AGRICULTURAL SOURCES FOR LAKE POLLUTION: SOIL EROSION IN SLAPTON LEY CATCHMENT.

by

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ABSTRACT

The purpose of this study was to investigate the role of soil erosion as a factor in lake pollution and in particular the transport of phosphorus from field soils to streams and lakes in association with mobile sediment.

Four land uses were selected as representative of the Slapton Ley catchment area to investigate the levels of phosphorus in the soil. The surface soil samples from the selected land use areas were analysed to determine the water-soluble phosphorus level in solution and exchangeable phosphorus level in sediment.

Twelve experimental plots were studied in order to assess the erosional effects of overland flow and thus to determine the level of phosphorus from different land uses which may be influencing the eutrophication of the lake. It was concluded that slope angle, vegetation cover, surficial soil properties, animal influence and agricultural practice are the main factors influencing sediment transportation by overland flow.

Estimated results for the agricultural fields indicated that the actual phosphorus loss to the Ley is always greater in sediment than solution and actual phosphorus loss in sediment is greater in arable (root) and cereal than in grass.

The point water samples (136) from 13 different sources were grouped. Mean value of phosphorus concentration from the point sources indicated that the agricultural land uses such as arable and cereal provide 2 times more exchangeable phosphorus attached to sediment than the other land uses whereas farm and sewage provided 5 times more soluble phosphorus in water than other sources.

Phosphorus concentration during peak discharge was examined for the Gara catchment. The results indicated that the ratio of phosphorus concentration in suspended sediment to phosphorus concentration in water is 240: 0.3 and that there is a linear relationship between phosphorus in water and phosphorus in sediment during the peak discharge.

Sediment phosphorus levels in the marsh area were also examined. The results indicated that the top layers of the marsh sediment particularly at the surface, have higher phosphorus concentration than the lower layers and that there are higher levels in sediment than in water.

From these results the conclusion was drawn that the soluble phosphorus in water is at highest concentration in sewage works effluent. However this effluent contributes a small proportion of phosphorus load to the Ley compared with the arable (root), cereal and grass lands in the catchment. Agricultural sources, particularly arable sources such as root and cereal play an important role on soil erosion as a factor in lake pollution and in particular in the transport of phosphorus from field soils to streams and lakes in association with mobile sediment in the Slapton Ley catchment.

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CHAPTER 1

AIMS OF THE RESEARCH

This chapter outlines the general aims of the research and the specific objectives.

1.1 AIM:

The fundamental aim of this research was to investigate and classify the roles of soil erosion as a factor in lake pollution and in particular the transport of phosphorus from field soils to streams and lakes in association with mobile sediment. Phosphorus is largely insoluble in field soils and is therefore not liable to be leached out in large quantities; it is, however readily adsorbed onto soil particles and therefore soil erosion and sediment movement are liable to be important factors in the downstream transport of phosphorus in lake catchments.

1.2 EUTROPHICATION:

Phosphorus has been identified as a major element nurturing the process of lake eutrophication and sewage and urban runoff are common sources (Lund, 1972). The enrichment of water bodies by nutrients imported from a catchment is termed "eutrophication". It is a slowly - occurring natural process, but human intervention in the input of nutrient can greatly accelerate the process. The nutrients status of lakes in natural situations however may be strongly influenced by the input of agriculturally derived phosphorus compounds as well as sewage. The area of phosphate-associated solution and sediment is under-researched.

Lakes are liable to disturbance from human pressures such as agriculture, urbanization, industry and recreation. The changes that these activities can effect are often subtle, extremely complex and may not be immediately recognised as either harmful or undesirable. The leaching of soil-applied inorganic fertilisers and the disposal of domestic sewage and other wastes can considerably add to the natural sources of dissolved nutrients and suspended substances from a lake's catchment. This artificial entrichment has been termed "man-made" eutrophication, to distinguish it from natural eutrophication (e.g. Reynolds and Sinker, 1976).

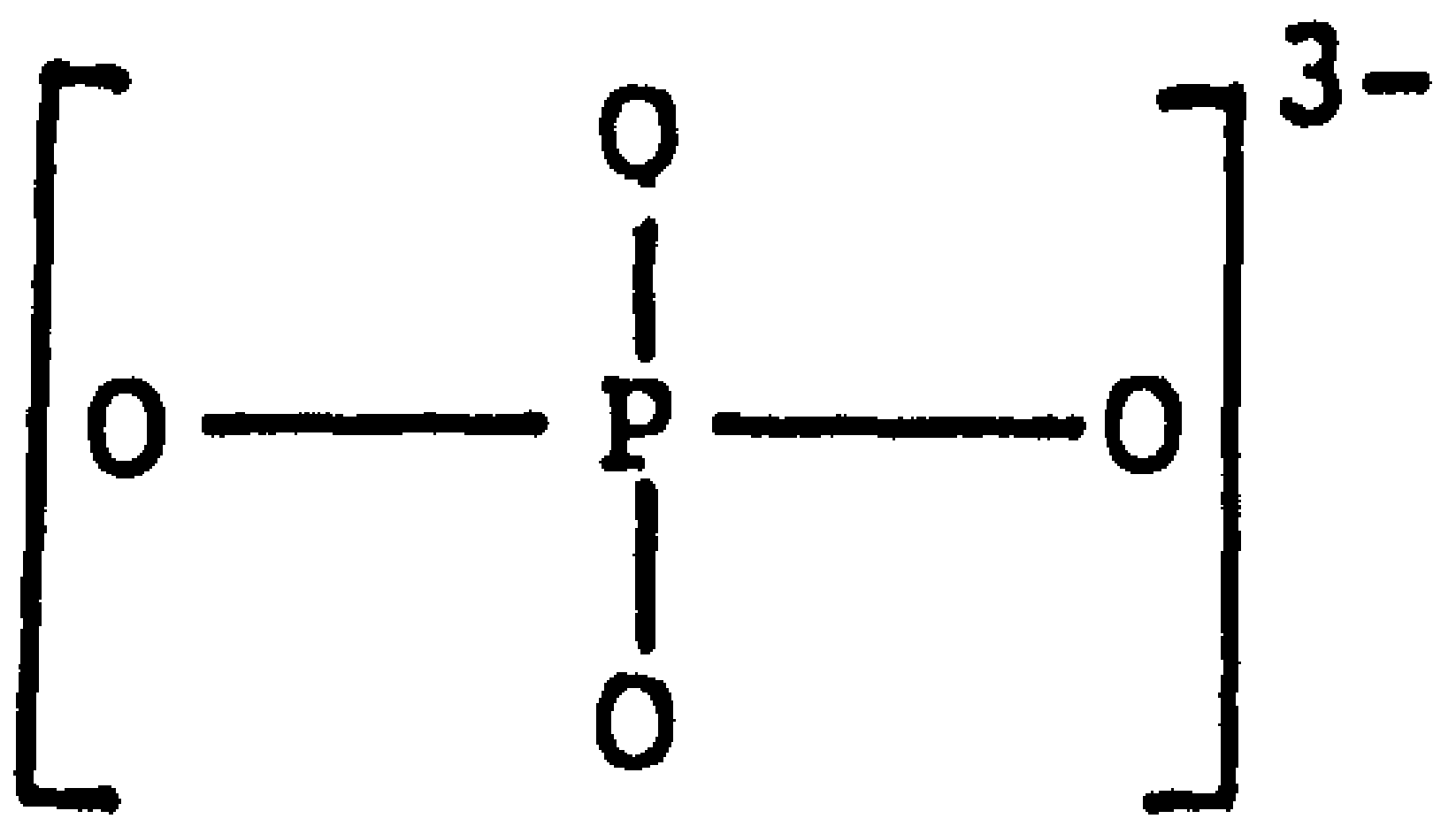
The term "eutrophication" is now generally taken to imply accelerated nutrient enrichment producing the effect of "blooms" of uncontrolled plant growth and ultimate "death" of the lake.The particular cause of excessive planktonic blue-green algae growth is an abundance of nitrate and phosphate. Excess growth of primary producers, especially planktonic blue-green algae, can shade out macrophytes on the lake bed. The rotting vegetation will deplete the supply of oxygen, as the amounts of plant and animal tissue may exceed the decomposing capacity of the bacterial population. Together with dwindling food supplies, this will eventually cause a decline in fish species. Experience indicates that accelerated eutrophication and the appearance of algal blooms are most likely to occur:

i) in standing bodies of water
ii) during the high light, high temperature conditions of summer
iii) when the P concentration of the water exceeds 0.05 ppm and the ratio of dissolved N:P is 20 or less (White, 1979)

Although, phosphorus is a minor constituent of the lithosphere, it plays important roles in limnology and oceanography and in water supplies. Its aquatic transformations (dissolution, transport, distribution, precipitation and accumulation) are interrelated and are interdependent with those of other significant components of natural waters.

1.3 PHOSPHORUS SPECIES IN NATURAL WATER SYSTEMS:

Phosphorus occurs in nature almost exclusively as phosphate, the fully oxidized state, with formal oxidation number 5 and coordination number 4. Phosphate occurs in all known minerals as orthophosphate, the ion form of which is represented as:

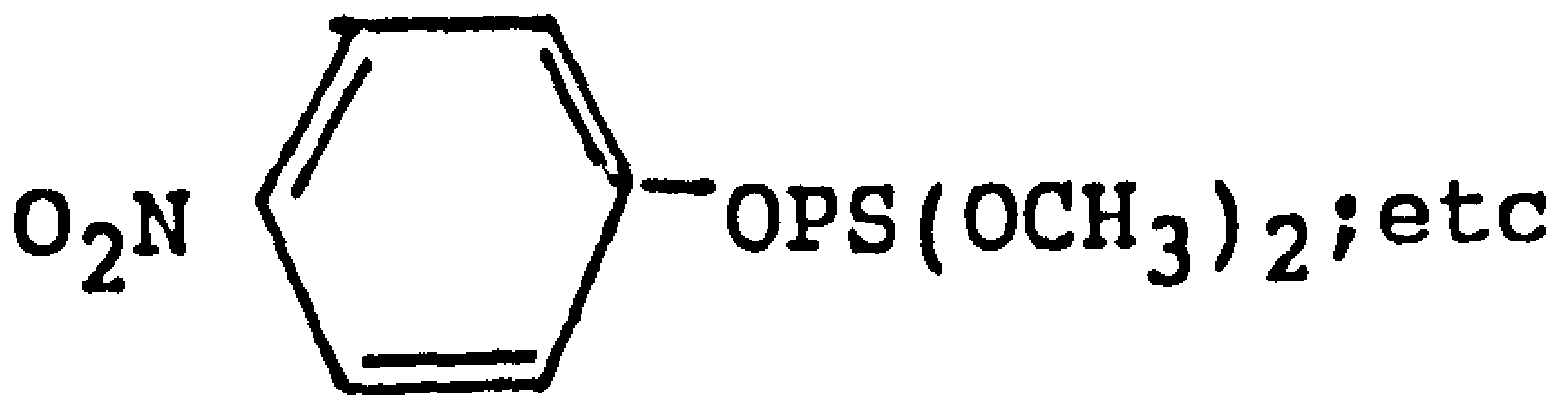


or$[PO_4]^{3-}$ (Table: I).

Phosphate is found in the dissolved form in natural waters as a result of the natural weathering and

TABLE: I

Dissolved Phosphorus Forms of Possible Significance in Natural Water System

Form	Representative of Compounds or Species
ORTHOPHOSPHATE	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}, $FeHPO_4^+$, $CaH_2PO_4^+$
INORGANIC CONDENSED PHOSPHATES:	
pyrophosphate	$H_2P_2O_7^{2-}$, $HP_2O_7^{3-}$, $P_2O_7^{4-}$, $CaP_2O_7^{2-}$, $MnP_2O_7^{2-}$
tripolyphosphate	$H_2P_3O_{10}^{3-}$, $HP_3O_{10}^{4-}$, $P_3O_{10}^{5-}$, $CaP_3O_{10}^{3-}$
trimetaphosphate	$HP_3O_9^{2-}$, $P_3O_9^{3-}$, $CaP_3O_9^-$
ORGANIC ORTHOPHOSPHATES:	
sugar phosphates	Glucose-1-phosphate, adenosine monoposphate
inositol phosphates	Inosital monophosphate, inositol hexaphosphate
phospholipids	Glycerophosphate, phosphatidic acids, phosphatidyl choline
phosphoamides	phosphocreatine, phosphoarginine
phosphoproteins	
ORGANIC CONDENSED PHOSPHATES:	Adenosine-5'-triphosphate, coenzyme A
PHOSPHORUS-CONTAINING PESTICIDES:	

Source: Stumm and Morgan (1970).

solution of the phosphate minerals, soil erosion and transport, soil fertilization and resultant phosphorus transport, biological transfer, assimilation and dissimilation processes involving phosphate compounds in detergent manufacture, water treatment and industry (domestic and industrial waste water)(Table: II).

There is convincing evidence to show that the appearance and mass production of some species of blue-green algae (Microcystis species, Aphanizomenon species, Anabaena species) and the flagellate Prymnesium parvum sometimes result in the death of livestock and fish which come into contact with extracellular toxins released during algal growth (Gorham, 1964; Shilo and Shilo, 1955). The collapse of algal blooms may be accompanied by a rapid deoxygenation of surface waters (Barica, 1975). Increased turbidity in the water column, due to phytoplankton growth and the influx or resuspension of particulate materials can significantly reduce light availability for submerged macrophytes and has been implicated in the decline of several Norfolk Broads (Moss, 1977). Accelerated rates of sedimentation are of little immediate consequence in deep lakes but in shallow waters they may promote the encroachment of marginal vegetation and the invasion of marsh and carr floras, and possibly the premature disappearance of the limnological lake.

Eutrophication is not irreversible. The recovery

TABLE: II

Solid Phase Forms of Phosphorus of Possible Significance in Natural Water System.

Form	Representative Compounds or Substances
SOIL AND ROCK MINERAL PHASES.	
hydroxyapatite	$Ca_{10}(OH)_2(PO_4)_6$
brushite	$CaHPO_4.2H_2O$
carbonate Fluorapatite	$(Ca,H_2O)_{10}(F,OH)_2(PO_4,CO_3)_6$
variscite, strengite	$AlPO_4.2H_2O,FePO_4.2H_2O$
wavellite	$Al_3(OH)_3(PO_4)_2$
MIXED PHASES, SOLID SOLUTIONS, SORBED SPECIES,ETC.	
clay-phosphate (e.g, Kaolinite)	$[Si_2O_5Al_2(OH)_4.(PO_4)]$
metal hydroxide-phosphate	$[Fe(OH)_x(PO_4)_{1-x/3}]$, $[Al(OH)_x(PO_4)_{1-x/3}]$
clay-organophosphate	$[Si_2O_5Al_2(OH)_4.ROP]$, clay-pesticide,etc.
metal hydroxide-inositol phosphate	$[Fe(OH)_3$.inositol hexaphosphate]
SUSPENDED OR INSOLUBLE ORGANIC PHOSPHORUS.	
bacterial cell material plankton material plant debris proteins	Inositol hexaphosphate or phosphoprotein, nucleic acids, polysaccharide phosphate

Source: Stummm and Morgan (1970).

response of a eutrophic lake depends on the degree of its enrichment (Lorenzen, 1974), as well as the relative importance of any internal nutrient loading from the sediments (e.g. Bengtsson, 1975; Ryding and Forsberg, 1977; Osborne and Phillips, 1978). The implementation of corrective measures is quite feasible in the case of point sources of nutrient enrichment; the diversion and /or more efficient treatment of sewage may be sufficient to reduce the external loading of phosphorus below a level critical to the onset of eutrophic conditions.

A detailed programme of hydrological monitoring started at Slapton in 1970, aimed at evaluating the importance of fertilisers and land-use patterns in the supply of nutrients to the lake (see: Troake _et_ _al_., 1976). Despite the documented evidence regarding the causes and effects of eutrophication, little progress has been achieved in establishing the mechanisms of its interaction with other environmental processes. There is considerable dissimilarity beteen the responses of lakes to different sources of enrichment whether natural, agricultural or cultural and to varying levels from the same source.

Studies (e.g Li, _et_ _al_., 1973) on lake sediments have indicated that lakes can, and do, progress to a more oligotrophic condition (less productive) when nutrient input from river catchments slows down or ceases. Thus, eutrophication can be reversed, although it is the entire drainage basin, and not just the lake or stream, which must be considered as the ecosystem unit if water pollution and soil erosion problems are to be successfully dealt with. This is especially relevant to the present study, as the field site drains into Slapton Ley.

Many of the recent studies have documented eutrophication due to nitrogen but phosphorus is also important. The relationship between sediment yield, phosphorus on sediment and phosphorus in solution is largely unknown.

1.4 PROCESSES:

Phosphate is easily adsorbed onto soil particles. Hence the build up of phosphorus in the soil is more than that of nitrogen and also less likely to be dissolved in soil water.

In natural waters phosphorus usually occurs oxidized as phosphate of which the ortho and poly- forms are the major derivatives (Stumm and Morgan, 1970). The chemical differentiation of these phosphates is based on an operational division into 'sestonic' (particulate) and 'collidal'and 'dissolved'(soluble) fractions; see Olsen (1967)for a critical appraisal of current terminology. The particulate fraction includes phosphates of insoluble salts (e.g. $FePO_4$,$Ca_3(PO_4)_2$), adsorption complexes, and various biogenic compounds. In the dissolved state, free ions of orthophosphate (HPO_4^{2-},$H_2PO_4^-$,etc.) and soluble organic compounds (proteins, phospholipids, sugar phosphates) are the most important components available for biological uptake. Orthophosphates can be readily detected by their reaction with acidified molybdate to form, upon reduction, an intensely blue-coloured complex (Osmond, 1887, Deniges, 1920). The expression, "Soluble reactive phosphorus" was proposed by Strickland and Parson (1965) to be synonymous with the dissolvedfraction of orthophosphate. The. production of insoluble phosphate can be illustrated indicating successive stages in the dissolution of a monocalcium phosphate (MCP) granule in soil (after Tisdale and Nelson, 1975) as in Fig. 1.1.

Phosphate is predominatly associated with sediments (Duley,1926), therefore the adsorption of phosphate on sediments is important in lake pollution.

1.5 ADSORPTION OF PHOSPHATE:

Adsorption of phosphate is most significant for the oxidised forms. There are two types of adsorption.

i). Physical adsorption due to the attraction of Van der Waal's intermolecular attraction forces.

ii). Chemisorption - Chemical bonding which may be so tight that ions may not be recovered.

The adsorption of phosphate is complicated because the charge on the adsorbent surface and on the phosphate anion varies with pH. Phosphate anions have a strong affinity for iron and alumino- oxides and are adsorbed to them by chemisorption processes, but this only usually occurs at a pH of below 5. Phosphate is also most strongly adsorbed in the $H_2PO_4^-$ form, which only exists at low pH so strong chemisorption of phosphate requires a

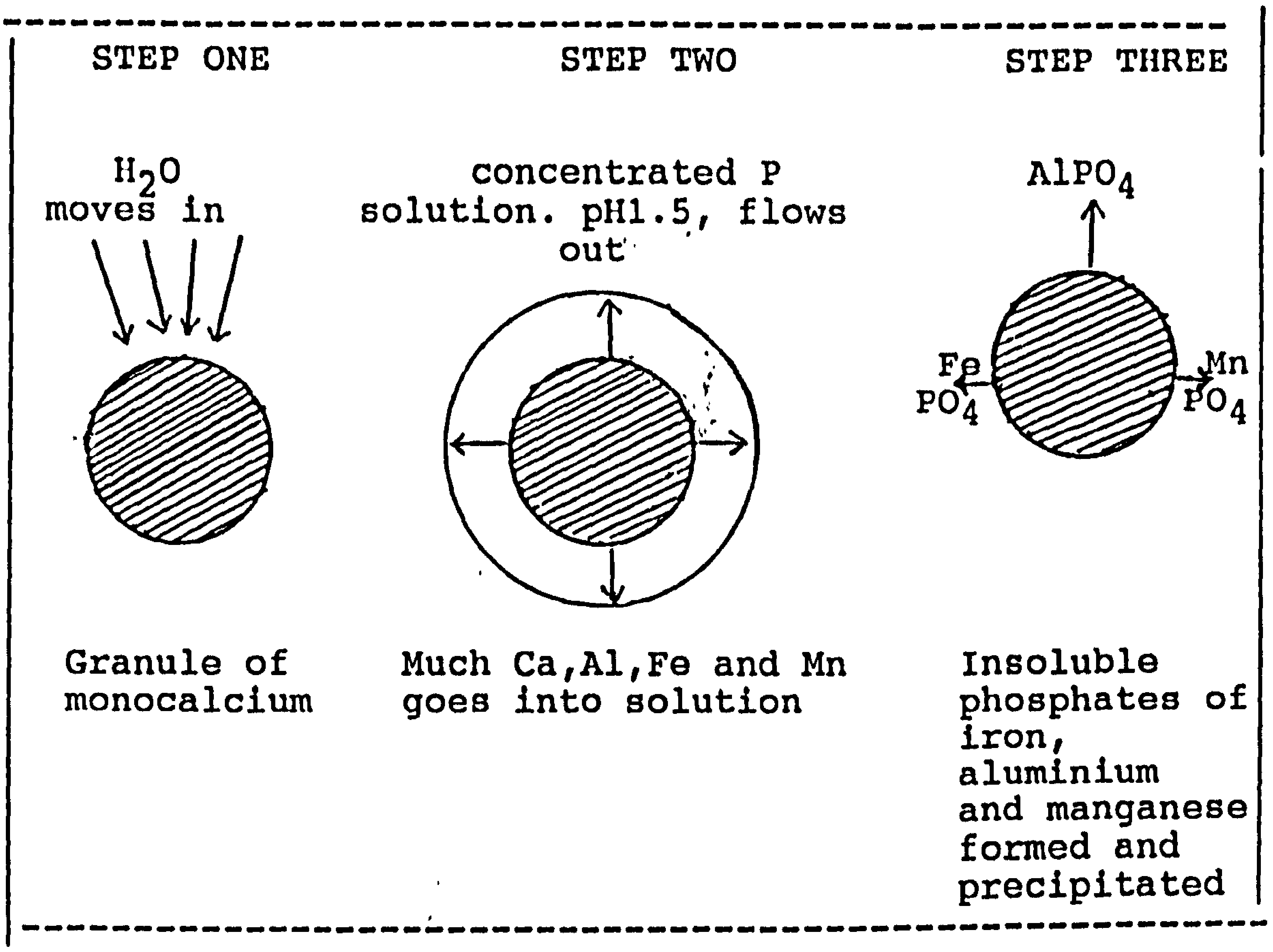


Fig: 1.1 Successive stages in the dissolution of an monocalcium phosphate (MCP) granule in soil. (after Tisdale and Nelson, 1975).

low pH. Desorption occurs by raising the pH or introducing another anion with a higher affinity for the iron or aluminium. The pH at which there are equal numbers of positively and negatively charged ions on the surface of the adsorbent (e.g: iron and alumino- oxides and organic matter)is known as the "Point of zero charge" (PZC). If pH<PZC, anions in solution will be attracted onto the surface from solution. Several authors have noted a correlation between organic carbon content and the amount of phosphorus adsorbed by soils and sediments (Williams et al., 1970; Woodruff and Kemprath, 1965; Ahenkorah, 1968), and it is thought that it is aluminium and to a lesser extent iron adsorbed by the organic colloids which are active in phosphorus adsorption. Therefore, adsorption of phosphorus onto organic carbon would increase with a decrease in pH. At a high pH (e.g;pH>7) phosphorus is adsorbed onto calcareous complexes, but these have a lower capacity to adsorb phosphate (Wetzel, 1975).

Solute transport data have been used for a variety of purposes including studies of biogeochemical cycling in small drainage basins (e.g; Likens et al., 1977; Waylen, 1979); evaluations of material transport to the oceans (e.g; Clarke, 1924; Alekin and Brazhnikova, 1968; Meybeck, 1976, 1979); assessments of the environmental impact of non-point pollution and other human activity (e.g; Steel and Gibroy, 1971; Holes and Pearson, 1977). In studying solute transport by rivers, it is essential to recognise that the chemical character of water flowing in a river channel will reflect the spatial and temporal integration of the complex sequence of pathways interposed between precipitation input to the drainage basin and output as channel flow and the associated evolution of the water chemistry (cf. Walling,1980a; Eriksson,1981). Thus, whereas a number of early workers attempted to account for the solute content of river water in terms of dissolution of the channel bed material, it is now clear that attention must be turned to processes operating throughout the whole of the basin (Walling and Webb,1986). Processes related specifically to the channel environment,such as sediment/solute interactions (e.g; Green et al.,1978; Cullen and Rosich,1979; Casey and Farr,1982), biotic uptake (e.g; Edwards,1974; Casey and Ladle,1976) and chemical precipitation (e.g; Blanc and Conrad,1968) may exert a significant effect, but they must be viewed as subordinate to the basin-wide processes governing the evolution of runoff chemistry (Walling and Webb,1986).

Therefore, careful consideration had to be given to the phosphorus which was adsorbed onto the soil under different land uses the sediment deposited in the marsh land, suspeded sediment in the stream and the transported sediment on slopes, in order to study the sources for phosphorus for lake pollution due to soil erosion.

1.6 TRANSFORMATION OF PHOSPHORUS IN FRESH WATER:

Phosphorus may limit biological productivity and the rates of production are governed to a large extent by the rate of phosphorus cycling. An increase in phosphorus inputs into a lake or stream system will therefore extend the limit of biological production. Over 90% of phosphorus is in the organic form as cellular constituents of living particulate matter. Orthophosphate (PO_4^{3-}) is the only significant inorganic form of phosphorus in natural water. It is highly soluble but is consistently low at less than 5% total phosphorus,as it is cycled very rapidly. Phosphorus has the characteristic of converting from one to another of many possible forms (table I,II) and commonly exists in the oxidised form.

1.7 SOURCES OF PHOSPHORUS IN A LAKE SYSTEM:

Dissolved and particulate PO_4 loads arise from point and non-point(diffuse) sources. Examples of point sources are effluents from factories, sewage works, intensive livestock units such as large cattle feed lots and dairies. Non-point sources comprise the drainage from the remaining agricultural and non-agricultural land, grassland fields and forest.It also includes: (i) Native compounds, i.e. from weathering of rocks- this is a very slow process and probably does not significantly contribute to phosphorus loads over a short time period. (ii) Precipitation and fallout concentration is highly variable and the load is usually less than that of nitrate (Chapin and Ultormark, 1973). (iii) Ground water inputs are usually low (Wetzel, 1975).

Losses of phosphorus from a lake basin include:

(i) Effluent outflow and seepage from the basin.

(ii) Loss of phosphorus-containing compounds in the sediment.

In natural waters a major component of the phosphorus cycle is the exchange between water and sediment. Phosphorus compounds adsorbed onto sediment surface are unavailable to plants. Harter (1968) found sediments in eutrophic lakes were capable of adsorbing large amounts of phosphorus from the overlying water. Lake sediments also contain much higher concentrations of phosphorus than the overlying water (Olsen, 1958, 1964; Holden, 1961). Exchange of phosphorus is affected by redox conditions and usually occurs in the top 10cm of sediment (Hynes and Greib, 1970). Particulate phosphorus is adsorbed onto organic complexes such as clays, carbonates, ferric hydroxides and dead organic matter.

The two elements which are the main problems for lakes when supplied in excess, are nitrogen and phosphorus. These come from many sources. One of the earliest detailed studies was carried out on a group of lakes in Wisconsin by Sawyer (1947) who found that treated sewage effluents formed 15% of the water inflow, but contributed 75% of the nitrogen and 88% of the phosphorus, the remainder coming from agricultural runoff. A study in England on the Great Ouse River (Owens and Wood, 1968) also showed a high proportion of phosphorus coming from sewage (80%), but less than 20% of the nitrogen from sewage with the remainder coming from agricultural land. However, these results may have been influenced by unusually high proportions of sewage discharge, and the overall assessment by the Task Force of the American Water Works Association (M^{c}Carty, 1967) was rather different. Its conclusion was that runoff from agricultural land is by far the greatest contributor of both nitrogen and phosphorus, as shown in Table. III.

TABLE: III

ESTIMATE OF NUTRIENT CONTRIBUTIONS BY RUNOFF FROM VARIOUS SOURCES

Source	Nitrogen (Millions of lb/year)	posphorus (Million oflb/year)
Domestic waste	1100 - 1600	200 - 500
Industrial waste	>1000	*
Rural runoff:		
Agricultural land	1500 - 15000	120 - 1200
Non-Agricultural land	400 - 1900	150 - 750
Farm animal waste	>1000	*
Urban run-off	110 - 1100	11 - 170
Rainfall	30 - 590	3 - 9

Source: M^{c}Carty, (1967).
* Insuffficent data available to make estimate.

When erosion takes place from arable land, the eroded soil nearly always has a higher concentration of phosphorus than the soil remaining. This is because the nutrients are likely to be in greater concentration in the top layers of soil. The finer soil fractions are more easily washed away,and the nutrients, particularly phosphorus, are adsorbed on to the particle surface,and so they are more abundant in the fine particles with a greater surface area. The ratio of plant nutrients in the eroded soil to those in the parent material is called the enrichment ratio and some observed values are shown in Table IV.

The general pattern is that while total loss of nutrients increases with total loss of solids, a dilution effect accompanies higher soil loss and the nutrient

TABLE: IV

ENRICHMENT RATIOS (Eroded Parent Material)

Plant Nutrients	Extreme Values		Majority values	
	Low	High	Low	High
Nitrogen	1.35	4.20	1.90	2.30
Organic Carbon	1.35	4.20	1.80	2.20
Phosphorus	1.15	5.56	2.20	2.60

Source: Hudson and Jackson, (1959).

concentration (and hence average enrichment ratio) decreases. Similar enrichment ratios have been reported by Fippin (1945), and by Massey and Jackson (1952).

Soluble nutrients like nitrate-nitrogen, will be mainly linked with water run-off while phosphorus will be mainly linked with the erosion of solids. The interchange of phosphate between the sediment and solution has been studied by Latterel _et al_., (1971), who showed that sediment has a high capacity to remove ortho-phosphate from solution, but subsequent release will only occur when the concentration in the water is low.

1.8 FIELD SITE:

Opportunities for research in agriculturally-enriched lakes are generally confined to the deeper basins of upland Britain, although Stewart _et al_., (1976) have reported some relevant findings for a shallow loch on the east coast of Scotland. Slapton Ley is the largest natural fresh water body in Southwest England. Four main streams which contribute the freshwater suspended sediment and nutrients, drain into the Higher and Lower Leys. The measured data are available from 1970 at Slapton Field Centre. Suspended sediment is an important factor in the infilling of the Ley and silting of lake shore habitats, most visibly around the Higher Ley. This silting alters the physical fabric of the nature reserve and promotes ecological changes through modification of nutrient status, particularly phosphorus. The inputs draining into the Ley represent a great loss for the combined drainage area. Therefore, there is clearly a need to determine the sources of sediment for silting in the lake catchments.

1.9 SPECIFIC OBJECTIVES:

a) Review and analyse existing data available for the field site at Slapton Ley Field Centre.

b) Identify the drainage basin and distinguish the different land-uses.

c) Select an area to represent the land-uses over the whole area.

d) Collect soil samples in the different land-use areas and sediment samples especially in the marshes and streams to determine water soluble and exchangeable phosphorus level.

e) Monitor and measure the sediment and soil loss caused by overland flow using runoff troughs in different land-use areas and measure the slope angle, infiltration capacity, soil texture, soil particle size, phosphorus in solution, phosphorus in sediment, rainfall amount and rainfall intensity for the rainfall hours.

f) Monitor and collect the water samples from automatic water samplers at each gauging station as well as hand samples from streams and the Ley.

g) Collect the point water samples from different sources within a catchment after a heavy storm.

h) Analyse the water soluble phosphorus and exchangeable phosphorus for the soil samples, sediment samples and water and suspended sediment samples.

i) Through this analysis attempt to determine the important sources and level of phosphorus with respect to lake pollution due to soil erosion.

1.10 ORGANISATION OF THE THESIS:

The thesis has been arranged in ten chapters. The present chapter has outlined the general aim of the research and the specific objectives. The second chapter describes the study area in its regional context. The third chapter explains the methods used. The fourth chapter reviews the available data. The fifth chapter estimates the soil phosphorus (water soluble and exchangeable) levels in land use area. In the sixth chapter, evidence of phosphorus and sediment transportation by overland flow from the experimental plots is described. In the seventh chapter, the CREAMS model was applied to predict the soil and phosphorus losses for the arable field. The implications of the predications for modelling were also discussed. In the eighth chapter, various sources of phosphorus to the stream and down stream changes, phosphorus associated with suspended sediment and dissolved in the stream, and the level of phosphorus in stream bed and marsh sediment are estimated. The ninth chapter summarises the previous chapters and present the conclusions. The tenth and final chapter suggests recommendations for strategies to minimise losses of phosphorus from arable fields.

CHAPTER 2

THE STUDY AREA

This chapter describes the study area in its regional context.

The study area (Fig. 2.1), the Slapton Ley catchment, occupies 46km^2 of the south east corner of Devon known as the South Hams. The area is composed mainly of lower Devonian strata, structurally aligned east-west.

Along the southern coast of Great Britain, a number of natural impoundments have been created by the landward migration of sand or shingle materials to form spits and barrier beaches (see King, 1959; Steers, 1964).The majority of these basins are of the lagoon type and in some instances, receive insignificant river drainage from the surrounding landscape(e.g. Chesil Fleet; Dorset). On the south west Peninsula, barrier formation has been chiefly associated with the damming of small estuaries and the subsequent isolation of shallow bodies of freshwater behind raised shingle beaches (e.g Loe Poole, Cornwall; Slapton and Widdicombe Ley, Devon. Their evolution has endowed them with peculiar characteristics of hydrography, sedimentology and water chemistry which have contributed to distinct patterns of vegetation succession. Coastal lakes are subject to the same ecological pressures as lowland lakes inland but may be more sensitive to change due to the additional stress of their maritime position.

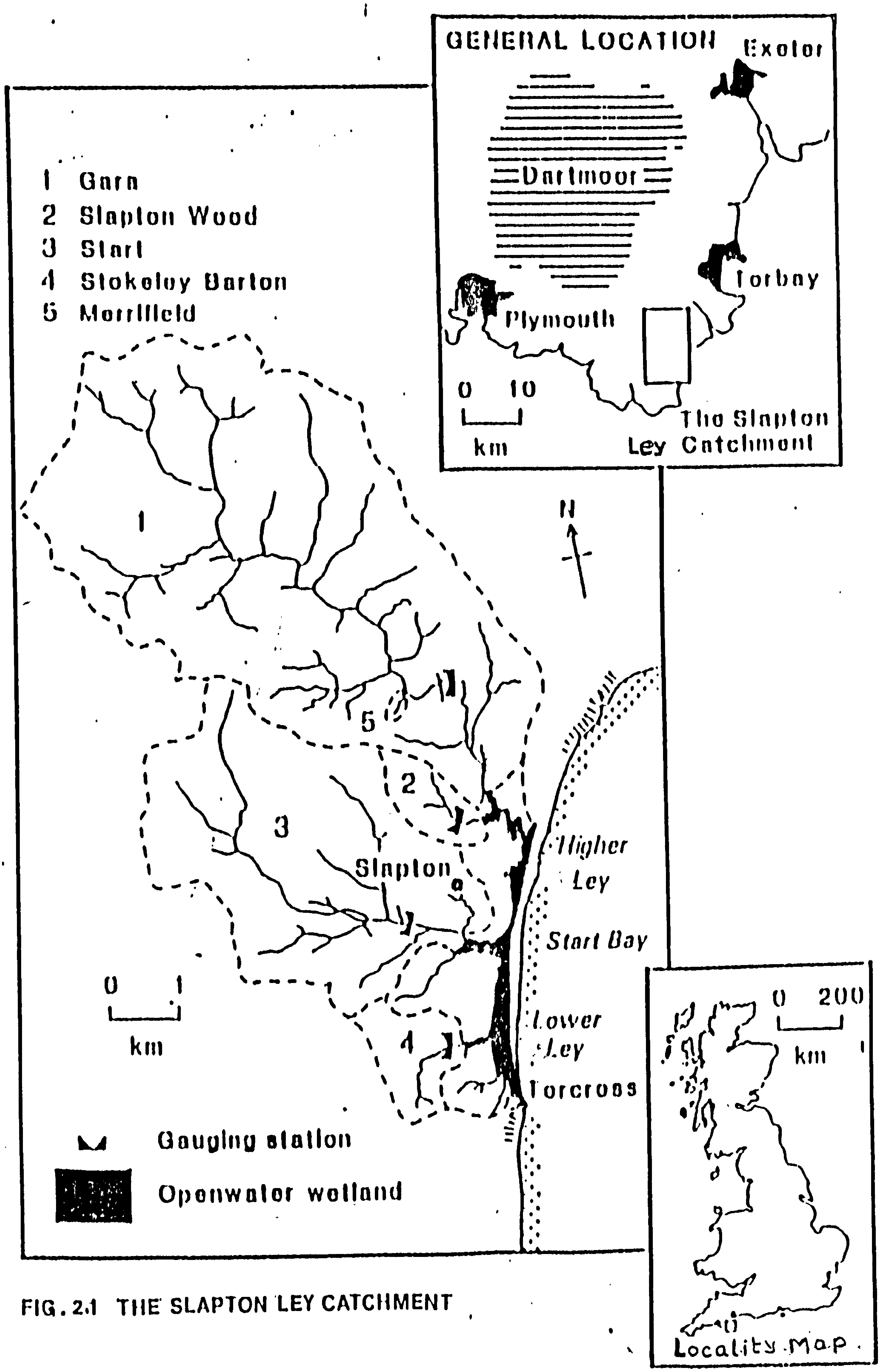


FIG. 2.1 THE SLAPTON LEY CATCHMENT

A detailed geological account of the study area has been given by Ussher (1890, 1904, 1906) and Dineley (1961) and is illustrated in Fig. 2.2. The slates have been weathered into fairly free-draining brown earths of clay-loam texture (Highweek Series; Clayden, 1964) but in some areas the soils are more akin to the podzolic type of the Dartington Series. Shallow, acid soils predominate on the hill slopes but the valleys have been infilled with local head deposits derived by periglaciation during the Pleistocene (Waters,1965) which now provide a rich alluvium up to 5m thick (Troake and Walling,1973). The relief rises to over 200m in the upper reaches of the Gara basin and is dominated by a series of steeply dissected platforms, each the product of past emergences (See Mercer, 1966) and now containing a dense dendritic network of streams, many of which rise at springs.

The geology at the field site consists of Dartmouth Beds of the Lower Devonian Slates. These slates, originally low nutrient muds, have been compressed and metamorphosed into a bedrock of low permeability. The topography of the Slapton Ley catchment is characterised by gently sloping ground (5^0) above the 90m contour, but at this height there is a distinct break of slope below which are steep valley sides of 5^0 - 35^0.

The climate at Slapton is generally "warm and wet", due to its maritime location in South West England. It is a relatively frost-free environment, on average the air

FIG. 2·2 GEOLOGICAL FEATURES UNDERLYING THE CATCHMENT OF SLAPTON LEY (USSHER 1906) minimum temperature falls to 0^0c or below on only 22 occasions each year (Coles, 1985). The ten year annual mean rainfall (1963 - 73) is 1075.5mm and a interesting feature of the rainfall is its variability, the coefficient of variation for each month in no case being less than 40% (Ratsey, 1975). In general, the spring and autumn months show greater variability than the summer and winter ones. Seventeen year annual average of rainfall is 1005mm. A distribution of annual rainfall data (source: Slapton Field Centre) is given in Fig. 2.3.

The soils at the study area are brown earths of the Denbigh Series, described in general terms as "well - drained fine loamy or fine silty soils" (Trudgill, 1983). The weathering of the slate bedrock has yielded quartz and kaolinite as the dominant minerals, and the oxidation of large amounts of iron in the rock has imparted a fairly strong red-brown colour to the soil (Munsell Colour Code 5YR 4/8). Long-term weathering, uninterrupted by direct glacial removael of soil, has resulted in soil profiles 60 to 100cm deep. There has, however, been periglacial influence, which has resulted in some downslope movement of soil. Soil horizons are present, though indistinct, since the soil is undisturbed and well-mixed by a large soil faunal population. A reddish-brown A horizon extends from the surface to approximately 30cm depth. Below this occurs gradual change to a lighter coloured, less compact 'B' horizon, characterised by greater amounts of iron oxides

FIG. 2·4 SLAPTON LEY

(either redeposited or formed in situ.) and less organic matter. At approximately 80cm is a discrete translocation to a C(g) horizon showing evidence of both seasonal gleying (mottling) and perennial gleying. A full description of soils under natural woodland at Slapton is given by Trudgill(1983).

The hydrology of the Slapton catchment has been described by Troake and Walling (1973). The water balance is characterised by a large storage potential and the stream 'storm' hydrograph is produced by a very small proportion of the stream basin,consisting largely of direct channel precipition and surface flow from adjacent saturated areas.

The agricultural land use of the area is mixed. The flatter land is mostly devoted to root crops, brassicas, wheat and barley and steeper slopes largely support low-intensity sheep and cattle grazing.

Slapton Ley is divided into two unequal basins, the Higher and Lower Leys, linked by an open water channel, and separated from the sea by a raised shingle beach 3.5km long. (Fig. 2.4). The two Leys exhibit remarkably different patterns of vegetation cover (see Brookes and Burns (1969) for a detailed species account of the macrophytes). In the Higher Ley, reedswamp, dominated by *Phragmites australis* and *Typha angustifolia*, and willow- alder carr have encroached over the whole basin, limiting the open water to small pools and a discontinuous channel. In the Lower Ley reed swamp has been restricted to the lake margins and inflow deltas, and

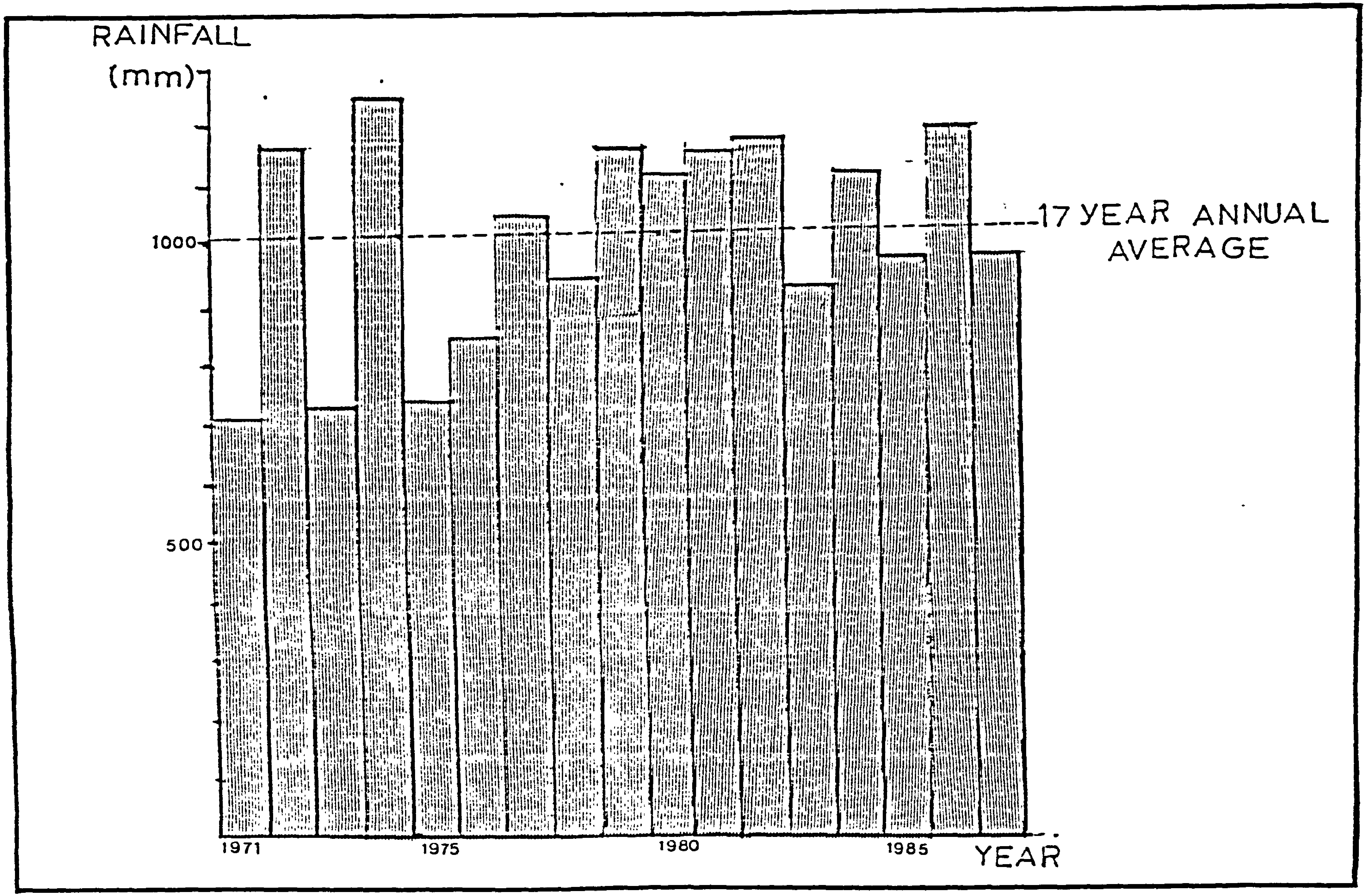


FIG 2·3 A DISTRIBUTION OF ANNUAL RAINFALL AT SLAPTON

84% if its area is open water. Brookes and Burns (1969) recorded 13 species of submerged hydrophytes. Extensive growths of *Ranunculus* spp., *Potamageton* spp., *Myriophyllum* spp., and *Elodea canadensis* occur in Ireland Bay. In the mouth of the channel from the Higher Ley and, in the shallow, sheltered area south of Stokeley Bay, *Polygonum amphibium* (Amphibious Bistort) and *Nymphaea alba* (White water lily) are also common, the latter being particularly dense at Torcross. The inflows drain through marshland which is separated from the lake by man-made causeways,and often the channelling of water becomes multiple and indistinct. Including these adjacent marshes, the wetland of Slapton Ley occupies an area of 1.16 km^2. The Slapton Ley fresh water lake has been impounded as a coastal lagoon and radiocarbon dating suggests that it is no more than 1000 years since the impounding (Morey, 1976).

CHAPTER 3

METHODOLOGY:

This chapter explains the methods used for this study.

Many geomorphological problems can be modelled in quantitative and often mathematical terms, but sometimes there is still a wide gap between theoretical considerations and real field conditions. This gap must be bridged if the related research studies are to be meaningful in a wider context.

The following methodology was adopted to achieve the objective of this study.

The Slapton Ley drainage area was studied to distinguish the different land uses in its catchment using aerial photographs and the latest land-use maps. Then four representative land uses; arable, grass, cereal and woodland were selected.

Soil samples were collected in each selected land use area using a grid method. Point water samples along the stream, bottom sediment samples along the stream, and marsh sediment samples were collected. For each sample, water soluble phosphorus and exchangeable phosphorus were determined.

