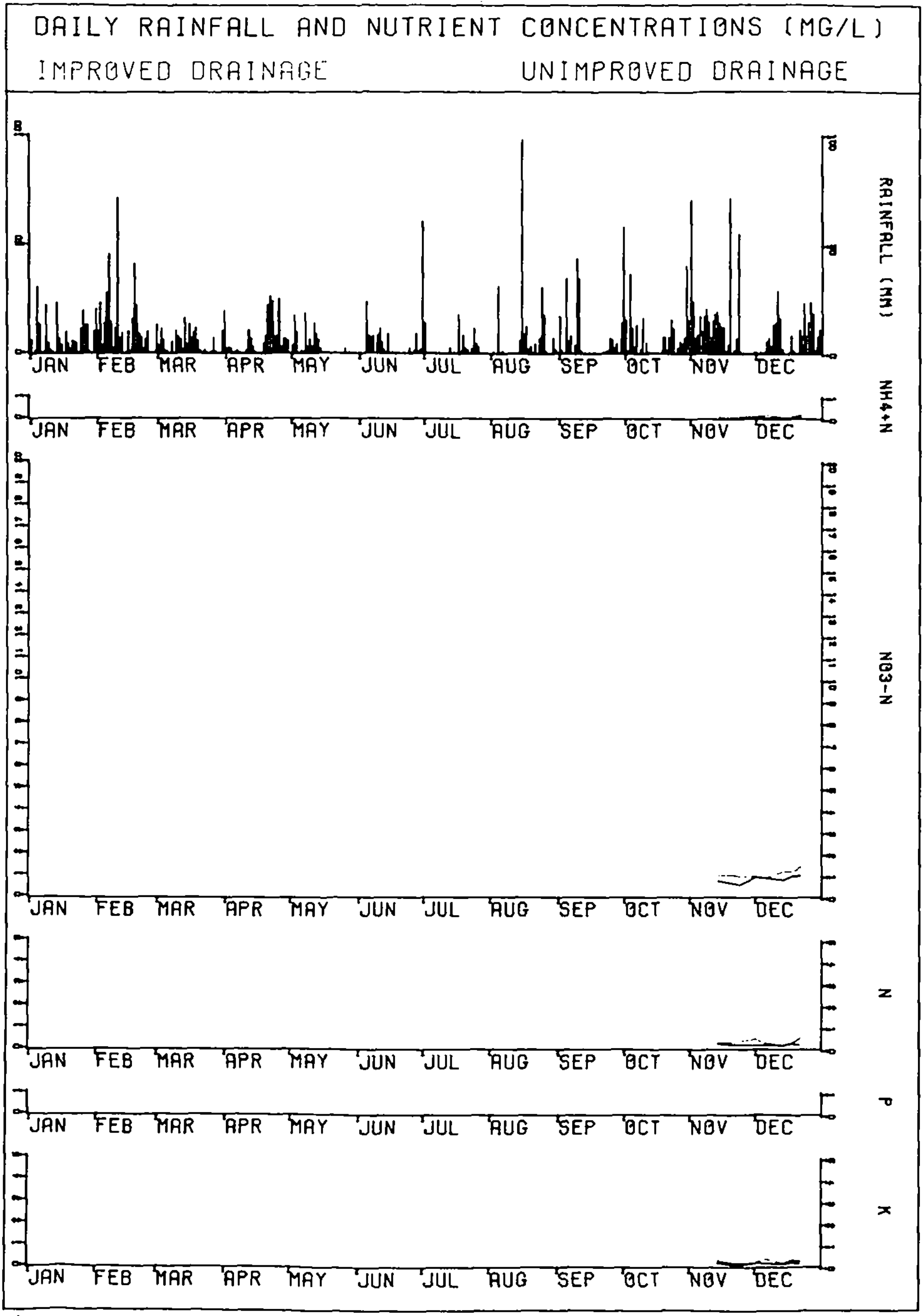

FIG. 6a NUTRIENT CONCENTRATION IN THE DRAIN DISCHARGES FOR 1977