Twelve runoff plot were set up with wooden frames (1m X 2m) in the selected land use areas for the purpose of erosion study. Each runoff plot was carefully examined, recording the land use, slope angle, infiltration capacity and soil texture. Then the runoff and sediment were collected after each storm event. The phosphorus which moved with the sediment in the exchangeable form, and the soluble form, in the runoff water was measured.

3.1 SAMPLING:

Soil samples were collected in different land uses, sediment samples in the marshland, point water and bed sediment samples along the stream and water samples using Rock and Taylor Water samplers (see plate 1) at the gauging station for whole catchment.

3.1.1 SOIL SAMPLING WITHIN DIFFERENT LAND USE TYPES:

Sampling schemes that have been used in slope studies can be grouped into three main types (Reynolds,1975).

1) the haphazard (areal) hillslope scheme (Furley,1966,1968; Norton and Smith,1930);

2) the plot or areal scheme (Bunting,1964; Perring 1959; Stoeckeler and Curtis,1960; Walker _et al._,1968), and

3) the linear scheme (Carson,1967; Furley,1966,1968, 1971; Young,1958).

A linear scheme was adopted to develop a grid method in the study area, where sampling sites within the four land use areas were located. At first, samples were taken beside the river (randomly) over the chosen land use.

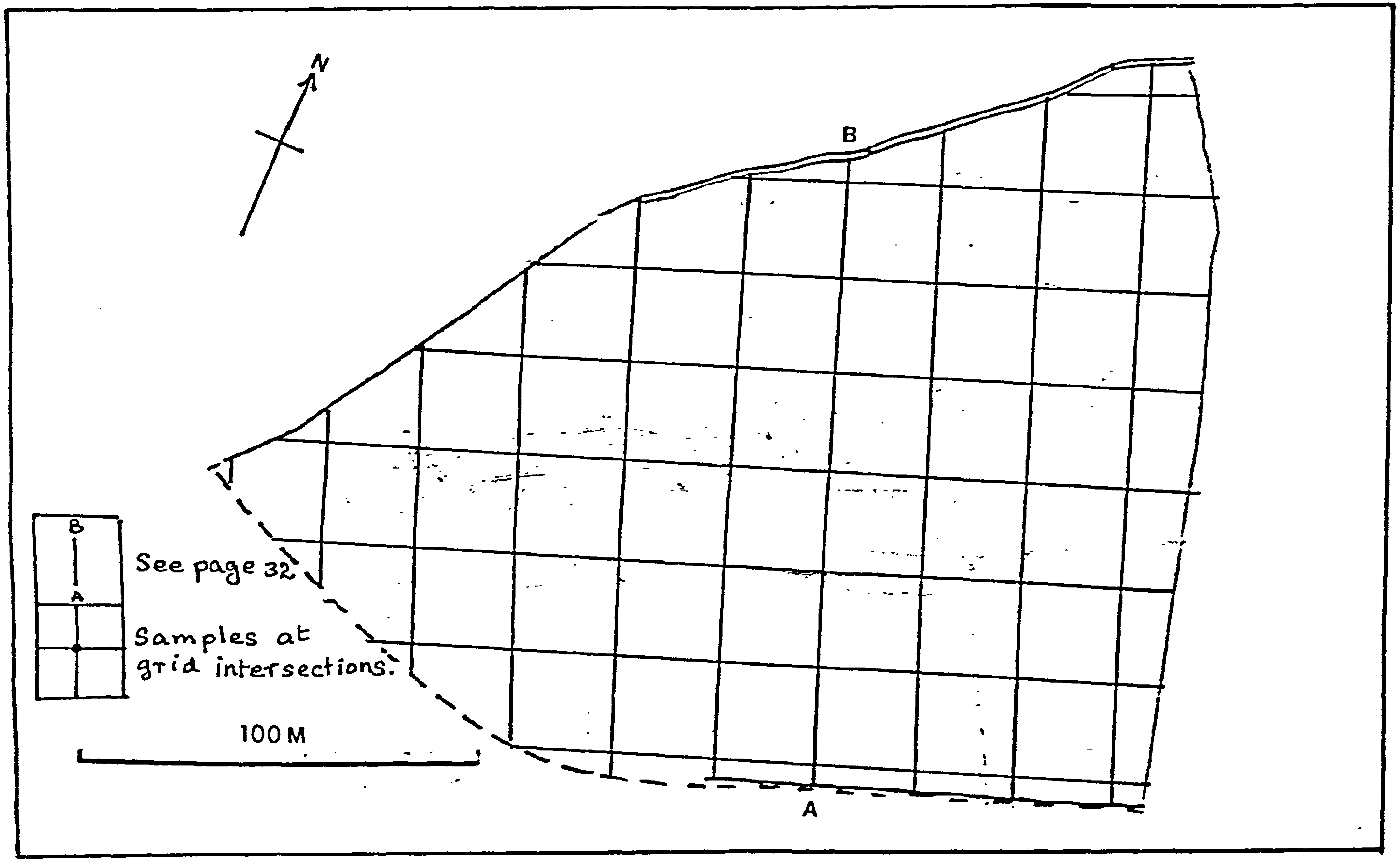


FIG. 3·1 ILLUSTRATION OF GRID SAMPLING METHOD USED ON EACH LANDUSE

After various trials a sampling procedure was devised in which a linear transect was laid out from the crest of the slope down to the valley (AB in Fig. 3.1). Commencing from B (at the edge of the river) the profile line was set out by a series of successively inter-visible ranging poles at 25m intervals and samples were taken at each of these points. From the sampling point B at the edge of the river another line was set out perpendicular to the first line, and soil samples were taken along it at 25m intervals from the first line. Through each of these points a further line was set out parallel to AB. Samples were then taken along each of these linear transects at 25m intervals.

By using a 4.5 inch (11.42 cm) diameter soil auger, surface soil samples were taken from each sampling point, placed in polythene bags and stored in a cool place. The slope angle was measured using a clinometer over a one metre line from the sampling point.

3.1.2 SEDIMENT SAMPLING IN THE MARSH LAND:

The sediment samples were collected by making a vertical bore hole into the marsh land using a 5.5cm diameter and 120cm length plastic tube. Three samples were taken at each sampling point: one is at the surface, the second at 25cm depth and the third at 50cm depth. These sediment samples were placed in polythene bags and stored in a cool place.

3.1.3 POINT WATER AND STREAM BED SEDIMENT SAMPLING:

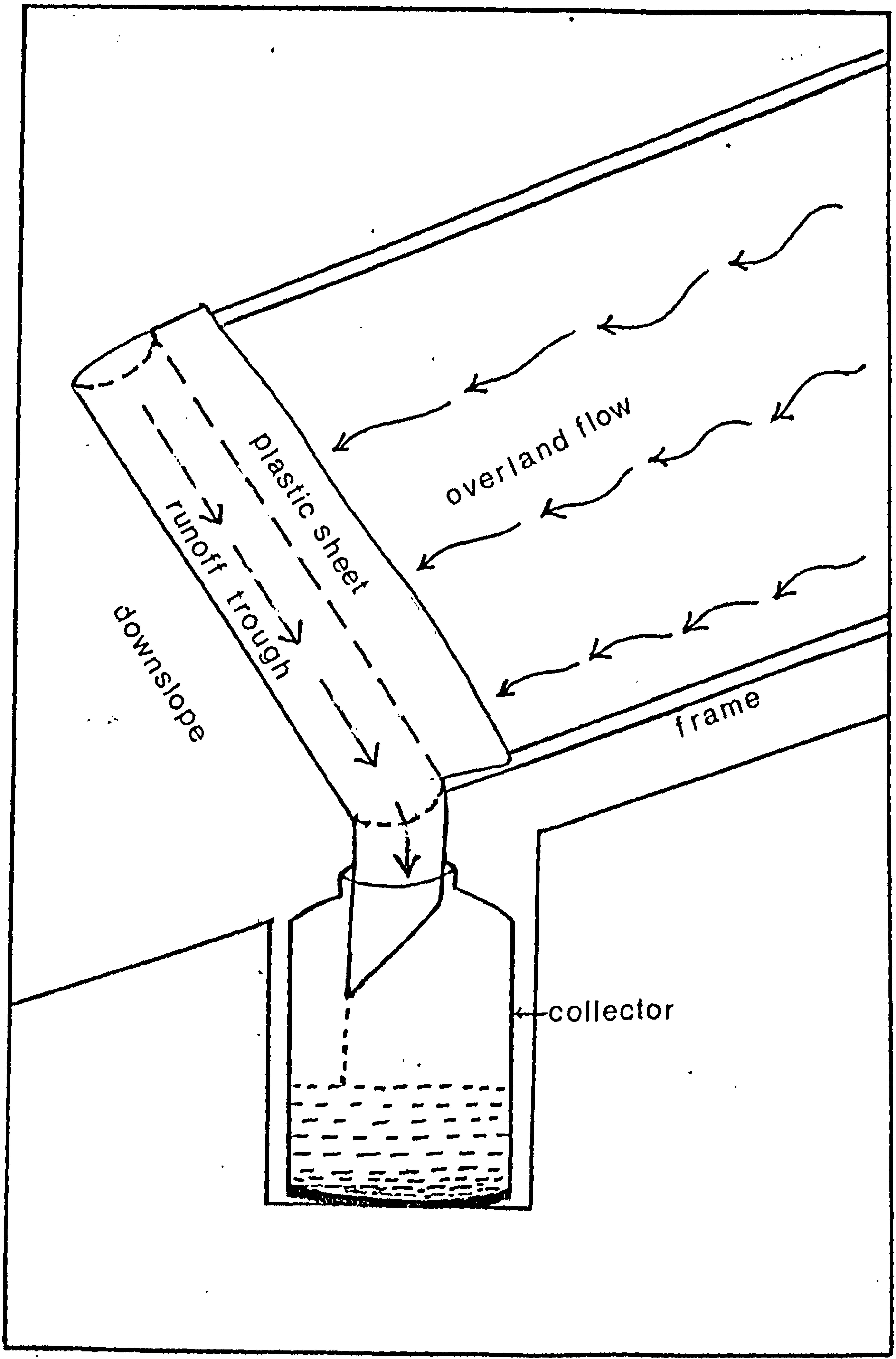


FIG.3·2 ILLUSTRATION OF COLLECTOR

Point water samples from different sources, water samples from the stream, and stream bed sediment samples were collected along the stream. Sampling sites are located in Figs. 8.1 and 8.7. Water samples were taken as a grab sample in polythene bottles (de-ionised and prewashed in distilled water followed by a rinse in stream water, which was discarded before the final sample was taken). Stream bed sediment was taken and placed in polythene bags to store in a cool place until proceeding with the analysis.

3.1.4 WATER SAMPLING AT THE GAUGING STATION FOR GARA CATCHMENT:

A Rock and Taylor water sampler was already fixed at the Higher North Mill for the Gara catchment. Water samples were collected during an intense strom.

3.2 RUNOFF PLOTS:

Twelve runoff plots were selected to measure the transportation of soil materials and attached phosphorus by surface runoff. Two square metre (2m x 1m),area plots were framed by wood. Troughs and the collector bottles were placed.at the downslope edge of each plot towards which overland flow carries the surface runoff to the two litre collector bottle. The other three sides of the frame were sealed in order to prevent the entry of surface runoff from outside (see Plate 2 & 3). Plate 2 looking upslope and Plate 3 looking downslope. The troughs were one metre long and ten centimetre wide and set in the soil so that the upper lip was flush with the soil surface. Care was taken to ensure a

Plate 1. A Rock and Taylor water sampler (Left centre)

Plate 2. Runoff trough on the arable land

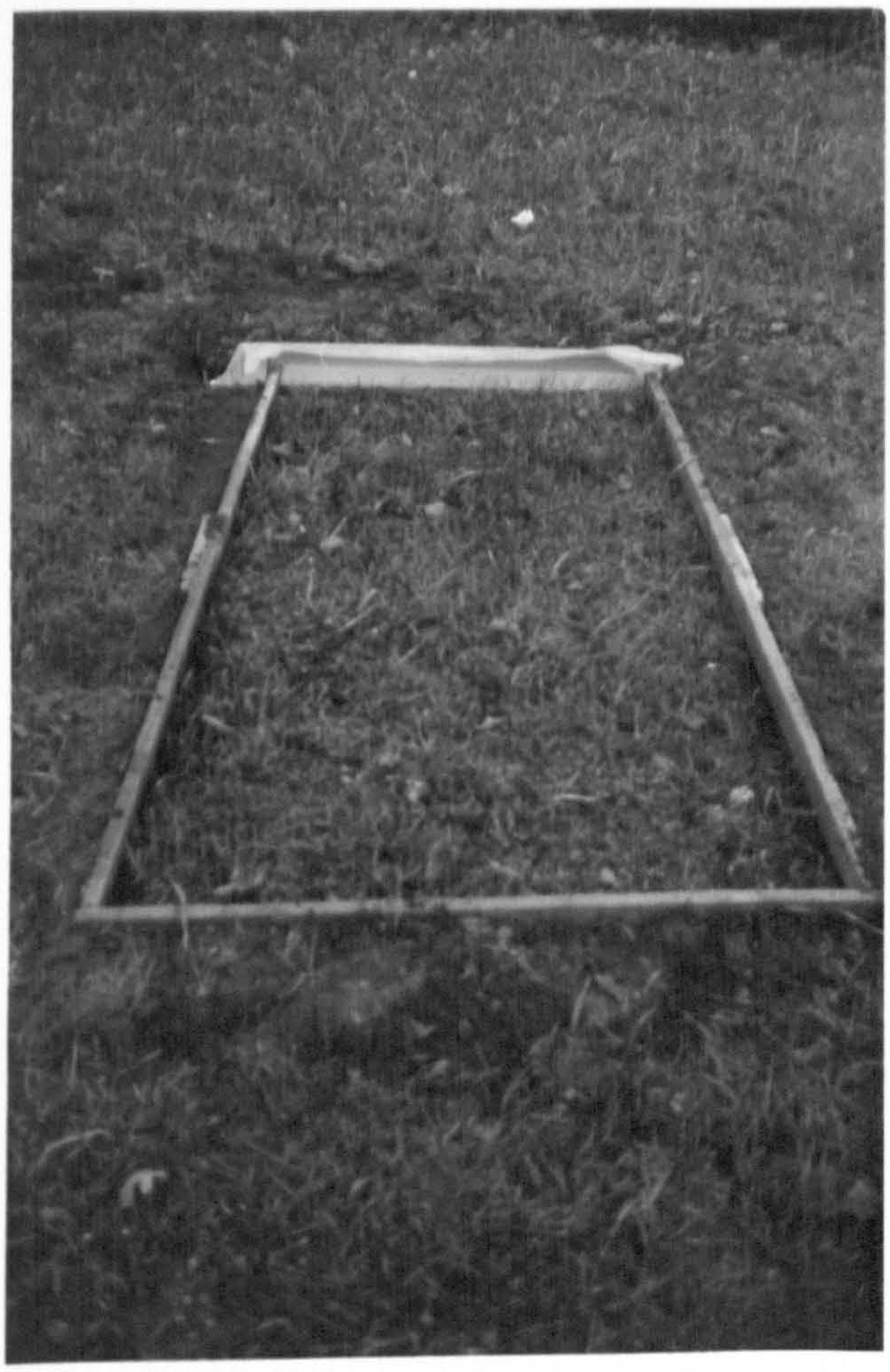


Plate 3. Runoff trough on the grass land

good seal between the upper lip of the trough and the soil surface and the troughs were roofed by plastic sheet to exclude direct precipitation. Fig. 3.2 shows the collector.

Whenever possible, the sediment and water in the troughs on the slopes were collected immediately after a period of rainfall and in any case each morning, the amount collected during the previous 24 hour period in which rainfall occurred was measured and recorded. From a rain gauge chart covering the period of study, the duration and amount of each period of rainfall was obtained to estimate the rainfall intensity.

3.3 INFILTRATION MEASUREMENT USING A CONSTANT HEAD INFILTROMETER:

Infiltration was measured in the upper and lower parts of each of the plots using the constant head infiltrometer. Fig. 3.3 shows on illustration of the constant head infiltrometer. To overcome the problem of the depth of water in an infiltration ring varying during an infiltration experiment, a constant head device was incorporated. This consists of a column of clear tubing forming a water reservoir which is sealed with an air- tight bung at the top and at the bottom with a second bung fitted with two rubber tubes of slightly differing length. The longer one acts as a water outlet, the shorter as an air inlet. These can be opened or closed with a screw clamp when set up over an infiltration ring until the water level closes off the air inlet tube. As water is lost into the soil, the water

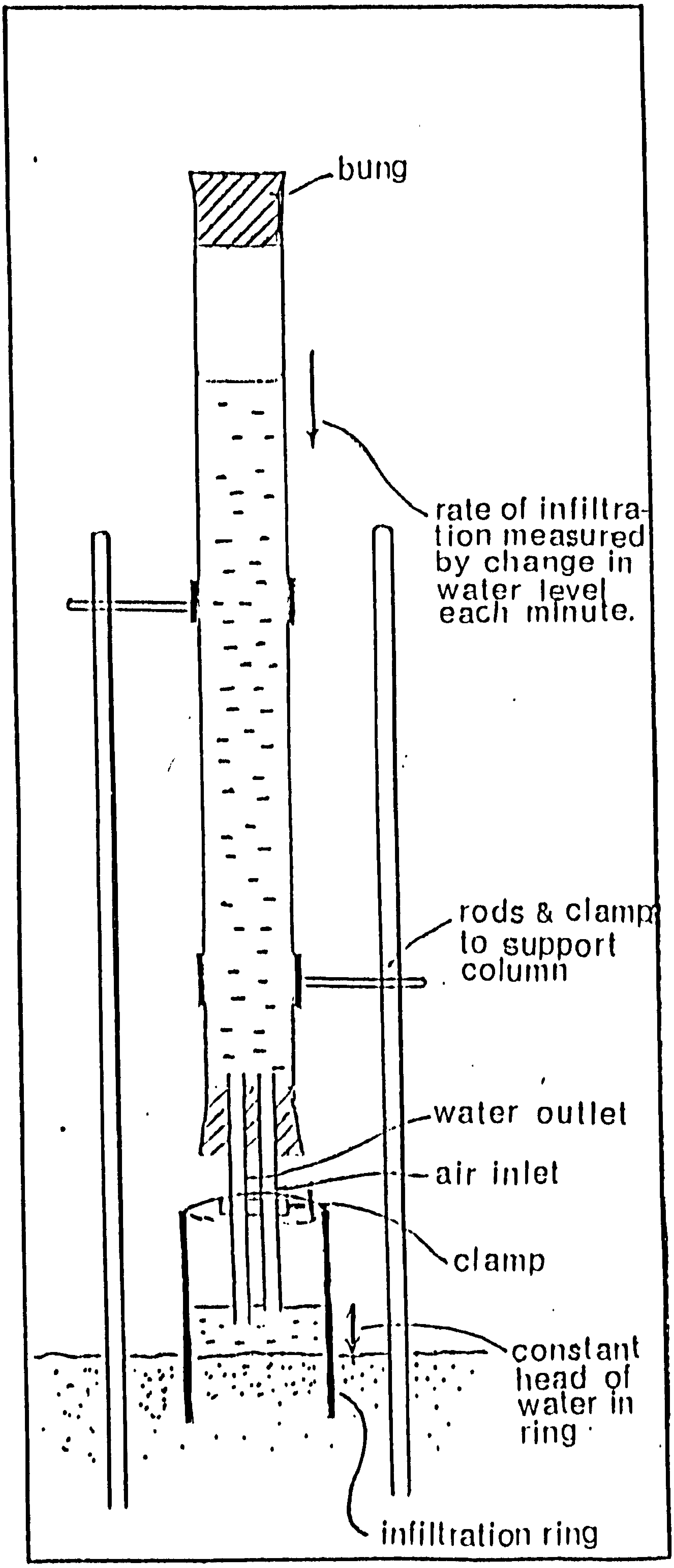


FIG. 3·3 ILLUSTRATION OF CONSTANT HEAD INFILTROMETER level in the ring will drop allowing air bubbles to enter the water reservoir thus releasing water and restoring the water level in the ring. While a more or less constant head of water is maintained in the ring, the rate of infiltration can be monitored by recording the drop in water level in the reservoir.

3.4 RAINFALL INTENSITY:

From a rain-gauge chart covering the period of study the duration of each period of rainfall was obtained to estimate the rainfall intensity. Intensity was calculated for the rainfall hours and half hour period intensity was estimated using rain gauge charts for each storm. The maximum half hour intensity was chosen as an effective erosion process.

3.5 LABORATORY METHODS:

All the point water samples, stream water samples and plot runoff water were filtered and soluble phosphorus in the water was measured using an auto-analyser on the same day. Sediment on the filter paper was stored after drying at 105^{0C} overnight and exchangeable phosphate was measured in the sediment.

The plot runoff sediment was weighed and the amount of soil loss was calculated by measuring the volume of soil lost from the plots.

Soil samples from each plot were air dried and ground

Soil samples from each plot were air dried and ground to pass the 2 mm sieve. Clay (0.002mm diameter) and silt-sized (0.02 - 0.002mm diameter) fraction were determined by the standard hydrometer method, using sodium hexametaphosphate as the dispersing agent, subsequent to the removal of organic matter with hydrogen peroxide. Sand fractions were determined using the sieves. The international particle size range triangle was used to determine soil textural classes.

Soil samples from four land-uses (cereal /temporary grass, arable , grass, woodland), sediment samples from stream bed and marshland and soil samples from plots were air dried after measuring the water soluble phosphate. Then the exchangeable phosphate was measured.

After various trials, the method proposed by Olsen (1967)(Appendix.1) was used to extract the exchangeable phosphate from suspended sediment, stream bed sediment, marsh sediment, plot sediment and different land use soils.

Numerous investigations have been carried out in an attempt to develop more precise methods for phosphate determination. After extracting the samples using the above methods phosphate was determined by a two-stage modification of the methods of Murphy and Riley (1962) and Stephens (1963), as outlined in Golterman (1969). (Appendix.1). The analysis was carried out the same day as sample collection, to avoid chemical transformation (cf.Ryden et al.,1972), after filtration of the preserved samples. The first method stage, using ascorbic acid as a reducing agent in conjunction with an acidified solution of ammonium molybdate and antimony potassium tartrate, was suitable for nearly all measurements of soluble reeactive phosphate. The method is supposedly specified for orthophosphate, but Olsen (1967) noted that rèagent acidity might hydrolyze some inorganic polyphosphates if the analysis was prolonged.

Interference by other phosphate radicals was also reported by Rigler(1968) but as Reynolds(1971) pointed out, the method's failure to detect phosphorus on several occasions indicated that the forms otherwise measured were available for biological uptake and therefore of consequence to a study of nutrient/algal growth dynamics.

The amounts of sediment-bound P equilibrating with several extracting solutions have been studied as predictors of algal available P (Chiou and Boyd,1974; Cowen and Lee,1976; Porcella et al., 1970).

P in runoff water was measured as phosphate-phosphorus in mg l^{-1}. Therefore, for comparison, the results of water soluble and exchangeable phosphate for the soil and sediments are expresed as phosphate- phosphorus in ppm.

3.6 STATISTICAL ANALYSIS:

The analysis of variance, Mann-Whitney 'U' test, correlation analysis and discriminant analysis were applied to the data using the SPSSX package.

The analysis of variance test ('F'-test) requires the comparison of two variances and a test for the significance of the difference between the calculated variances. Therefore, the 'F'- test was applied to analyse the soil phosphorus data to find whether there are any differences between the soil phosphorus concentration in the different land uses.

Mann - Whitney 'U' test was applied to compair the variation of phosphorus levels within the land uses. This method provides more detail information within the land use for non-normal data.

The correlation analysis was applied to find out the relationship between the phosphorus concentration and the factors such as rainfall, rainfall-intensity, runoff and sediment volume in the experimental plots, and between the angle of slope and phosphorus level within the landuses.

Discriminant analysis can be used to distinguish to best advantage several multivariate classes. In this study exchangeable phosphorus in suspended sediment and soluble phosphorus in water for point sources were grouped. From the results of discriminant analysis, the significant characteristic groups of sources of phosphorus were observed.

Classical discriminant theory was developed to analyse this kind of situation, and solutions to the allocation problem were found by Fisher (1936) for the two-class case and by Rao (1948, 1952) for more than two classes. Cox and

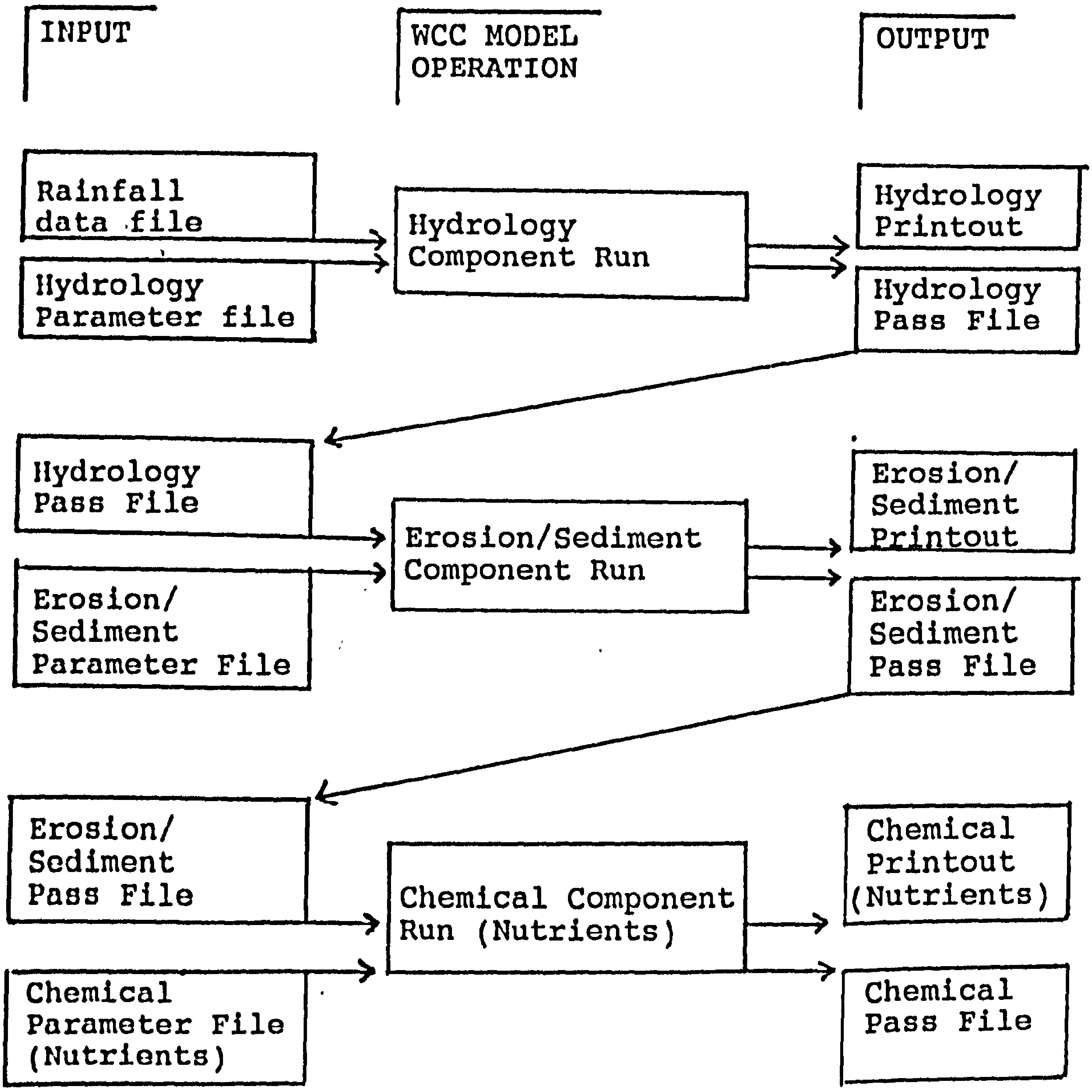
Martin (1937) first applied the theory to soil, though Oertel (1961) seems to have been the first soil scientist to attempt allocation in this way. He assigned soil profiles to one or other of two classes of soil after calculatng Fisher discriminant functions. Hughes and Lindley (1955) applied discriminant analysis both to measure and to test differences between pairs of soil types. Pomerening and Knox (1962), Van den Driessche and Maignien (1965), Little et al.(1968), and Horton et al., (1968) used discriminant analysis to confirm or establish differences between classes. The lack of application is no doubt partly because large matrices must be handled by computer. Moreover the technique is difficult to understand with a geometric interpretation. With the advent of computers Norris (1970) foresaw wider use of discriminant analysis in soil survey, and Norris and Loveday (1971) discussed its relation to human decision- making. So, discriminant analysis suggests that it has more promise than some other methods of computer-based classification.

3.7 CREAMS MODEL (WCC version).

The CREAMS model (WCC version) of Knisel, et al. (1983) was applied to predict the soil loss and phosphorus loss from the Slapton Ley drainage area within the agricultural fields.

The CREAMS model was developed by a task force formed by the Agricultural Rsearch Service (ARS) in Washington. Its

Fig: 3.4 FLOW CHART OF CREAMS MODEL OPERATION (WCC VERSION)



(This version of CREAMS is stored in a computer in the Washington, D.C., USDA Computer Center (WCC). The WCC version of the model can be accessed from any remote Harris terminal or compatible microcomputer with modem).

purpose is to simulate the effects of management systems on non-point source water pollution. The model is divided into three components.

a) hydrology

b) erosion and sedimentation and

c) chemistry (nutrients and pesticides).

Each component operates independently. A flow chart in Fig. 3.4 shows how the model operates.

3.7.1 GENERAL APPROACH FOR USING CREAMS:

1) Choose a field that represent the area suspected of causing an identified problem of non-point water pollution.
2) Gather field information needed to operate the model. This information includes precipitation data, topographic map, and other data for the input parameter files. One can design a worksheet as in the appendix 2.
3) Organize data on field operations chronologically for a base or existing management system, so that it is possible to know everthing that happpens in the field to affect parameter values. These operations include all tillage, mowing or grassing.
4) Develop the necessary parameter files for the selected cropland field.
5) Run the model for the base or existing management system.

6) Select an alternative agricultural system (using different structural, management or vegetative measures for simulation and organize the data for the alternatives.

7) Compare the results from the alternative and base systems, and determine how the alternative affects loading of nonpoint source pollutants. Alternative systems have differtent effects on different pollutants. Therefore, you may want to devise a means of ranking the systems by effect on specific pollutants.

CHAPTER 4.

REVIEW OF THE AVAILABLE DATA

This chapter reviews the available data for the field area which is relevant to the topic of this thesis.

Studies relating sediment load to runoff discharge in open channels show a linear relationship between the two variables (Leopold and Maddock, 1953; Negev, 1969; Walling, 1974; Puvanewaran, 1985). The relationship of suspended sediment concentration to runoff discharge is more complex and data from several individual storm events show that peak sediment concentration often precedes peak discharge (Einstein _et al_., 1940; Walling, 1974). A positive linear relationship has been observed between discharge and suspended sediment concentration in a number of studies (Schick, 1970; Walling, 1971, 1974; Oxely, 1974; Schick and Sharon, 1974; Smith and Newson, 1974).

The available data for Slapton Ley also show that peak sediment concentration precedes peak discharge. Data for 1974 from Slapton Field Centre records were drawn up in Figures 4.1, 4.2, 4.3, 4.4. These figures show the seasonal variation (i.e high discharge in February and low discharge in June, July and August for each catchment and the relationship between discharge, suspended sediment concentration and soluble phosphorus concentration. The total annual inputs of runoff to Slapton Ley from the combined Slapton Wood and Stokeley Barton catchments contribute 4%, and Start and Gara

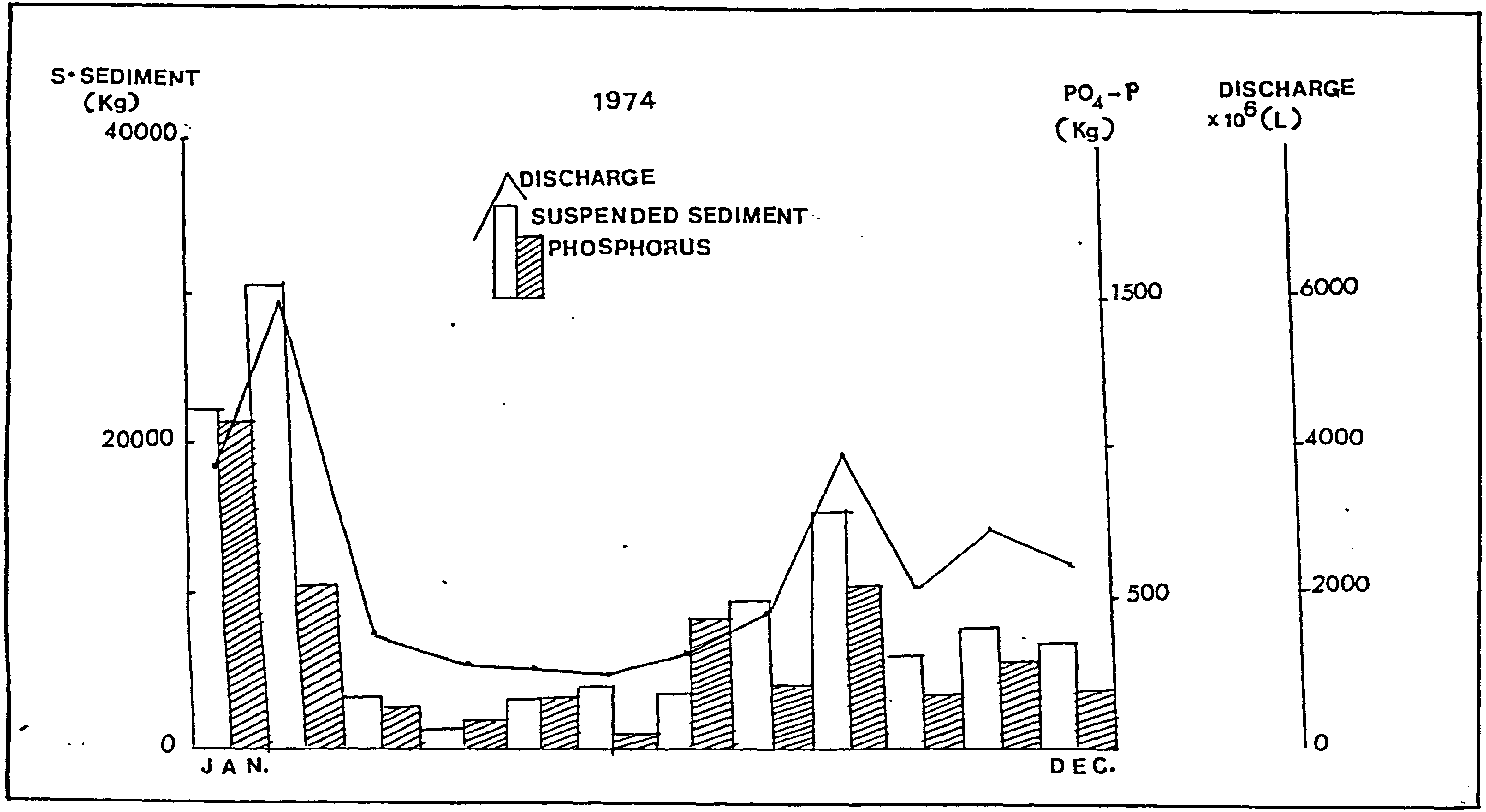


FIG. 4·1 MONTHLY LOAD OF SUSPENDED SEDIMENT, DISCHARGE & SOLUBLE PHOSPHORUS FOR GARA

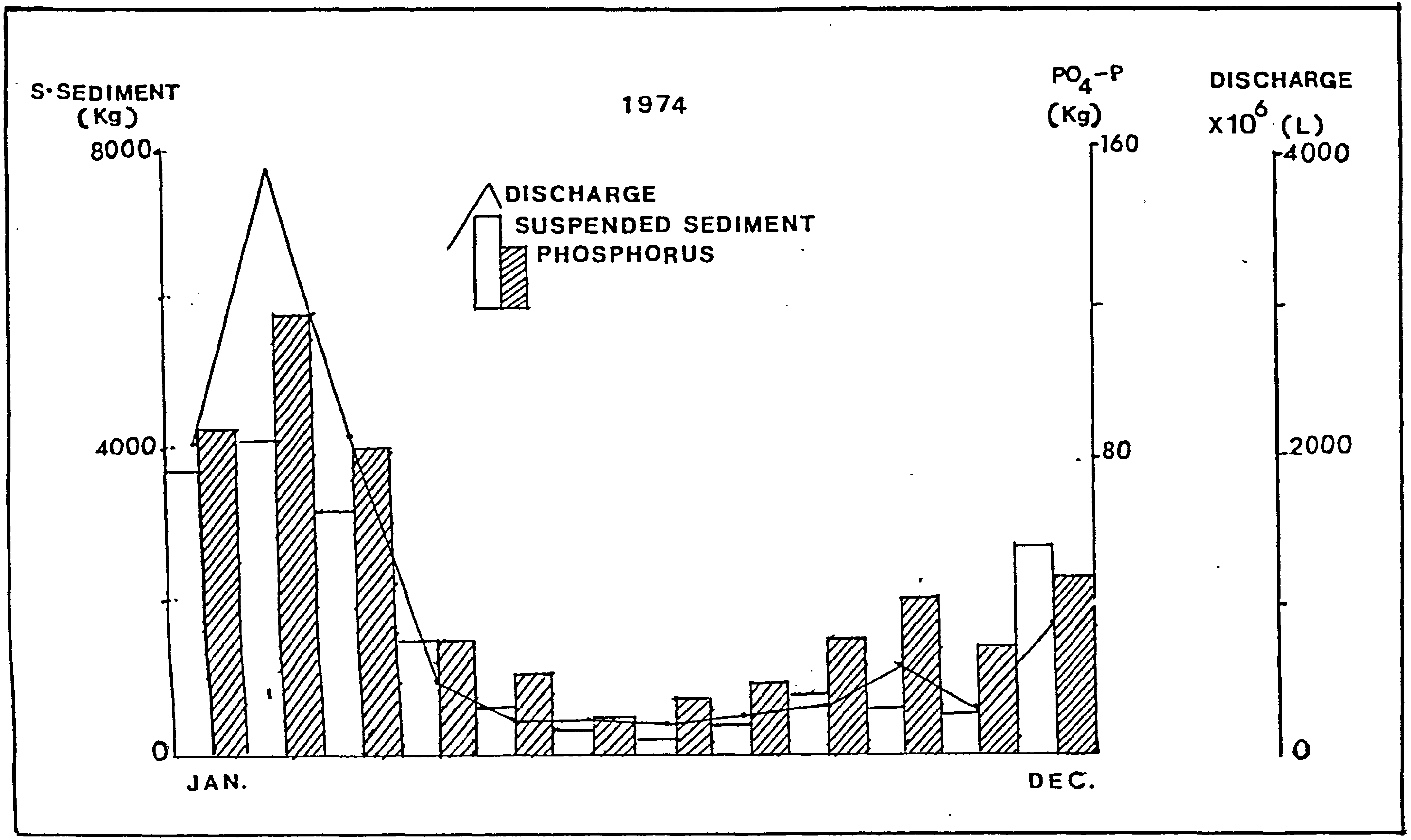


FIG.4·2 MONTHLY LOAD OF SUSPENDED SEDIMENT, DISCHARGE & SOLUBLE PHOSPHORUS FOR START

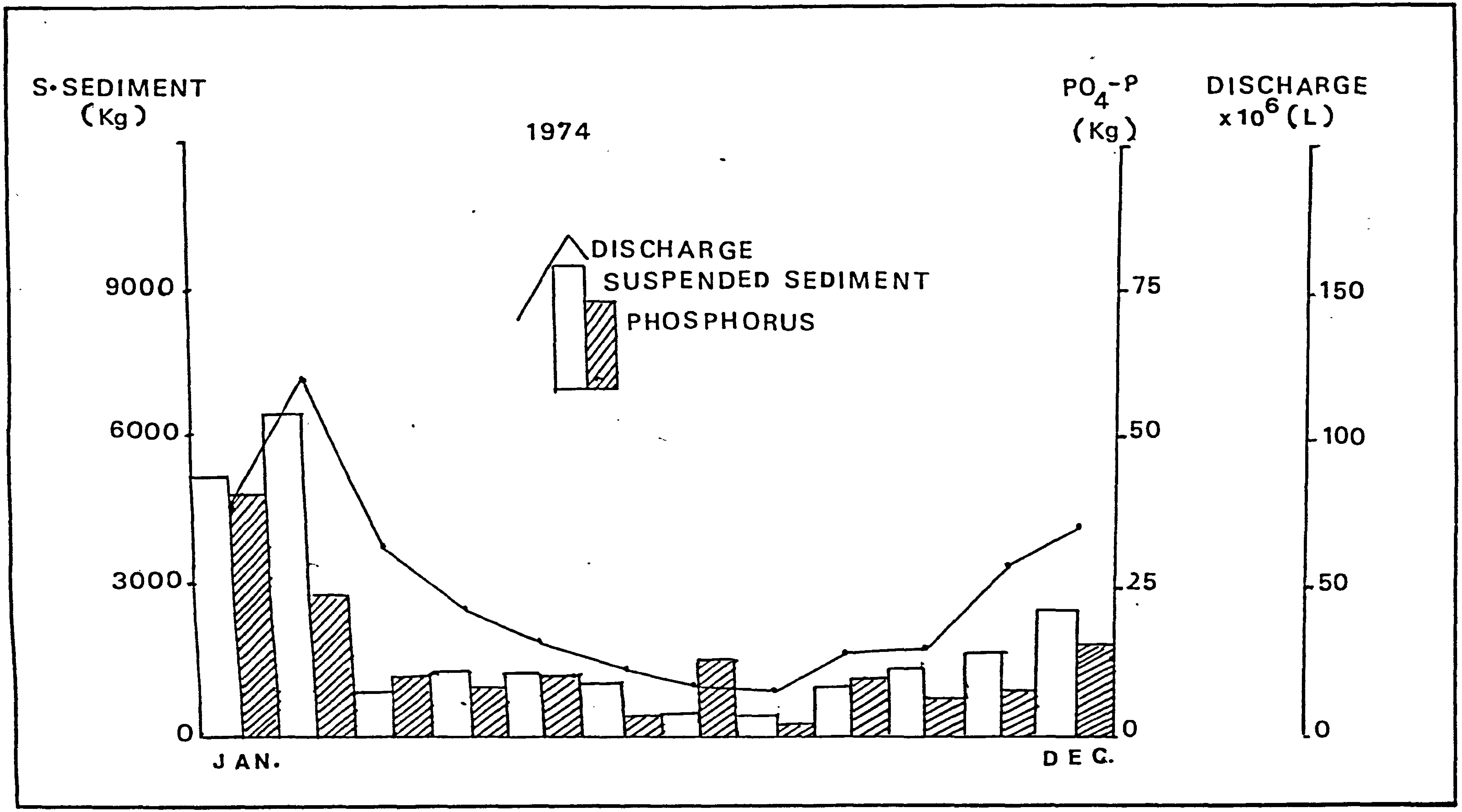


FIG. 4·3 MONTHLY LOAD OF SUSPENDED SEDIMENT, DISCHARGE & SOLUBLE PHOSPHORUS FOR STOKELY BARTON

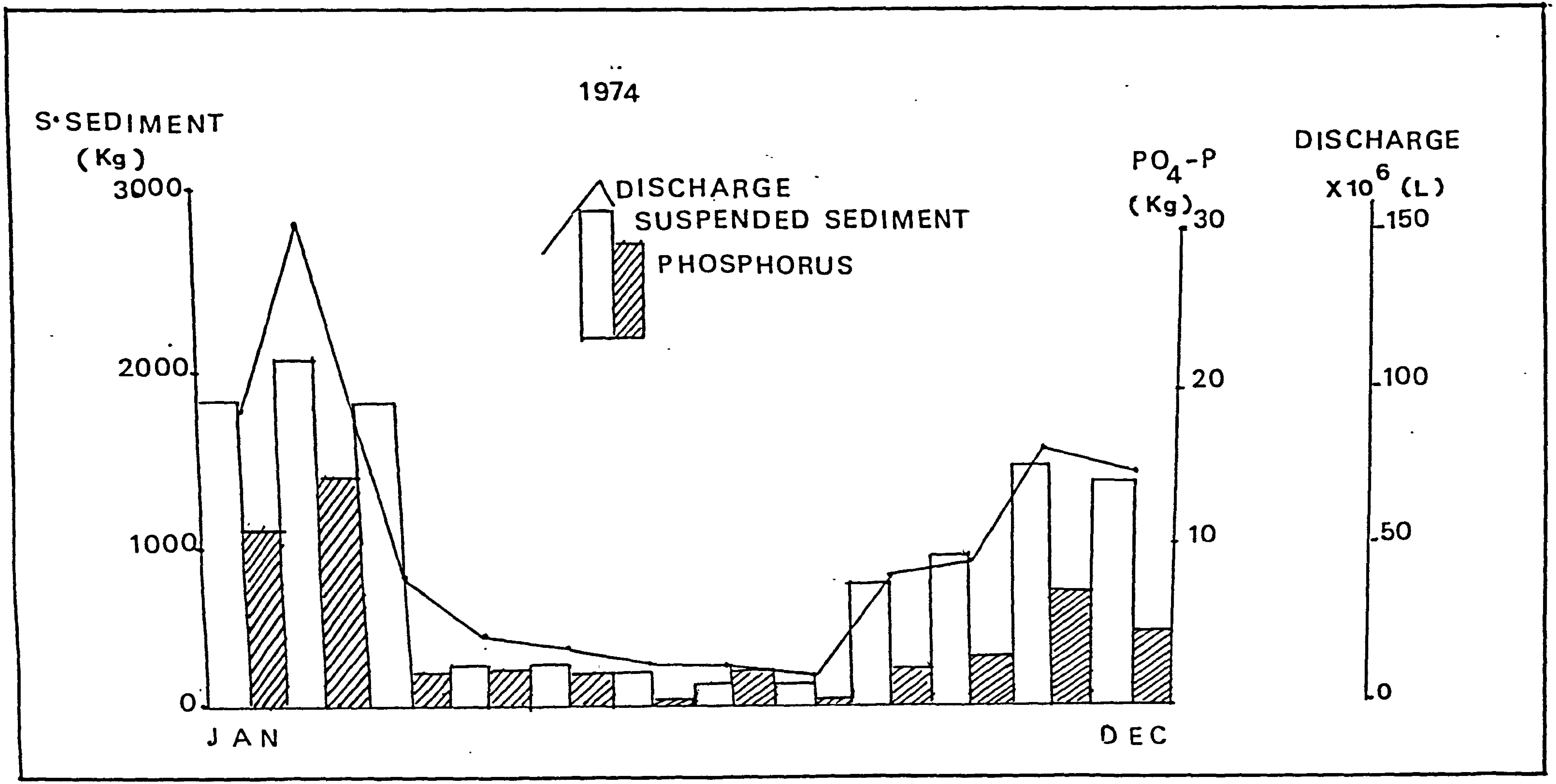


FIG. 4·4 MONTHLY LOAD OF SUSPENDED SEDIMENT, DISCHARGE & SOLUBLE PHOSPHORUS FOR SLAPTON WOOD.

catchments contribute 23% and 73% of the total annual runoff to Slapton Ley respectively. The annual inputs of water soluble phosphorus and suspended sediment (kg $ha^{-1}a^{-1}$) to Slapton Ley from each catchment for 1974 and *April 1987 to March 1988 are given in Table V. The figures indicate an increase of soluble phosphorus in water and suspended sediment load over the 13 year period.

TABLE V

THE ANNUAL SUSPENDED SEDIMENT AND WATER SOLUBLE PO_4-P LOADS IN WATER FOR SLAPTON CATCHMENTS FOR 1974 AND *APRIL 1987 TO MARCH 1988. (kg $ha^{-1}a^{-1}$).

Catchment	Area (ha)	Suspended Sediment 1974	Suspended Sediment Ap87-Ma88	PO_4-P 1974	PO_4-P Ap87-Ma88
Gara	2362	189.90	218.48	0.39	0.43
Slapton Wood	93	59.20	67.76	0.18	0.22
Start	1079	78.42	104.36	0.32	0.51
Stokeley Barton	153	36.41	47.83	0.36	0.47

* April 1987 to March 1988 data is from Heathwaite _et al_., (1988).

The environmental impact of land use changes inevitably affects the stream system. Plate 4 shows land use changes from grass land to arable land by ploughing. A comparison of 1986 land use with that of 1972 (Troake _et al_., 1976) for the Slapton Wood and Stokeley Barton catchments is given in Table VI : there is an obvious shift from pasture to arable land use. This gives a 77% and 26% increase in arable land for the Slapton Wood and Stokeley Barton catchments respectively. (Aerial photographs in Plates 5, 6 shows the land use in 1951 and

Plate 4. Land use changes from grass land to arable land by ploughing

1980 for Slapton wood catchment). This shift will increase the ploughed acreage of the catchments thus probably increasing the erosion potential. If trends in these two land uses apply to the catchment as a whole, a significant shift to cereal and root production, primarily associated with a decrease in the production of pasture, is evident (Heathwaite _et al_., 1988).

TABLE: VI

A COMPARISON OF LAND USE IN THE SLAPTON WOOD AND STOKELEY CATCHMENTS FOR 1972 AND 1986

Catchment	1972		1986		Increase
	ha	(%)	ha	(%)	(%)
Slapton Wood					
Arable	22	23	39	42	77
Pasture	60	65	40	42	
Wood	11	12	11	12	
Stokeley Barton					
Arable	74	48	93	61	26
Pasture	57	37	45	29	
Wood	10	07	03	02	

% percentage of total catchment area occupied by land use category.
Source: Heathwaite _et al_., 1988.

Table VII summarizes the phosphorus application to crops in each catchment for 1986 and it can be seen that arable crops have a high phosphorus input. In total 210 tonnes of phosphorus (catchment average 43 kg ha^{-1} a^{-1}) were applied in inorganic fertilizers for the 1985/86 season (Heathwaite _et al_.1988). Average U.K. fertilizer application rates for the same period (Fertilizer Review

Plate 5. Aerial photographs shows the land use for Slapton wood catchment in 1951

Plate 6. Aerial photographs shows the land use
for Slapton wood catchment in 1980

1986) were: grassland 12 kg ha^{-1} a^{-1} phosphorus, cereals 23 kg ha^{-1} a^{-1} phosphorus and roots 65 kg ha^{-1} a^{-1} phosphorus. The figures for the Slapton catchment (Table VII) exceed the U.K. average for phosphorus inputs with the exception of root crops. Table VII suggests that the general shift to arable land use in the catchment will have substantially increased the phosphorus load to the system.

TABLE VII

PHOSPHROUS FERTILIZER APPLICATION RATES (kg ha^{-1} a^{-1}) FOR THE SLAPTON CATCHMENTS (1986)

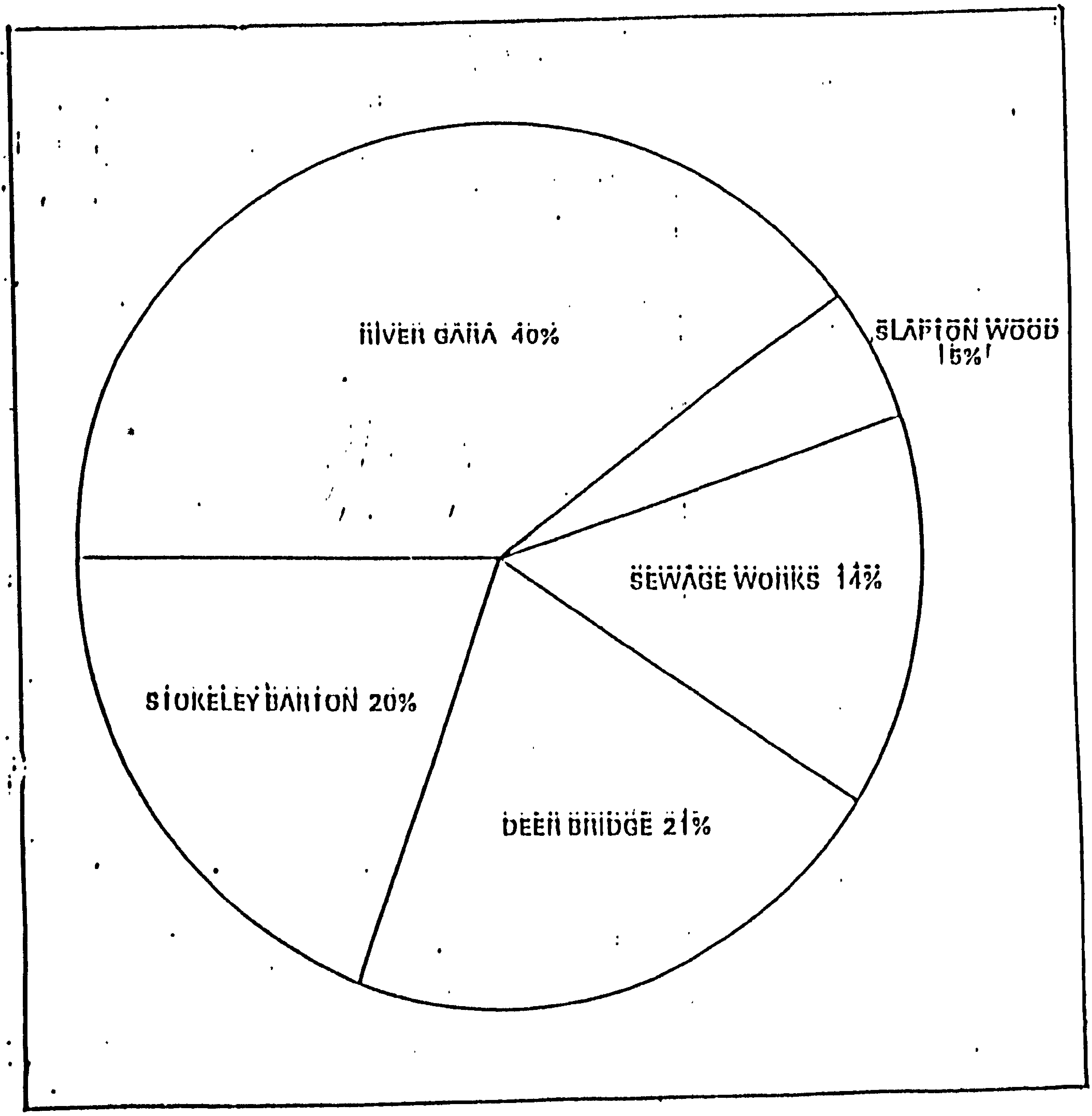
Catchment	Grassland		Arable land		Weighted mean application
	Perm.	Temp.	Cereals	Roots	
Gara	37	57	53	109	46
Slapton wood	17	19	33	164	32
Start	36	41	73	132	58
Stokeley barton	44	28	70	175	56

Source: Heathwaite _et al._, 1988.

Estimates of phosphate load inputs to Slapton Ley 1984 data (Source: Slapton Field Centre) presented in Fig. 4.5 indicate that the phosphate load inputs to Slapton Ley came not only from the general catchment area but also 14% from sewage works of urban area.

Phosphorus from sewage is widely thought to be one of the major causes of water weed growth and fishery decline (South Hams, Gazette, 7- 8- 1987). There is evidence at Slapton Ley over the last 44 years that reeds

FIG. 4.6 PHOSPHATE LOAD INPUTS TO SLAPTON LEY, 1984



Source: Slapton field centre

have grown over the Higher Ley. Plate 7 is of the Higher Ley at Slapton Bridge in 1943 showing open water.The same view in 1987 shows extensive reed beds in Plate 8 (Source: Slapton Field Centre). In addition, phosphorus is one of the major cause of algae growth. Plate 9 shows the evidence of such algae growth at Slapton Bridge.

Plate 7. The Higher Ley at Slapton Bridge showing open water in 1943

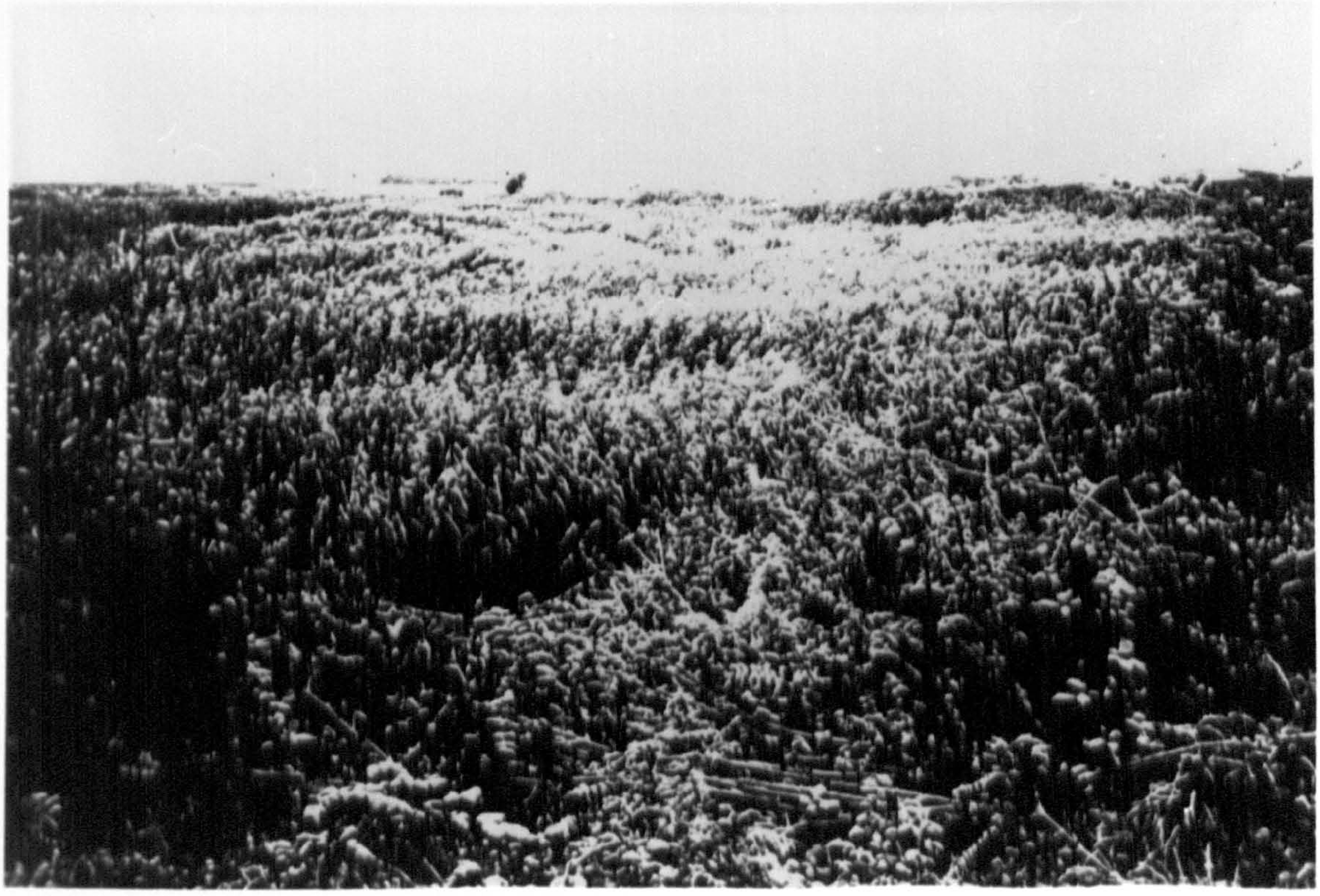


Plate 8. The Higher Ley at Slapton Bridge showing extensive reed beds in 1987

Plate 9. The evidence of algae at Slapton Bridge

CHAPTER:5

SOIL PHOSPHORUS LEVELS

This chapter discusses the soil phosphorus levels in the four representative land use areas. The Slapton Ley catchment land use was identified using aerial photographs, the latest available land use map (Johnes, 1986) and a field survey of a part of the Start , Gara and Slapton Wood areas and from this information was produced the land use map in Fig. 5.1. The Slapton Ley catchment has four main types of land use categories: cereal, arable (roots), grass and woodland. A representative area from each main land use was selected as a basis for studying the variations in phosphorus level in soil for the Slapton Ley catchment.

5.1 DESCRIPTION OF THE LAND USE AREAS:

The cereal land use area, which was temporary grass during the study, is situated in the Gara River catchment at Merrifield (Fig. 5.2a adopted from Heathwaite et al.1989) and has a maximum slope of 27^{0}. The area of this land use is approximately 1050 m^2. The higher part of the area is about 130 m a.s.l. and the lower part of the area is about 110 m a.s.l. The results of the soil particle analysis show that the surface soil contains 49.3% silt, 41.3% sand, 9.4% clay. The detail is given in Chapter 6. The crop of this area is barley / temporary grass. Plate 10 shows a part of the cereal land use area.

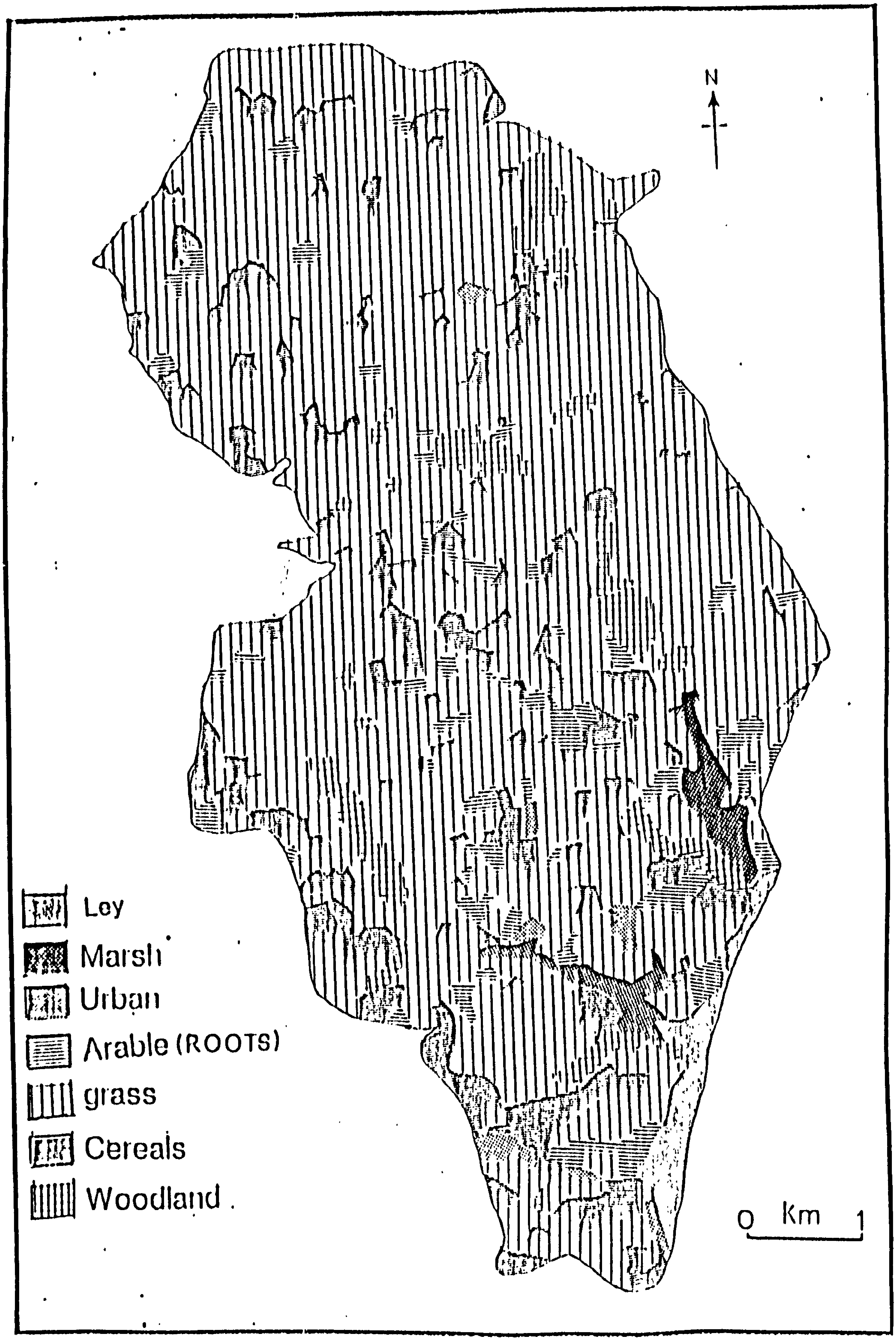


FIG.5·1 LAND USE IN THE CATCHMENT OF SLAPTON LEY

The arable (root) land use area is situated beside the cereal land use area at Merrifield (Fig. 5.2a) with a maximum slope of 30^0 and an area of approximately 1150 m^2. The highest point of the area is 130 m a.s.l. and the lowest is 90 m a.s.l. Tho results of the soil particle analysis showed that the surface soil contains 50.3% silt, 41% sand and 8.7% clay. The detail is given in Chapter 6. The root crop of the area is kale. Plate 11 shows a part of the kale land use area.

The grass land use area is situated beside the arable land at Merrifield (Fig. 5.2a) with a maximum slope of 30^0 and an area of approximately 1450 m^2. The highest point of the area is 130 m a.s.l. and the lowest is 90 m a.s.l. The surface soil contains 47.2% silt, 47% sand and 5.8% clay. The detail is given in Chapter 6. This area is covered with permanent pasture.

The woodland area is located a short distance (1.30 km)) from the other three land use areas in the Slapton Wood stream catchment at Eastergrounds (Fig. 5.2b) with a maximum slope of 32^0 and an area of approximately 375 m^2. The highest point of the area is 100 m a.s.l. and the lowest is 35 m a.s.l.

5.2 SOIL PHOSPHORUS:

The most significant characteristics of soil phosphorus are its low water solubility and high adsorptivity. Much of the fertilizer phosphorus applied to soil is rapidly converted to the slightly less soluble compounds of the

Plate 10. Arable and cereal/ temporary grass land use at Merrifield

Plate 11. Arable land use at Merrifield

FIG. 5·2 LOCATION OF THE REPRESENTATIVE LAND USES (* ADOPTED FROM HEATHWAITE 1989) calcium, magnesium, iron and aluminum forms (see Chapter 1). This greatly decreases the amount of soluble P in soil water whether replenished by either mass flow or diffusion. Some phosphate compounds formed are crystalline and dissolve slowly or are transformed further to progressively less plant-available and less water- soluble forms (Black, 1970). In either case, most of the added P released does not stay in solution but is strongly sorbed by the finely divided soil particles (Marshall, 1964). Soluble orthophosphorus (PO_4-P) concentrations in the soil vary with soil pH, type of phosphate compounds, and soil texture (Murrmann and Peech, (1969) and Olsen et al., (1977)). In relation to the effect of different phosphate compounds, Romkens and Nelson (1974) stated that the Davidson soil they were washed on had the largest percentages of clay and $Fe_2\ O_3$, but less extractable P and soluble orthophosphate than any of the other soils at corresponding rates of P addition. Apparently, the presence of large amounts of Fe_2O_3 led to the formation of iron phosphate which is less water soluble and less extractable with the NH_4F: $HC\ell$ reagent used.

Topsoils vary greatly in their total P content, ranging from 200 to 10000 kg/ha, depending mostly on their inherent fertility and to a lesser degree on their fertilization history ($M^cDowell$, et al., 1980). Only a small amount of the total P is available for terrestrial plant growth, perhaps 1 to 10 percent. Applying excess P fertilizers over several years increases the total P content of soils.

For the present study, in the selected four land use areas, the surface soil samples were taken using a grid sampling method (Fig. 3.1) and each sample split into two duplicate subsamples, each of which was analysed to determine the water-soluble and exchangeable phosphorus levels.

Comparing the results obtained for exchangeable phosphorus concentration in soil with water-soluble phosphorus concentration in soil, water-soluble phosphorus is at much lower (<1 mg/l) concentrations. This is possibly because, as Holt et al., (1970) found that low concentrations of dissolved P in runoff water from soil having deep incorporation of fertilizers.

Exchangeable phosphorus has been used as an index of available P in soil (Tandon and Kurtz, 1968). Fig. 5.3 shows that the spacing of isolines is narrower and that the level of exchangeable phosphorus concentration is lower on the steep mid-slope than at the top and the bottom of the slope. The levels of water-soluble phosphorus concentration in soil do not show such pattern of spacing isoline (Fig. 5.4).

Analysis of variance (F- Test) was applied to the water-soluble phosphorus concentration data and exchangeable phosphorus concentration to test any significant differences between the land-uses. Data used for analysis of variance are averages of duplicate (see Appendix 3)

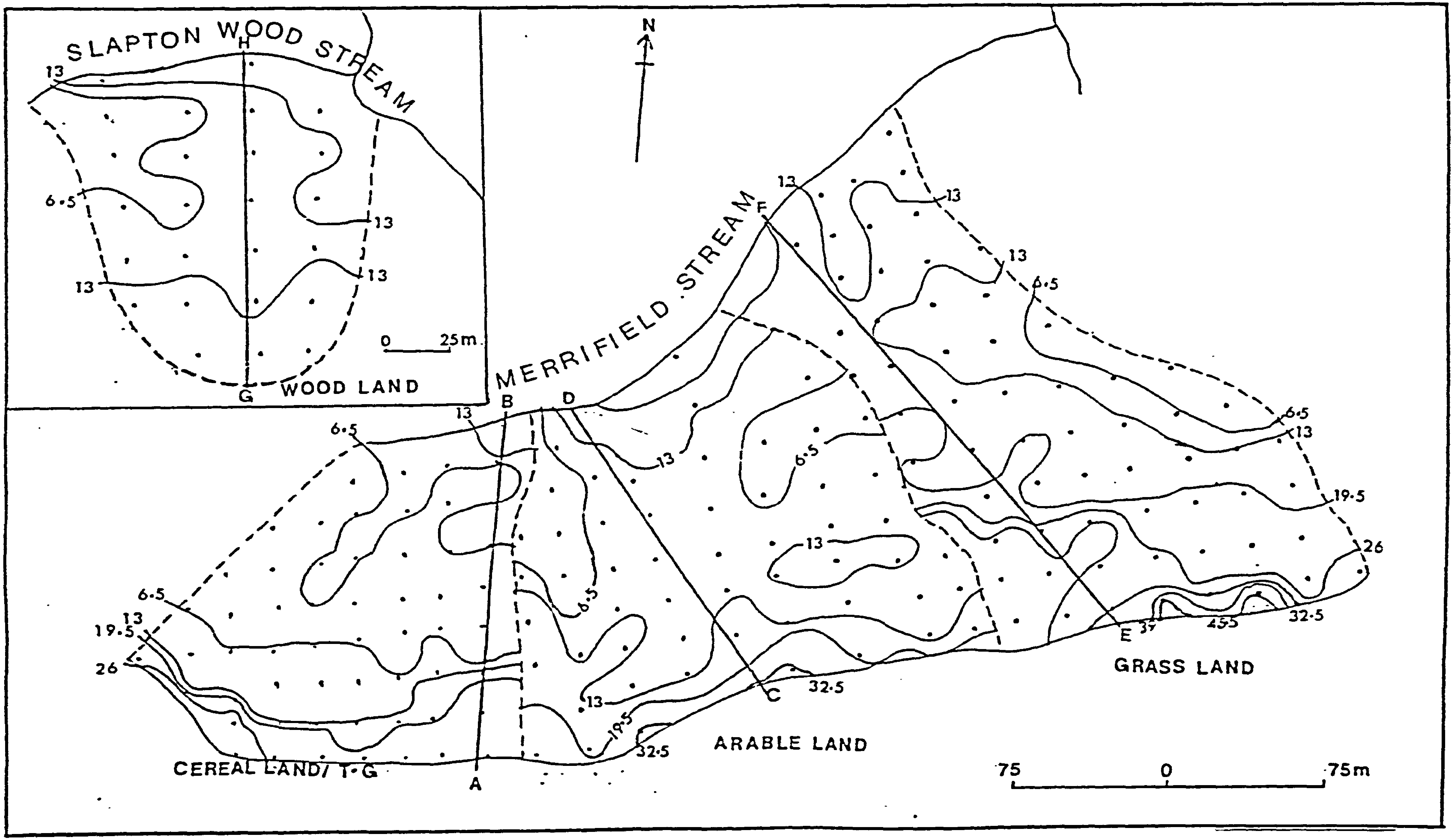


FIG. 5-3. ISOLINE OF EXCHANGEABLE $[PO_4^{-}P]$ IN THE CEREAL / TEMPORARY GRASS, ARABLE, GRASS & WOOD LAND'S SOIL

FIG. 5·4 WATER SOLUBLE PHOSPHORUS CONCENTRATION IN THE LAND USES determinations and values reported for soil are on a moisture-free basis.

The results of the analysis of variance (Table VIII) show that there are significant differences for exchangeable phosphorus concentration and water-soluble phosphorus concentrations in soil between the land use types but the significance levels show the differences are at different levels. This indicates that there is greater variation between the land-use types for exchangeable phosphorus concentration.

TABLE: VIII

ANALYSIS OF VARIANCE OF WATER-SOLUBLE AND EXCHANGEABLE PHOSPHORUS CONCENTRATION IN SOIL FOR LAND USES

	Concentration	F	dF1	dF2	Significance level
Four Land-uses	Water Soluble Phosphorus	2.954	3	210	0.034
	Exchangeable Phosphorus	8.406	3	210	<0.001

To locate the major differences between the particular land uses, the Mann-Whitney 'U' test was applied for water-soluble phosphorus and exchangeable phosphorus concentration in soil since these data are non-normal. Fig. 5.5 shows the frequency distributions of the above data which is non-normal. The highest frequency is 27 which is between 0 and 6 ppm PO_4-P for cereal, 30 which is between 6 and 12 ppm PO_4-P for arable, 24 which is between 12 and 18 ppm PO_4-P for

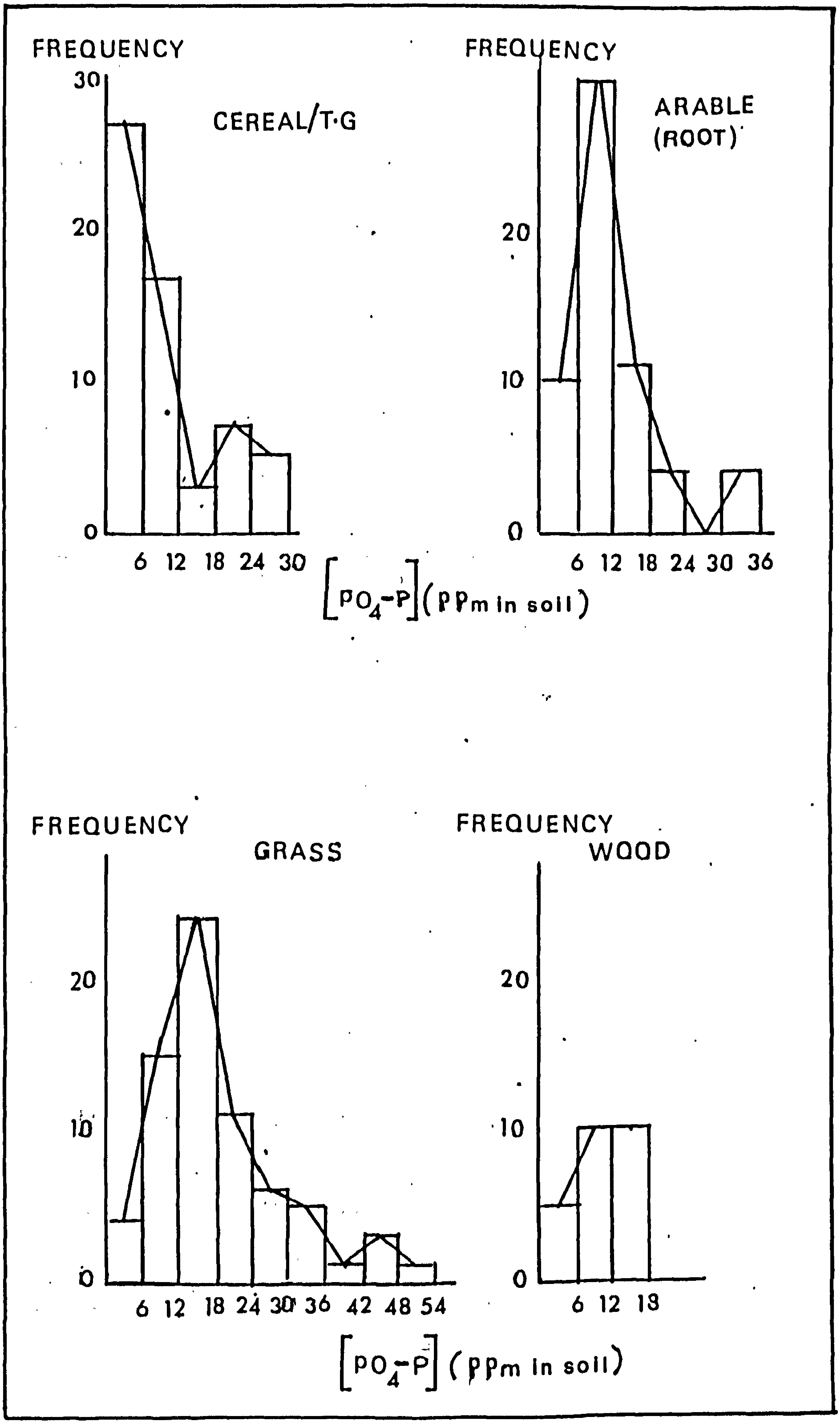


FIG. 5·5 FREQUENCY DISTRIBUTION OF EXCHANGEABLE [PO_4-P] IN SOIL FOR LAND USES grass and 10 which is between 6 and 12 ppm PO_4-P for Wood respectively. The significance levels of the Mann-Whitney 'U'test between the land uses are shown in Table IX for water-soluble phosphorus concentration to the right side of the diagonal and for exchangeable phosphorus concentration between the land uses to the left side.

TABLE: IX

SIGNIFICANCE OF 'U' VALUE FROM MANN-WHITNEY 'U'TEST FOR COMPARISON OF FOUR LAND USES OF WATER SOLUBLE AND EXCHANGEABLE PHOSPHORUS CONCENTRATION IN SOIL

		WATER-SOLUBLE			
EXCHANGEABLE		Cereal	Arable	Grass	Wood
	Cereal		0.0691 CA (n=120)	0.1979 CQ (n=129)	0.0484 CW (n=84)
	Arable	0.0086 CA (n=120)		0.3849 AG (n=131)	0.0457 AW (n=86)
	Grass	<0.0001 CG (n=129)	<0.0001 AG (n=131		0.0370 GW (n=95)
	Wood	0.0004 CW (n=84)	<0.0001 AW (n=86)	<0.0001 GW (n=95)	

Values <0.05 indicate a significant difference between mean phosphorus levels at the 5% level. The low values indicate that there are significant variations between the land uses in phosphorus concentration level, particularly for exchangeable phosphorus.

For the water-soluble phosphorus concentration, the significance of U-test values is comparatively low for all fields except between woodland and arable, woodland and cereal and woodland and grass which are significant at the 5% level. This indicates that wood land's water-soluble phosphorus concentration level is lower and different from other fields' water-soluble phosphorus concentration level.This is probably due to the lack of fertilizer application in woodlands.

The phosphorus concentration levels may depend on slope gradients and slope position within the land-use due to erosion. i.e loss on the steep slope and deposition downslope. Therefore rank correlation coefficients for the relationships between the phosphorus concentration level and slope angle were determined to ascertain whether there are any significant statistical relationships between gradient and phosphorus concentration levels. Table X shows that the correlation between slope angle and phosphorus concentration in soil for land-uses are negative. This is thought to be due to soil erosion and loss of phosphate-rich surface soil, when slope angle increases. Phosphorus concentration is low mostly on steep agricultural slopes because, during intense, storms the finer particles which are associated with phosphorus (see Munn <u>et al</u>. 1973), may be transported downslope, having been exposed by ploughing. Also " r " values for exchangeable are greater than water soluble for cereal and arable not for grass and wood.

TABLE: X

SPEARMAN RANK CORRELATION BETWEEN SLOPE ANGLE AND SOIL PHOSPHORUS CONCENTRATION FOUR LAND USES

r	Cereal/T.G n=59	Arable n=60	Grass n=70	Woodland n=25
Slope/Ex.PO_4-P	-0.7387 (<0.0001)	-0.8816 (0.004)	-0.1620 (0.090)	-0.456 (0.001)
Slope/W.S.PO_4-P	0.0236 (0.430)	-0.1374 (0.002)	-0.1464 (0.002)	-0.5927 (0.013)

Transects from each land use show that arable and cereal/temporary grass have less soil phosphorus concentration on steep mid-slopes (position of slope) than the grass and woodland (see Figs. 5.6 and 5.7). However, the grassland soils have a higher level of exchangeable phosphorus concentration than the arable and cereal soils. Woodland soil has lower level exchangeable phosphorus concentration than all other land uses (Table: XI).

TABLE: XI

MINIMUM AND MAXIMUM LEVEL OF EXCHANGEABLE PHOSPHORUS IN SOIL FOR FOUR LAND USES

Ex.PO_4-P level(ppm)	Cereal (T.G)	Arable	Grass	Woodland
Minimum	3.6	3.3	7.2	1.6
Maximum	29.4	32.5	46.0	16.6

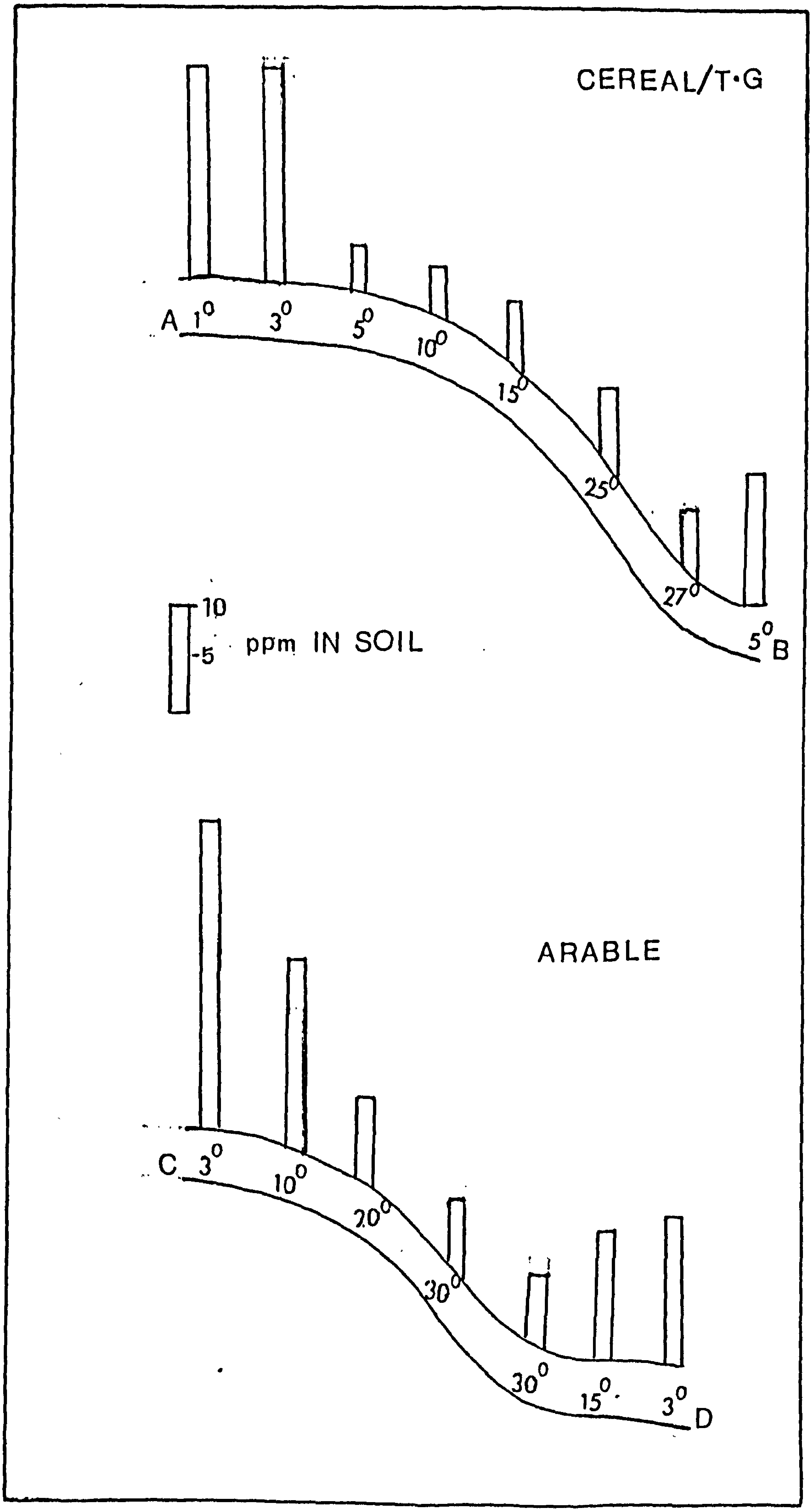


FIG. 5·6 SOIL $\left[PO_4\text{-}P\right]$ ON TRANSECTS OF LAND USES

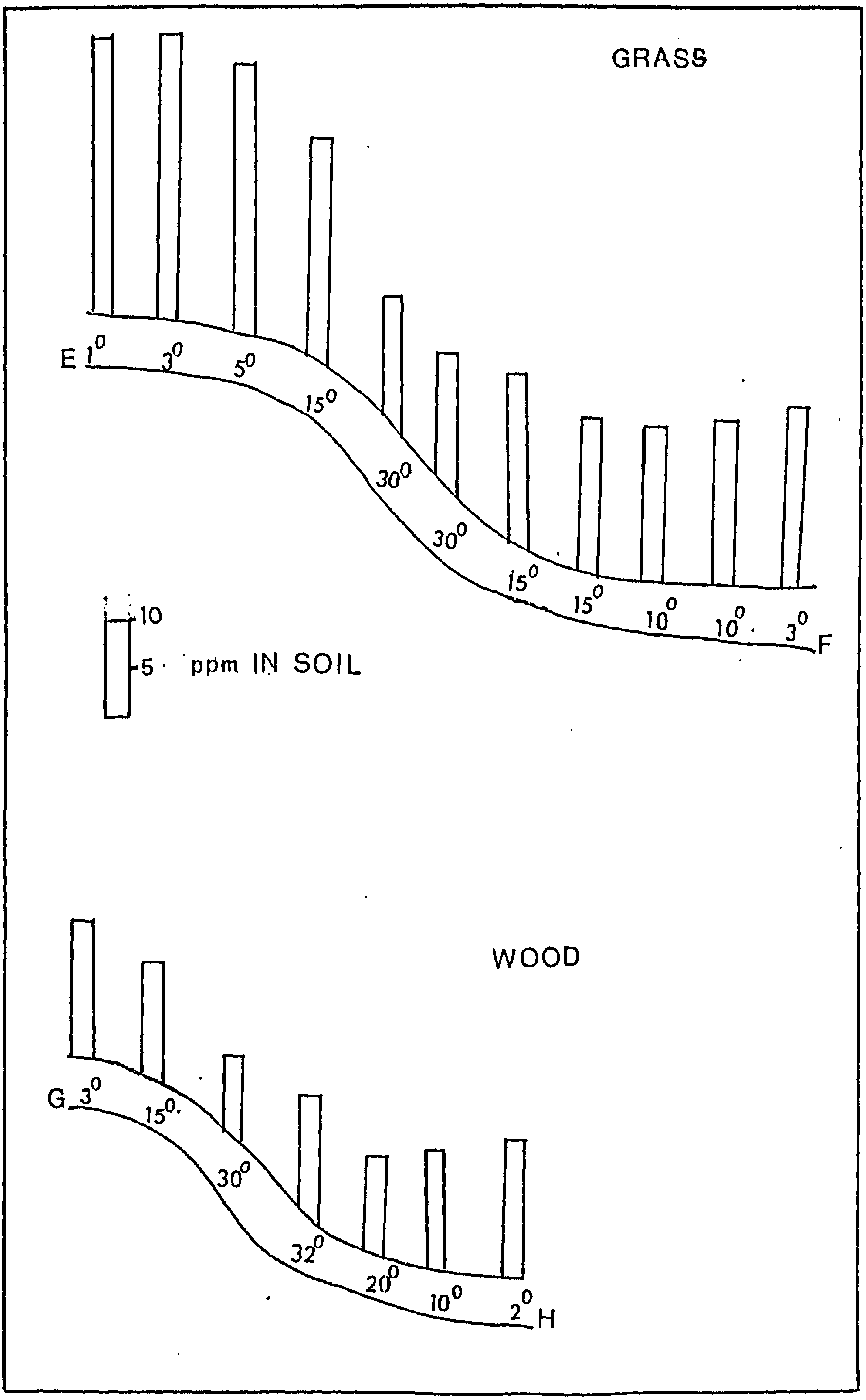


FIG. 5·7 SOIL $[PO_4-P]$ ON TRANSETS OF LAND USES

These variations of phosphorus concentration levels are probably due to the inputs from sheep dung in grass land (Plate 12 shows a part of the grass land behind the kale land on the right edge of the plate where sheep are grazing) agricultural practices and subsequently more movement due to erosion on arable and cereal lands and the lack of fertilizer application in woodland.

Plate 12. A part of the grass land behind the kale land on the right side edge of the plate where sheep are grazing

CHAPTER 6

EVIDENCE FROM THE EXPERIMENTAL PLOTS:

This chapter discusses the evidence obtained from the runoff trough experiments. It attempts to assess the erosional effects of overland flow and thus to determine the level of phosphorus losses from different land uses which may be influencing the eutrophication of the lake.

6.1 OVERLAND FLOW AND ITS EFFECTS - A REVIEW:

The erodibility of soils will be affected by soil moisture content (Barnett and Rogers, 1966) and by ground cover (Anderson, 1951; Lang, 1975) amongst other factors. The amount of erosion which occurs in any given circumstance will be influenced by both, rainfall and soil characteristics and studying the processes of soil erosion can be simplified by considering the two aspects separately. The properties of the rain in soil erosion are referred to as 'erosivity' and the properties of the soil are referred to as 'erodibility'. Erosivity is the potential of rain to cause erosion and is a function of the physical characteristics of rainfall. Erodibility is the vulnerability or susceptibility of the soil to erosion. It is a function of both the physical characteristics of the soil and its management.

The resistance of a soil to erosion depends on many factors and so to assess erodibility numerically an assessment has to be made of each factor.

Surface runoff or overland flow from eroding fields affects lakes through transporting sediment with adsorbed phosphorus. Overland flow is defined as the flow of water over the land surface towards a stream channel and is the initial phase of surface runoff. It is referred to by Emmett (1978) as 'sheet flow' because the water is envisaged as moving in a sheet downslope over a plane surface to the nearest concentration point or channel.

The hydraulic characteristics of overland flow are dependent on many factors including the intensity and duration of precipitation, the texture or type of soil as reflected by its infiltration capacity, the antecedent soil moisture conditions, the density and type of vegetation, and topographic features of slope steepness, and length of slope. The geomorphic characteristics are generally dependent on the hydraulic characteristics, but no simple description of the hydraulics of overland flow on natural hillslopes is possible because the hydraulic parameters vary rapidly over time and space. Most overland flow is not laminar flow because of the disturbance by falling raindrops and the influence of micro-irregularities. Such a disturbed flow is capable of eroding and transporting sediments.

Meyer and Monke (1965) reported that the intensity of erosion increases with increasing slope steepness and runoff rates, but on a natural slope, the erodibility of soils will be affected by ground cover, soil moisture content and other factors. From plot experiments carried out in the Maluna creek catchment at Pokolbin, New South Wales, Loughran, et al., (1980) found that over an approximately average year for precipitation, considerable variation in erosion was caused by factors such as vegetation cover, position on the slope and soil type. Field investigations of overland flow in non-enclosed plots have been carried out by Emmett (1978). Here, the flow concentrations were mapped by dye tracing to show the general flow pattern. Each site exhibited a unique flow pattern dependent mostly on the physical characteristics of the slope.

Kessel (1977) and Peh Cheng Hock (1980) noted in different (tropical) forested areas the roof-shingle effect of the litter cover and an almost instantaneous overland flow response to rainfall. Kessell stated that on forested plots, and as a result of the canopy cover, only a small proportion of the raindrops fall directly to the ground, while Freise (1936) estimated that in the Brazilian rainforest one third of the rainfall reached the ground by flowing down tree trunks. Ruxton (1967) pointed out that water drops with a free fall of over 8m will be close to their terminal velocity when they strike the ground and can be an effective factor in soil erosion under rainforest. Puvaneswaran (1981) noted in the Woungong Brook catchment area in Western Australia, that though the height of the trees (more than 8m) is an effective factor influencing soil erosion, soil particle size is also an important factor. Trudgill (1977b) stated that it would be useful to be able to relate micro-erosion events to specific storm events. Horton's model of erosion by overland flow (Horton, 1945) is being increasingly questioned for its over-simplistic explanation (Chorley, 1978). It is probably most applicable to sparsely-vegetated semi-arid rangeland areas (Kirkby and Chorley, 1967). However, even in these environments the model neglects the erosive impact of falling rain (Williams, 1969) which is often a precursor to any significant erosion by overland flow.

Rainwash erosion is widely regarded as dominant on hillslopes in semi-arid areas (Fenneman, 1908; Bryan, 1922; Schumm, 1956). Runoff (Kringold and Beenhouwer, 1954) and soil erosion (Doren and Bartelli, 1959; Schmidt, 1964) both appear to be greater on soils late in their respective maturity sequences than for less highly developed soils, though other factors are equally important. For a given storm, soils of low permeability suffer more erosion by surface wash than do soils of high permeability and high rainfall acceptance (Ursic and Thames, 1959; Smith, 1951).

Furley (1968) found, in the Oxford area, that in the erosion zone there were significant associations between slope gradient and the soil properties examined, and confirmed that soil maturity was most advanced on the gentlest slopes.