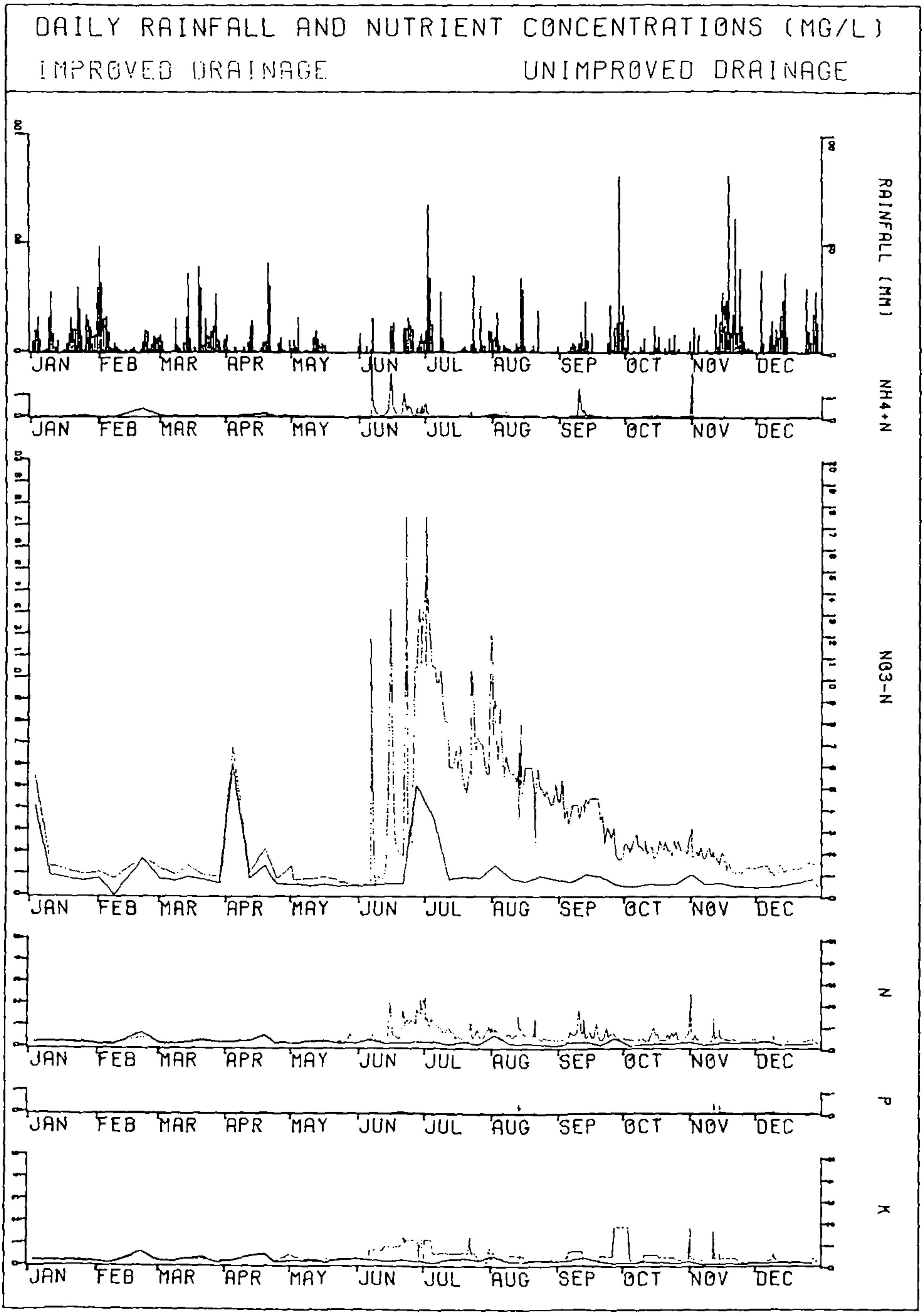

FIG. 6b NUTRIENT CONCENTRATION IN THE DRAIN DISCHARGES FOR 1978