In strongly structured soils considerable quantities of input water move in a non-uniform manner (Thomas and Phillips, 1979) along by-passing soil structures, in increasing amounts as rainfall intensity increases (Bouma et al., 1981). In the Slapton study catchment, soil outflow response, and the surface-to-output linkages by preferential flow, will also increase with rainfall intensity and in weakly-structured soils, soil moisture conditions can also provided a useful indicator of the probable occurrence of preferential flow and also surface flow (Coles and Trudgill, 1985). The combination of impermeable bedrock and steep slopes provides ideal conditions for the generation of surface hill slope runoff (Burt, et al., 1983). Overland flow can be produced by the whole catchment, if rainfall intensity exceeds the infiltration capacity for a long period of time.

The storm peak in stream discharge is often much earlier and shorter-lived than the through flow response, which emphasises that "storm runoff" is produced largely by surface rather than by subsurface flow, through it is important to note that there may be some contribution of throughflow to the "storm" peak, as macropores in the soil allow water to be rapidly transmitted down to the saturated wedge (Burt, et al., 1983). Troake and Walling (1973) noted that the area contributing rapid runoff during storm events at Slapton comprised a very small part of the catchment. In order to investigate the occurrence of overland flow, crest-stage tubes were used at the Eastergrounds site in Slapton Wood and confirmed that overland flow does occur (Burt, et al.1983). The lack of soil water mobility in the weakly-structured Slapton soil under dry antecedent conditions is in contrast to the existence of by-passing flow in dry, cracking clay soil with well-developed peds, as shown by

Kneale and White (1984), White, et al., (1983) and Bouma, et al., (1981). In the weakly- structured soils studied at Slapton the dry soil aggregates are able to absorb moisture, even at the highest rainfall intensities, because of the more diffuse nature of the flow pathways; it is only at high soil water values that the structural pathways operate preferentially (Coles and Trudgill 1985). Troake and Walling (1975) stated that the Slapton Wood catchment's relatively steep slopes (10- 24^0) would also provide favourable conditions for rapid runoff and nitrate removal by both surface and subsurface routes.

Knapp (1978) has shown that where thin soils overlie a less permeable substrate, infiltrating rainwater may occasionally fill up the soil storage, eventually leading to surface runoff.

Caesium 137 has been employed in drainage basin studies to determine soil erosion status and rates of sediment deposition (eg. Brown et al., 1981; Langmore et al., 1983; Loughran and Campbell, 1983; Mitchell et al., 1981). From the pioneering work of Ritchie and McHenry (1975) a simple model of 137_{Cs} redistribution in drainage basins by geomorphological processes was developed and tested (Campbell, et al., 1986). Walling and Kane (1985) measured 137_{Cs} concentrations on suspended sediment in Jackmoor Brook and related these to concentrations of 137_{Cs} on catchment soil, concluding that arable fields were the main source of sediment to the stream, rather than non- cultivated fields.

Many instances of water erosion of arable land have been recorded (Anon, 1977; Call, King and Wair, 1975; Evans,1971; Evans and Morgan, 1974; Hodgson and Palmer, 1971; Morgan, 1974, 1975, 1977; Peacock, 1976; Whitfield, 1971). Continuous arable cultivation of the soil reduces its organic-matter content (Skidmore, Carstenson and Banbury, 1975; Unger, 1968) and lack of sufficient organic matter can cause structural instability of the soil (Greenland, Rimmer and Payne, 1975). Soils with little organic matter, therefore, could be considered liable to erosion (Evans and Nortcliff, 1978).

Most soil erosion research has been on the physical erodibility of different soils in a variety of environments. But there is little information concering the chemistry of soil losses and in particular the relationship between sediment yield and phosphorus in the runoff sediment.

6.2 TRANSPORT OF PHOSPHORUS IN RUNOFF - A REVIEW:

Many consider phosphorus to be the key nutrient element in eutrophication of freshwater bodies. (Lee, 1973 and Lee _et al._, 1978). Research on the role of phosphorus concentration in water, that is sediment plus solution-phase phosphorus. Some sediment phosphorus is thermodynamically stable, however and therefore, not biologically available to support the growth of algae and larger plants. In some eutrophication studies, only soluble PO_4-P is measured. While soluble PO_4-P is readily available for plant growth, this phosphorus form usually underestimates the total quantity of P that is available for aquatic growth. Lee and others (1978), proposed that the biologically-available P is approximately equal to the PO_4-P plus 0.2 times the difference between the total P and PO_4-P. Other studies have indicated that 5 to 40 percent of the sediment P is labile (Johnson et al., 1976: Huettl et al., (1979), Schreiber et al., (1977), Taylor et al., (1971).

Duley (1926) found the major loss of P in runoff to be in the form of eroded soil. Many other studies have noted P losses through erosion under field conditions (Volk,1945; Scarseth and Chandler 1938; Rogers,1941 and Ensminger,1952). Small amounts of erosion, particularly of the <2μm fraction were found by Munn et al. (1973) to be responsible for major P losses.

Estimating P loadings to streams and impoundments requires measurements of the sediment and water discharges and the distribution of P concentrations between the solution and sorbed sediment phases. The distribution of P between the solution and sediment phases in runoff from a monocropped, unit source watershed is controlled by the same factors operating in the soil but with additional complicating factors. These additional factors include additional P sources, runoff-soil P extraction processes (desorption kinetics), and physical and chemical characteristics of the sediments, lower soil, solution ratios(lower sediment concentrations), and time in transport.

Measuring and analysing the phosphorus concentration from the eroded soil materials which are being transferred by overland flow from different landuses on the slopes and relating these with the factors such as slope angle, sediment volume, runoff, rainfall, rainfall intensity, infiltration, soil texture, it should be possible to obtain the level of phosphorus removed and the erosion rate. Thus determine whether the result indicates that overland flow influences the eutrophication of lakes due to the soil erosion through transporting phosphorus.

6.3 EXPERIMENTAL PLOTS AND THEIR CHARACTERISTICS:

Twelve experimental plots were studied, three from each of four selected land uses(Fig. 6.1): cereal /temporary grass, arable (root), grass and woodland. The experimental plots differ between landuses in characteristics such as crop or vegetation cover, surface soil texture, mean diameter of soil and slope angle. Table XII shows some of the characteristics of each plot.

6.4 SOIL TEXTURE:

In general, except plot 9, all the plots contain more silt than other soil particle sizes. Table XIII shows the percentage of sand, silt and clay for the surface soil materials at the upper boundary of each experimental plot. Figures 6.2, 6.3, 6.4, 6.5 show the particle size distribution of sand, silt and clay for each plot soil Plots 2 and 3 which are cereal/temporary grass, plots 3,4 and 5 which are arable (root), plots 7 and 8 which are grass and plot 12 which is woodland, are similar in texture of the soil which is silty loam. Plots

FIG. 6·1 LOCATION OF EXPERIMENTAL PLOTS AT MERRIFIELD & SLAPTON WOOD

TABLE: XII

CHARACTERISTICS OF EXPERIMENTAL PLOTS.

Plots	Slope Angle (0^0)	Landuse	Soil Texture	Mean Diameter of Soil Particle(μm)
1	3	Cereal/T.G*	Loam	41
2	3	Cereal/T.G*	Siltyloam	35
3	3	Cereal/T.G*	Siltyloam	41
4	5	Arable(root)	Siltyloam	31
5	5	Arable(root)	Siltyloam	41
6	5	Arable(root)	Siltyloam	35
7	10	Grass	Siltyloam	41
8	10	Grass	Siltyloam	33
9	10	Grass	Loamysand	125
10	12	Woodland	Loam	20.5
11	12	Woodland	Loam	20.5
12	12	Woodland	Siltyloam	35

T.G* = Temporary grass

TABLE: XIII

THE PERCENTAGE OF SAND,SILT, CLAY FOR THE SURFACE SOIL

Plots	Sand (%)	Silt (%)	Clay (%)
1	41	47	12
2	42	50	8
3	41	51	8
4	40.5	48.5	11
5	41.5	52.5	6
6	41	50	9
7	41	52.5	6.5
8	41	53	6
9	59	36	5
10	39	43	18
11	39	44	17
12	41	48	11

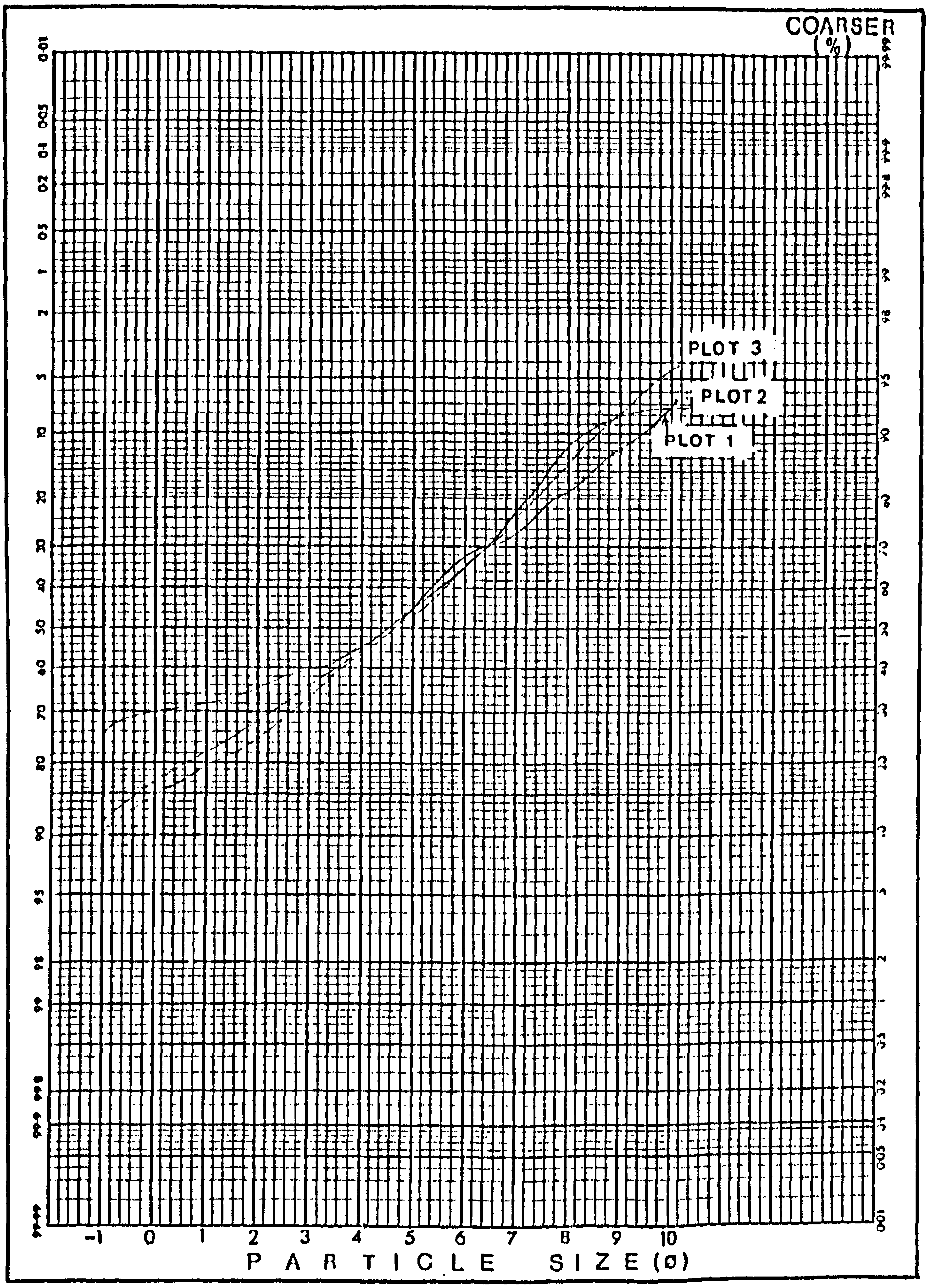


FIG. 6·2 PARTICLE SIZE DISTRIBUTION FOR PLOTS 1,2,3

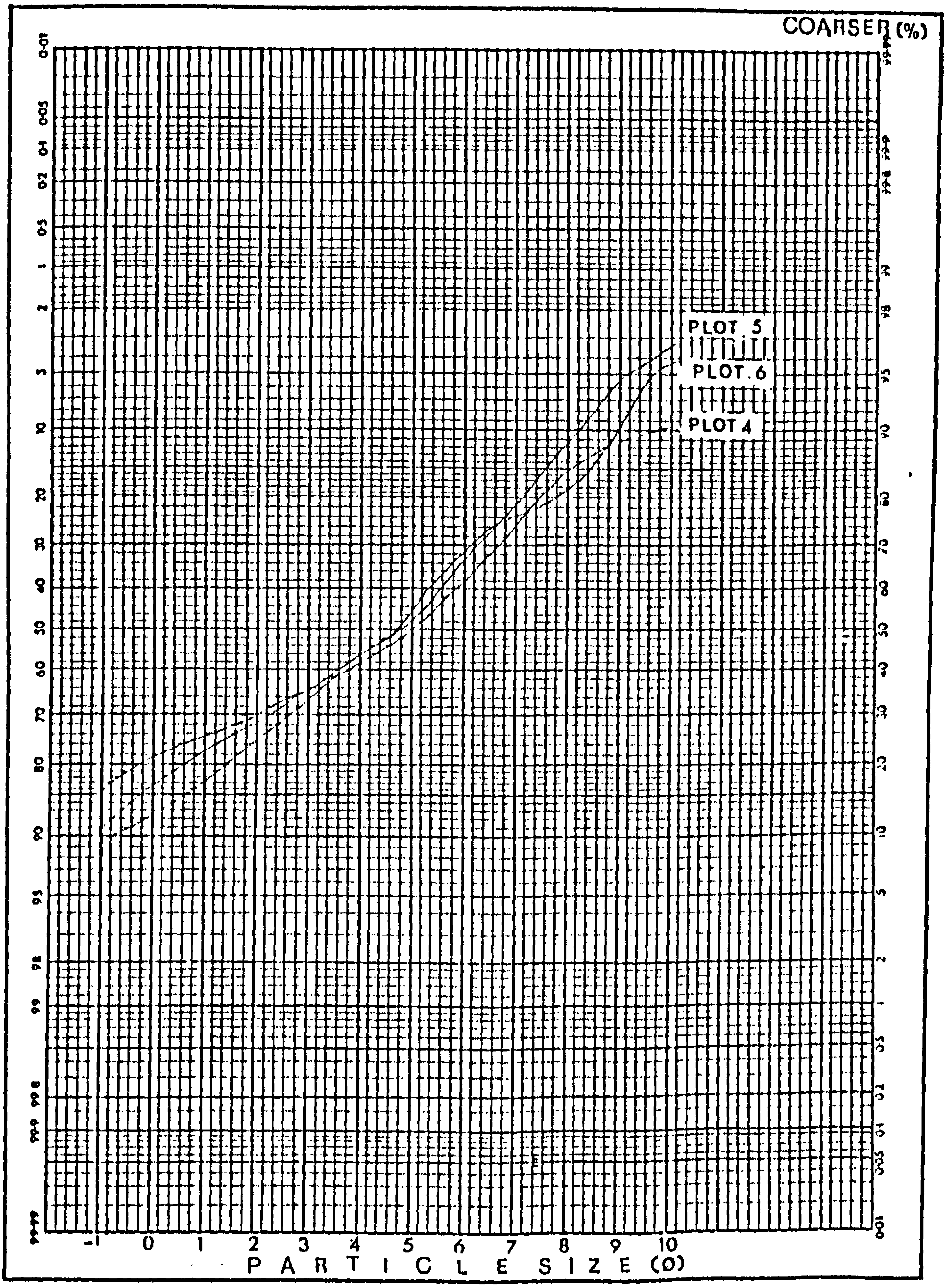


FIG. 6·3 PARTICLE SIZE DISTRIBUTION FOR PLOTS 4,5,6

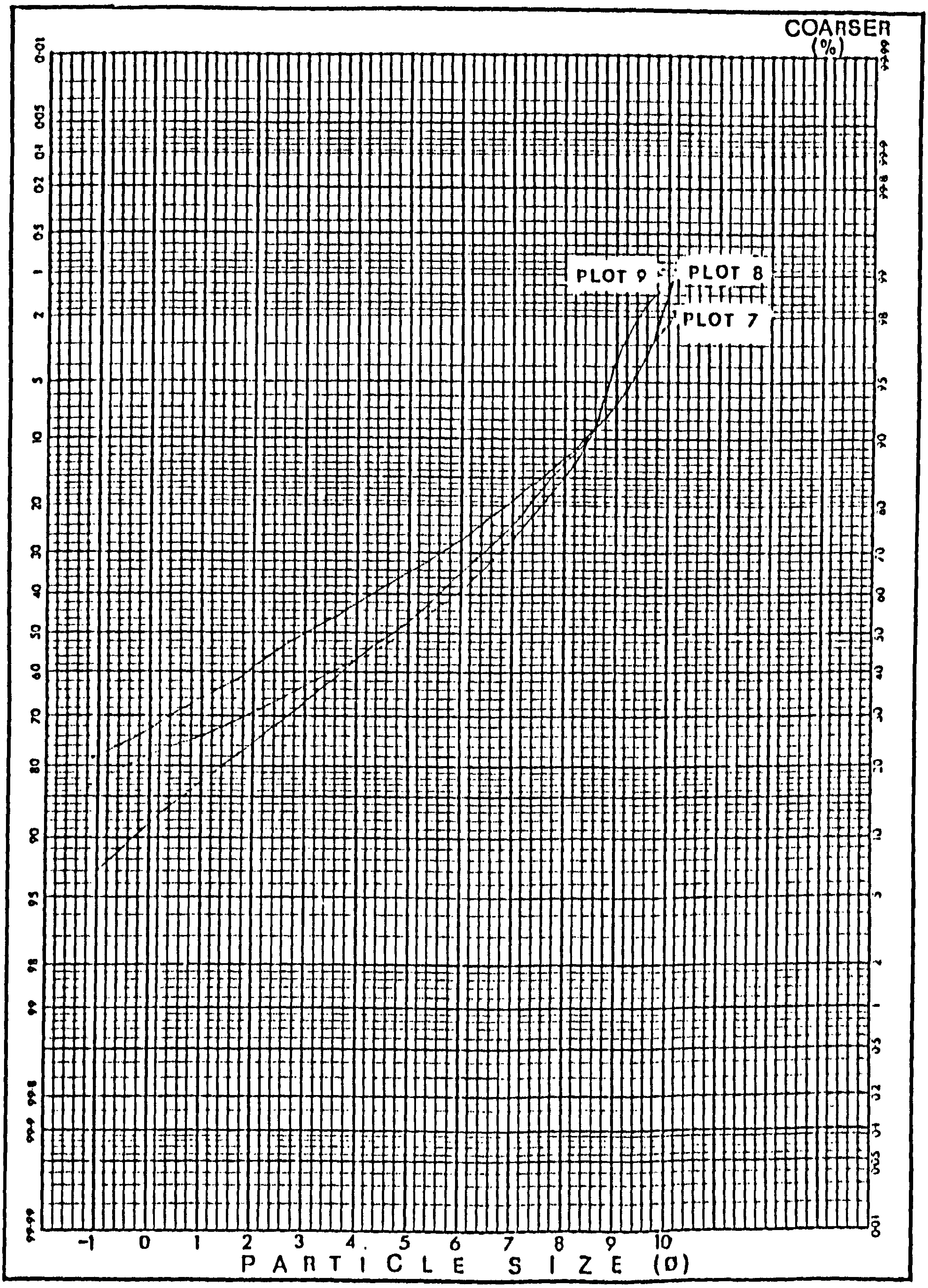


FIG. 6·4 PARTICLE SIZE DISTRIBUTION FOR PLOTS 7,8,9

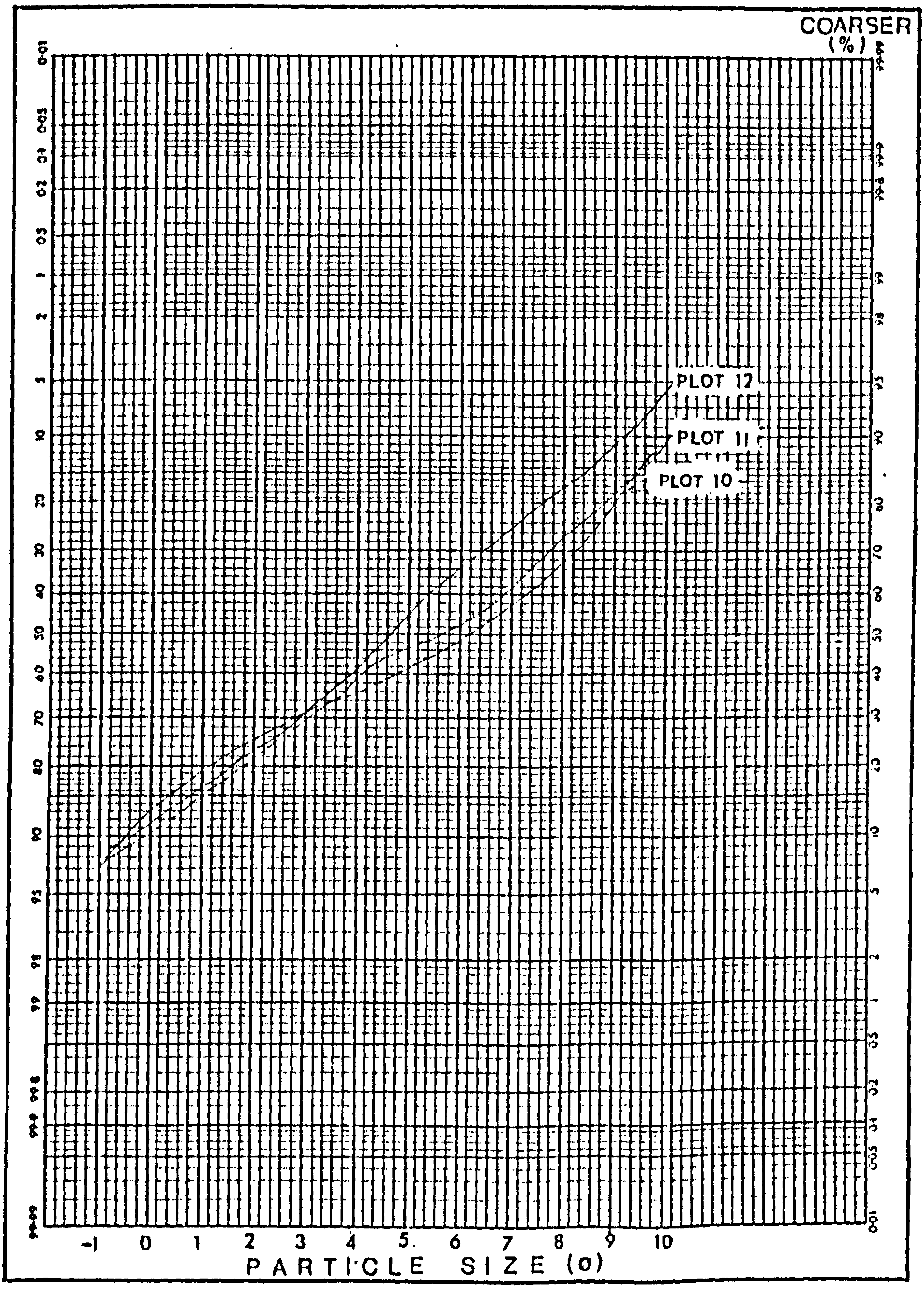


FIG. 6·5 PARTICLE SIZE DISTRIBUTION FOR PLOTS 10, 11, 12

1, 10 and 11 are similar in texture which is loam. Plot 9 is different from other plots in texture and is a loamy sand. Wood land plots 10 and 11 are different from most of the other land use plots.

6.5 RAINFALL INTENSITY:

Thirteen rainfall events were monitored with data from the pluviometer nearest to the experimental plots; the actual duration of each event was obtained and the intensity (mm hr^{-1}) was calculated (see Table XIV).

TABLE: XIV

RAINFALL AMOUNT AND RAINFALL INTENSITY DURING THE MONITORED EVENTS

RAIN-FALL EVENTS	DATES	RAINFALL AMOUNTS (mm)	RAINFALL INTENSITY (mm hr^{-1})	RAINFALL DURATION (hours)	MAX.RAIN-FALL IN HALF HOUR PERIOD(mm)
1	24 Dec.87	2.8	0.70	4	0.66
2	26 Dec.87	2.9	0.60	5	0.41
3	27 Dec.87	1.7	0.68	2.5	0.33
4	28 Dec.87	1.8	0.85	2	0.50
5	29 Dec.87	18.3	1.66	11	1.50
6	30 Dec.87	8.0	1.45	5.5	1.33
7	31 Dec.87	3.3	0.60	5.5	0.66
8	1 Jan.88	11.5	1.44	8	5.00
9	2 Jan.88	9.1	1.52	6	1.83
10	3 Jan.88	11.8	1.69	7	2.00
11	4 Jan.88	11.0	1.47	7.5	1.66
12	5 Jan.88	13.0	2.17	6	3.00
13	7 Jan.88	9.0	1.20	7.5	0.83

Furthermore, half hour rainfall intensity for each rainfall event was calculated. Figures 6.6, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12 show that the rainfall intensities within each event were variable. Comparing the rainfall intensity in the events, event 8 received the greatest

FIG.6.6 RAINFALL INTENSITY OVER HALF HOUR PERIODS

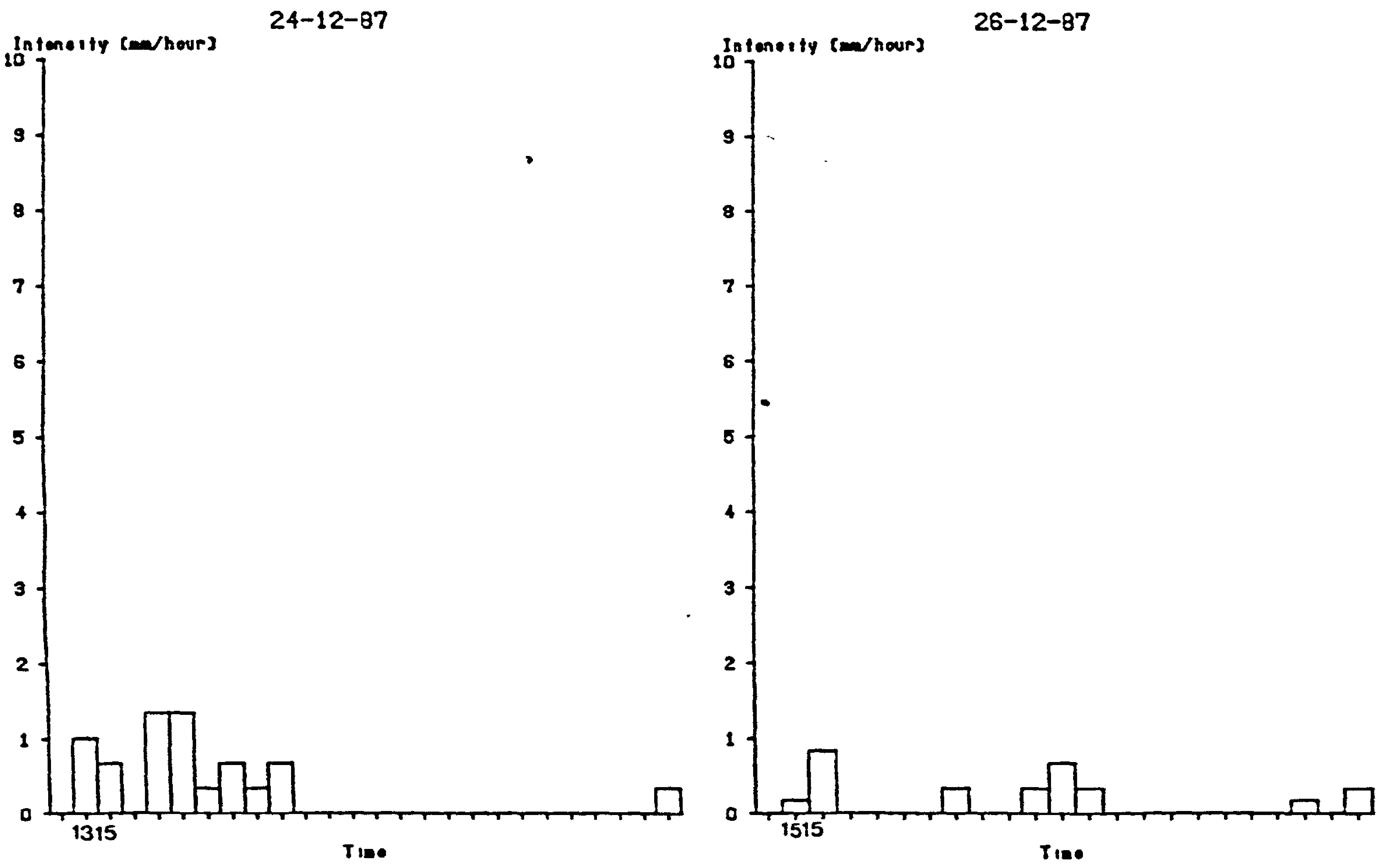


FIG. 6·7 RAINFALL INTENSITY OVER HALF HOUR PERIODS

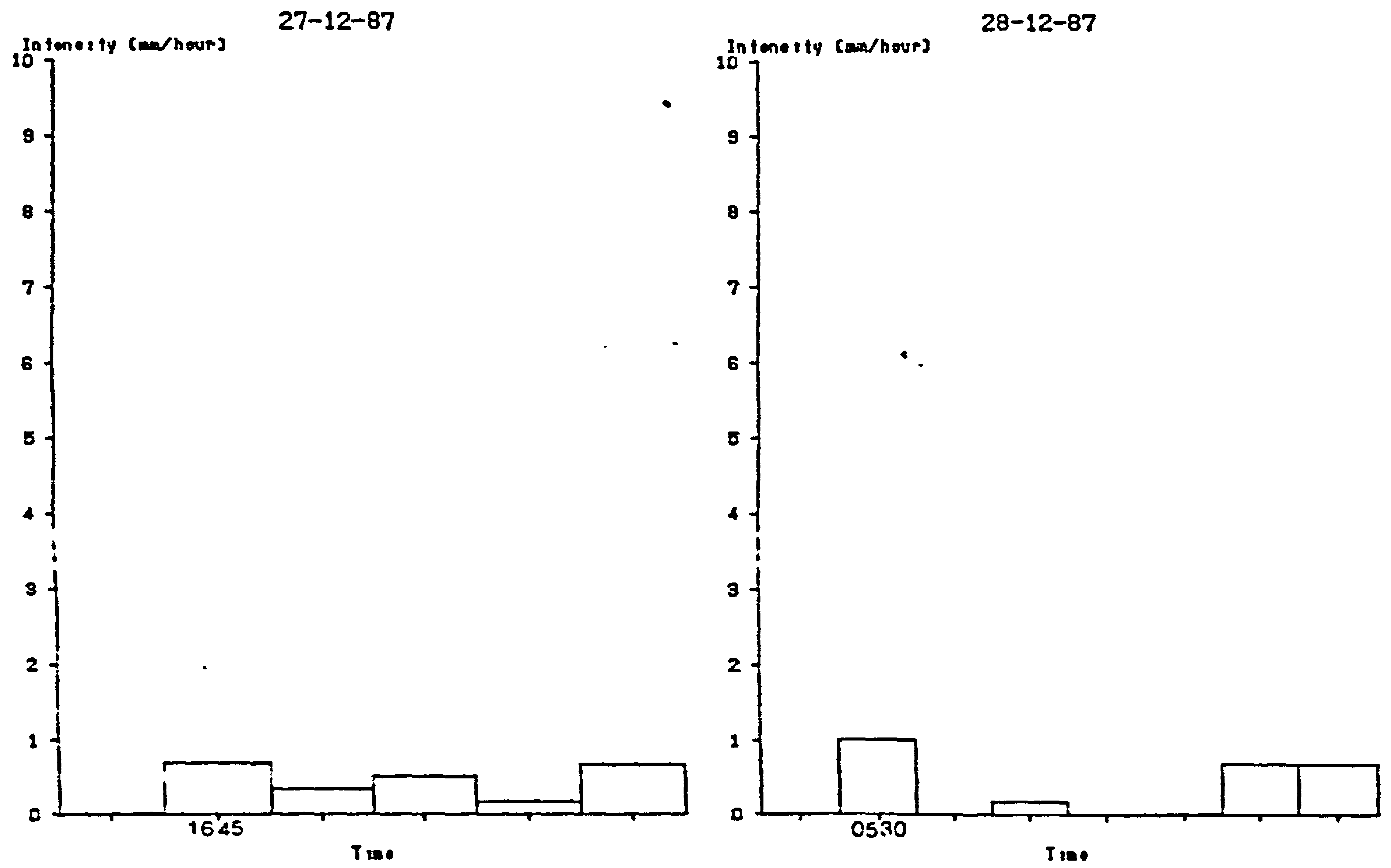


FIG. 6-8 RAINFALL INTENSITY OVER HALF HOUR PERIOD

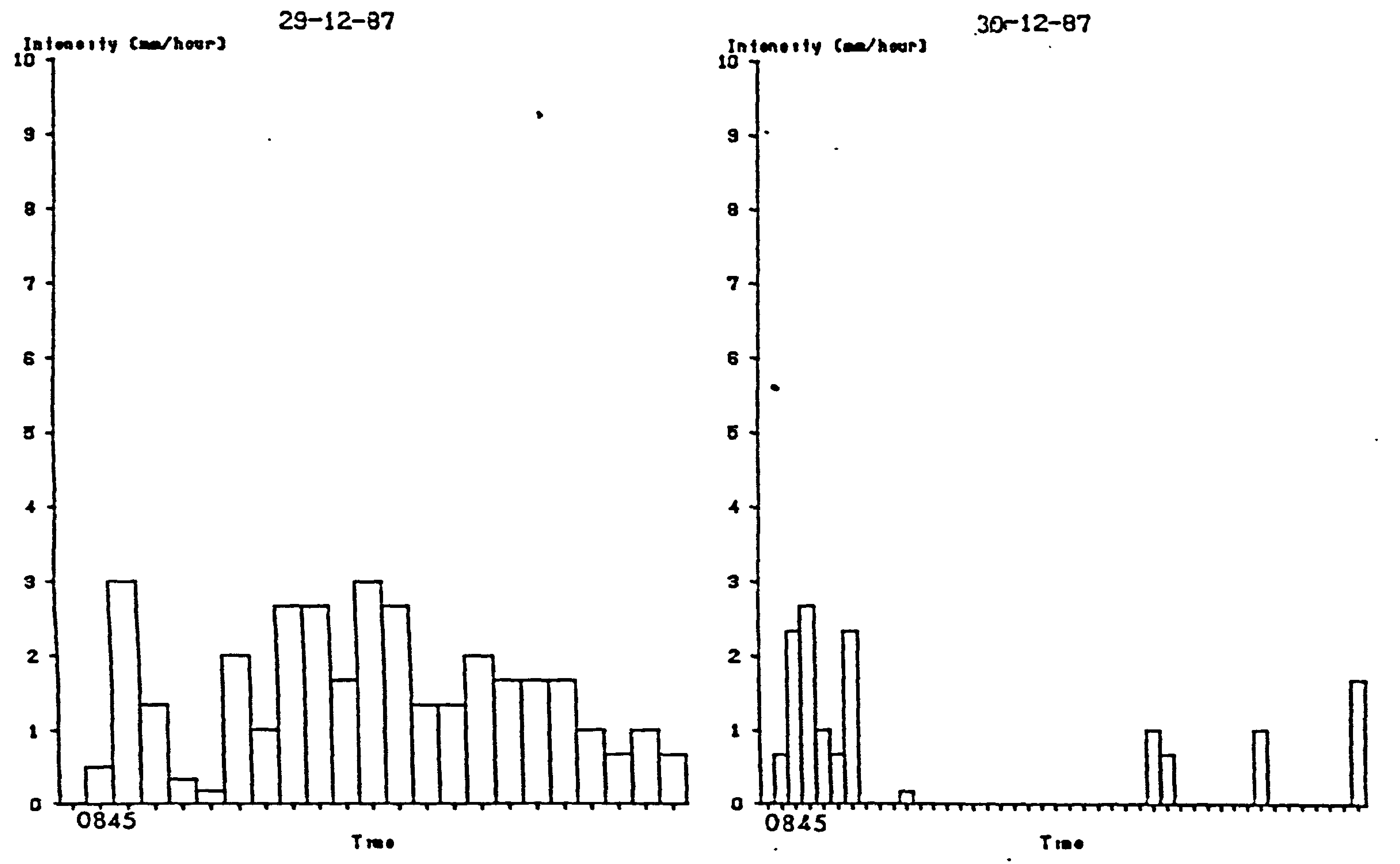


FIG. 6·9 RAINFALL INTENSITY OVER HALF HOUR PERIODS

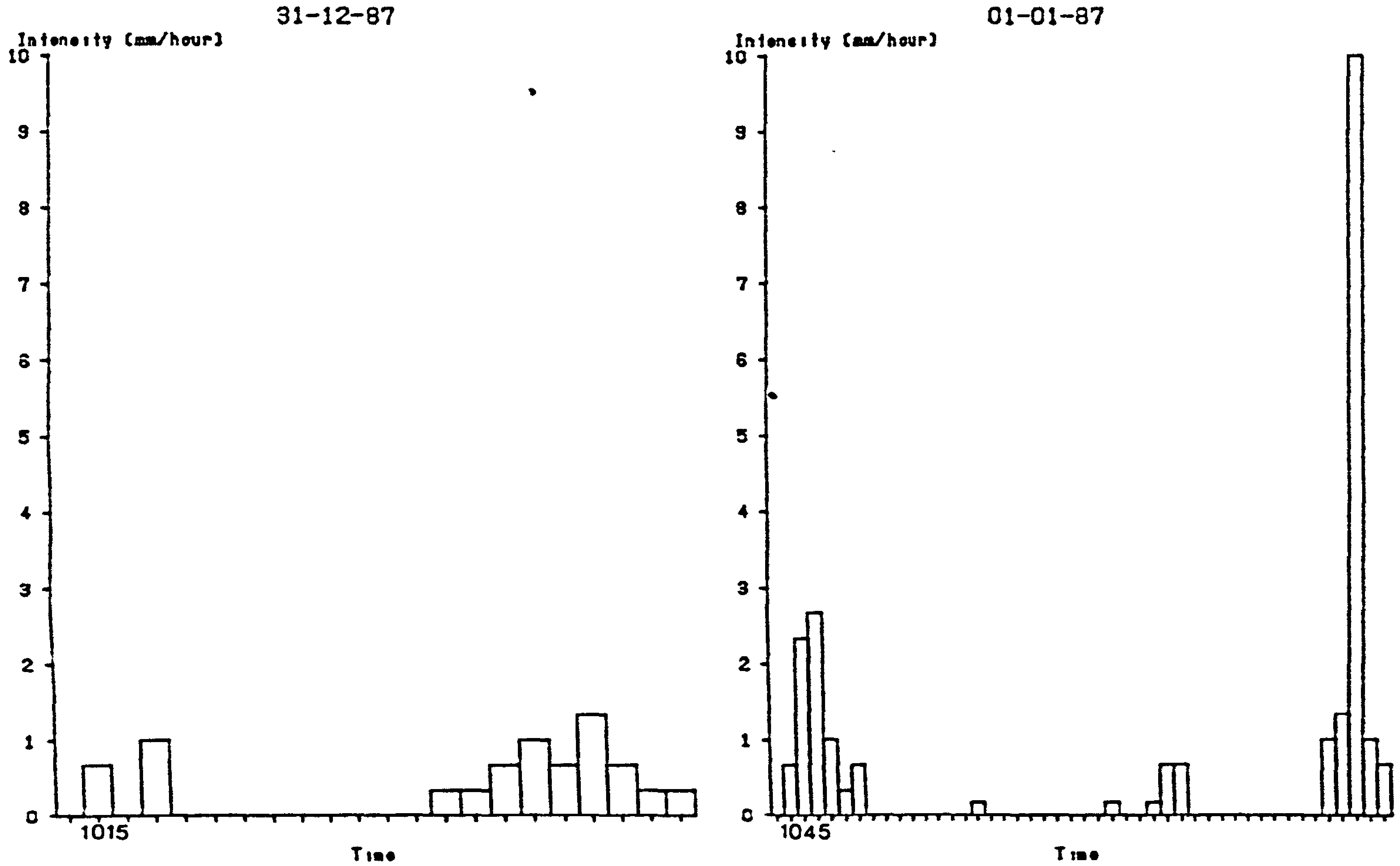


FIG. 6·10 RAINFALL INTENSITY OVER HALF HOUR PERIODS

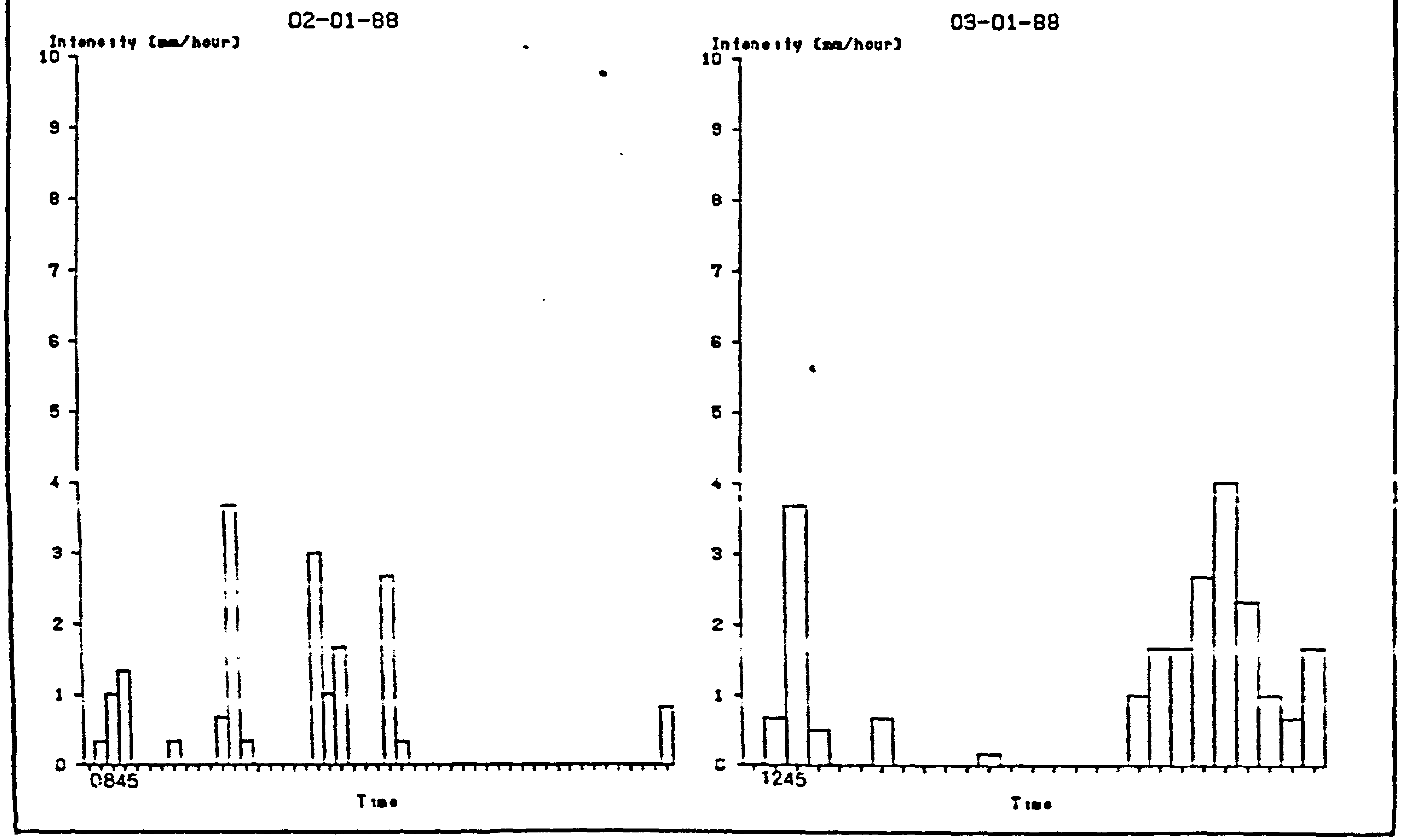


FIG.6.11 RAINFALL INTENSITY OVER HALF HOUR PERIODS

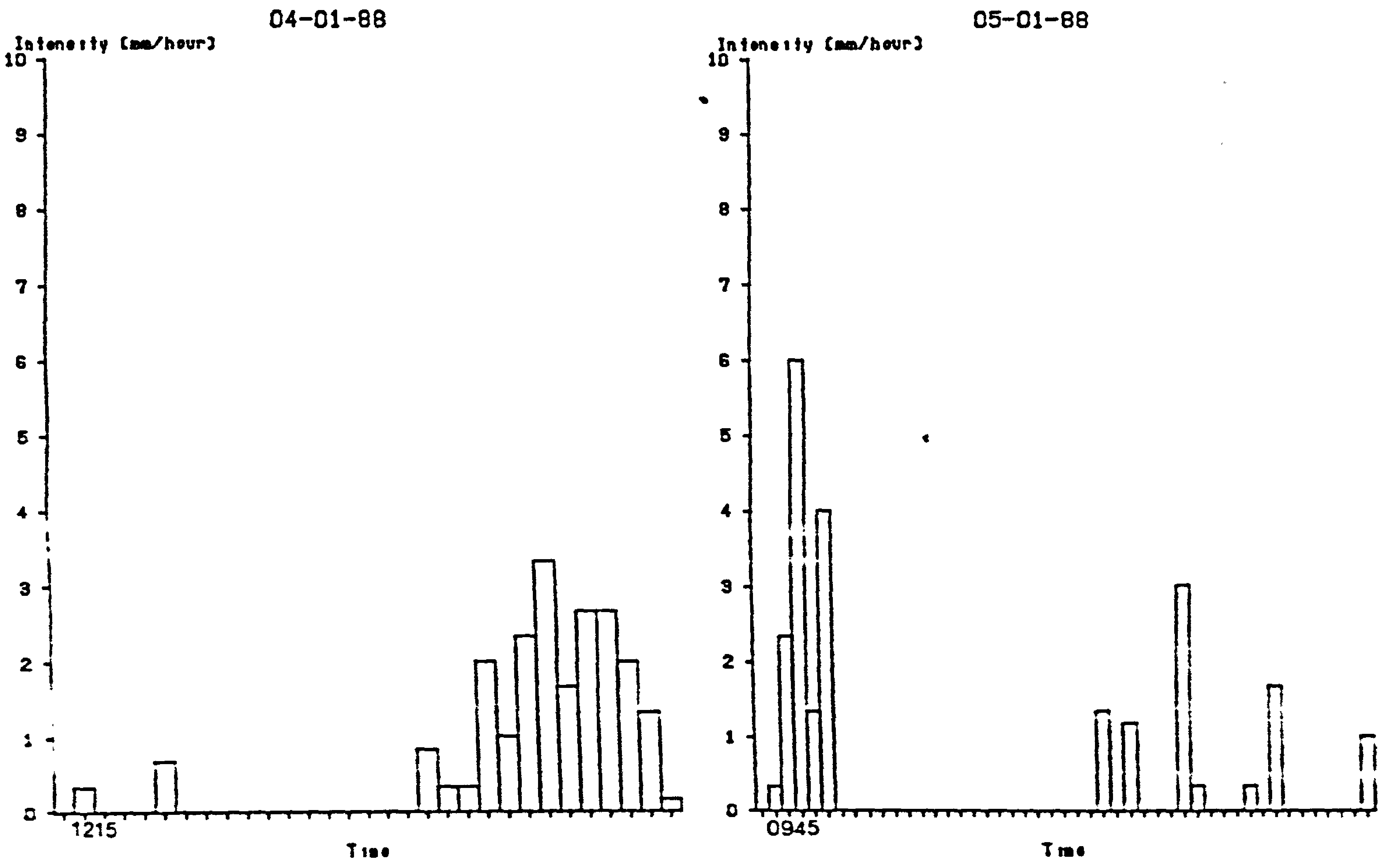
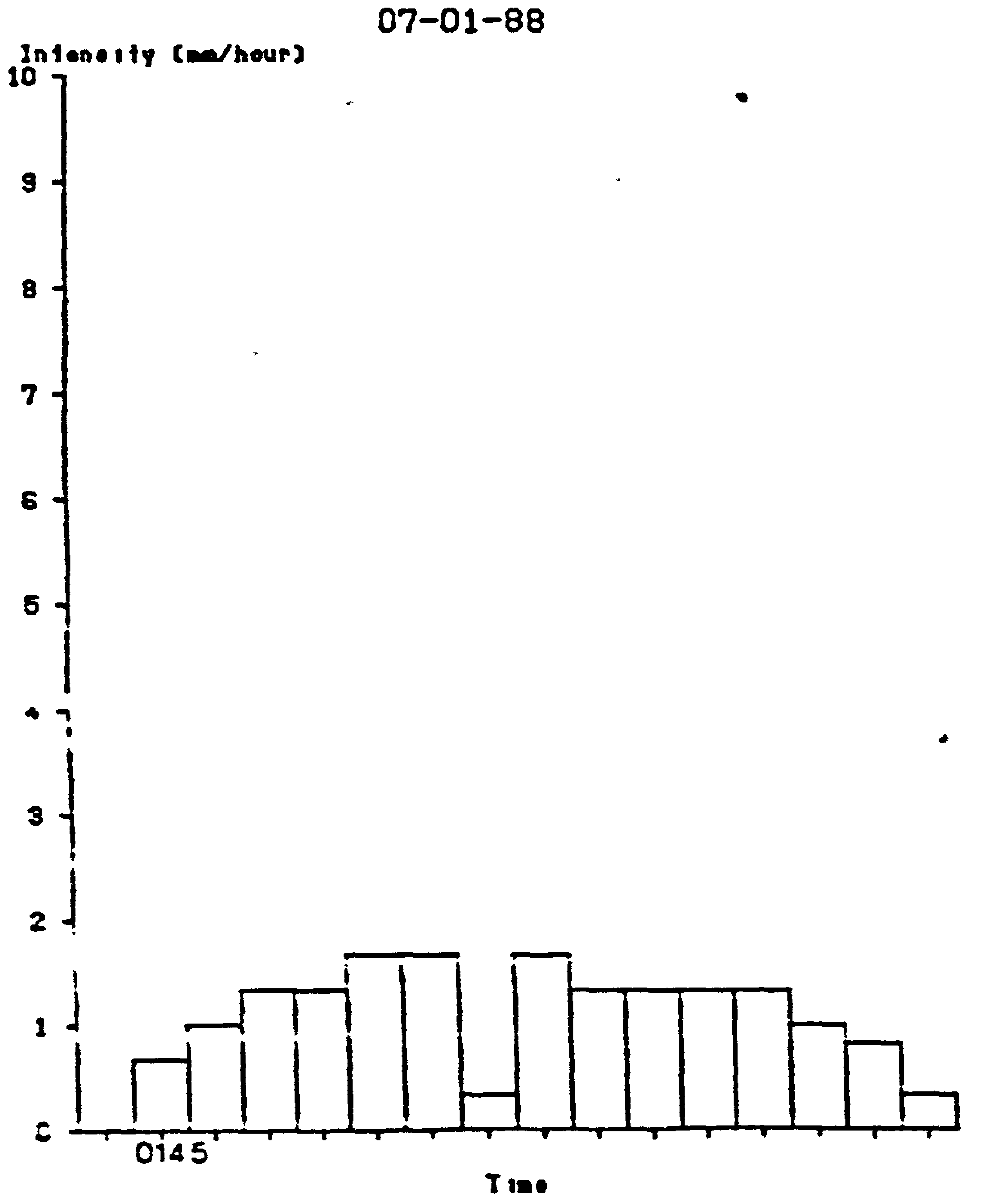


FIG.6·12 RAINFALL INTENSITY OVER HALF HOUR PERIODS



half hour intensity of rainfall. Table XIV shows the maximum half hour intensity for each storm.

6.6 INFILTRATION CAPACITY:

Infiltration capacity was calculated from the measurements obtained in the upper and lower parts of each plots using the constant head infiltrometer. Graphs (Figures 6.13a,b; 6.14a,b; 6.15a,b; 6.16a,b) show the differences from plot to plot and from lower part to upper part of the plot. This variation is possibly due to the soil texture, the position of the slope, land use cover, litter cover, soil thickness, slope steepness and the permeability of the soil. These factors will be discussed later.

6.7 OVERLAND FLOW:

Overland flow generated by the thirteen rainfall events varied from land use to land use, and from plot to plot. Table XV shows the total overland flow volume generated by each rainfall event on each plot. Plot 6 produced the highest total of 10748 ml. Factors which may influence this include land use, soil texture, slope angle, total rainfall, intensity of rainfall and infiltration capacity. The intensity of rainfall is similar on all plots. Therefore some other factors must be responsible for its higher runoff. This is probably due to the low infiltration capacity of the lower part of the plot (Fig. 6.14b). Furthermore, most parts of this plot are covered with litter because, at that time, the kale crop dropped many leaves on the ground leaving

FIG.6.13 INFILTRATION FOR PLOT1 PLOT2 PLOT3 (UPPER)

INFILTRATION FOR PLOT1 PLOT2 PLOT3 (LOWER)

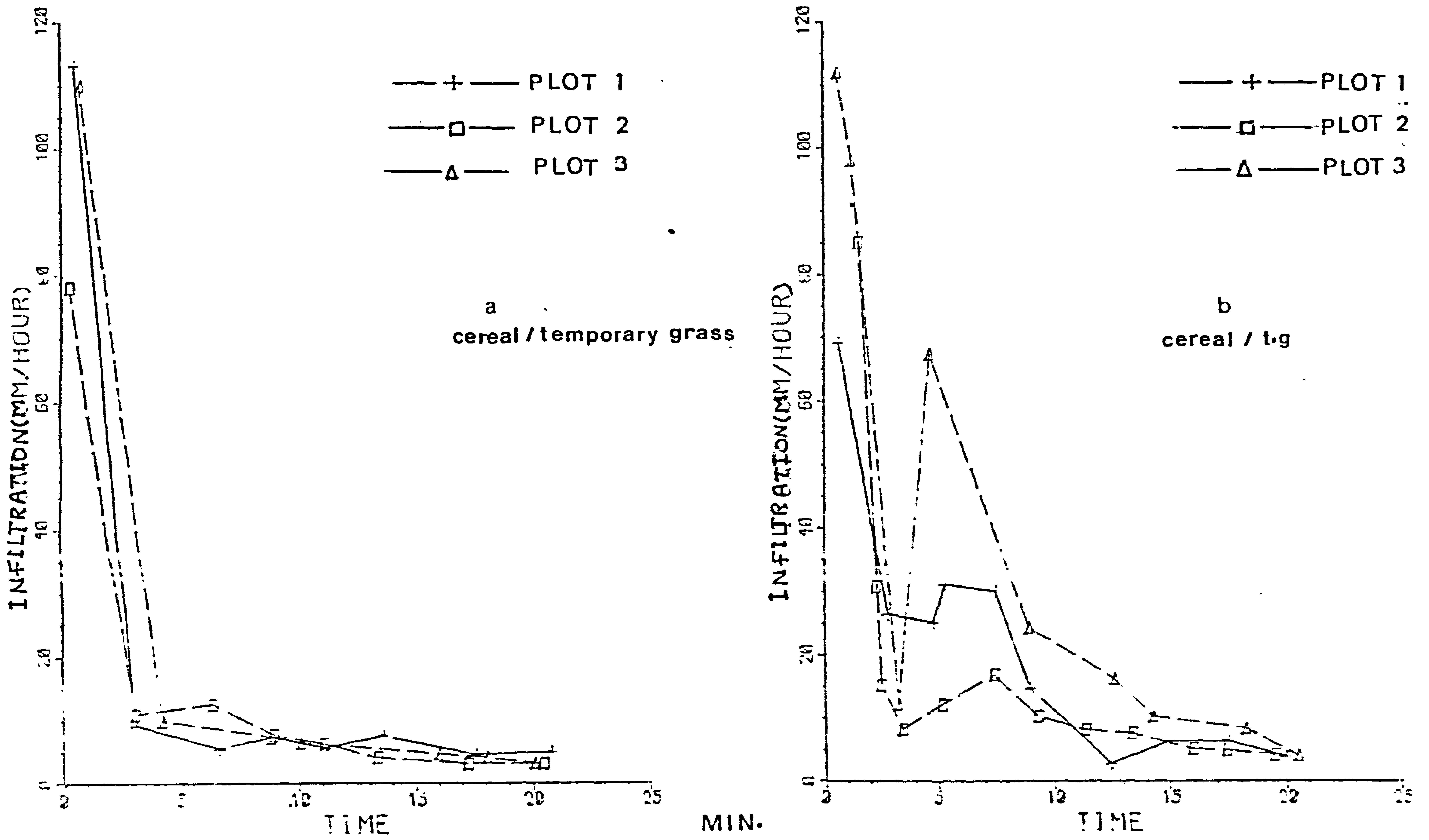
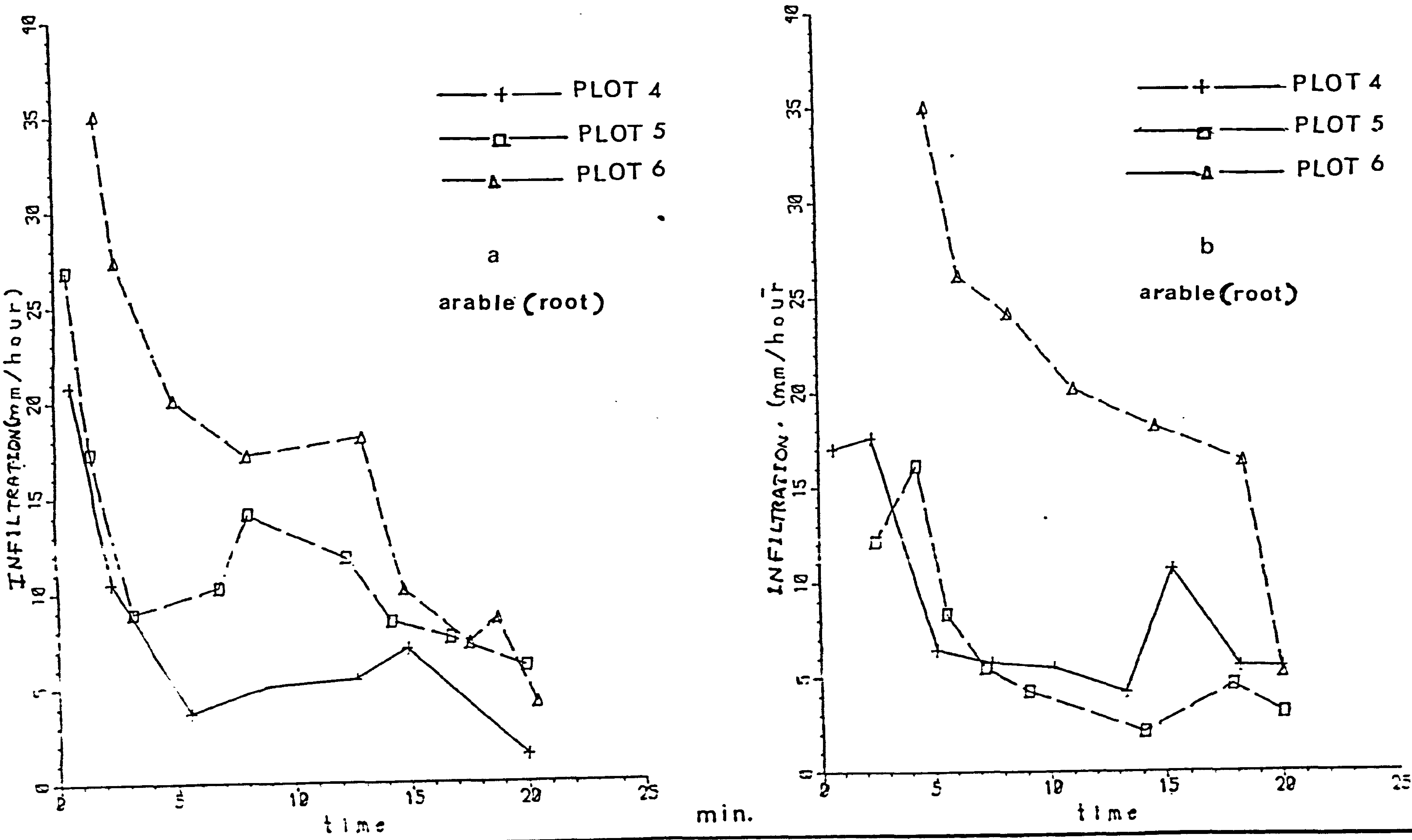


FIG.6.14 infiltration for plot4 plot5 plot6 (upper)



infiltration for plot4 plot5 plot6 (lower)

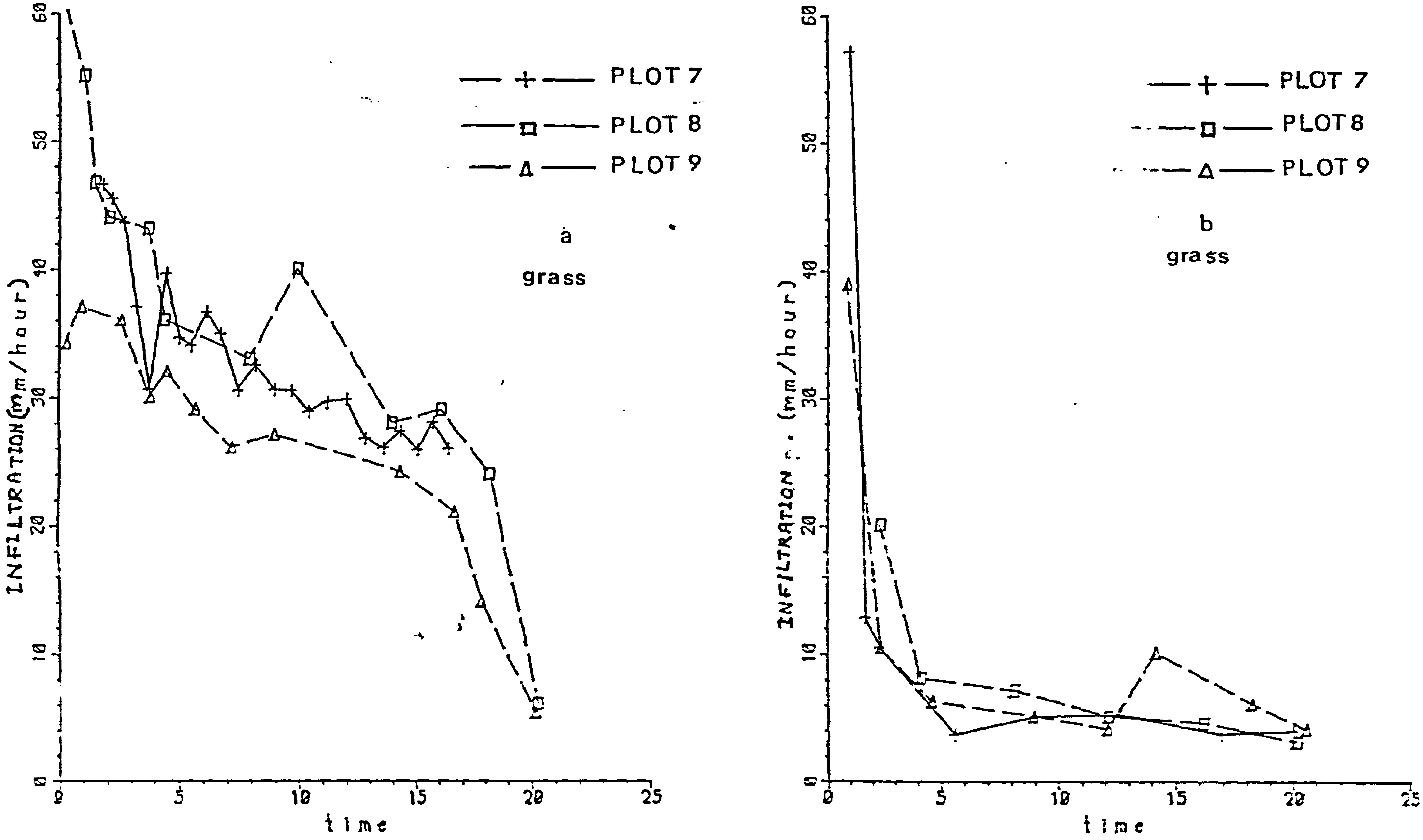
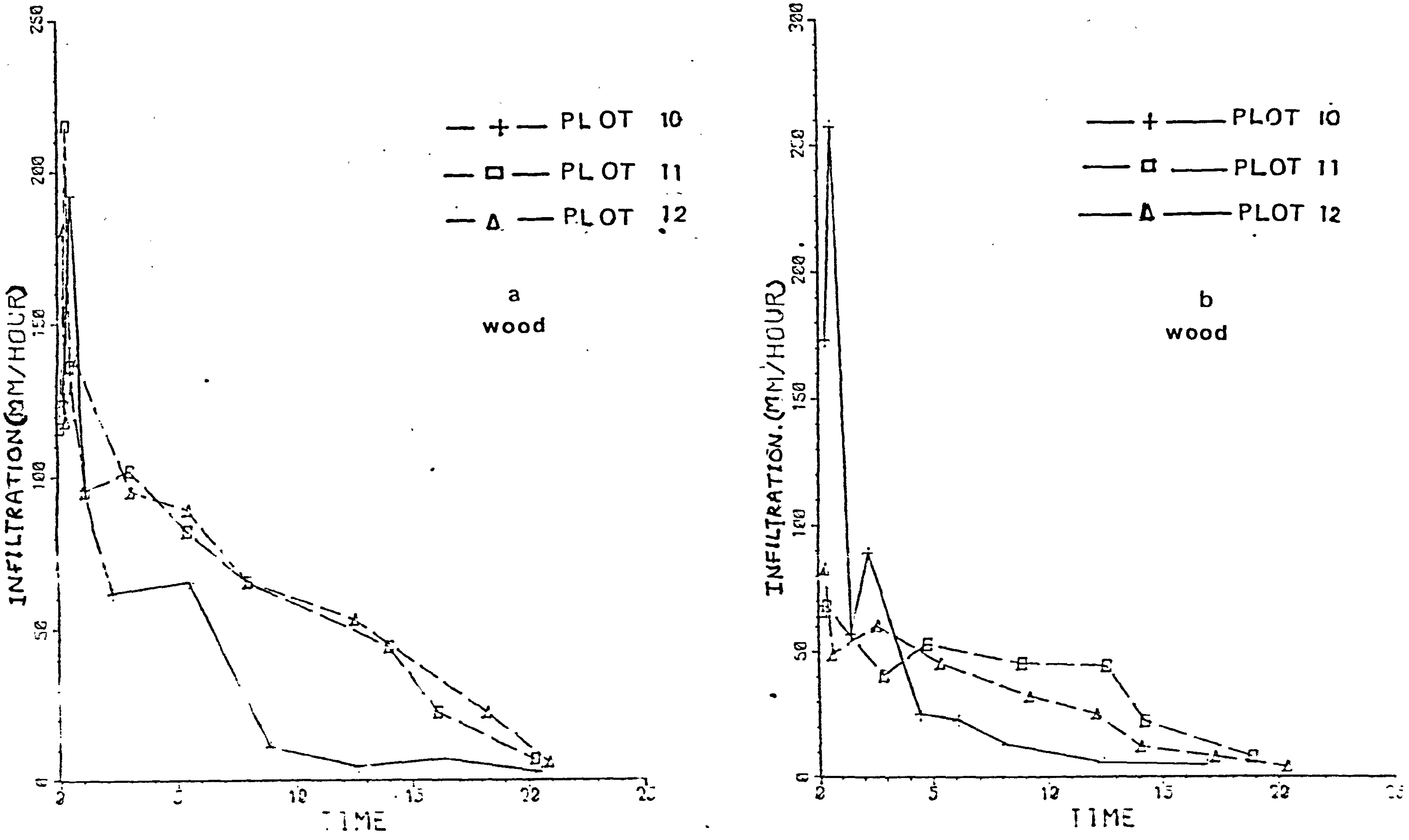


FIG.6-15 Infiltration for plot7 plot8 plot9 (upper)

Infiltration for plot7 plot8 plot9 (lower)

FIG.6.16 INFILTRATION FOR PLOT10 PLOT11 PLOT12 (UPPER)

INFILTRATION FOR PLOT10 PLOT11 PLOT12 (LOWER)



little bare soil. Therefore the total overland flow volume is high. This seems to reflect the "roof- shingle effect" of the litter cover in generating immediate overland flow as observed by Kessel (1977) on forested slopes in Guyana and Peh Chang Hock (1980) in a tropical rainforest lowland in Malaysia. Plot 11 produced 1876 ml total overland flow, lower than that produced from any other plot. This is probably due to the high infiltration capacity although the slope is steeper (12^0) than other plots. Plot 1 and 3 produced similar total overland flow, 9416 ml and 9427 ml respectively, whereas plot 2 from similar land use produced 4571 ml although the infiltration capacity for the upper part of these three plots is similar. In plot 2, the lower part has higher infiltration capacity than in plots 1 and 3. Therefore, the lower part of plot 2 allows more infiltration and produces less total overland flow than plots 1 and 3 (Fig. 6.13). Here the position on the slope is possibly responsible for the total overland flow. These three plots were covered by temporary grass during the study period though they were previously under cereals. Plots 4 and 5 which are kale plots produced less overland flow than plot 6 although it has the same land use. High infiltration capacity in the upper and lower parts of the plot may be the reason for lower overland flow in plot 5 and instrument disturbance in plot 4. Plots 7,8 and 9 produced similar, intermediate totals of overland flow. Here the infiltration capacity influenced the total overland flow, because the upper part of all three plots have higher infiltration capacity than the lower part as expected in plot 9 which is texturally a loamy sand and more permeable. Although plots 10,11 and 12 are in woodland, there are differences in the measured overland flow (Table XV). This is probably due to the variations in infiltration capacity and position of the plot: i.e. because infiltration capacity is higher in the upper part of plots 11 and 12 than in plot 10 (Fig. 6.16a) Therefore, infiltration capacity appears to be a major factor influencing the total overland flow production. This will be tested for a major storm at the end of this chapter.

Rainfall intensity may be another factor affecting overland flow. Maximum half hour intensity is 10mm for the 8th event and 6mm for 12th event but plots 1,2,3 and 9 produced more overland flow during 12th event (6mm) than 8th event (10). Therefore some other factors also must be involved other than the maximum half hour intensity in these plots. However Table XV shows that during the higher maximum half hour intensity (i.e. events 8,9,10,11,12), overland flow also increases accordingly in most of the plots. Therefore maximum half hour intensity is also one of the factors responsible for the variation in overland flow during storm events. The temporal variations of overland flow volumes per unit area at each plot were found to be significantly correlated with rainfall. Table XVI shows that there is a positive and generally high correlation between rainfall and overland flow (significant at 0.01 level).

TABLE: XV

TOTAL OVERLAND FLOW IN THE PLOTS PER UNIT AREA(ml/2m^2)

RAINFALL EVENTS	PLOTS											
	CEREAL /T.G			ARABLE(ROOT)			GRASS			WOOD		
	1	2	3	4	5	6	7	8	9	10	11	12
1	16	48	78	23	88	92	47	23	26	10	16	16
2	52	105	275	04*	110	130	205	41	59	34	45	52
3	15	32	56	15*	72	76	45	20	21	44	22	15
4	87	185	970	50*	156	276	980	118	80	700	85	87
5	1100	330	680	235*	415	580	865	1800	590	638	188	100
6	565	109	290	20*	125	205	162	60	24	96	34	96
7	20	52	90	34*	96	105	60	34	40	22	24	20
8	1825	655	1920	1425	425	1750	1200	1855	1803	1200	382	825
9	205	355	267	255	155	930	420	230	340	330	125	205
10	1905	125	351	432	279	1839	410	389	90	145	110	905
11	1326	315	>2000	1034	220	>2000	400	>2000	>2000	710	210	326
12	>2000	>2000	>2000	111*	1665	1665	600	800	>2000	1200	185	200
13	300	260	450	400	166	1100	635	75	>2000	450	450	300
TOTAL	9416	4571	9427	4038	3972	10748	6029	7445	5948	5579	1876	3146

* Instrumental problem (Trough has been disturbed)

The percentages of rainfall recorded as overland flow in each plot after each rainfall event are shown in Table XVII.

Table XV shows that plot 11 had the least overland flow during most of the rainfall events as expected due to its high infiltration capacity i.e >50 mm/hour (see fig. 6.16a,b). Plots 3,6,and 7 had the greatest overland flow proportions. Table XV shows that plot 3 had the maximum mean overland flow during the rainfall events. This may be due to the soil texture, which is silty loam, having low infiltration capacity. Although plots 6 and 7 also have the same soil texture condition, as mentioned earlier, plot 6 was influenced by litter cover, and the lower part of plot 7 hadlow infiltration capacity (Fig. 6.15). Also plot 7 may be influenced by its slope angle (10^0) to some extent.

In general, the fourth rainfall event produced relatively high overland flow (runoff) from plots 3 and 7, and the second rainfall event produced high overland flow from plot 10 (Table XV). This must have increased the mean overland flow as percentage of rainfall (Table XVII). Here a slight increase in rainfall is followed by a marked increase in runoff. Therefore, the correlation is relatively low between rainfall and overland flow for plots 3,7 and 10 (Table XVI). All this evidence shows the influence of factors such as slope, litter cover and land use.

6.8 SEDIMENT MOVEMENT:

TABLE: XVI

SPEARMAN RANK CORRELATION BETWEEN THE FACTORS (AMOUNT OF RAINFALL AND RUNOFF, SEDIMENT VOLUME, SEDIMENT CONCENTRA TION; RUNOFF AND SEDIMENT CONCENTRATION, SEDIMENT VOLUME

PLOTS		AMOUNT OF RAIN FALL AND RUNOFF	AMOUNT OF RAIN FALL AND SEDIMENT VOLUME	AMOIUNT OF RAIN FALL AND SEDIMENT CONCEN.	RUNOFF AND SEDIMENT CONCENTRA - TION	RUNOFF AND SEDIMENT VOLUME
C	1	0.8638**	0.8556**	0.8609**	0.7730**	0.7747**
	2	0.7538**	0.6162*	0.6162*	0.5824*	0.5824*
	3	0.5950*	0.5669*	0.5283*	0.5959*	0.6152*
A	4	0.6933**	0.4743	0.5959*	0.6869**	0.5824*
	5	0.8473**	0.6465*	0.6718**	0.8105**	0.7967**
	6	0.7455**	0.7766**	0.7766**	0.7741**	0.7741**
G	7	0.4979*	0.3384	0.3384	0.4011	0.4011
	8	0.7978**	0.6212*	0.7434**	0.6777**	0.5915*
	9	0.6999**	0.7895**	0.8748**	0.6630**	0.3867
W	10	0.5840*	0.8226**	0.8292**	0.7824**	0.7840**
	11	0.6713**	0.5612*	0.6226*	0.6575**	0.4725
	12	0.7373**	0.5942*	0.6717**	0.4419	0.5110*

r 0.05 one tail = 0.4835*   (n = 13)
r 0.01 one tail = 0.6484**
C= cereal/ temporary grass,   G= grass
A= arable(root),   W= wood

TABLE: XVII

OVERLAND FLOW AS PERCENTAGE OF RAINFALL FOR EACH PLOT

RAINFALL EVENTS	P	L	O	T	S							
	CEREAL/ T.G			ARABLE(ROOT)			GRASS			WOOD		
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.29	0.86	1.39	0.41	1.57	1.64	0.84	0.41	1.23	1.29	0.65	0.29
2	1.08	2.19	5.73	0.08	2.29	2.71	4.27	0.85	0.62	20.59	2.50	1.08
3	0.44	0.94	1.65	0.44	2.12	2.24	1.32	0.59	2.35	1.74	0.51	0.44
4	2.56	5.44	28.53	1.47	4.59	8.12	28.82	3.47	1.61	0.60	0.21	2.56
5	3.01	0.90	1.86	0.64	1.13	1.58	2.36	4.92	0.15	0.33	0.36	0.27
6	3.53	0.68	1.81	0.13	0.78	1.28	1.01	0.38	0.61	5.22	1.66	0.60
7	0.30	0.79	1.36	0.52	1.45	1.59	0.91	0.52	7.84	1.81	0.69	0.30
8	7.93	2.85	8.35	6.20	1.85	7.61	5.22	8.07	1.87	0.61	0.47	3.50
9	1.13	1.95	1.47	1.40	0.85	5.11	2.31	1.26	0.38	3.23	0.95	1.13
10	8.07	0.53	1.49	1.83	1.18	7.79	1.74	1.65	9.09	4.62	0.71	3.83
11	6.03	1.43	>9.09	4.70	1.00	>9.09	1.82	>3.08	>11.11	2.50	2.50	1.48
12	>7.69	>7.69	>7.00	0.43	6.40	6.41	2.31	0.42	>0.18	0.29	0.45	0.77
13	1.67	1.44	2.50	2.22	0.92	6.11	3.53	0.46	>0.71	0.94	0.63	1.67
MEAN	3.36	2.13	5.56	1.57	2.01	4.71	4.71	4.34	2.90	3.37	0.95	1.38

> 2 Litre bottle overflowed.

The amount of sediment transported by overland flow on the plots varied considerably between plots and events. Table XVIII shows the volume of sediment produced from the plots for each event. Plot 1 registered the greatest amount of sediment movement, followed by plots 10,7,6,4,3,9,2 and 5. Insignificant amounts were measured from plots 8,11 and 12.

Table XIX shows the volumes of sediment which were transported as cumulative form and Fig. 6.17 shows the data presented as cumulative curves.

Except plot 4 there was only a small amount of soil loss in all the plots during the first seven rainfall events, although 18.3mm rainfall occurred in the 5th event only the arable plot (plot 4) responded for the higher rainfall: Evans (1984) suggested intense storms of 10mm or more can cause erosion. During the 8th rainfall event all the plots showed an increase in the amount of soil loss. In plot 10, which was covered by woodland on a slope angle of 12^0 during the 8^{th} rainfall event (11.5mm rainfall), a fallen tree which would bring soil up around its base was noticed. This is possibly a cause for more sediment volume. Plot 1 had the greatest amount of soil loss, about twice that in plot 4 and 6. Plot 4 and 6 was covered by kale whereas plot 1 was ploughed for cereals and left for temporary grass.

In plot 7, some parts of the plot were disturbed by cattle during the study period. This disturbance occurred after the 4th storm and the soil was exposed to erosion during the next big storm. Therefore plot 7, although it

FIG. 6-17 Volume of sediment presented as cumulative form

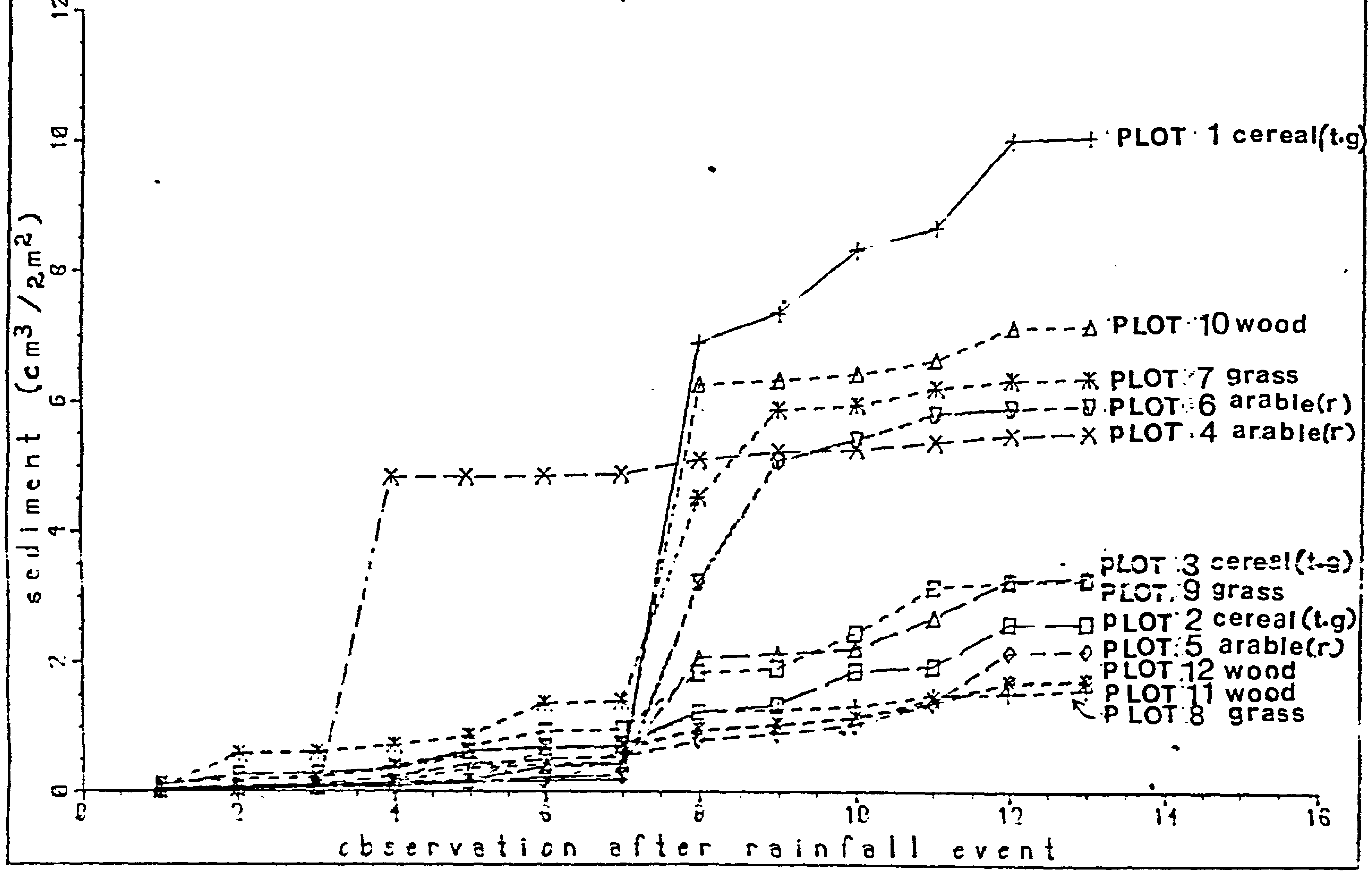


TABLE: XVIII

VOLUME OF SEDIMENT FOR EACH PLOT (CM^3)

RAINFALL EVENTS	SEDIMENT VOLUME											
	CEREAL/T.G			ARABLE(ROOT)			GRASS			WOOD		
	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5	PLOT 6	PLOT 7	PLOT 8	PLOT 9	PLOT 10	PLOT 11	PLOT 12
1	0.0379	0.0963	0.0496	0.0396	0.0377	0.0241	0.0530	0.0242	0.0591	0.0235	0.1122	0.1211
2	0.0120	0.1573	0.0117	0.0040	0.0408	0.0120	0.5275	0.0157	0.0216	0.0405	0.0769	0.0654
3	0.0163	0.0202	0.0176	0.0261	0.0270	0.0248	0.0252	0.0252	0.0288	0.0159	0.0285	0.0158
4	0.0137	0.0860	0.0498	4.7826	0.1257	0.0217	0.1133	0.0151	0.0137	0.0543	0.1755	0.1544
5	0.0572	0.2673	0.0384	0.0119	0.2009	0.0687	0.1440	0.0739	0.5827	0.2296	0.2348	0.2112
6	0.0200	0.0632	0.2260	0.0133	0.0741	0.0686	0.5084	0.5117	0.2308	0.0609	0.0474	0.0523
7	0.0352	0.0387	0.0387	0.0284	0.0392	0.0391	0.0396	0.0339	0.0370	0.0387	0.0390	0.0326
8	6.7205	0.5169	1.6459	0.2136	0.2693	2.9834	3.1380	0.5421	0.8741	5.8155	0.2522	0.3253
9	0.4597	0.1115	0.0608	0.1261	0.1002	1.8663	1.3434	0.0465	0.0663	0.0653	0.0787	0.0716
10	0.9811	0.5085	0.0746	0.0333	0.1238	0.3272	0.0735	0.0438	0.5421	0.0982	0.1057	0.0897
11	0.3424	0.0764	0.4827	0.1113	0.3451	0.4022	0.2602	0.1667	0.7048	0.2216	0.2935	0.2432
12	1.3461	0.6538	0.5750	0.1055	0.7795	0.0768	0.1174	0.0328	0.0841	0.4948	0.2404	0.3215
13	0.0439	0.0175	0.0348	0.0363	0.0266	0.0487	0.0335	0.0591	0.0235	0.0274	0.0361	0.0332
TOTAL	10.0860	2.6136	3.3056	5.5320	2.1899	5.9636	6.3771	1.5907	3.2696	7.1862	1.7209	1.7373

TABLE: XIX

VOLUME OF SEDIMENT PRESENTED AS CUMULATIVE FORM $(cm^3/2m^2)$

RAINFALL EVENTS	VOLUME OF SEDIMENT											
	CEREAL/T.G			ARABLE(ROOT)			GRASS			WOOD		
	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5	PLOT 6	PLOT 7	PLOT 8	PLOT 9	PLOT 10	PLOT 11	PLOT 12
1	0.0379	0.0963	0.0496	0.0396	0.0377	0.0241	0.0531	0.0242	0.0591	0.0235	0.1122	0.1211
2	0.0499	0.2536	0.0613	0.0436	0.0785	0.0361	0.5806	0.0399	0.0807	0.0640	0.1891	0.1865
3	0.0662	0.2738	0.0789	0.0697	0.1055	0.0609	0.6058	0.0651	0.1095	0.0799	0.2176	0.2023
4	0.0799	0.3598	0.1287	4.8523	0.2312	0.0826	0.7191	0.0802	0.1232	0.1342	0.3931	0.3567
5	0.1371	0.6271	0.1671	4.8642	0.4321	0.1513	0.8631	0.1541	0.7069	0.3638	0.6279	0.5679
6	0.1571	0.6903	0.3931	4.8775	0.5062	0.2199	1.3715	0.6658	0.9377	0.4247	0.6753	0.6202
7	0.1923	0.7290	0.4318	4.9059	0.5454	0.2590	1.4111	0.6997	0.9747	0.4634	0.7143	0.6528
8	6.9128	1.2459	2.0777	5.1195	0.8147	3.2424	4.5491	1.2418	1.8488	6.2789	0.9665	0.9781
9	7.3725	1.3574	2.1385	5.2456	0.9149	5.1087	5.8925	1.2883	1.9151	6.3442	1.0452	1.0497
10	8.3536	1.8659	2.2131	5.2789	1.0387	5.4359	5.9660	1.3321	2.4572	6.4424	1.1509	1.1394
11	8.6960	1.9423	2.6958	5.3902	1.3838	5.8381	6.2262	1.4988	3.1620	6.6640	1.4444	1.3826
12	10.0421	2.5961	3.2708	5.4957	2.1633	5.9149	6.3436	1.5316	3.2461	7.1588	1.6848	1.7041
13	10.0860	2.6136	3.3056	5.5320	2.1899	5.9636	6.3771	1.5907	3.2696	7.1862	1.7209	1.7373

is permanent grass, produced three times that in plots 2 and 5 which are cereal and arable plots.

Ploughed areas such as the arable and cereal /temporary grass areas like plots 1, 4, and 6 produced more erosion than the permanent grass and woodland areas like plots 8,9,11 and 12 under normal circumstances.

Correlation coefficents between rainfall amount and sediment concentration are high (0.6 to 0.8) in plots 1,5,6,8,9,10 and 12. In the plots 2,3,4, and 11, when rainfall increases sediment also increases but the relationship is less consistent (0.5 to 0.6) (Table XVI). Except for plot 12, the correlation coefficients between overland flow and sediment concentration are similar to correlation coefficients of rainfall and sediment concentration in plots 1,5,6,8,9 and 10 (Table XVI). This is obvious, because when rainfall increases, runoff also usually increases. Table XVI shows significant positive correlation between rainfall and runoff. Under same conditions, correlations between amount of rainfall and runoff and between runoff and sediment concentration are greater in arable (root), and cereal land use plots than the grass and woodland land use plots (Table XVI).

6.9 PHOSPHORUS CONCENTRATION IN THE PLOT SOILS:

Data for the water-soluble phosphorus concentration and exchangeable phosphorus concentration in the soil of the plots are presented in Table XX. Permanent grass plots provided the highest exchangeable phosphorus concentration followed by arable plots, cereal/temporary grass plots and woodland plots. In the bottom sediment from the stream which is downstream of the each land-use area, exchangeable phosphorus concentration is greater in bed sediment downstream of the arable field than the downstream of the grassland field (Table XXI). This is due to erosion in ploughed areas, and possibly due to the fertilizer application. Water-soluble phosphorus concentration does not show much variation in cereal, arable and grass areas.

There are always slightly lower PO_4-P concentrations in the woodland plots (0.04ppm) than the other land-use plots (0.6 to 0.8ppm). Table XXI shows that exchangeable phosphorus concentration is always higher than water soluble in bed sediments (i.e 13.10 for cereal/t.g, 15.11 for arable (root), 10.36 for grass and 4.19 for woodland).

6.10 PHOSPHORUS IN RUNOFF AND ERODED SEDIMENT:

Soluble phosphorus concentration in runoff water and exchangeable phosphorus concentration in eroded sediment were analyzed. The results are presented in Tables XXII, XXIII. The mean soluble phosphorus concentration in water and mean exchangeable phosphorus concentration in sediment were relatively higher in arable plots than in other plots and relatively low in woodland plots. Cereal (temporary grass) and grass plots provided similar amounts of exchangeable phosphorus. During the study period cattle were grazing on both land uses. This may be a cause for the similar phosphorus concentrations.

The mean exchangeable phosphorus concentrations for all twelve plots are presented in Fig. 6.18 which shows

TABLE: XX

WATER SOLUBLE AND EXCHANGEABLE [PO_4-P] (ppm) IN THE SOILS OF DIFFERENT LAND USE

Plot	Landuse	Water soluble [PO_4-P]	Exchangeable [PO_4^--P]
1	Cereal/(T.G)	0.21	26.1
2	Cereal/(T.G)	0.66	25.4
3	Cereal/(T.G)	0.32	22.6
4	Arable	0.46	33.7
5	Arable	0.62	32.8
6	Arable	0.51	26.9
7	Grass	0.45	46.4
8	Grass	0.52	37.8
9	Grass	0.57	46.2
10	Woodland	0.04	11.5
11	Woodland	0.03	12.7
12	Woodland	0.05	11.0

TABLE: XXI

WATER SOLUBLE AND EXCHANGEABLE [PO_4-P] (ppm) IN STREAM BED SEDIMENT FOR FOUR LAND USE FIELDS.

Landuse Field	Water Soluble [PO_4^--P]	Exchangeable [PO_4^--P]
Cereal/T.G	0.6	13.10
Arable	0.8	15.11
Grass	0.6	10.36
Wood	0.04	4.19

TABLE: XXII

[PO_4-P] (mg/l in solution) IN RUNOFF WATER FROM PLOTS

LAND USE	CEREAL/T.G			ARABLE(ROOT)			GRASS			WOOD		
Rainfall Events	PLOT 1	PLOT 2	PLOT 3	PLOT 4	PLOT 5	PLOT 6	PLOT 7	PLOT 8	PLOT 9	PLOT 10	PLOT 11	PLOT 12
	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P	PO_4-P
1	0.03	0.02	0.03	0.02	0.04	0.05	0.04	0.02	0.02	0.01	0.02	0.04
2	0.04	0.02	0.03	0.08	0.05	0.02	0.04	0.03	0.03	0.02	0.02	0.01
3	0.02	0.04	0.04	0.03	0.04	0.03	0.04	0.06	0.04	0.02	0.02	0.03
4	0.04	0.05	0.06	0.07	0.04	0.04	0.04	0.04	0.04	0.02	0.03	0.04
5	0.04	0.04	0.03	0.03	0.05	0.03	0.04	0.03	0.02	0.04	0.03	0.02
6	0.03	0.04	0.02	0.08	0.06	0.13	0.04	0.03	0.02	0.02	0.02	0.04
7	0.02	0.05	0.05	0.05	0.05	0.08	0.03	0.04	0.03	0.01	0.02	0.03
8	0.04	0.02	0.02	0.05	0.04	0.06	0.05	0.04	0.02	0.03	0.03	0.02
9	0.05	0.03	0.03	0.04	0.03	0.05	0.02	0.05	0.10	0.02	0.03	0.03
10	0.01	0.03	0.04	0.05	0.01	0.21	0.01	0.06	0.04	0.03	0.04	0.02
11	0.03	0.04	0.05	0.03	0.08	0.08	0.03	0.04	0.03	0.02	0.02	0.01
12	0.02	0.02	0.03	0.05	0.03	0.04	0.04	0.03	0.05	0.03	0.03	0.02
13	0.03	0.04	0.04	0.03	0.05	0.04	0.03	0.02	0.05	0.04	0.02	0.02
MEAN	0.031	0.034	0.036	0.045	0.044	0.066	0.035	0.038	0.038	0.024	0.025	0.025

TABLE XXIII

[PO_4-P] (ppm) IN ERODED SEDIMENT FROM PLOTS

Landuse		Cereal/T.G			Arable			Permanent Grass			Woodland		
Date	Rainfall Events	Plot 1	Plot 2	Plot3	Plot 4	Plot5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot11	Plot12
24 Dec.87	1	54.1	72.4	106.2	108.7	125.5	147.1	50.7	106.9	20.2	41.7	30.2	11.3
26 Dec.87	2	19.3	27.5	38.1	44.5	42.4	152.6	27.6	8.0	60.4	8.4	7.2	19.3
27 Dec.87	3	10.3	22.1	19.3	62.1	48.3	69.8	30.4	34.7	41.5	21.4	26.9	22.3
28 Dec.87	4	10.7	6.8	6.8	169.3	80.7	55.0	34.3	18.2	9.1	14.9	50.2	6.7
29 Dec.87	5	18.9	40.4	18.2	28.4	41.8	19.0	44.8	35.0	29.5	7.7	15.4	6.6
30 Dec.87	6	86.3	35.5	23.8	73.5	43.6	36.2	19.1	24.2	35.4	20.7	23.3	5.0
31 Dec.87	7	49.1	42.0	36.5	68.5	71.5	56.8	46.4	38.4	38.1	8.9	15.7	8.2
1 Jan.88	8	75.6	15.3	31.2	79.6	40.1	66.2	65.7	10.0	35.7	8.8	28.4	22.6
2 Jan.88	9	57.2	75.2	65.4	93.7	61.1	79.3	72.0	25.7	27.7	12.5	23.1	40.8
3 Jan.88	10	37.7	41.2	27.5	29.5	26.2	73.9	42.5	41.9	40.6	32.8	45.1	13.4
4 Jan.88	11	45.6	21.2	47.9	48.4	76.2	69.4	35.3	9.2	62.5	16.7	41.6	18.9
5 Jan.88	12	78.2	60.8	67.3	43.0	53.8	47.6	53.2	29.8	44.3	16.7	13.5	4.1
7 Jan.88	13	51.6	56.1	34.3	44.8	53.0	50.9	29.3	39.8	42.3	28.0	30.2	32.9
MEAN		47.7	39.7	40.2	68.0	58.8	71.0	42.4	32.6	37.6	18.4	27.0	16.3

that the exchangeable phosphorus concentrations vary significantly between the three landuse plots and vary to a lesser extent within the each landuse plot.