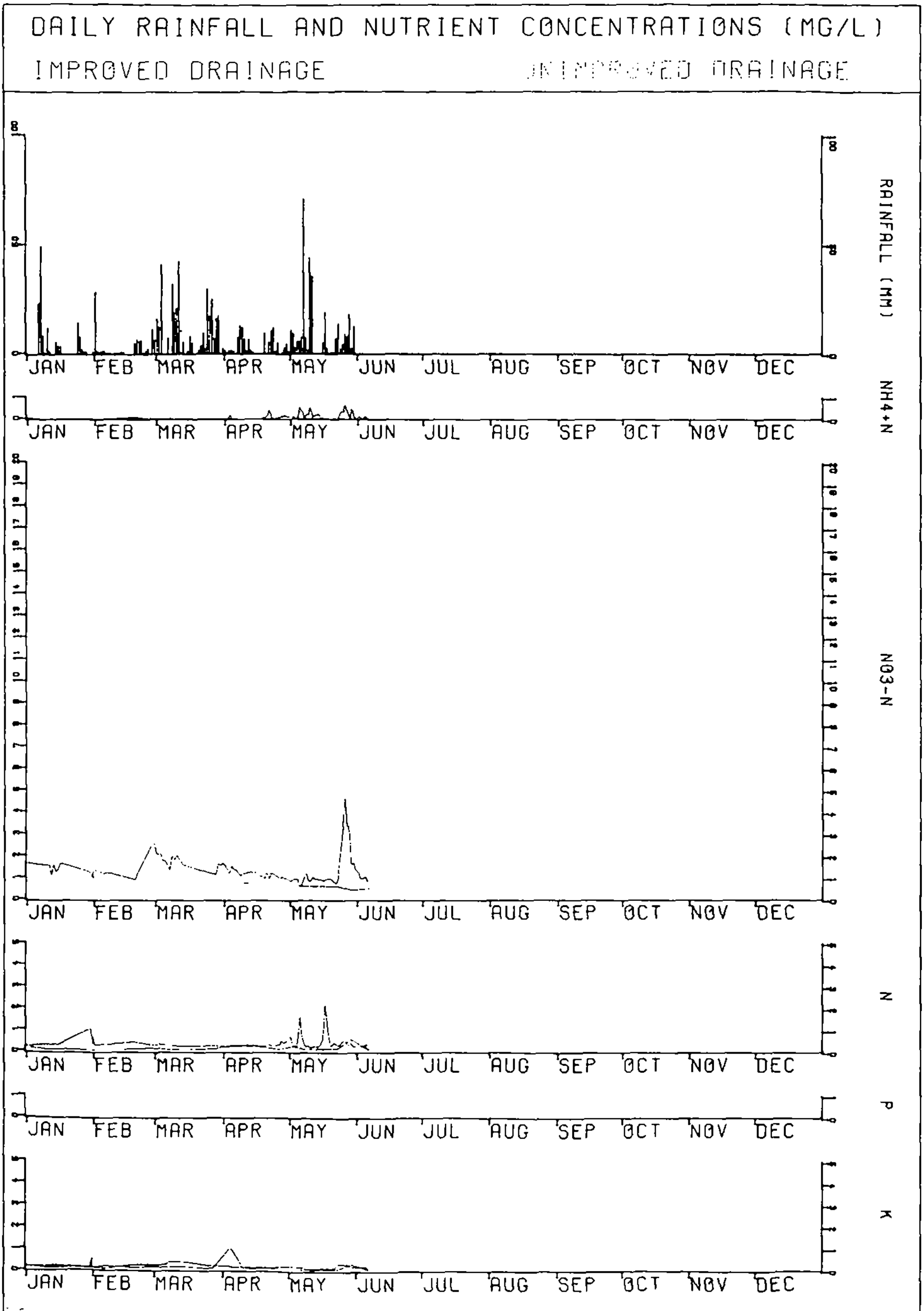

FIG. 6c NUTRIENT CONCENTRATION IN THE DRAIN DISCHARGES FOR 1979