Results of the analysis of variance in Table XXIV show that there are variations of water soluble phosphorus concentration and exchangeable phosphorus concentration between and within the twelve land use plots at different significance levels.

TABLE: XXIV
ANALYSIS OF VARIANCE FOR [PO_4-P] BETWEEN THE PLOTS

Concentration	F	df1	df2	Sig. level
Water soluble PO_4-P	2.923	11	155	0.005
Exchangeable PO_4-P	5.393	11	155	<0.0001

The total losses of PO_4-P (mg/plot) (see Table XXV) vary according to the PO_4-P concentration in the sediment and weight of sediment lost. Reasons for the variation of sediment loss in the plots have been stated earlier, when discussing the total overland flow and total sediment losses.

In order to estimate the exchangeable phosphorus in eroded sediment, the data for exchangable phosphorus are expressed as PO_4-P as percentage of sediment in Table XXVI.

Correlation between the factors such as rainfall, rainfall intensity, rainfall duration, maximum half hour period intensity runoff and sediment volume, and PO_4-P in

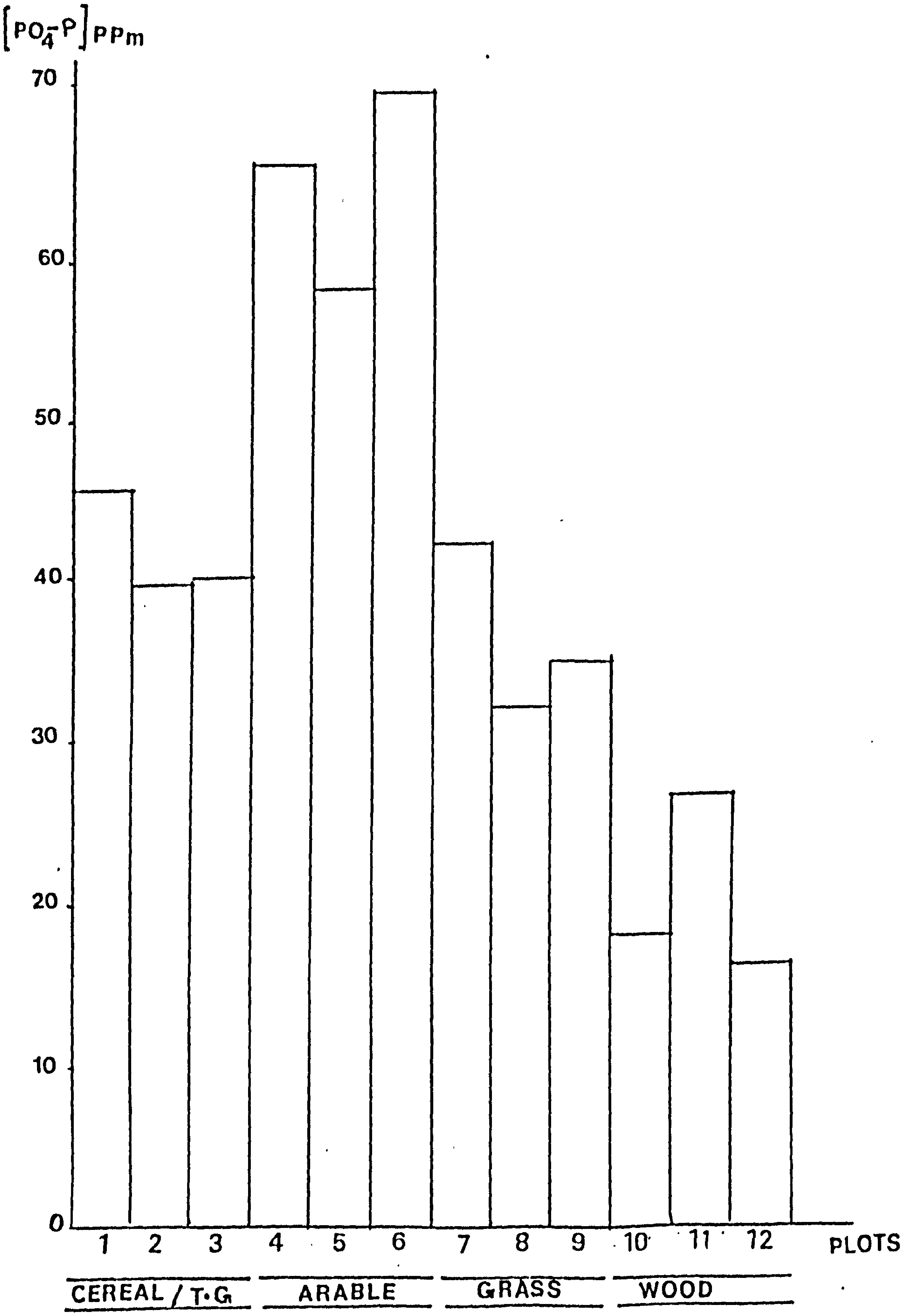


FIG.6.18 Mean exchangeable PO_4^--P concentration in sediment for plots

TABLE: XXV

LOSSES OF PO_4-P (mg/$2m^2$ plot) IN THE PLOTS

LAND USE	CEREAL/T.G			ARABLE(ROOT)			GRASS			WOOD		
	P			L			O			T		
RAINFALL EVENTS	1	2	3	4	5	6	7	8	9	10	11	12
1	0.47	1.60	1.21	0.99	1.09	0.82	0.62	0.59	2.74	0.23	0.08	0.10
2	0.05	0.99	0.10	0.004	0.42	0.42	3.34	0.03	0.30	0.08	0.13	0.05
3	0.04	0.10	0.08	0.37	0.30	0.40	0.18	0.20	0.27	0.08	0.18	0.15
4	0.03	0.13	0.08	0.19	2.33	0.27	0.89	0.06	0.03	0.19	2.03	0.13
5	0.25	2.48	0.15	0.08	0.55	0.30	1.49	0.59	1.33	0.42	0.94	0.24
6	0.40	0.52	1.24	0.23	0.74	0.57	2.24	2.85	1.88	0.23	0.27	0.08
7	0.39	0.37	0.32	0.45	0.64	0.51	0.42	0.30	0.32	0.08	0.13	0.05
8	5.19	1.82	11.80	0.96	1.97	25.46	4.74	1.25	7.18	0.51	1.74	2.11
9	6.05	1.93	0.92	2.72	1.41	24.05	2.22	0.27	0.42	0.23	0.40	1.04
10	8.51	4.82	0.47	0.23	0.75	5.56	3.19	0.42	5.07	0.80	1.04	0.23
11	3.59	0.37	5.31	21.24	16.05	6.42	2.11	0.35	10.13	1.13	3.59	1.50
12	20.21	9.15	8.90	21.04	19.64	0.80	1.44	1.14	7.18	1.13	0.88	0.16
13	0.52	0.23	0.27	0.37	0.32	0.57	0.23	0.30	0.82	0.18	0.25	0.27
TOTAL	46.43	24.51	30.85	48.87	46.19	66.19	22.83	8.35	37.42	5.29	11.66	6.11

runoff water were calculated in Table XXVII. The figures suggest that when sediment volume increases [PO_4-P] in runoff water also increases, in Plot 9, [PO_4-P] increases according to intensity of rainfall. In plot 11, except for sediment volume, other factors possitively influence for the increase of [PO_4-P] in runoff water (Table XXVII). This is probably due to the woodland leaves, as Cowen and Lee (1973) stated that leaves can act as source of phosphorus to runoff, dissolved during intense rainfall. In plot 2, there is an inverse correlation between sediment volume and [PO_4-P] in runoff water as expected.

The figures in Table XXVIII suggest that when sediment volume increases, PO_4-P concentration in sediment also increases in Plot 1 and Plot 4 as expected due to fertilizer application in arable fields. There are positive correlations between maximum rainfall in half hour periods and PO_4-P concentration in sediment in plot 1 and 7. This suggests that maximum rainfall in half hour periods is an effective factor. In plot 9, when duration of rainfall increases the [PO_4-P] in sediment also increases. In plot 4, there is an inverse correlation between rainfall and PO_4-P in sediment. Again in Plot 5, there is a inverse correlation between duration of rainfall and PO_4-P in sediment. These two plots are arable plots and therefore agriculture practice (ploughing) and fertilizer application influence the phosphorus concentration. In general except as mentioned above the correlation between the above factors and PO_4-P

TABLE: XXVI

PO_4-P WEIGHT IN SEDIMENT AS PERCENTAGE OF SEDIMENT WEIGHT FOR EACH PLOT

LAND USE	CEREAL/T.G			ARABLE(ROOT)			GRASS			WOOD		
RAINFALL EVENTS	P			L			O			T		
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5	0.7	1.1	1.1	1.2	1.4	0.5	1.0	1.9	0.5	0.3	0.3
2	0.2	0.3	0.3	0.04	0.4	1.4	0.3	0.08	0.6	0.09	0.2	0.3
3	0.1	0.2	0.2	0.6	0.5	0.7	0.3	0.3	0.4	0.2	0.3	0.5
4	0.1	0.07	0.07	1.9	0.8	0.5	0.3	0.2	0.1	0.1	0.5	0.03
5	0.2	0.4	0.2	0.3	0.1	0.2	0.5	0.3	1.0	0.08	0.2	0.05
6	0.8	0.3	0.2	0.8	0.4	0.4	0.2	0.2	0.4	0.2	0.2	0.06
7	0.5	0.4	0.4	0.6	0.7	0.6	0.5	0.4	0.4	0.09	0.1	0.06
8	0.8	0.2	0.3	0.2	0.3	0.7	0.7	0.1	0.4	0.00	0.3	0.3
9	0.6	0.7	0.9	0.6	0.8	0.7	0.2	0.3	0.2	0.2	0.2	0.6
10	0.4	0.4	0.3	0.3	0.3	0.7	1.9	0.4	0.4	0.3	0.4	0.1
11	0.5	0.2	0.5	0.5	0.8	0.7	0.4	0.07	0.6	0.2	0.5	0.2
12	0.8	0.6	0.7	0.4	0.5	0.5	0.5	0.3	0.5	0.1	0.2	0.03
13	0.5	0.6	0.3	0.5	0.5	0.5	0.3	0.4	0.4	0.3	0.3	0.4

TABLE: XXVII

SPEARMAN RANK CORRELATION BETWEEN THE FACTORS (SEDIMENT VOLUME, RAINFALL AMOUNT, RAINFALL INTENSITY, RUNOFF, RAINFALL DURATION, MAXIMUM RAINFALL IN HALF HOUR PERIOD AND PO_4-P CONCENTRATION IN RUNOFF WATER.

Plot	Sediment Volume And PO_4-P	Rainfall And PO_4-P	Rainfall Intensity And PO_4-P	Runoff And PO_4-P	Rainfall Duration And PO_4-P	Max.Rain fall in Half Hour Period And PO_4-P
1	-0.154	-0.326	-0.278	-0.191	-0.149	-0.045
C 2	-0.688**	-0.289	-0.124	-0.253	-0.146	-0.432
3	-0.307	-0.326	-0.181	0.019	-0.259	-0.408
4	-0.549*	-0.252	0.111	-0.253	-0.268	-0.233
A 5	-0.133	-0.156	-0.295	-0.195	0.128	-0.334
6	0.544*	0.260	0.229	0.388	0.226	0.474
7	0.241	-0.163	-0.262	0.162	-0.163	-0.114
G 8	0.014	-0.037	0.219	0.116	-0.096	0.094
9	0.141	0.463	0.699**	0.357	0.332	0.445
10	-0.056	-0.188	0.262	0.171	-0.219	-0.137
W11	0.309	0.516*	0.653**	0.649**	0.567*	0.554*
12	-0.222	0.178	0.214	0.138	0.183	0.039

r 0.05 one tail = 0.4835* (n = 13)
r 0.01 one tail = 0.6484**
C= cereal/temporary grass G= grass
A= arable(root) W= wood

TABLE: XXVIII

SPEARMAN RANK CORRELATION BETWEEN THE FACTORS (SEDIMENT VOLUME, RAINFALLAMOUNT, RAINFALL INTENSITY, RUNOFF, RAINFALL DURATION, MAXIMUM RAINFALL IN HALF HOUR PERIOD) AND PO_4-P CONCENTRATION IN SEDIMENT

Plot	Sediment Volume and PO_4-P	Rainfall and PO_4-P	Rainfall Intensity and PO_4-P	Runoff and PO_4-P	Rainfal Duration and PO_4-P	Max.Rainfall in Half Hour Period and PO_4-P
1	0.500*	0.366	0.250	0.401	0.279	0.604*
C 2	0.060	0.256	0.143	0.055	0.097	0.203
3	0.200	0.132	-0.058	-0.061	0.039	0.258
4	0.574*	-0.514*	-0.297	-0.258	-0.566*	-0.324
A 5	-0.126	-0.468	-0.407	-0.385	-0.484*	-0.280
6	-0.143	-0.385	-0.415	-0.176	-0.356	-0.209
7	0.242	0.470	0.278	0.275	0.323	0.604*
G 8	-0.118	0.121	-0.030	-0.346	0.053	-0.022
9	0.253	0.454	0.333	0.453	0.500*	0.088
10	-0.445	-0.182	-0.066	-0.264	-0.224	-0.055
W11	0.170	-0.171	-0.063	0.066	-0.061	0.033
12	-0.308	-0.212	-0.231	0.187	0.094	-0.082

r 0.05 one tail = 0.4835* (n = 13)
r 0.01 one tail = 0.6484**
C= cereal/ temporary grass G= grass
A= arable(root) W= wood

concentration in runoff water and in sediment is very poor.

6.11 PHOSPHORUS CONCENTRATION DURING AN INTENSE STORM:

One plot from each land use was selected to monitor the effect of the 34.3mm rainfall event on 20th March 1988. The figures in Table XXIX indicate that the highest sediment concentration, PO_4-P concentration in runoff water and in sediment is from the arable plot although the runoff is less than cereal (T.G) and grass plots. It shows erosion is less in woodland although slope angle (12^0) is higher than other plots. The cereal (T.G) plot is also relatively higher in sediment concentration and PO_4-P concentration in sediment than the grass plot (Table XXIX).

TABLE: XXIX

INFILTRATION CAPACITY, RUNOFF, SEDIMENT WEIGHT, SEDIMENT CONCENTRATION, PO_4-P CONCENTRATION IN RUNOFF WATER AND PO_4-P CONCENTRATION IN SEDIMENT DURING 20 MARCH 1988 STORM

Landuse	Infiltration Capacity (mm/hr)	*Runoff (ml/$2m^2$) (overland flow)	Sediment Weight (g/$2m^2$)	PO_4-P in Runoff Water	PO_4-P in Sediment
Cereal/ (T.G)	77	2725	15.13	0.06	132.1
Arable	102	2554	23.42	0.14	181.3
Grass	21	2913	3.13	0.08	109.3
Woodland	154	1722	4.10	0.03	30.8

*(2000 ml bottle was placed twice during 20th March 1988 storm in each plot).

Here, in the woodland, overland flow depends on the infiltration capacity (see Fig. 6.19) i.e high infiltration capacity less overland flow in the wood land), so that overland flow produced less sediment whereas in the arable land, although the infiltration capacity is higher than cereal/T.G and grass land (see Fig. 6.19), overland flow produced more sediment which has higher concentration of PO_4-P in runoff water and sediment than the other plots. This is probably due to the application of fertilizer and other agriculture practices.

These observations indicated that arable(roots) and cereal/temporary grass represented the area suspected of causing an identified problem of non-point source water pollution. Although only 5% of rainfall runs off overland , the remaining 95% travelling as throughflow or ground water is not thought to convey a significant amount of P to the stream (see page 1). Therefore, in the following chapter, the amounts of soil loss and phosphorus loss by erosion from the agricultural fields in the Slapton Ley catchment will be estimated.

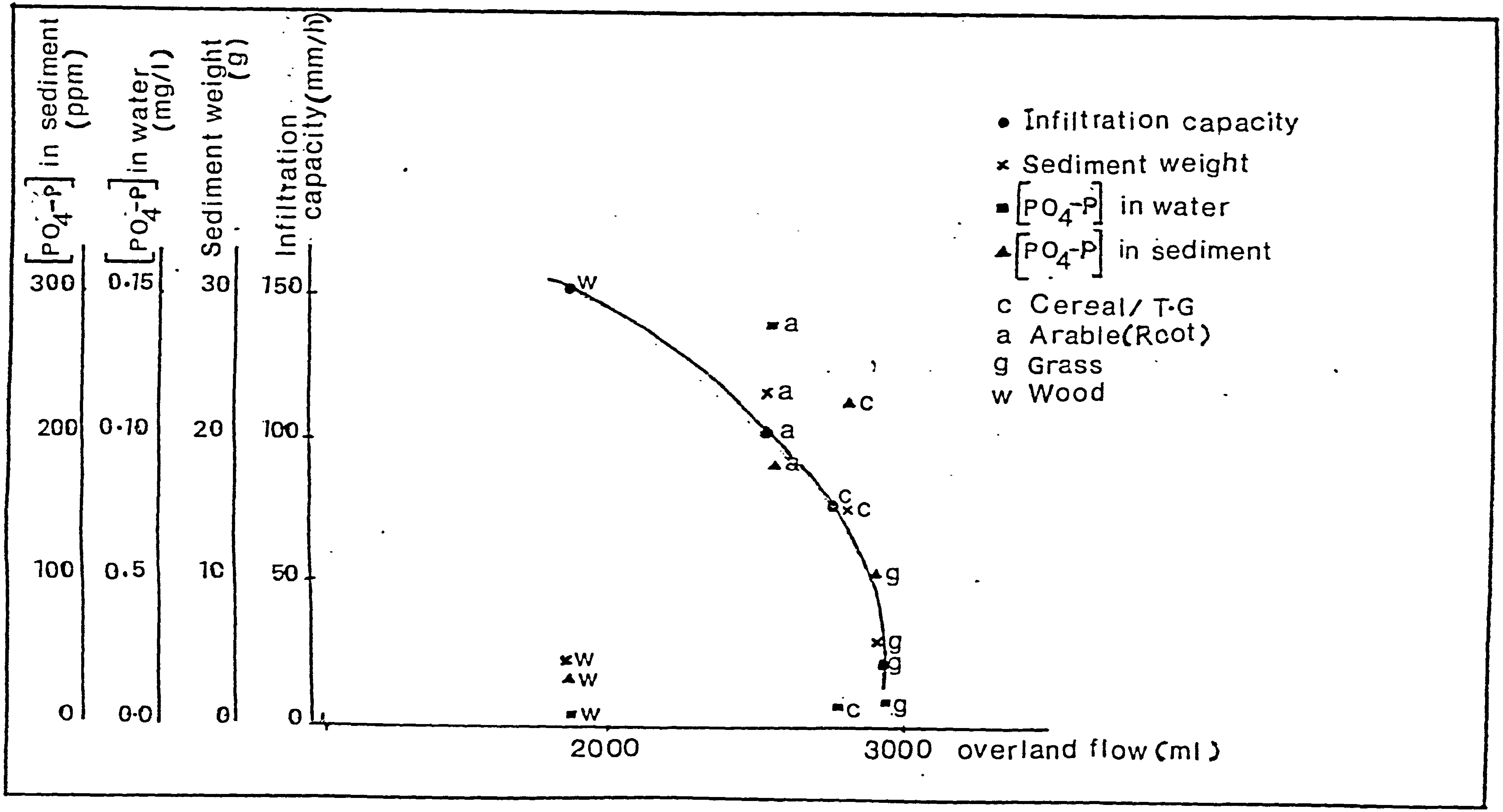


Fig 6·19 RELATIONSHIP BETWEEN OVERLAND FLOW & RESPONSES.

CHAPTER 7

PREDICTION OF SURFACE SOIL AND PHOSPHORUS LOSSES FROM NON-POINT SOURCES

Chapter 6 presented the evidence obtained from the runoff trough experiments and attempted to assess the erosional effects which have resulted from overland flow. Thus an attempt was made to determine the role of erosion as a factor in lake pollution and in particular the transport of phosphorus from field soils to streams and lakes in association with mobile sediment. These observations indicated that arable fields such as roots and cereal, represented the area suspected of causing an identified problem of non-point source water pollution. The amounts of soil loss by erosion and phosphorus loss from the agricultural field (non-point source) within the Slapton Ley catchment have also been estimated using the CREAMS model (WCC version,1984) on an AMSTRAD microcomputer.

7.1 PREDICTIVE MODEL - A REVIEW:

Most of the models used in soil erosion studies are of the empirical grey-box type. They are based on defining the most important factors and through the use of observation, measurement,experiment and statistical techniques, relating them to soil loss. In recent years it has been realized that this approach is less than satisfactory in meeting another important objective in formulating models, that of increasing understanding of how the erosion system functions and responds to changes in the controlling factors.

Significant advances have been made in understanding the mechanics of erosion and the interrelationships between erosion processes. However, all the early predictive equations discussed refer to drainage basins and do not provide a suitable technique for assessing soil loss from smaller areas such as hillslopes and fields.

The first attempt to develop a soil loss equation for hillslopes was that of Zingg (1940) who related erosion to slope steepness and slope length. Further developments led to the addition of a climatic factor based on the maximum 30-min. rainfall total with a two year return period (Musgrave,1947), a crop factor to take account of the production-effectiveness of different crops (Smith, 1958), a conservation factor and a soil erodibility factor. Changing the climatic factor to a rainfall erosivity index ultimately yielded the Universal Soil-Loss Equation (Wischmeier and Smith,1962) which is:

$$E = R.K.L.S.C.P.$$

where, E is mean annual soil loss (t $ac^{-1}y^{-1}$) R is the rainfall erosivity index, K represents the influence of the physical soil properties, L is the factor of the slope length, S is slope steepness, C is the crop factor and P is the conservation practice factor.

The Universal Soil-Loss Equation was developed as a design tool for conservation planning but, in spite of its simplicity, attempts have been made to use it as a research technique. Applying the equation to purposes for which it was not intended, however, cannot be recommended (Wischmeier, 1978). Also the equation was developed to estimate long-term, mean annual, soil loss and it should not be used to predict erosion from an individual storm.

Because of these limitations of the Universal Soil-Loss Equation, the erosion component of the CREAMS model (CREAMS model structure is given in Chapter 4) which predicts storm erosion, is used to predict erosion from an individual storm event.

7.2 CREAMS MODEL:

The CREAMS model (Knisel,1980) was developed by the USDA-Agricultural Research Service to estimate delivery of runoff, sediment and agricultural chemicals from field size areas. It was also developed to evaluate the effects of alternate management practices on non-point pollutant loads. It has been used successfully by Federal and State agencies and consultants in the United States, as well as in numerous other countries (Del vechio and Knisel, 1982; Foster and Ferreira,,1981; Foster and Lane,1982; Knisel *et al.*, 1983; Svetlosanow and Knisel,1982). Comparisons between simulation and observation, without calibration, have generally been good (Foster and Ferreira, 1981; Knisel,1980, Svetlosanow and Knisel,1982).

The CREAMS model predicts the delivery of runoff, sediment and nutrients from a drainage area within a field. When using the CREAMS model, the instructions are to choose a field or fields that represent the area suspected of causing an identified problem of non-point source water pollution (User's Guide WCC version,1984). For this research purpose, the CREAMS model was suitable to apply to the arable field which was identified as the main problem of non-point source water pollution in the Slapton Ley catchment from the study of overland flow during storm events in Chapter 6.

The model is divided into three components: hydrology, erosion and chemicals. Each component can operate independently. There are two modelling options for the precipitation file in the hydrology component: Option 1, the daily rainfall model and Option 2, the hourly or break point rainfall model. A field data worksheet for the CREAMS model is given in Appendix 3.

7.3 HYDROLOGY PARAMETERS:

Here, the daily rainfall model (Option 1) was used for two years'(1987&1988) rainfall data. The hydrology parameters (Table XXX) are data on watershed characteristics required by the hydrology component.

The data were gathered from different sources which are given below.

x Calculated data.
* Measured data.
0 Default data.
\+ User's Guide for the CREAMS computer model WCC(1984).
1 Burt (1976).
2 Coles and Trudgill (1985).
3 Monthly Met report (1987,1988).
4 Watson (1952).
5 Fertilizer Review (1986).
6 Heathwaite <u>et</u> <u>al</u>.(1988).

TABLE: XXX

THE HYDROLOGY PARAMETERS FILE

Hydrology parameters		Run 1 (under kale)	Run 2 (under barley)
BDATE	The beginning date for simulation (This must be less than first storm date).	87000	87000
DACRE	Drainage area (acres) within the field.	8.96*	8.96*
RC	Effective saturated conductivity (in/hr) of the soil.	0.25[1]	0.25[1]
FUL	Fraction of pore space filled at field capacity.	0.34[2]	0.34[2]
BST	Fraction of available water content that is filled when simulation begins.	0.29[2]	0.29[2]
CONA	Soil evaporation parameter	4.5+	4.5+
POROS	Soil porosity (in/in)	0.43[2]	0.43[2]
BR15	Wilting point- immobile soil water content (in/in) at 15 bar tension.	0.1859[2]	0.1859[2]
CHS	Hydrologic slope (ft/ft) for the.field. $CHS = \frac{\text{Max.difference in field elevation (ft)}}{\text{Length of longest flow path in field (ft)}}$	0.167*	0.1859*
WLW	Ratio of watershed length to width. $WLW = \frac{(\text{Length of longest flow path, ft.})^2}{\text{Drainage area, ft}^2}$	29.08*	29.08*

Hydrology parameters		Run 1	Run 2
RD	Effective rooting depth(in)	24.00*	24.00*
UL	Total soil water storage(in) for each of seven soil storages.		
UL(1) = [(POROS - BR15)xBD]x1/36		0.163^{x}	0.163^{x}
UL(2) = [(POROS - BR15)xBd]x5/36		0.814^{x}	0.814^{x}
Ul(3-7)=[(POROS - BR15)xBD]x1/6		0.976^{x}	0.976^{x}
TEMP	Average monthly temperature (degrees F)		
	TEMP (JAN)	42.4^{3}	42.4^{3}
	TEMP (FEB)	42.3^{3}	42.3^{3}
	TEMP (MAR)	44.4^{3}	44.3^{3}
	TEMP (APR)	48.0^{3}	48.0^{3}
	TEMP (MAY)	52.7^{3}	52,7^{3}
	TEMP (JUN)	57.7^{3}	57.7^{3}
	TEMP (JUL)	60.8^{3}	60.8^{3}
	TEMP (AUG)	60.8^{3}	60.8^{3}
	TEMP (SEP)	58.1^{3}	58.1^{3}
	TEMP (OCT)	52.9^{3}	52.9^{3}
	TEMP (NOV)	47.3^{3}	47.3^{3}
	TEMP (DEC)	44.6^{3}	44.6^{3}
RADI	Average monthly solar radiation values (Langleys/day)		
	RADI (JAN)	62.09^{3}	62.09^{3}
	RADI (FEB)	109.85^{3}	109.09^{3}
	RADI (MAR)	226.85^{3}	226.85^{3}
	RADI (APR)	351.04^{3}	351.04^{3}
	RADI (MAY)	441.78^{3}	441.78^{3}
	RADI (JUN)	355.81^{3}	355.81^{3}
	RADI (JUL)	472.82^{3}	472.82^{3}
	RADI (AUG)	398.80^{3}	398.80^{3}
	RADI (SEP)	238.80^{3}	238.80^{3}
	RADI (OCT)	152.83^{3}	152.83^{3}
	RADI (NOV)	81.19^{3}	81.19^{3}
	RADI (DEC)	40.60^{3}	40.60^{3}
LDATE	Date (crop grown)	001^{4}	004^{+}
		182^{4}	105^{+}
		197^{4}	120^{+}
		213^{4}	135^{+}
		228^{4}	150^{+}
		244^{4}	165^{+}
		259^{4}	180^{+}
		274^{4}	195^{+}
		289^{4}	210^{+}
		305^{4}	225^{+}

Hydrology parameters	Run 1	Run 2
	320^4	240^+
	327^4	258^+
	335^4	366^+
	366^4	
AREA LEAF AREA INDEX FOR THE CROP GROWN	0.00^4	0.00^+
	0.00^4	0.00^+
	0.10^4	0.29^+
	0.20^4	0.59^+
	0.80^4	0.60^+
	1.70^4	0.60^+
	2.30^4	1.06^+
	2.50^4	2.01^+
	2.10^4	2.01^+
	2.10^4	2.01^+
	1.80^4	0.77^+
	1.70^4	0.00^+
	0.00^4	0.00^+
	0.00^4	0.00^+

7.4 EROSION/SEDIMENT PARAMETERS:

The erosion/sediment component, which operates on the same watershed as the hydrology component, computes erosion, sediment yield, and particle composition of the sediment on a storm-by-storm basis. To operate, the erosion/sediment component requires the hydrology pass file and the erosion/sediment parameter file (Table XXXI).

TABLE: XXXI

.THE EROSION/SEDIMENT PARAMETER FILE

Erosion/Sediment Parameters		Run 1 (Kale Crop)	Run 2 (Barley Crop)
BYEAR	Last two digits of the year when simulation begins	87	87
EYEAR	Last two digits of the year when simulation ends	88	88

Erosion/Sediment Parameters		Run 1	Run 2
NPART	The number of particle types (sediment) to be read in.	3^{*}	3^{*}
KINVIS	Kinematic viscosity (ft^2/sec)	$1.21E\text{-}05^{0}$	$1.21E\text{-}05^{0}$
NBAROV	Manning's "n" for overland flow over bare soil	0.01^{0}	0.01^{0}
WTDSOI	Weight density of soil (lb/ft^3), default value.	96.00^{0}	96.00^{0}
KCH	Soil erodibility for erosion by concentrated flow in a channel(default value) ((lb/ft^2/sec)(ft^2/lb)$^{1.05}$)	0.135^{0}	0.135^{0}
NBARCH	Manning's "n" for channel flow over bare soil, default value.	0.03^{0}	0.03^{0}
YALCON	Yalin constant for sediment transport, default value	0.635^{0}	0.635^{0}
SOLCLY	Fraction of clay in the surface layer exposed to erosion	0.087^{*}	0.087^{*}
SOLSLT	Fraction of silt in the surface soil layer exposed to erosion.	0.503^{*}	0.503^{*}
SOLSND	Fraction of sand in the soil layer exposed to erosion.	0.41^{*}	0.41^{*}
SLORG	Fraction of organic matter in the surface soil layer exposed to erosion.	0.10^{+}	0.10^{+}
SSCLY	Specific surface area of clay particles. (m^2/g of soil)	10.0^{+}	10.0^{+}
SSSLT	Specific surface area of silt particles. (m^2/g of soil).	1.0^{+}	1.0^{+}

Erosion/Sediment Parameters		Run 1	Run 2
SSSND	Specific surface area of sand particles. (m^2/g of soil).	0.01^{+}	0.01^{+}
SSORG	Specific surface area of organic matter. (m^2/g of soil).	100.0^{+}	100.0^{+}
DAOVR	Area (acres) represented by overland flow profile	8.96^{*}	8.96^{*}
SLNGTH	Slope length (ft) of representative overland flow profile. (This is a horizontal measurement)	577^{*}	577^{*}
AVGSLP	Average slope (ft/ft) of representative overland flow profile	0.1733^{*}	0.1733^{*}
SB	Slope (ft.ft) at the upper end of profile.	0.0909^{*}	0.0909^{*}
SM	Slope (ft/ft) of mid-section.	0.2766^{*}	0.2766^{*}
SE	Slope (ft/ft) at the lower end of profile.	0.1130^{*}	0.1130^{*}
XIN	Horizontal distance (ft) from top of slope to the point where the uphill end of the mid-uniform section begins.	165^{*}	165^{*}
YIN(3)	Elevation (ft) of the point at the uphill end of the mid-uniform section.	30^{*}	30^{*}
Xin(4)	Horizontal distance (ft) from top of the slope to the point above the downhill end of mid-uniform section.	235^{*}	235^{*}
YIN(4)	Elevation (ft) of the point at the downhill end of mid-uniform section.	20^{*}	20^{*}
NXK	Number of slope segments differentiated by changes in soil erodibility factor.	1^{*}	1^{*}

Erosion/Sediment Parameters	Run 1	Run 2
XSOIL(I) Relative horizontal distance (ft) from the top of the slope to the bottom of the segment.	0.96^*	0.96^*
KSOIL(I) Soil erodibility factor (ton/acre) for slope segment	0.25^+	0.25^+
NYEARS The number of years in this rotation.	2	2
CDATE(1) The days on which sets of parameters take effect. (Year 1)	156^x 197^x 244^x 312^x 349^x 363^x	156^x 197^x 244^x 312^x 349^x 363^x
CDATE(2) The days on which sets of parameters take effect. (Year 2)	80^x 203^x 244^x 279^x 382^x 334^x 362^x	80^x 203^x 244^x 279^x 382^x 334^x 362^x

7.5 NUTRIENT PARAMETERS:

The chemical component contains a model that predicts the loss of nutrients on a storm by storm basis in the field. To operate, the nutrient component requires the erosion/sediment pass file and the nutrient parameter file (Table XXXII). This study needed to know nitrogen parameters also included in the nutrient parameters file.

TABLE: XXXII

THE NUTRIENT PARAMETERS FILE

NUTRIENT	PARAMETERS	RUN 1 (Kale Crop)	RUN 2 (Barley Crop)
SOLN	Soluble nitrogen (kg/ha) in surface 1cm,	0.2[+]	0.2[+]
SOLP	Soluble phosphorus (kg/ha) in surface 1cm.	0.2[+]	0.2[+]
NO3	Nitrate (kg/ha) in root zone.	20.0[+]	20.0[+]
SOILN	Total soil nitrogen (kg/ha) in surface 1cm.	0.0005[+]	0.0005[+]
SOILP	Total soil phosphorus (kg/kg) in surface 1cm.	0.0002[+]	0.0002[+]
EXKN	Extraction coefficient for nitrogen.	0.07[2]	0.07[2]
EXKP	Extraction coefficient for phosphorus.	0.05[*]	0.05[*]
AN	Enrichment exponent for nitrogen.	7.4[+]	7.4[+]
BN	Enrichment coefficient for nitrogen.	-0.2[+]	-0.2[+]
AP	Enrichment exponent for phosphorus.	7.4[+]	7.4[+]
BP	Enrichment coefficient for phosphorus.	-0.2[+]	-0.2[+]
RCN	Concentration of nitrogen in rainfall (mg/l).	1.1[2]	1.1[2]
PDATE	First date on which the updatable nutrient parameters are valid.	182.0[4]	105.0[4]
CDATE	Last date on which the updatable nutrient parameters are valid.	327[x]	258[x]

Nutrient Parameters		Run 1	Run 2
NF	Number of fertilizer applications.	1^x	1^x
DENERG	Day of plant emergence.	197^x	120^x
DHRUST	Day of plant harvesting.	327^x	258^x
YP	Potential yield (Kg/ha) in root zone.	3200^x	5700^x
DMY	Dry matter yield ratio.	4.2^+	4.2^+
POTM	Potential mineralizable nitrogen (Kg/ha) in root zone.	47.0^+	47.0^+
DOM	Midpoint (number of days) of nitrogen uptake cycle.	73^+	73^+
SD	Standard deviation of (DOM) midpoint of nitrogen uptake cycle.	30^+	30^+
PU	Potential nitrogen uptake.	250^+	250^+
DF	Date of fertilizer application.	182	105
FN	Nitrogen applied (kg/ha).	206^6	170^6
FP	Phosphorus applied (kg/ha).	109^6	53^6
FA	Surface fraction of application.	0.1	0.1

7.6 PREDICTED LOSSES:

Table XXXIII shows that the CREAMS model predicted no surface runoff from in the monitored plots for December 1987 and January 1988. However, the monitored plots (in Chapter 6) showed actual surface losses during the monitored period of December 1987 and January 1988. During this monitored period, the maximum daily storm rainfall was 2.44cm. The model predicts surface runoff for the 2.54cm rainfall

TABLE: XXXIII

PREDICTED SURFACE RUNOFF IN THE MONITORED PLOTS USING CREAMS MODEL FOR DECEMBER 1987 AND JANUARY 1988

MONTHLY SUMMARY	NUMBER OF STORMS	TOTAL RAINFALL(CM)	TOTAL RUNOFF
December 1987	17	9.8	0
January 1988	26	24.03	0
All the storms are < 2.44 cm rainfall day^{-1}			

in September 1988 under Barley crop management. This may be due to the antecedent wetness which changes the threshold.

Table XXXIV shows the comparison of predicted surface losses with monitored surface losses for the 20th March 1988 storm. In comparing predicted surface losses in a kale field with monitored surface losses in a kale plot., it is immediately obvious that predicted surface losses are over estimated. This is probably due to the number of default values used to run the CREAMS model and also perhaps due to the area sizes which are 2m^2 for the monitored plots and 3.63 ha for the predicted field.

To see the changes of losses and threshold level of rainfall amount, alterations were made to only the crop management parameters (see Tables XXX, XXXII) such as crop type (Kale to Barley), leaf area index, growing season and date of fertilizer application.

Model-predicted losses are more than the monitored actual losses during the 20th March 1988 storms under both kale and barley management. There is a small difference in

TABLE: XXXIV

COMPARISON OF PREDICTED SURFACE LOSSES (USING CREAMS MODEL) WITH MONITORED SURFACE LOSSES FOR THE 20TH MARCH 1988 STORM.

LOSSES	PREDICTED LOSSES IN THE FIELDS (KALE)	(BARLEY)	MONITORED LOSSES IN THE KALE PLOT
Runoff (cm)	0.178	0.178	0.128
Soil loss (kg/ha)	627.6	627.6	117.71
PO_4-P in runoff (kg/ha)	0.0041	0.0041	0.0018
PO_4-P in sediment (kg/ha)	0.2561	0.2423	0.0212
Field area = 3.63ha, Rainfall = 3.43cm, Plot area=2m^2			

runoff amounts and in phosphate content of runoff but greater differences in soil loss and phosphate in sediment. But, though soil loss, runoff and phosphorus in runoff are the same, predicted phosphorus loss in sediment is slightly grater (Table XXXIV) from kale crop management than from barley crop management. The difference of phosphorus loss in sediment is probabily due to the amount of fertilizer application.

TABLE: XXXV

NUMBER OF STORMS AND TOTAL ANNUAL RAINFALL FOR 1987 AND 1988

YEAR	NO.OF STORMS	TOTAL ANNUAL RAINFALL
1987	158	89.43 cm.
1988	164	111.28 cm.

The number of storms and total annual rainfall for 1988 were more than that in 1987 (Table XXXV).

Table XXXVI shows the predicted annual surface runoff, annual soil loss, phosphorus in runoff and phosphorus with sediment from the monitored landuse field for two years (1987 and 1988).

TABLE: XXXVI

PREDICTED ANNUAL SURFACE LOSSES UNDER KALE CROP AND BARLEY CROP MANAGEMENT USING THE CREAMS MODEL.

YEARS	PREDICTED ANNUAL SURFACE LOSSES.	KALE CROP	BARLEY CROP
1987	Runoff (cm)	0.025	0.00
	Soil loss (kg/ha)	44.83	0.00
	PO_4-P in water (kg/ha)	0.0006	0.00
	PO_4-P in sediment (kg/ha)	0.0310	0.00
Number of storms producing losses		1	0
1988	Runoff (cm)	0.84	1.12
	Soil loss (kg/ha)	3429	4707
	PO_4-P in water (kg/ha)	0.0183	0.0130
	PO_4-P in sediment (kg/ha)	1.1666	0.7865
Number of storms producing losses		4	5

area = 3.63 ha.

The field is under kale crop management for which the model predicted surface losses only during one storm of 2.79 cm rainfall out of 158 storms in 1987 and four storms of more than 2.87cm rainfall out of 164 storms in 1988.

In 1987, under barley management the model did not predict surface losses during any of the storms, but in 1988, five storms out of 164 storms, each producing more than 2.54 cm rainfall, predicted surface losses.

Consequently, the antecedent soil moisture levels are generally higher during 1988 than 1987. Therefore, there were no significant losses under either management in 1987, but in contrast, in 1988, surface losses were predicted during the five major storms, the minimum effective storm rainfall being 2.54 cm. Here, the management parameters influence the reponses because of the lower leaf area index and shorter growing season for barley leave the ground exposed for a longer period than under kale management.

Model-predicted losses under kale crop management are less than the predicted barley crop management losses in 1988 only for soil. The fertilizer application shows in Table VII that the kale field received 109kg/ha phosphorus whereas barley crop management received 53kg/ha. However, the predicted results show that the phosphorus losses are more particularly in sediment. Therefore it can be suggested that a shift from cereal crop management to root crop management with less application of phosphorus may reduce the erosion potential and phosphorus losses.

However, the CREAMS model seems to overestimate the losses of soil. Re-running the model with new variable sets is very time consuming as whenever data has been changed, a new file must be created. The Erosion/

Sediment component file takes about 1/2 hour to run. The model generates a large volume of out-put for individual storms. Therefore the model does not appear to be designed to allow easy investigation of the effects of changes of the values of single variables. Therefore a simple model will be adopted to estimate the actual losses from the agricultural sources to the Ley using field measurements. It is self-evident that field measurements, where possible and even if minimal, will be superior to desk calculations (Moss et al.,1988).

7.7 IMPLICATIONS FOR MODELLING:

The model adopted here is basically that of Jorgenson (1980). This model estimates the areal nutrient load upon a lake by summing outputs from all potential sources. Here, in this study phosphorus output to the Ley from agricultural sources was estimated during a big storm (34.4mm) event using a portion of the model.

Thus, $$L = \sum_{i=1}^{n} (Ai.Ei) \qquad \text{.................Equ.(1)}$$

where L= Loss of phosphorus (kg $storm^{-1}$)

Ai= Area of each agricultural land use (ha)

Ei= Export coefficient for different land use types in the catchment (kg ha^{-1} $storm^{-1}$)

Thus, $$L = A_c.E_c + A_a.E_a + A_gE_g \qquad \text{..............Equ.(2)}$$

where, $_c$ = cereal land use

$_a$ = arable land use

$_g$ = grass land use

Areally weighted mean phosphorus loss was calculated using the Equation (3).

$$AWMPL = \frac{A_c E_c + A_a E_a + A_g E_g}{A_c + A_a + A_g} \quad \ldots\ldots\ldots\ldots\ldots \text{Equ.(3)}$$

The estimate of phosphorus losses is shown in Table XXXVII below.

TABLE: XXXVII

ESTIMATED PHOSPHORUS LOSSES FROM AGRICULTURAL SOURCES DURING THE 20th MARCH 1988 STORM

	Loss of phosphorus from agricultural area to the Ley (kg)	Areally-weighted mean phosphorus loss from agricultural area to the Ley (kg/ha)
In sediment	19.76	0.0046
In solution	4.84	0.0011

Detail of the data used for the model

	kg/ha		kg/ha		ha
E_c(sed.)=	.00999;	E_c(solu.)=	.00082;	area of cereal	915.2
E_a(sed.)=	.02121;	E_a(solu.)=	.00180;	area of arable	249.7
E_g(sed.)=	.00171;	E_g(solu.)=	.00117;	area of grass	3114.3

The actual phosphorus loss to the Ley from agricultural sources is greater (19.76 kg) in sediment than in solution (4.84kg). Therefore sediment is a more important source for eutrophication if the P is equally available to algae etc.

Using equation 4, phosphorus losses from arable land (cereal and root) and equation 5, phosphorus losses from grass land to the Ley were estimated particularly in sediment.

Thus, $L = A_c.E_c + A_a.E_a$ ....Equ.(4)

$L = A_g.E_g$ ....Equ.(5)

TABLE XXXVIII

ESTIMATED PHOSPHORUS LOSS IN SEDIMENT FROM ARABLE (CEREAL & ROOT) AND GRASS LAND USES TO THE LEY DURING 20th MARCH 1988 STORM

Total PO_4-P loss in sediment from arable (cereal & root) area (kg)	Areally-weighted mean PO_4-P loss in sed. from arable area (kg/ha)	Total PO_4-P loss in sediment from grass area (kg)	Areally-weighted mean PO_4-P loss in sed. from grass area (kg/ha)
14.44	0.0124	5.33	0.0017

Table XXXVIII shows estimated PO_4-P losses in sediment from arable (cereal and root) and grass sources.Arable phosphorus losses is greater (14.4) than the grass phosphorus losses (5.33). Therefore the estimated results in Table XXXVIII indicate that the arable fields are the major source for eutrophication of Slapton Ley.

CHAPTER 8

IDENTIFICATION OF POINT SOURCES OF PHOSPHORUS AND DOWN STREAM CHANGES

In this chapter, 1) the point sources of phosphorus to the stream, and 2) phosphorus concentration in the a) stream bed, b) during peak discharges, c) in the marsh land and d) in Slapton Ley are discussed.

8.1 POINT SOURCES OF PHOSPHORUS:

Recent studies suggest that phosphorus is of major importance for growth of algae and other aquatic weeds in surface waters (Ryden et al., 1973; Li et al., 1973; Syers et al.,(1973). Sawyer (1974) concluded that agricultural runoff and drainage alone could enrich a lake to the point of supporting phytoplankton blooms. However, considerable controversy exists over the relative sources of phosphorus in effecting this eutrophication process in surface waters.

Suspended sediment influences light penetration and, hence, algal production (Ganf, 1974; Levering and Fish,1956). Suspended sediments also influence the chemical composition of water, because of associated sorbed materials including phosphorus (P). However, the biological significance of suspended-sediment sorbed P is unclear (Hott, et al., 1973) although there is no doubt that the availability of P associated with suspended sediment depends upon the mechanism of P sorption, as well as the P form

(Golterman, 1973). Suspended sediments have been described as buffers with respect to phosphate content of water, releasing P from sediments to sustain growth of an algal bloom. The typical dissolved P content has been shown to only be able to support observed photosynthesis rates for about 1 day (Marlynova, 1971). Many limnologists consider P as the key element causing accelerated eutrophication in most freshwater (Lee, 1973). To predict algal blooms on the basis of the nutrient status of waters, the chemistry of P in lakes and reservoirs must be understood (Lee, 1973). Since the turnover rate of P in eutrophic lakes can be rapid, it is important to know how the P status of the suspended sediment changes as it moves along the stream from different sources.

Since P is predominantly associated with sediment (Duly, 1926; Munn _et al._, 1973), there is a need to determine the exchangeable P which is readily available to aquatic plants from various types of sediment sources. Owing to the chemical pollution of water mainly by phosphate fertilizer from farms and arable fields and by sewage, rapid eutrophication may take place in water-ways with all the undesirable consequences of this for the ecosphere. Phosphorus associated with suspended sediments in tributaries often represents a large portion of the total annual P loading to lakes (Sonzogni _et al._, 1982).

Vollenweider (1968) stated that forestry is also one of the P sources along with agriculture and urban development for P loading in many areas.

To assess the impact of P loadings on Slapton Ley, their sources must be known. Plates 12, 13, 14, 15, show the evidence of runoff through tractor paths, woodlands road banks and man made water way.

8.2 SOURCES GROUPED USING DISCRIMINANT ANALYSIS

Point water samples from different runoff sources and the stream (Fig. 8.1) were collected from 1400 to 1900hr. on 20th March 1988, during and immediately after the highest flood peak of the year and analysed to determine the concentrations of dissolved P in water and the exchangeable P associated with suspended sediment. The point water samples (136) from 13 sources (arable, cereal, grass, wood, farmyard, marsh, roadbank, tractor path, foot path, stream bank, pond, sewage, Ley bank) were grouped according to the level of soluble and exchangeable P concentration (See Appendix 4) using discriminant analysis. Data of the samples are mingled and the circles overlap (Fig. 8.2).

In discriminant analysis the influence of the selected factors on decisions, fragmentary information, sampling error, and classification frameworks based on sub-sets of the properties of interest, can cause overlap between classes (Webster and Burrough, 1974). However when overlap is shown to be present, the means of identification need to be reconsidered. Therefore, according

Plate 13. Evidence of runoff through tractor path at Easter ground

Plate 14. Evidence of runoff through wood land at Slapton wood

Plate 15. Evidence of runoff on the road edge at Start area

Plate 16. Evidence of runoff by man made water way at Stokely Barton area

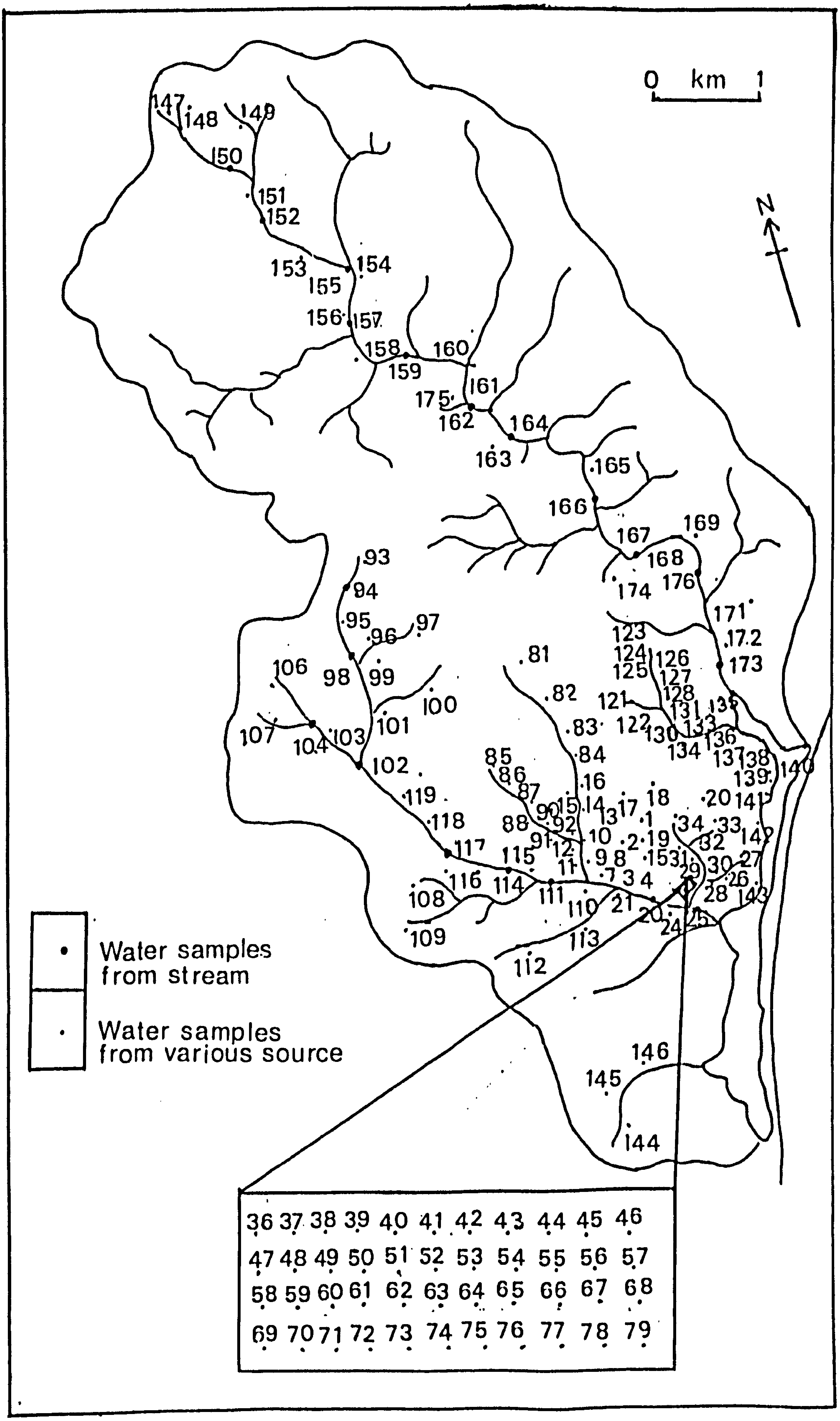


FIG.8.1 Location of water samples from point sources

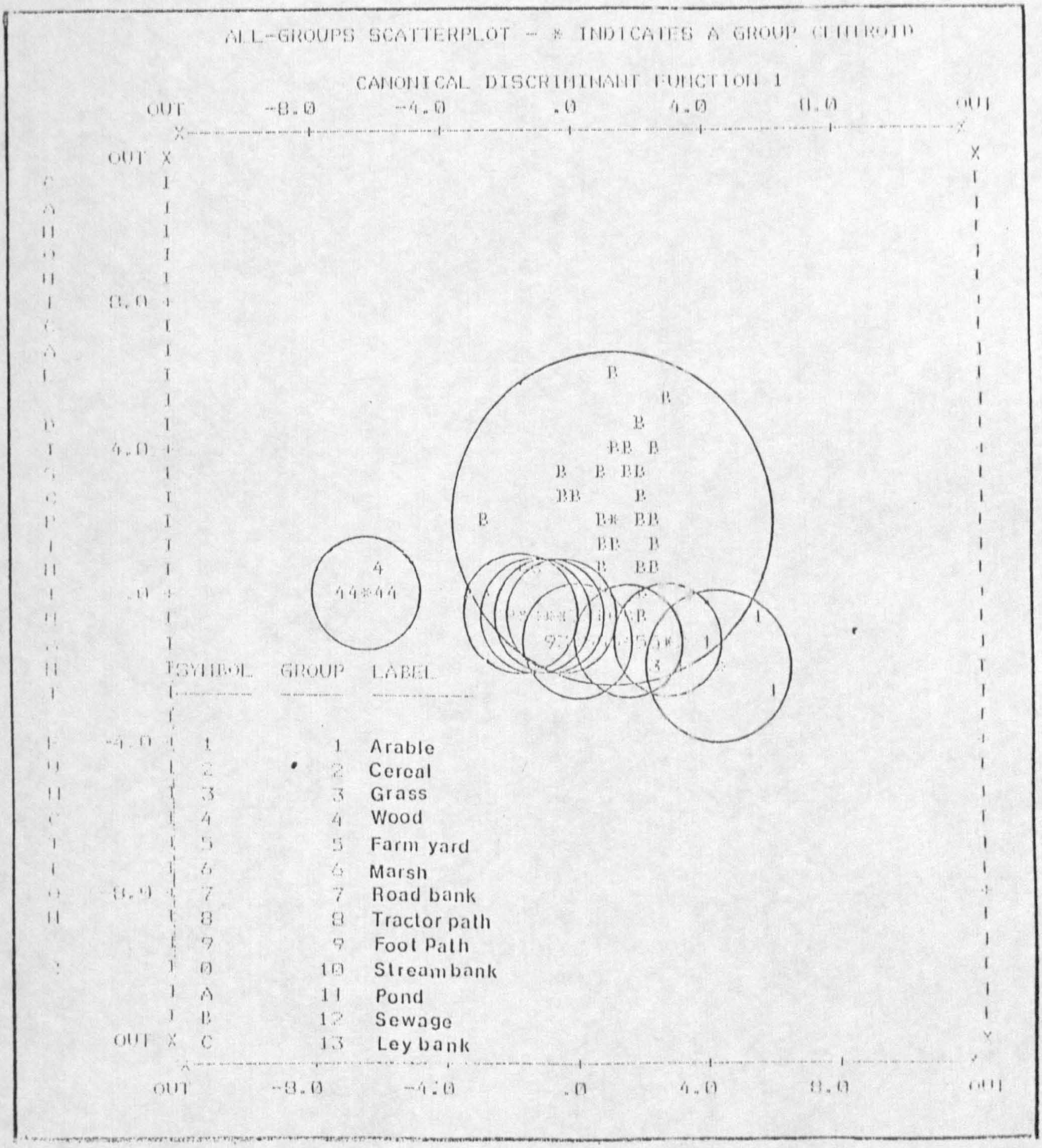


Fig. 8·2:13 Canonical discriminant groups for sources of PO_4-P in the Slapton Ley Catchment to the mean level of phosphorus concentration, the sources can be grouped under the 6 categories: 1) arable and cereal, 2) farm and sewage, 3) grass, 4) road bank, tractor path, foot path, stream bank and ley bank, 5) marsh water and pond, 6) wood.

Point samples from source 6 are grouped. The samples from sources 3, 4 and 5, however are mingled with those from 1 and 2, and the circles overlap (Fig. 8.3). In this case, level of phosphorus concentration is similar for most of the point samples in sources 3, 4 and 5. Though, group 1 and group 2 overlap Fig. 8.3 indicates that there are variations in their characteristics to some extent. Therefore groups 3,4,5 are considered as one group which is group 2 in Fig. 8.4. Appendix 5 shows the actual group and the highest probability group for the reconsideration under four main groups (Fig. 8.4) This clearly indicates that groups 3,4 and 5 (in fig. 8.4) are very similar in phosphorus level.

The mean value of the exchangeable phosphorus concentration shows (Table XXXVII) that agricultural land uses such as arable and cereal provide more phosphorus than the other land uses (four times more from sewage and farm, three times more from grass land and six times more from wood land) whereas the mean value of the soluble phosphorus concentration shows that farm and sewage provide more phosphorus than other sources (Table XXXIX). The woodland provides least phosphorus to the stream.

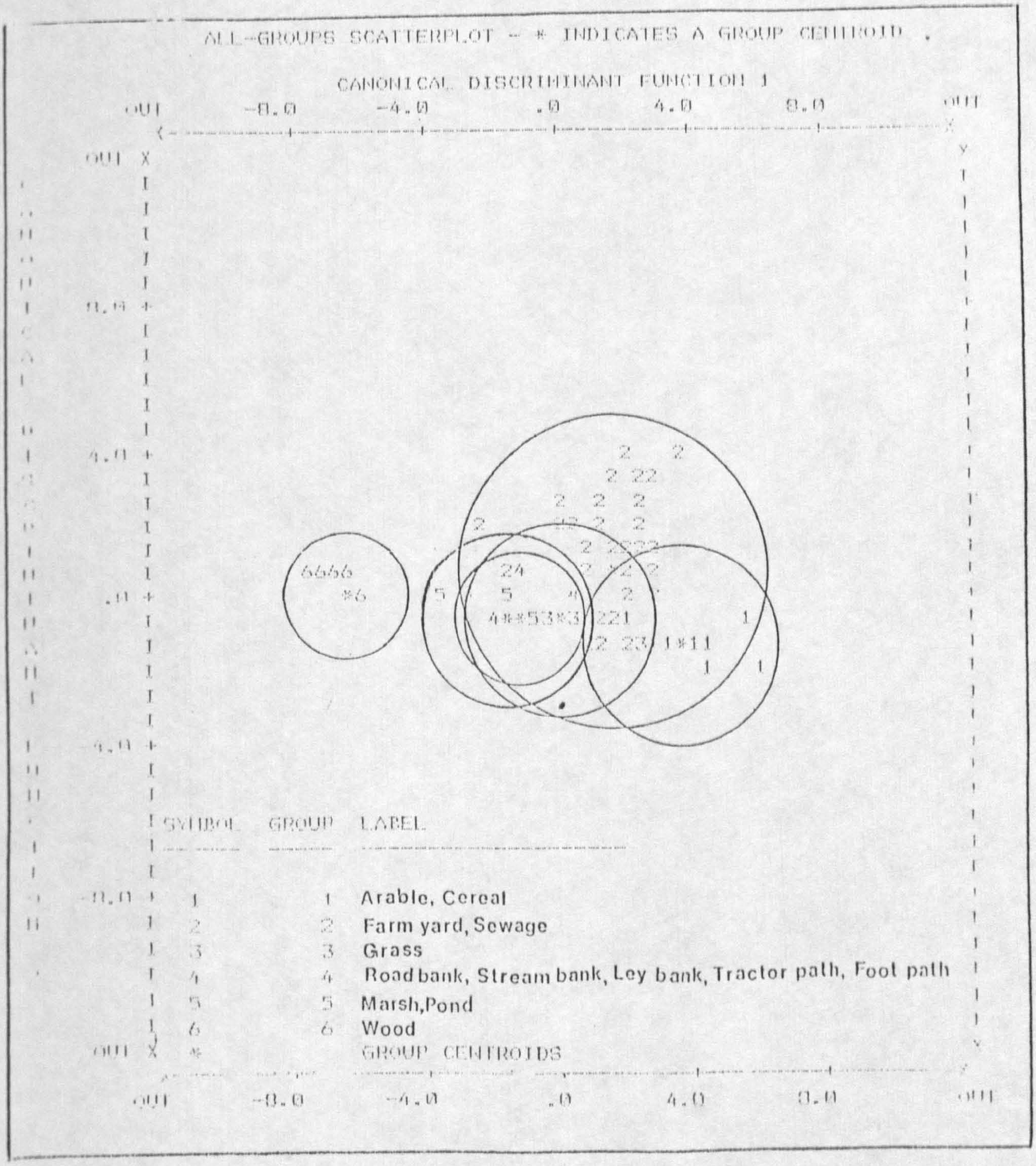


Fig. 8·3: 6 Canonical discriminant groups for sources of PO_4-P in the Slapton Ley Catchment

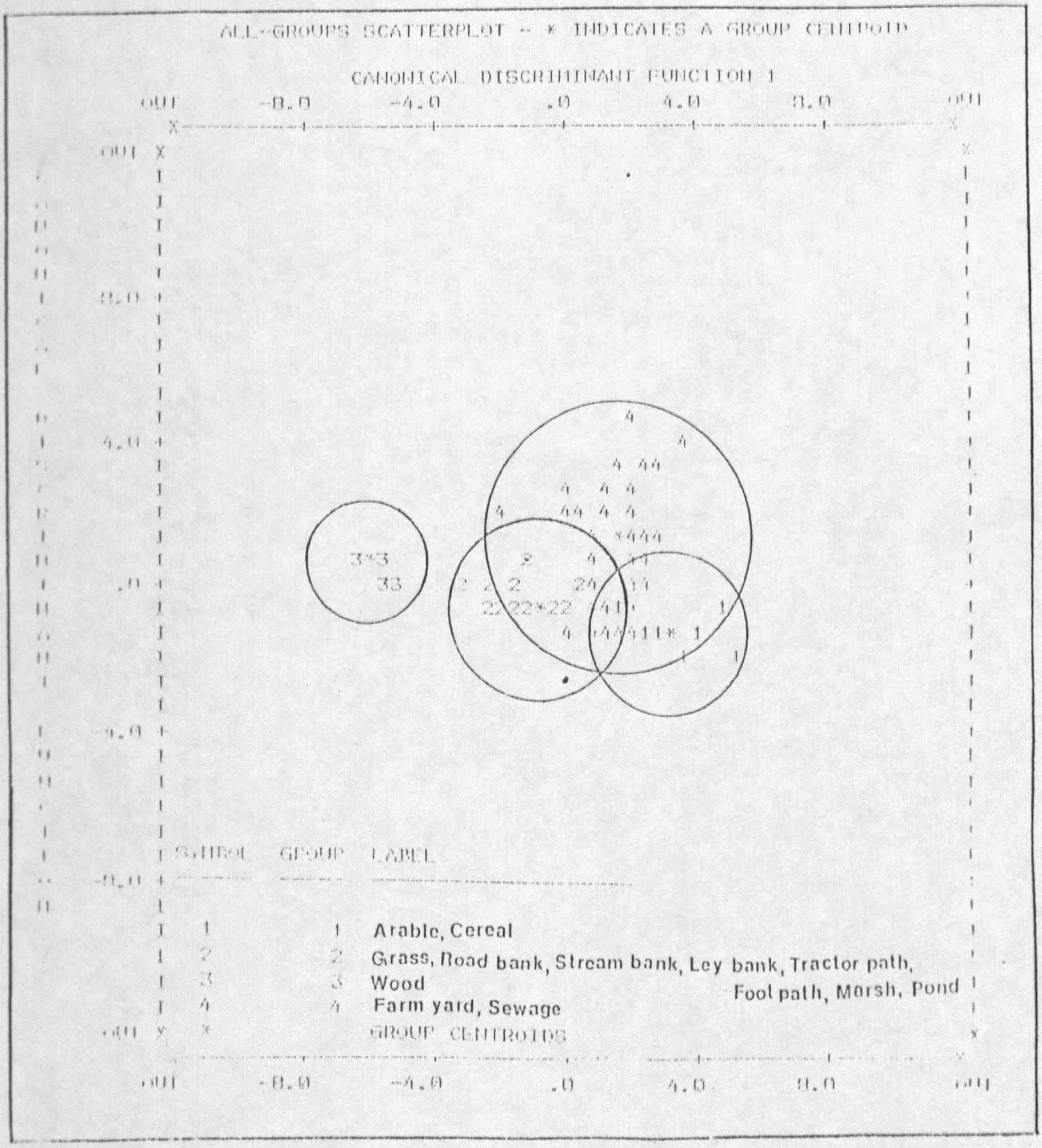


Fig. 8·4: 4 Canonical discriminant groups for sources of PO_4-P in the Slapton Ley Catchment

TABLE: XXXIX

MEAN VALUE OF PHOSPHORUS CONCENTRATION FROM THE POINT SOURCES.

Number of Groups from Discriminant Analysis			Sources	Mean Phosphorus Concentration (ppm)	
First Run	Second Run	Third Run		Exchangeable	Soluble
1	1	1	Arable	211.7	0.45
2	1	1	Cereal	200.5	0.36
3	3	2	Grassland	140.7	0.05
4	6	3	Woodland	36.4	0.002
5	2	4	Farm	172.9	2.50
6	5	2	Marsh Water	133.2	0.23
7	4	2	Road Bank	126.0	0.02
8	4	2	Tractor Path	120.0	0.03
9	4	2	Foot Path	120.0	0.02
10	4	2	Stream Bank	126.6	0.03
11	5	2	Pond	132.0	0.015
12	2	4	Sewage	172.0	3.15
13	4	2	Ley Bank	127.0	0.02

8.3 INPUTS OF PHOSPHORUS TO THE STREAM

The soluble P concentration in water is much less than the exchangeable P on suspended sediment in runoff water. Inputs of phosphorus associated with suspended sediment from major sources to the stream are illustrated in Fig. 8.5 and 8.6. The figures suggest that there is a downstream change in the PO_4-P concentration, when the streams receives runoff from agricultural land, farm yards and sewage sources. When

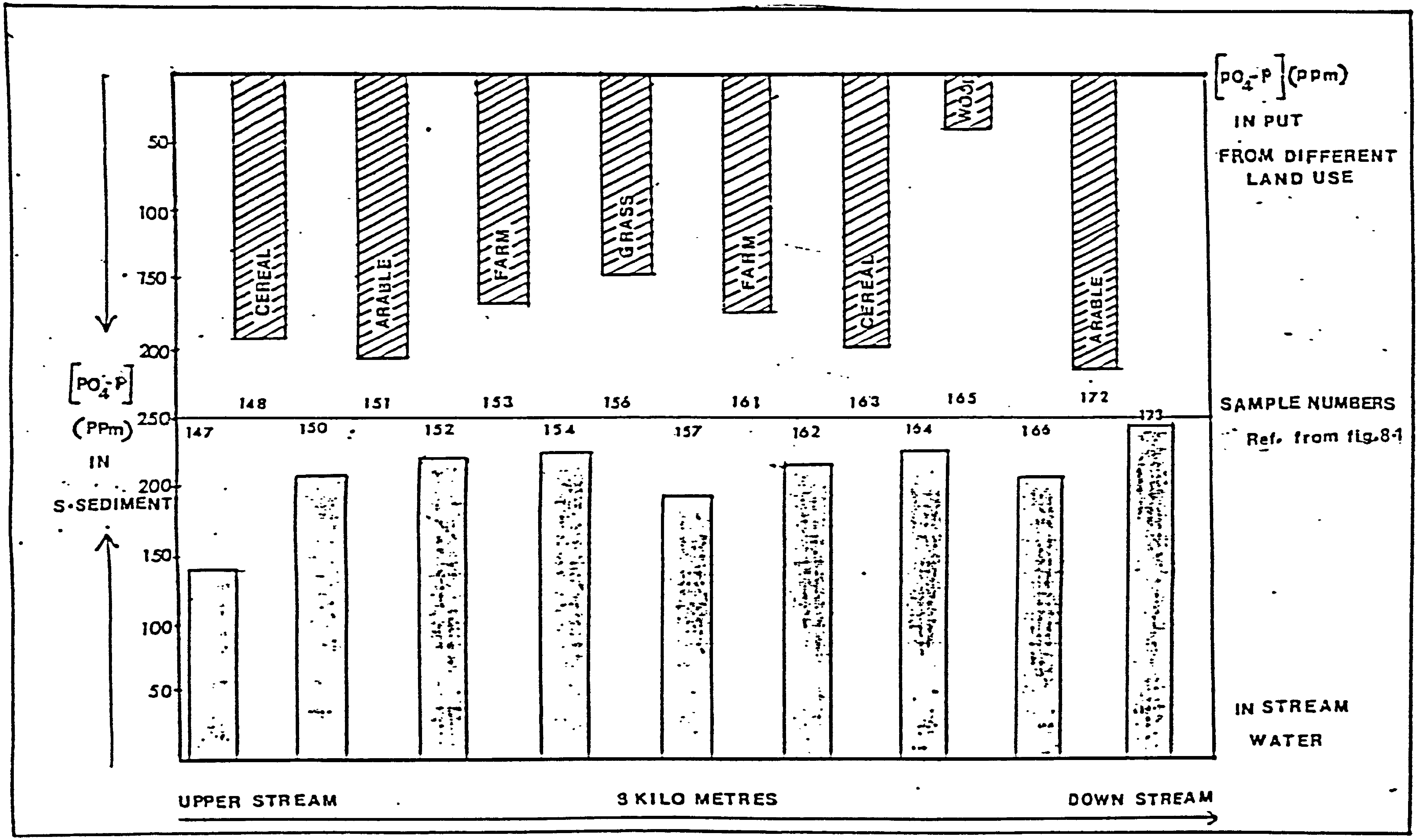


FIG. 8.5. MAJOR PHOSPHORUS INPUT FROM SOURCES FOR RIVER GARA ON 20 MARCH 1988 STORM

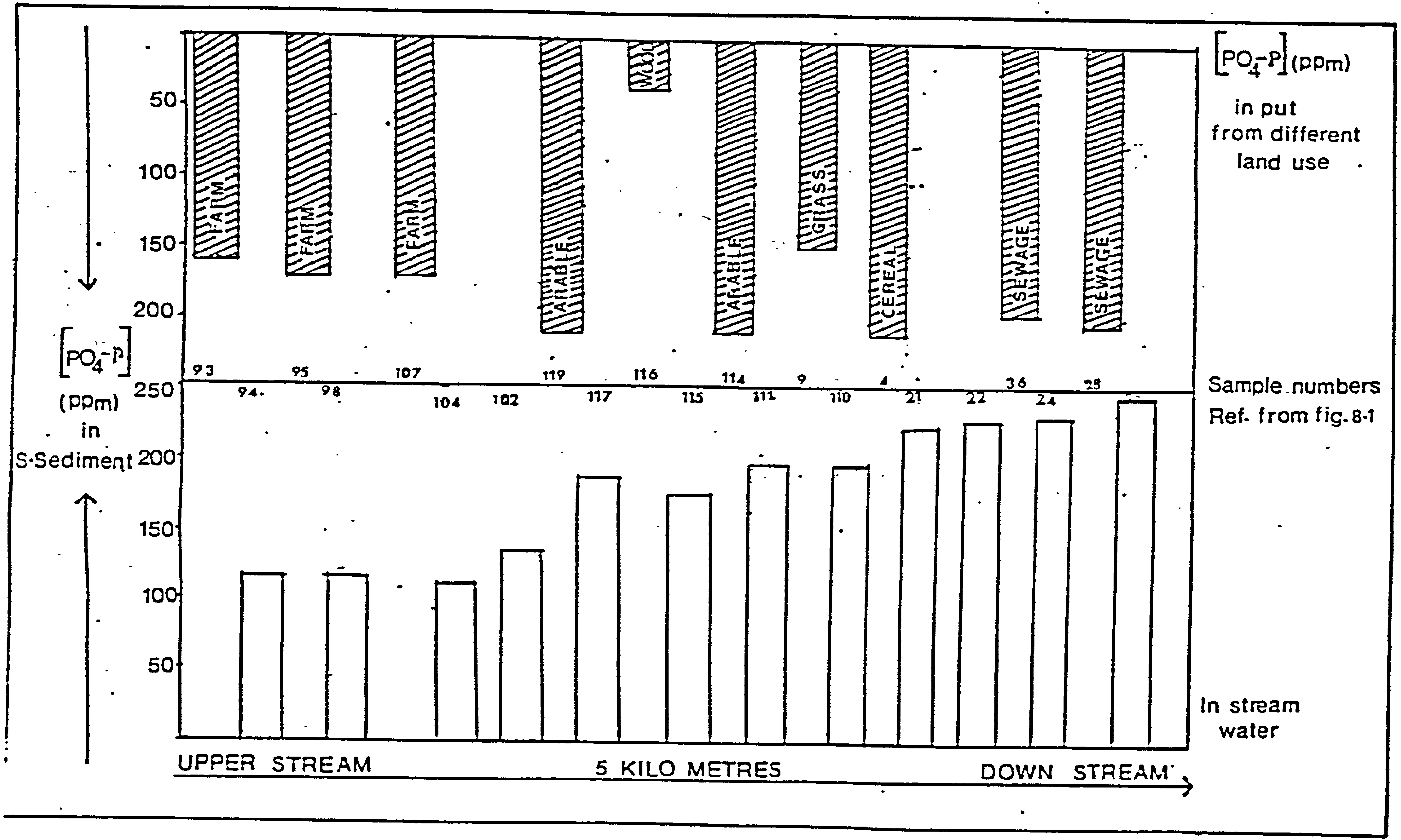


FIG. 8·6 MAJOR PHOSPHORUS IN PUT FROM SOURCES FOR RIVER START ON 20 MARCH 1988 STORM the stream receives runoff from woodland or grass land, however, there is no increase in phosphorus concentration of the stream suspended sediment. Phosphorus concentration is less in the suspended sediment as the runoff from woodland or grassland probably brings lower concentrations of P in suspended sediment. These land uses do not receive fertilizer like arable land and due to the lack of erosion in grassland and wood land. Of the various agricultural sources, runoff from feedlots and stockyards is considered to be an important P source (Stanford, England and Taylor, 1970). However in the study area, surface runoff from agricultural land is considered to be a major source of phosphorus to the stream as TASK Group 2710 P (1967) noted. Sewage and farmyards can be considered as secondary P sources.

8.4 PHOSPHORUS CONCENTRATION IN BED SEDIMENT

Water soluble phosphorus concentration and exchangeable phosphorus concentration were measured in stream bed sediment and Figs. 8.7 and 8.8 show the distribution of the phosphorus concentrations. Here also the water soluble P is much less than the exchangeable P in bed sediment. In the Start catchment both water soluble and exchangeable phosphorus concentration are higher in the downstream than the upstream sediment samples. However, some parts of the upper stream around the farm yard show the highest concentration of phosphorus in the bed sediment within the Ley catchment. This suggests that some

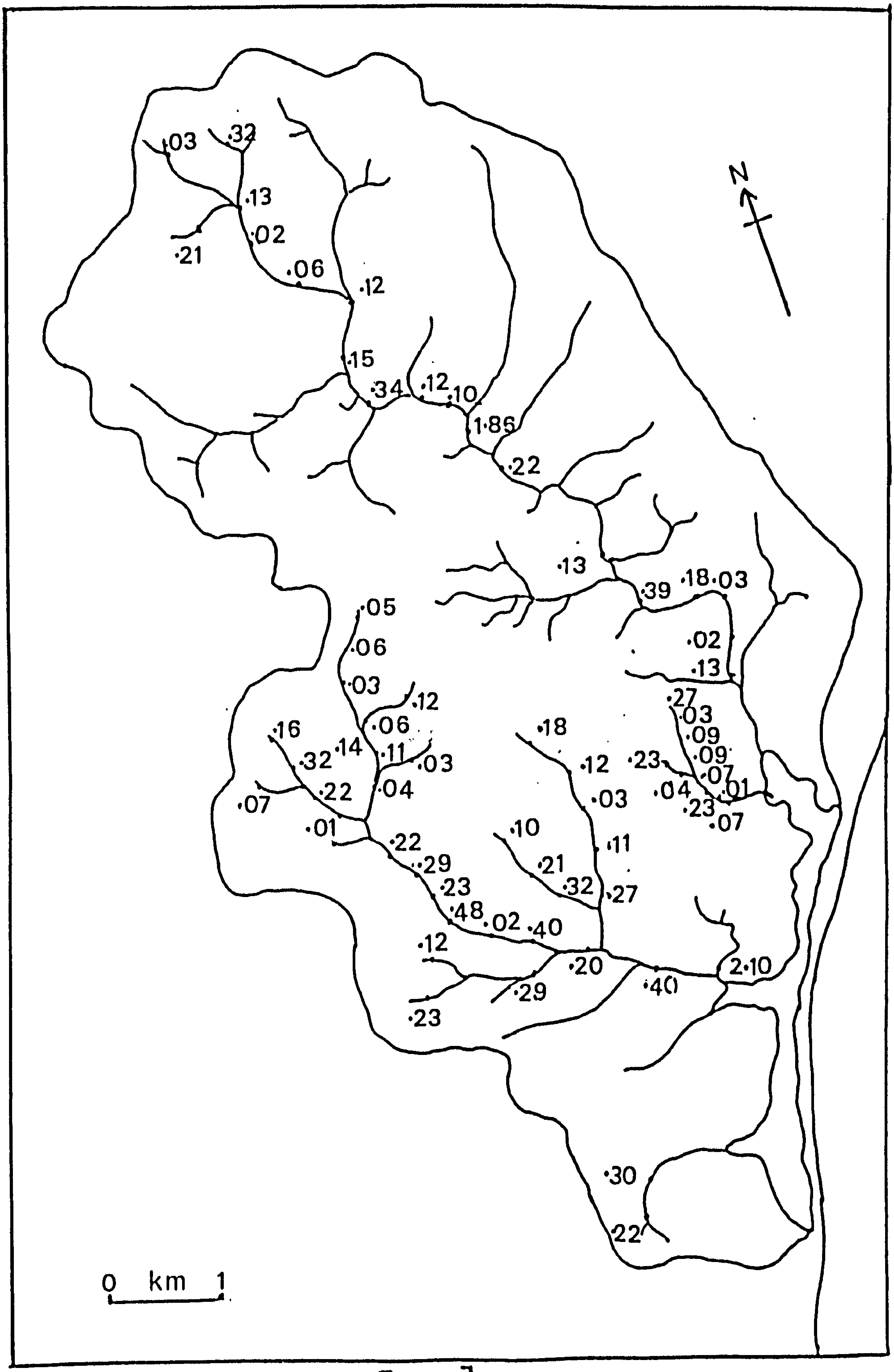


FIG.8·7 WATER SOLUBLE [PO_4-P] IN STREAM BED SEDIMENT

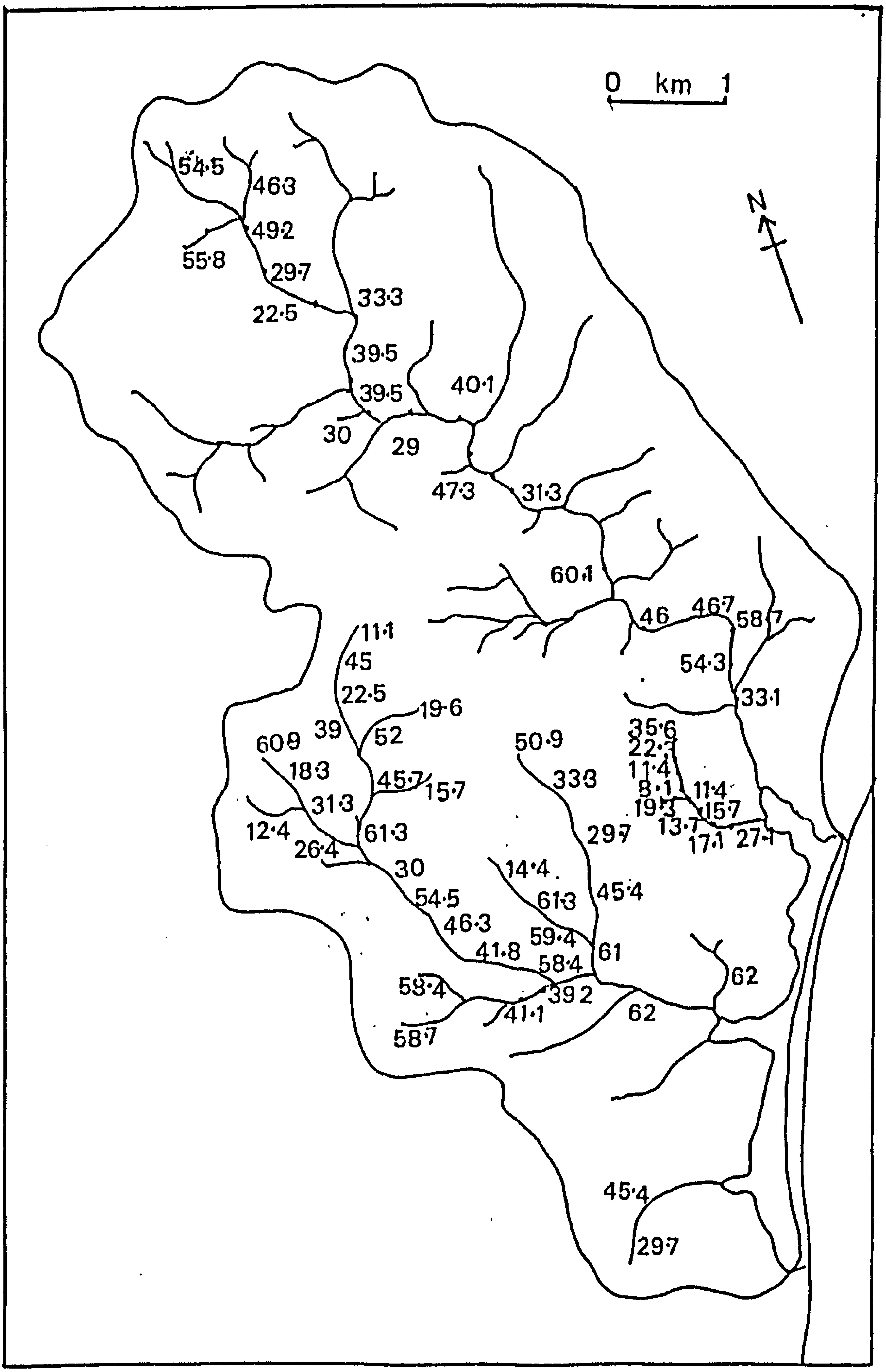


FIG. 8·8. EXCHANGEABLE $[PO_4-P]$ IN STREAM BED SEDIMENT particulate phosphorus is deposited on to the stream bed before the water reaches the Ley.

8.5 PHOSPHORUS CONCENTRATION DURING THE PEAK DISCHARGE

Water samples collected on the 20th March '88 at Higher North Mill (Fig. 2.1) where the automatic water sampler was fixed for the Gara catchment, were also analysed to obtain the exchangeable phosphorus concentration for water and suspended sediment.

Fig. 8.9a shows the discharge, suspended sediment load, phosphorus concentration in water and phosphorus concentration in suspended sediment. The ratio of phosphorus concentration in suspended sediment to phosphorus concentration in water is 240 : 0.3 during the peak discharge (Fig. 8.9a). Fig. 8.10 shows a linear relationship between phosphorus concentration in suspended sediment and phosphorus concentration in water at High North Mill through a storm (20th March 1988). Figs. 8.11 and 8.12 show that during increasing discharge, phosphorus concentration in suspended sediment and phosphorus concentration in water also increase. Peak discharge shows peak suspended sediment load (Fig. 8.9a). This is due to soil erosion during intense rainfall from the agricultural areas dominating the composition of suspended sediment load at peak discharge.

Fig. 8.9b shows the "mass flow" of phosphorus delivered from the Gara catchment at Higher North Mill in water and suspended sediment to the Ley.

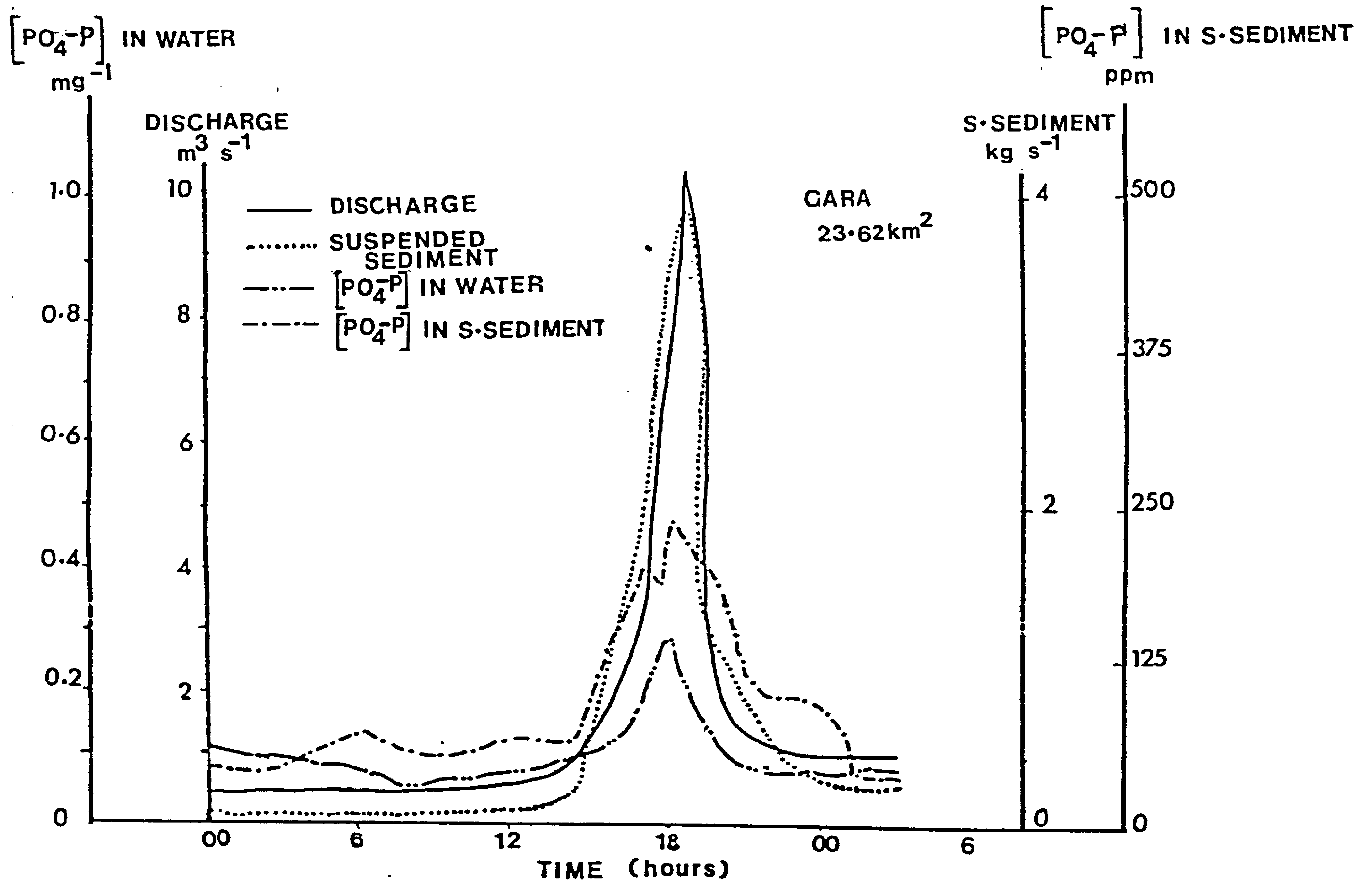


FIG. 8·9a DISCHARGE, SUSPENDED SEDIMENT & $[PO_4-P]$ AT HIGHER NORTH MILL FOR GARA CATCHMENT ON 20 MCRCH 1988 STORM

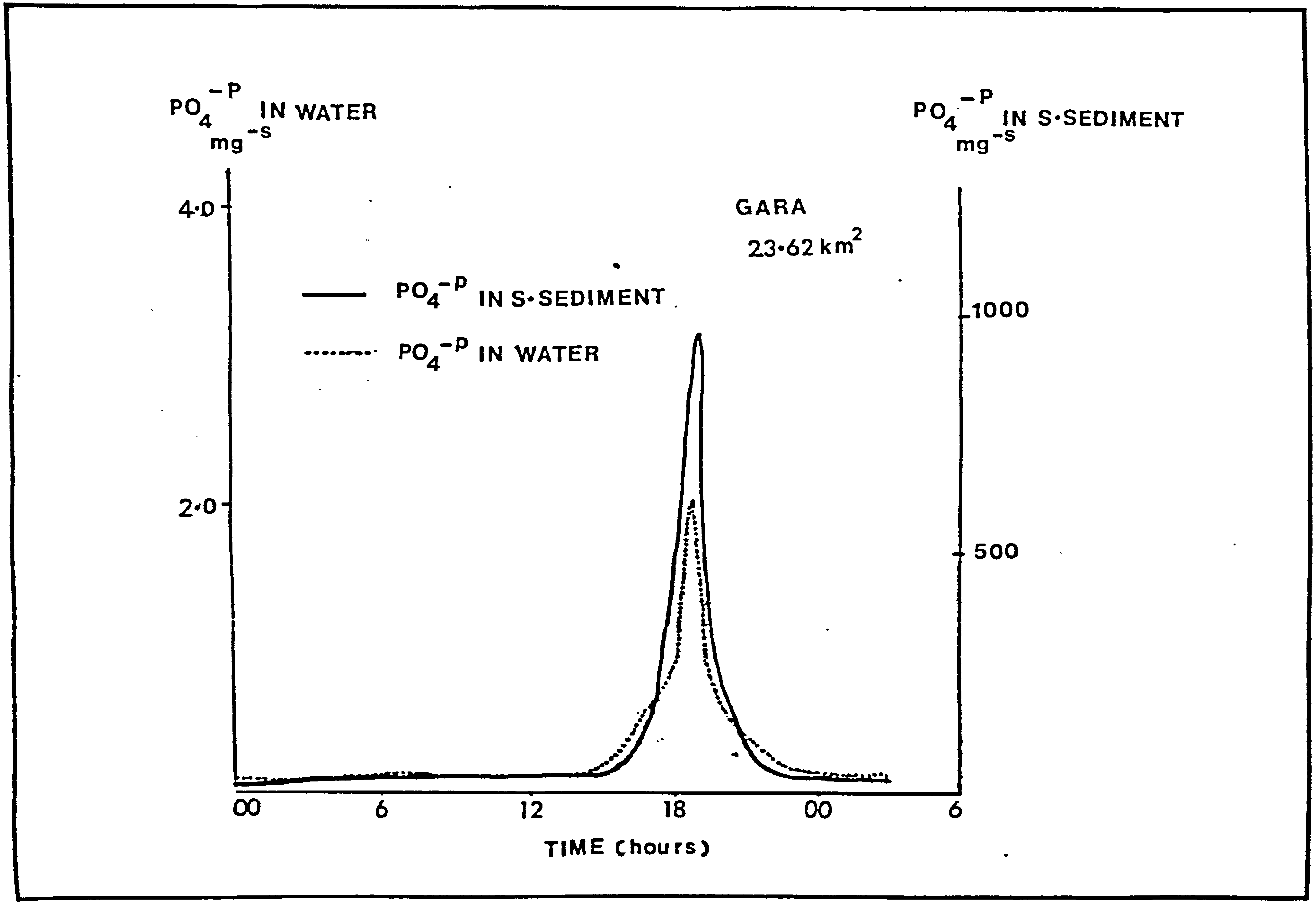


FIG. 8·9b MASS FLOW OF PO_4^{-P} IN WATER AND SUSPENDED SEDIMENT ON 20 MARCH 1988 STORM

FIG. 8.10 RELATIONSHIP BETWEEN [PO$_4$-P] IN SUSPENDED SEDIMENT AND [PO$_4$-P] IN WATER AT HIGHER NORTH MILL ON 20 MARCH 1988

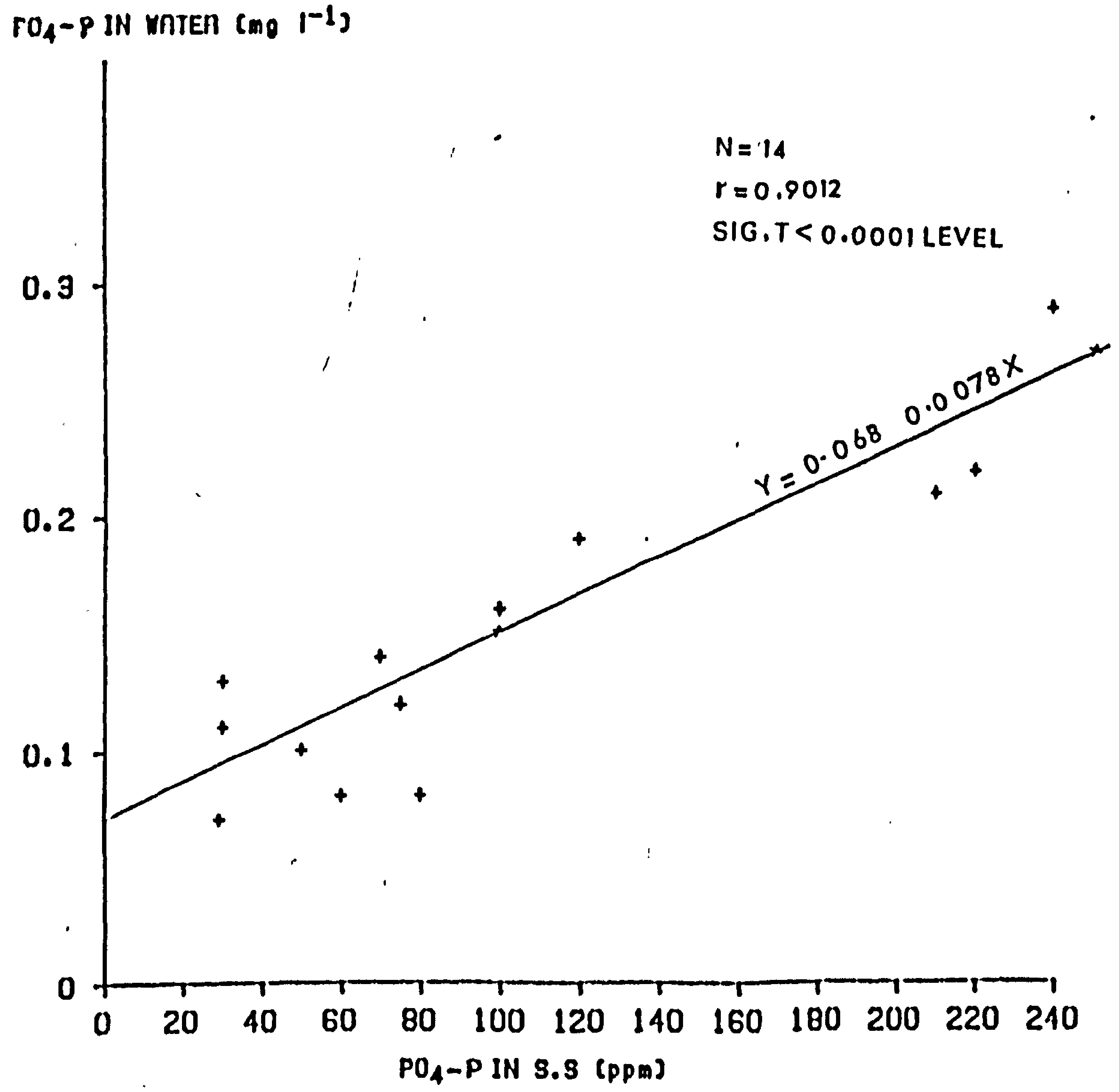


FIG. 8·11 RELATIONSHIP BETWEEN DISCHARGE AND [PO_4-P] IN SUSPENDED SEDIMENT AT HIGHER NORTH MILL ON 20 MARCH 1988

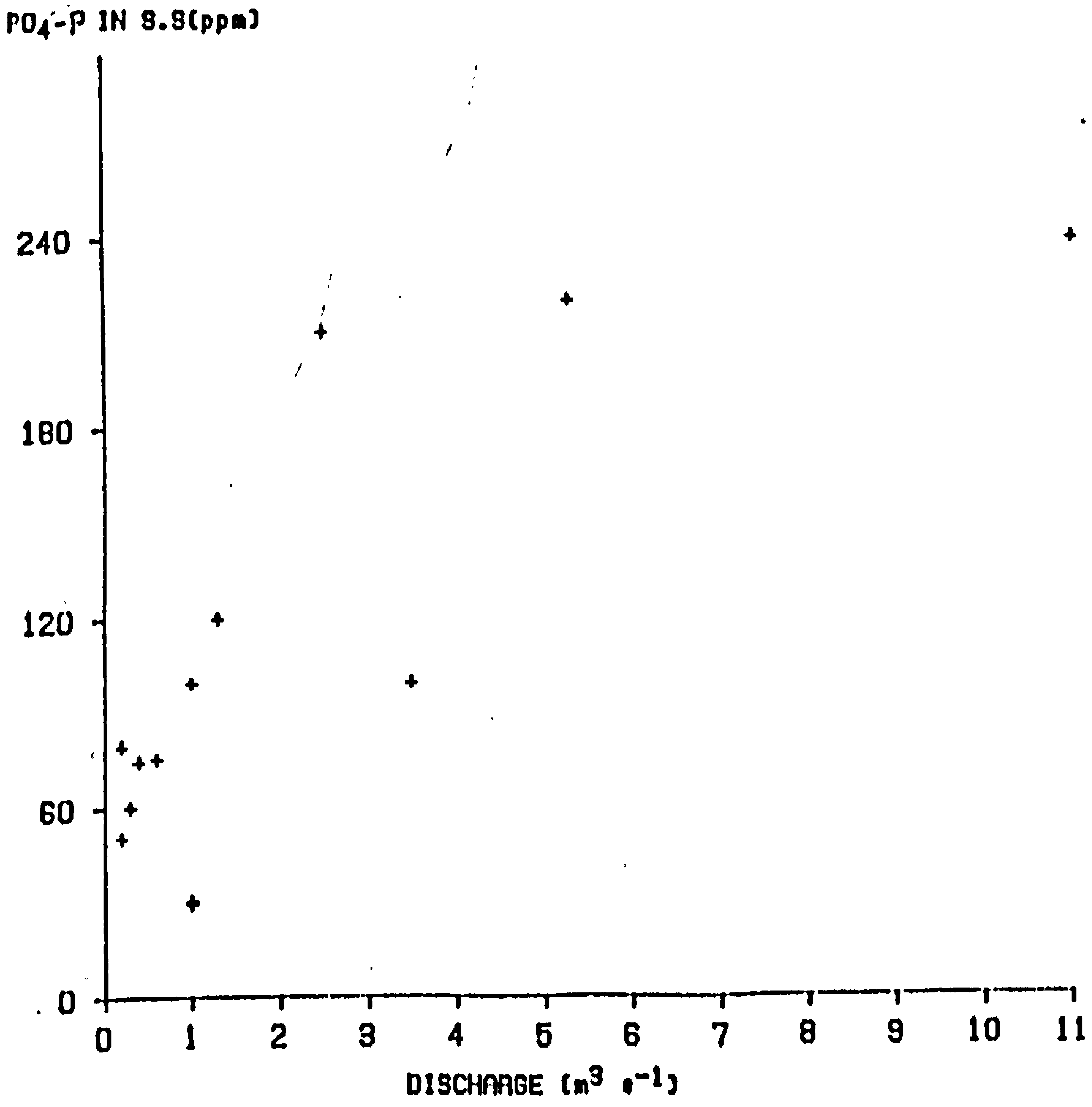
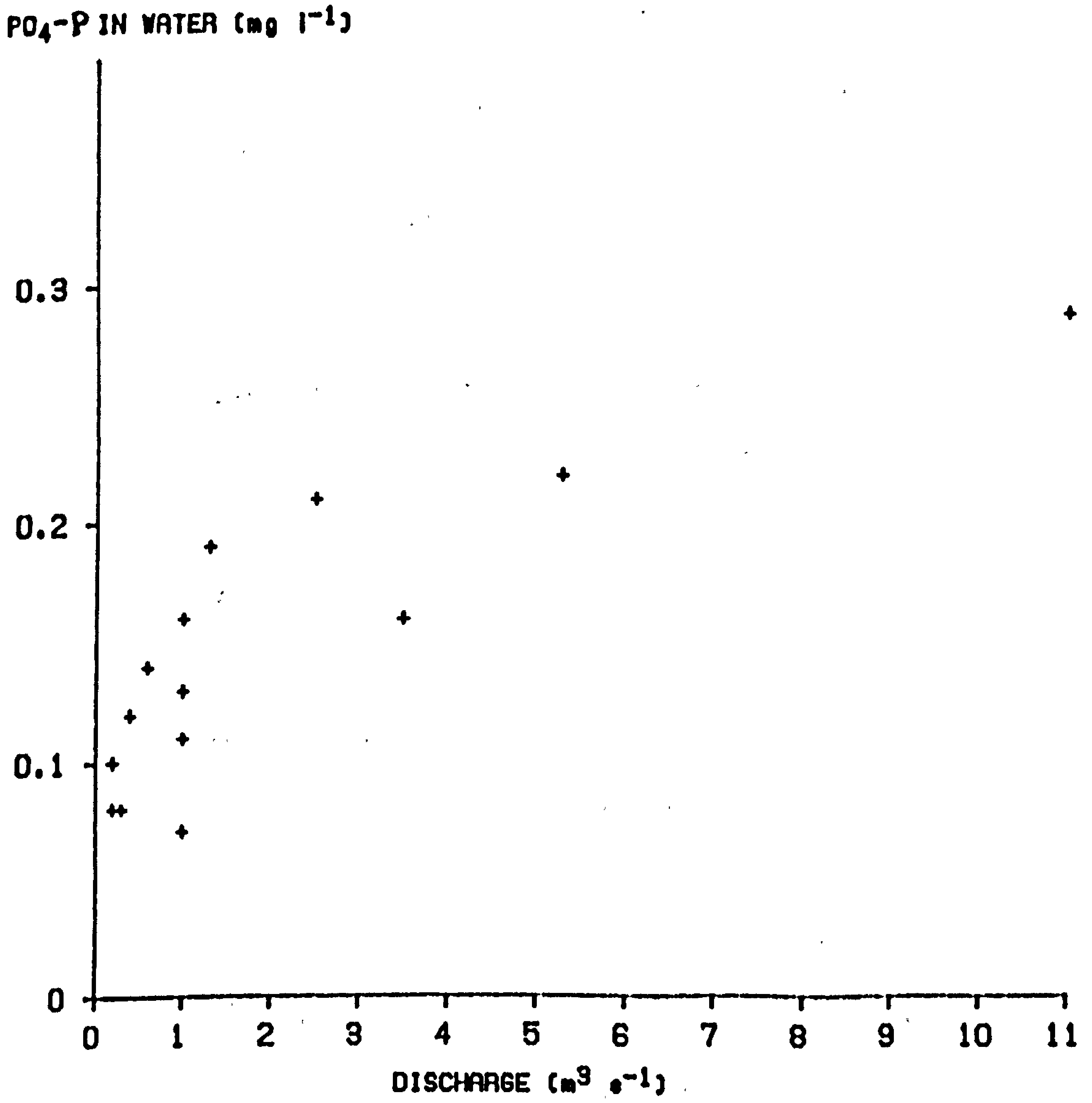


FIG.8·12 RELATIONSHIP BETWEEN DISCHARGE AND [PO_4-P] IN WATER AT HIGHER NORTH MILL ON 20 MARCH 1988



8.6 PHOSPHORUS CONCENTRATION IN MARSH AREA:

The marsh area (Fig. 8.13) receives sediment-associated phosphorus from all parts of the catchment via the stream. Samples of the sediment from the marsh area were analysed. Figures 8.14 and 8.15 show the water- soluble and exchangeable phosphorus concentration in the marsh sediment in the Lower and Higher Leys at three depths from each sampling location (Fig. 8.13). Water-soluble phosphorus concentration is comparatively low whereas exchangeable phosphorus concentration is very high, particularly at the surface of the marsh compared with sub layers at 25 and 50 cm depth.

8.7 PHOSPHORUS CONCENTRATION IN THE LEY

The interchange of P between sediments and lake water may play an important role in determining the available P status of lake water. The uptake and release of P by sediments is a function of interacting physical, chemical and biological processes (Syers et al. 1973). The direction of net P transport is generally from lake water to the sediments, presumably due to particle settling and adsorption processes.

Water samples from Slapton Ley were taken (3 replicates of each) at different depths and Fig. 8.13 shows the sampling location. Mean soluble phosphorus concentration in water samples is highest at 1 metre depth (Table XXXX). However, the mean exchangeable phosphorus concentration in

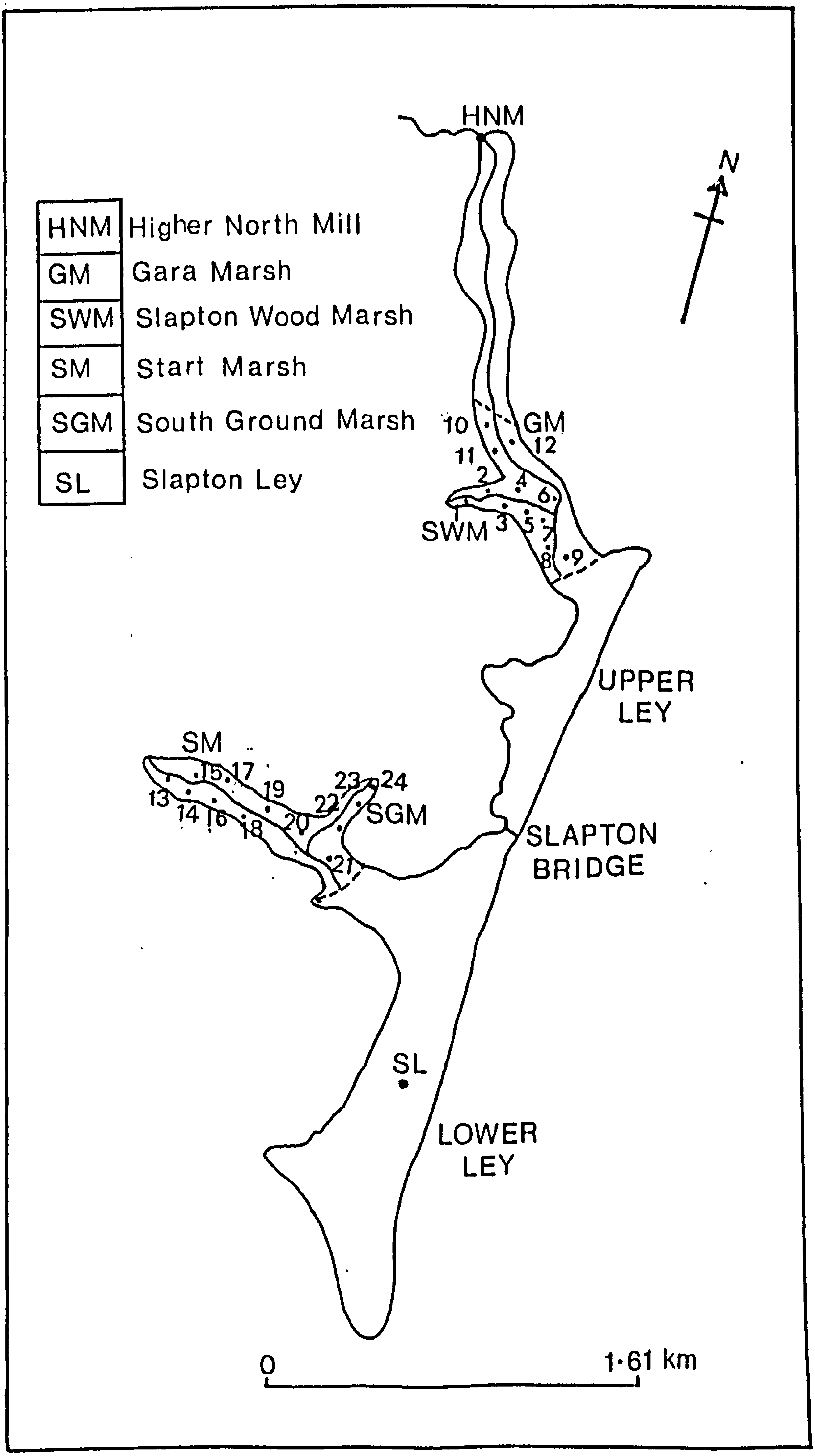


FIG. 8·13 LOCATION OF SAMPLING POINTS AT MARSH

FIG. 8·14. LEVEL OF PO_4–P CONCENTRATION FOR START AND SOUTH GROUND MARSH (s·n from fig.8·13)

FIG. 8.15. LEVEL OF PO_4^--P CONCENTRATION FOR SLAPTON WOOD AND GARA MARSH (s·n REF. FROM FIG. 8·13)

suspended sediment for three samples is greatest in the deeper parts of the Ley.

TABLE: XXXX

SOLUBLE PHOSPHORUS CONCENTATION IN WATER AND EXCHANGEABLE PHOSPHORUS CONCENTRATION IN SUSPENDED SEDIMENT IN SLAPTON LEY

SAMPLE DEPTHS IN Metre	MEAN SOLUBLE [PO_4-P] IN WATER (mg/l)	MEAN EXCHANGEABLE [PO_4-P] IN SUSPENDED SEDIMENT (ppm)
0.5	0.01	241.02
1.0	0.035	281.62
1.5	0.025	252.42
2.0	0.02	448.09

This is possibly due to the adsorption and desorption processes. Dissolved phosphorus compounds added to lake water rapidly disappear from solution. Although this can be explained partly by biological uptake, it is largely due to adsorption of the phosphate ion onto the lake sediment. Phosphorus adsorption increases with decreasing particle size due to. specific surface effects and thus will be most marked in muds of the deeper parts of lake.

Though farm and sewage effluent have high concentrations of phosphorus in soluble form, the proportion of the area compared with the agricultural area is a small portion of the entire catchment. However, the exchangeable phosphorus associated with sediment which is bio-available phosphorus received from arable land, plays an important role with soil erosion as a factor in lake pollution and in particular the transport of phosphorus from field soils to streams and lakes in association with mobile sediment.

CHAPTER 9

SUMMARY AND CONCLUSIONS

This chapter summarises the previous chapters and present the conclusions.

The aim of this study was to investigate and characterise the role of soil erosion as a factor in lake pollution and in particular the transport of phosphorus from field soils to streams and lakes in association with mobile sediment in the Slapton Ley catchment.

Four main streams which contribute freshwater, suspended sediment and nutrients, drain into the Higher and Lower Leys. Suspended sediment contributes to the infilling of the Ley and silting of lake shore habitats most visibly around the Higher Ley. This silting alters the physical fabric of the nature reserve and promotes ecological changes through modification of nutrient status particulaly phosphorus. The inputs of phosphorus draining into the Ley represent a great loss for the combined drainage area. The available data show an increase of soluble phosphorus in water and suspended sediment load over the 13 year period (i.e. from 1974 to 1987/88) (Table V). The environmental impact of land use changes inevitably affects the stream system. There is an obvious shift from pasture to arable land use which will increase the ploughed acreage of the catchments thus probably increasing the erosion potential.

Four land uses; cereal/temporary grass, arable, grass and woodland were selected as representative of the

Slapton Ley catchment for studying the variations in phosphorus level in soil. The surface soil samples were taken using a grid sampling method and each sample was analysed twice to determine the water soluble and exchangeable phosphorus levels. The results from the different land uses were analysed using statistical techniques such as analysis of variance and Mann Whitney U test. Transects from each land use were classified according to the level of phosphorus as well as slope angles using Spearman's rank correlation procedure. The results from the different land uses were compared.

During thirteen rainfall events evidence was gathered of overland flow, sediment translocation, soil loss and phosphorus loss from four representative land use areas which represent non-point sources. The various factors responsible for these losses, such as soil texture, rainfall, rainfall intensity, infiltration capacity, slope angle and crop cover were analysed.
The monitored losses were compared with the predicted losses which were obtained using the CREAMS model.

Wherever possible point water samples from thirteen different sources were taken (136 in all) and analysed to determine the level of phosphorus during an intense storm over the whole catchment. Similar levels of phosphorus were grouped using discriminant analysis.

During an intense storm, evidence was gathered concerning stream discharge, stream suspended sediment, phosphorus in discharge water and suspended sediment transfer to the Ley from the Gara catchment. Levels of phosphorus from stream bed sediment, marsh sediment and Ley suspended sediment were also determined.

With all the above evidence, soil erosion as a factor in lake pollution was evaluated.

In Chapter 1, the aim of the study, the eutrophication of lake, phosphorus species in natural water systems, field site, sources of phosphorus in a lake system, processes, adsorption of phosphate, specific objectives and the organisation of the thesis were outlined.

Several environmental factors thought to be responsible for lake pollution by soil erosion such as the regional physiography, geology, climate, soil hydrology and vegetation were investigated to examine the general nature of the overall environmental conditions in the study area. Differences in vegetation were noted, as was evidence of man's influence. These observations suggested that the configuration of the surface had been influenced to some extent by regional physiography and geology, and factors such as climate, soil hydrology and vegetation appeared to play a significant role in causing detailed variations in the level of phosphorus concentration due to soil erosion.

Chapter 4, reviewed the relevant available data. The annual inputs of water soluble phosphorus and suspended sediment to Slapton Ley from each catchment for 1974 were compared with April 1987 to March 1988 data. The observations indicated that there had been an increase of soluble phosphorus in water and suspended sediment load over a 13 year period. The investigation of land utilization suggested that there is a significant shift to cereal and root production thus increasing the ploughed acreage of the catchments. Also observation showed that the fertilizer application rates for the Slapton catchment exceeded the U.K average for phosphorus inputs with the exception of root crops. The high level for arable suggested that the general shift to arable land use in the catchment may have substantially increased the phosphorus load to the stream system.

Available soluble phosphate load inputs data to Slapton Ley for 1984 were noted. These indicated that the phosphate load inputs to Slapton Ley came not only from the general catchment area but also significantly 14% from the sewage works of the village. Available photographic evidence at Slapton Ley suggested that reeds have grown over the last 44 years. In the lower Ley reeds have begin to retreat at the edge of the Ley. This observation suggests that nuisance growths can occur in one geographical area but not in another. However, photographic evidence suggested that algae is growing at Slapton Bridge. Therefore the concentration of phosphorus of the Slapton Ley water is possibly more than the critical value for eutrophication.

Chapter 5 discussed the soil phosphorus levels in the four representative land uses areas. The Slapton Ley catchment landuse was identified using aerial photographs, the latest available land use map and a field survey, and from this information the land use map was produced which is given in Chapter 5. This shows that the Slapton Ley catchment has four main land use categories: cereal, arable, grass and woodland. In this chapter the four representative selected land uses were described. The land uses varied in size, elevation, slope angle and vegetation. Differences in surface soil texture were also noted. The surface soil samples from the selected land use areas were analysed twice to determine the water-soluble and exchangeable phosphorus levels. The results suggested that the water soluble phosphorus is at much lower concentration than the exchangeable phosphorus concentration for the four land uses. The results indicated that the concentration of exchangeable phosphorus is higher in grassland than the other land uses. The high level of phosphorus concentration in grassland can be attributed to the cumulative effect of the cattle waste. However, the observations indicated that, due to soil erosion and a loss of phosphate-rich surface soil, phosphorus concentration is low on steep agricultural slopes because, during intense storms, the finer particles which are usually associated with adsorbed phosphorus may be transported downslope, having been exposed by ploughing. These results indicated that the finer soil particles associated with phosphorus which have been moved downslope may be an important cause of the eutrophication problem.

Chapter 6 discussed the evidence obtained from the plot runoff experiments. It attempted to assess the erosional effects of overland flow and thus to determine the level of phosphorus from different land uses which may be influencing the eutrophication of the lake. The selected plots were described and their difference in slope angle, soil type and land use. Soil materials which were transported by overland flow were collected in sediment troughs and soluble phosphorus and exchangeable phosphorus were measured. Difference of phosphorus level and vegetation were noted, as was evidence of Man's influence. The results were examined to determine whether present processes such as overland flow, infiltration and rainfall intensity were responsible for soil translocation. The evidence led to the conclusion that these contemporary processes are important erosional factors. It was further concluded that slope angle, vegetation cover, surficial soil properties, animal influence and agricultural practice are the main factors influencing sediment transportation by overland flow. Detailed phosphorus variations, while influenced by contemporary processes, appeared to reflect land use and the operation of agricultural practice. It was noticed that the concentration of phosphorus in soluble and exchangeable forms in the transported material was higher for arable land than the other land uses and there are always lower phosphorus concentrations in the woodland. Therefore, from these observations it was concluded that it is the higher level of phosphorus in the transported sediment from arable landuse which may be influencing the eutrophication of the Ley thus supporting the tentative conclusion reached in Chapter 5.

In Chapter 7, prediction of surface soil and phosphorus losses from the agricultural field within the Slapton Ley catchment were estimated for two years (1987, 1988) using the CREAMS model. To see the changes of losses and the threshold level of rainfall amount alterations were made to the crop management input parameters.

The results indicated that predicted surface losses under barley management were more than for kale management during the minimum effective storm rainfall of 25.4mm. Phosphorus losses were more from kale management than barley management (perticularly in sediment) due to the fertilizer application. From these observations of the CREAMS model predications, it can be suggested that a shift from cereal crop management to root crop management and less application of fertilizer for the root crops may reduce the erosion potantial and phosphorus losses.

However, the actual phosphorus losses from the agricultural sources to the Ley using a simple model indicate that phosphorus losses from sediment are 5 times grater than the losses from solution and phosphorus losses from arable land uses such as cereal and root are about 3 times greater than grass land use.

Identification of point sources of phosphorus to the stream (phosphorus concentration in the stream bed, during peak discharges, in the marsh land and in Slapton Ley) was discussed in Chapter 8. The point water samples from 13 different sources were grouped according to the level of soluble phosphorus and exchangeable phosphorus concentration using discriminant analysis. The results indicated that these can be grouped under four levels of phosphorus sources namely 1)arable and cereal 2)grass, road bank, stream bank, tractor path, footpath, marsh and pond 3) wood 4) farm and sewage. Mean value of phosphorus concentration from the point sources was noted. These figures indicated that the agricultural land uses such as arable and cereal provide 2 times more exchangeable phosphorus attached to sediment than the other land uses whereas farm and sewage provided 5 times more soluble phosphorus in water than other sources. The woodland provides least phosphorus to the stream.

Inputs of phosphorus associated with suspended sediment from major sources to the stream were observed. These observation suggested there is a downstream change in the PO_4-P concentration, when the stream receives runoff from agricultural land, farm yards and sewage sources. When the stream receives runoff from woodland or grassland, however, there is no increase in phosphorus concentration of the stream's suspended sediment.

Phosphorus concentration level in stream bed sediment was observed. These observations suggested that the level of phosphorus concentration is higher in the downstream than the upstream bed sediment. It was noted that some parts of the upper stream, however, around the farm yard show the highest concentration of phosphorus in the bed sediment. These observations suggested that some particulate phosphorus is deposited on to the stream bed before the water reaches the Ley.

Phosphorus concentration during peak discharge was examined for the Gara catchment. The results indicated that the ratio of phosphorus concentration in suspended sediment to phosphorus concentration in water is 240: 0.3 and that there is a linear relationship between them during the peak discharge. Peak discharge shows peak suspended sediment concentration. These results suggested that due to soil erosion during intense rainfall, the agricultural areas deliver phosphorus associated with suspended sediment at peak discharge. The phosphorus input to the Slapton Ley from the Gara catchment and phosphorus level in the Slapton were observed. These observations suggested that there is a high PO_4-Pflow in mg/sec of phosphorus delivered from the catchments in water and suspended sediment to the Ley during an intense storm whereas in Slapton Ley surface water samples showed the phosphorus concentration level is lower than in the stream. This suggestion concluded that aquatic plant problems may develop in standing waters at phosphorus values lower than those critical in flowing streams.

Sediment phosphorus levels in the marsh area were also examined. The results indicated that the top layers of the marsh sediment particularly at the surface, have higher phosphorus concentration than the sub-layers and that there are higher levels in sediment than in water.

The level of phosphorus in Slapton Ley water samples was examined. The results indicated that the exchangeable phosphorus concentration in the water sediment is greatest in the deeper parts of the Ley due to phosphorus adsorption increasing with decreasing particle size so that this will be most marked in the suspended muds of the deeper parts of the Ley. From this evidence the following conclusion can be made, that standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments. This again confirms the earlier conclusion that the phosphorus delivered from the catchment due to soil erosion accumulates in the Ley sediment.

Soluble phosphorus is at higher concentration in sewage works effluent. However this effluent contributes a small proportion of P to the Ley compared with the arable land in the catchment.

Therefore it can be concluded that agricultural sources particularly arable land uses (cereal and root) play an important role on soil erosion as a factor in lake pollution and in particular in the transport of phosphorus from field soils to streams and lakes in association with mobile sediment in the Slapton Ley catchment.

9.1 SIGNIFICANCE OF THE THESIS FINDINGS:

In the study area, there are many factors such as litter cover, land use, infiltration capacity, slope angle, soil texture, position of the slope, rainfall amount, rainfall intensity and mainly agricultural management practice which influence overland flow erosion. From plot experiments carried out in the Maluna Creek catchment at Pokolbin, New-South Wales, Loughran, et al. (1980) found that over an approximately average year for precipitation amount, considerable variation in erosion was caused by factors such as vegetation cover, position on the slope and soil type. Ursic and Thames (1959) and Smith (1951) noted that for a given storm, soils of low permeability suffer more erosion by surface wash than do soils of high permeability and high rainfall acceptance. Burt et al. (1982) found that the combination of impermeable bedrock and steep slopes provides ideal conditions for the generation of surface hill slope runoff.

In the Slapton area the "roof- shingle" effect of the litter cover under a mature kale crop and an almost instantaneous response of runoff to rainfall were noted. Kessel (1977) and Peh Cheng Hock (1980) also noted the same response in a forested area.

Many instances of water erosion of arable land have been recorded for example by Anon, 1977; Call, et al. 1975;

Evans, 1971; Evans and Morgan 1974; Hodgson and Palmer, 1971; Morgan, 1974, 1975, 1977; Peacock 1976 and Whitfield, 1971. Skidmore, et al. (1975) and Unger (1968) noted continuous arable cultivation of the soil reduces its organic- matter content. Evans and Nortcliff (1978) found that soils with little organic matter, could be considered liable to erosion. Greenland et al. (1975) noted lack of sufficient organic matter can cause structural instability of the soil.

However, in the study area, during an intense storm the arable land produced greater erosion due to the agricultural management practice than the permanent grass and woodland areas and the phosphorus concentration was always greater in the eroded sediment from the arable land. Duley (1926) found that the major loss of P in runoff to be in the form of eroded soil. Volk (1945), Scarseth and Chandler (1938), Rogers (1941) and Ensminger (1952) noted P losses through erosion under field conditions.

Munn et al., (1973) found that small amounts of erosion particularly of the $< 2\mu m$ fraction were responsible for major P losses. However, in the Slapton area the exchangeable phosphorus concentration in the suspended sediment in stream water is greater than in the plot eroded sediment. This is may be due to the fraction of the eroded sediment which contains clay, silt, sand as Puvaneswaran (1982) noted in the Woung Brook catchment. But, the finer fraction which is in the suspended sediment has greater concentration of P. Sonzogni et al. (1982) also noted that phosphorus associated with suspended sediments in tributaries is high and often represents a large portion of the total annual P loading to lakes. Latterel et al.(1971) showed that sediment has a high capacity to remove orthophosphate from solution, but subsequent release will only occur when the concentration in the water is low. Black (1970) found some phosphate compounds formed are crystalline and dissolve slowly or are transformed further to progressively less plant-available and less water- soluble forms. In either case, most of the P released does not stay in solution but is strongly sorbed by finely-divided soil particles (Marshall, 1964). In the Slapton area, soluble phosphorus concentration in water is very low compared with exchangeable phosphorus concentration in sediment. Because soluble phosphorus is readily available for plant growth, it is called soluble reactive phosphorus. This soluble reactive phosphorus is at higher concentration in sewage works effluent. However this effluent contributes a small proportion of P to the Ley compared with the arable land in the catchment.

Phosphorus has been identified as a major element nutturing the process of lake eutrophication and sewage and urban runoff are common sources (Lund 1972). Sawyer (1947) found that treated sewage effluents formed 15% of the water inflow to a lake but contributed 75% of the nitrogen and 88% of the phosphate inflow, the reminder coming from agricultural runoff in lakes in Wisconsin. Owens and Wood (1968) showed a high proportion of phosphate coming from sewage (80%) but less than 20% of nitrogen from sewage with the remainder coming from agricultural land in the Great Ouse River catchment. Vollenweider (1968) stated that forestry is also one of the P sources along with agriculture and urban development for P loading in many areas. However, in the study area, the agricultural land uses provide more exchangeable phosphorus attached to sediment than the other land uses whereas farm and sewage provides more soluble phosphorus in water than other sources. The wood land provides least phosphorus in either form. M_cCarty (1967) for the Task Force of the American Water Works Association, concluded that runoff from agricultural land is by far the greatest contributor of phosphorus.

White (1979) stated that accelerated eutrophication and the appearance of algal blooms are most likely to occur when the P concentration of the water exceeds 0.05ppm. In the Slapton area the soluble P concentration of P in stream water exceeds 0.05ppm for those stream which receive runoff from arable land (0.45 ppm), sewage (3.15 ppm) and farm (2.50 ppm) but as stated earlier sewage and farm contribute a small proportion of P to the Ley.

Trudgill (1989) stated that phosphate is strongly adsorbed in the soil and even if added in a fertiliser (as an N.P.K. fertiliser) there is little movement of soluble phosphate into stream. The main mechanism for phosphate movement into streams from agricultural land is the movement of phosphate attached to sediment during soil erosion. Also Trudgill (1989) stated that while sediment from soil erosion is a source of phosphate it is only a slowly available source of soluble reactive phosphate. Studies by Johnson, et al. (1976), Huettl, et al. (1979), Schreiber, et al. (1977) and Taylor, et al. (1971) have indicated that 5 to 40 percent of the sediment P is labile. Lee et al. (1979) stated bioavailability of particulate phosphorus has been assumed to be 20 percent of particulate phosphorus.

However, in the study area the principal source of exchangeable phosphate (0.1M NaOH extraction) which is available phosphate for the plant growth is mainly arable land. Golterman (1973) stated that there is no doubt that the availability of P associated with suspended sediment depends upon the mechanism of P sorption as well as the P form. The need to estimate the portion of particulate nutrients that is bioavailable has been recognized (Sharpley and Menzel, 1987; Smith et al. 1986). Sediment-bound nutrients may account for up to 90 percent of the total amount transported in runoff (Schuman et al. 1973a, b; Sharpley et al. 1987), with a variable proportion of this available for biological uptake in water bodies (Sharpley et al. 1988). The development of routine chemical procedures (0.1M NaOH extraction) to determine the bioavailability of particulate phosphorus (Bio P) has shown that it can vary from zero to 95 percent of particulate phosphorus (Dorich et al. 1985; Sharpley and Menzel, 1987; Williams et al. 1980; Wolf et al. 1985).

In the study area, suspended sediments can be described as buffers with respect to phosphate content of water, releasing P from sediments to sustain growth of an algal bloom.

CHAPTER 10

RECOMMENDATIONS FOR STRATEGIES TO MINIMISE PHOSPHORUS LOSSES THROUGH REDUCING EROSION POTENTIAL FROM AGRICULTURAL LAND

Phosphorus(P) in the form of phosphate (PO_4) is essential for plant growth and its application to agricultural land often improves crop yield. The increased plant cover that is possible with proper use of fertilizer can reduce soil erosion from the cultivated area. Addition of phosphorus to fish ponds may also increase fish production. Although P is not toxic, the continued application of P fertilizer can result in the buildup of natural trace contaminants (e.g cadmium, uranium, and radium) contained in the fertilizer. Also the transport of P from the terrestrial to the aquatic environment in surface runoff can result in a deterioration in water quality from accelerated eutrophication which causes algal blooms etc.
In addition to P, nitrogen(N) and carbon(C) are also commonly associated with these problems. However, control of accelerated eutrophication through limiting C and N inputs is restricted, due to the difficuty in controlling atmospheric exchanges of these elements. Thus, P is often the limiting element and its control is of prime importance in reducing the accelerated eutrophication of surface waters.

In the study area, the investigation showed that the catchment undoubtedly delivers P to the Ley. This P can directly stimulate the growth of algae. This rapid growth gives rise to numerous undesirable effects for the treatment of potable water, for fisheries and for recreation. Increase in algal growth is undoubledly caused by increased fertilization of the Ley through the influence of Man and also results from the increase of wastewater addition to the Ley. In addition, numerous washing and cleaning agents that contain a high percentage of phosphates enter into sewage and where this sewage flow is connected to a central purification plant, the flow can be eliminated in a tertiary treatment process before it reaches the Ley. Many isolated houses where the sewer will not be connected a central purification plant within a reasonable time can cause damage. For this reason it would be better to use new detergents which contain no, or very little, phosphate. Also, the need for precipitating material in the purification plants would then be correspondingly less and the running costs lower. New phosphate-free detergents must therefore be well-tested limnologically to safeguard water before they are put on the market.

Evidence indicates that: (a) high phosphorus concentrations are associated with accelerated eutrophication of waters when other growth promoting factors are present; (b) aquatic plant problems develop in standing waters at phosphorus values lower than those critical in flowing streams; (c) standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (d) phosphorus concentrations critical to noxious plant growths vary, and a given concentration will produce nuisance growths in one geographical area but not in another.

Extensive eutrophication caused by intensification of agriculture and by release of increasing volumes of sewage effluent to a waterway of low volume and discharge is occurring in the Slapton catchment. Therefore, it is essential to reduce the phosphorus concentration of Ley water as much as possible to increase the chances of success of further management.

Conventional wisdom recognises that the ultimate solution to eutrophication problems must be the reduction in input of at least one key nutrient to a concentration level which will severely limit algal growth. Because its compounds are relatively insoluble and easily precipitated, phosphate is usually chosen. Phosphorus also comes from many sources as described in Chapters 6 and 8. The restoration of a high-diversity ecosystem may eventually need phosphorus control.

10.1 PHOSPHORUS CONTROL:

Phosphorus control requires several steps:

a) determination of the various phosphorus sources.

b) establishment of a desirable target concentration.

c) calculation of how that target might be most economically achieved.

d) implementation of the necessary engineering works.

In the Slapton area, there is evidence of many individual sources of phosphorus. These include field drainage, effluent from the septic tanks of cottages, stock and silage effluent from farm yards and sewage treatment works effluent. The sewage treatment works are few compared with the other categories, and hence can be most effectively controlled. The other sources are too numerous to justify individual control and their influences may change greatly from year to year with changes in weather and farming practice. However, evidence shows that the level of phosphorus concentration is higher from the arable landuse sources than the other sources, followed by farms and sewage.

10.2 CONTROL OF CHEMICAL POLLUTION:

Theoretically it should be possible to adjust the application of fertilizer so that all is taken up by the plants, leaving no surplus to be leached out to create a pollution problem. In practice there will always be some leaching losses, although this is not at all the farmer's wish or intention. In areas of high rainfall the surplus will be removed by surface or sub-surface drainage, and this is bound to contain soluble nutrients. The only practical solutions are to minimize surface run-off and surface erosion and thus reduce the supply of nutrients to surface waters.

10.3 MANAGEMENT:

The principles of land management are well known, as they are the same as for other climatic zones: the importance of mulch or crop cover, the need for controlled flow of surface water, the association between efficient farming and good erosion control and many others (Hudson, 1971). Management practices such as intensification and mechanization, bring new erosion hazards. Therefore more local studies of different management practices are required.

10.3.1 SOIL, LAND AND CROP MANAGEMENT:

The best soil and land management might be defined (Morgan 1986) as " the most intensive and productive use of which the land is capable without causing any land degradation." Soil and land management practices are based on two broad principles.

a) those practices which help maintain soil infiltration rates at sufficiently high levels to reduce runoff to a negligible amount; and

b) practices which help safe disposal of runoff water from the field, should rainfall exceed the infiltration capacity of the soil.

Cultural practices which help maintain a high soil infiltration rate are essentially based on farming techniques which maintain a mulch or live vegetation on the soil, such as stubble mulching and no-tillage or minimum tillage, and use of cover crops. The safe disposal of runoff water may involve physical manipulation of soil, including land-shaping, construction of contour bunds, terraces, waterways, ridges or tied ridges (Hudson 1957).

In Slapton, the amount of soil erosion which occurred during the study period, particularly in 1988, was influenced not only by the soil itself, but by the treatment or management it received. Model estimates of soil losses were about 3429 kilograms per hectare in 1988 when used for the cultivation of kale crop, while similar soil under a barley crop lost about 4707 kilograms per hectare. The difference in erosion was presumably caused by the different management of the same soil. In fact erodibility is influenced more by management than by any other factors, and management includes both the broad issues of land management and the detailed decisions of crop management and the nature of the crop. This indicates that erosion is greatly affected by different kinds of land use, but within any particular land use, there can be large variations in the amount of erosion depending upon the detailed management of the crops. Therefore, it can be recommended that a shift from cereal land use to root land use for the whole catchment will probably reduce the erosion potential. However, the phosphorus losses are more from kale crop (1.17kg/ha than barley crop (0.79kg/ha) management. As stated earlier a root crop receives 109kg/ha whereas a cereal crop receives 53kg/ha. These clearly shows that more fertilizer application produces more P losses.

The estimated results indicate that the actual phosphorus loss is greater in sediment than in solution from in agricultural area and grater in arable (cereal and root) than in grass land to the Ley. Therefore it can be concluded that soil erosion is an important factor causing lake pollution by transporting phosphorus with sediment.

10.4 APPROACHES TO SOIL CONSERVATION:

Conservation policies of land-use must be positive and encouraging, not restrictive. There is no point in preserving soil and not using it - the demand of the world is for its resources to be used as efficiently as possible without waste.

The best aid to ensuring efficient land-use is undoubtedly land capability classification. The essential features are that, first, the available facts about a piece of land are collected in a special survey. These include items like the soil type, depth, drainage characteristics, and the slope of the land, which can all be measured or assessed in the field. On the basis of these measured variables the land is classified. These classes reflect the risk of soil erosion, and so indicate the combination of management practices which will be required if the land is to be used.

10.5 STRATEGIES:

The strategies for soil conservation must be based on covering the soil to protect it from raindrop impact, increasing the infiltration capacity of the soil to reduce runoff, improving the aggregate stability of the soil, and increasing surface roughness to reduce the velocity of runoff (Morgan, 1979).

Agronomic or biological measures for land conservation, utilize the role of vegetation in helping to minimize erosion. Soil management is concerned with ways of preparing the soil to promote dense vegetative growth and improve its structure so that it is more resistant to erosion. Mechanical or physical methods depend upon manipulating the surface topography, for example, by installing terraces or shelterbelts, to control the flow of water.

In the study area, as in Fig. 10.1, by growing grass belts at the bottom of the agricultural slopes, it would be possible to stop the sediment entering the river. This will definitly help to minimise the lake water phosphorus levels which are largely derived from suspended sediment from the catchment.

An erosion- control strategy is just as important as the ability of the engineer to design the conservation structures required. Correct identification of the major areas of erosion and therefore the main sources of sediment is essential as identified in this study.

Reducing the erosion potential of the catchment will definitely help to minimise the phosphorus losses which are a factor in lake pollution.

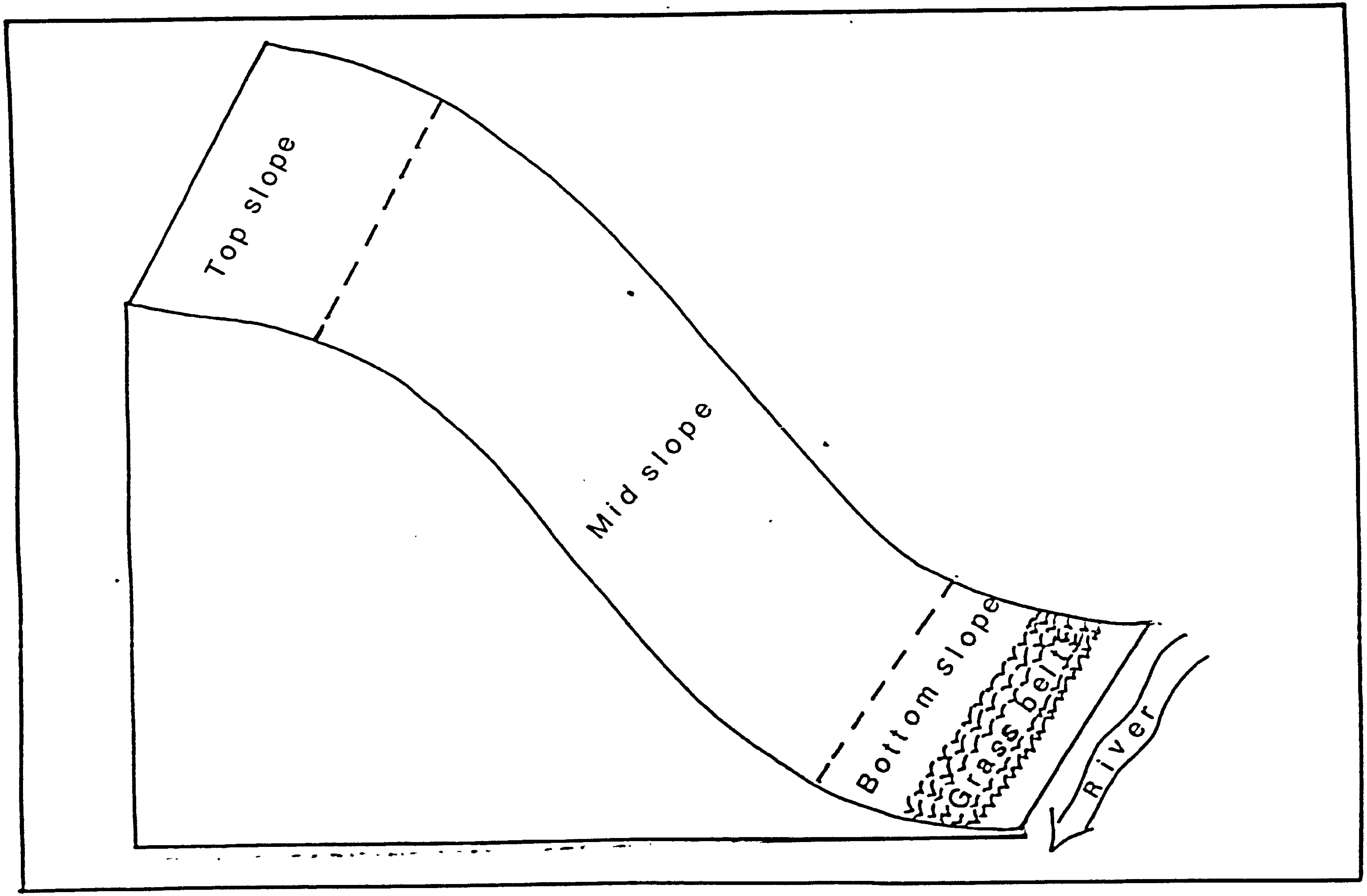


FIG. 10·1 GRASS BELT TO STOP SEDIMENT ENTERING THE RIVER

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APPENDIX 1

PROCEDURE FOR PHOSPHATE ANALYSIS:

1) Preparation of sample solution for water soluble phosphate
    - a) Weigh 12.5g wet soil
    - b) Determine moisture at time of weighing
    - c) Add 50ml distilled water
    - d) Shake 30 minites
    - e) Filter through No.1, 9.0cm and No. GF/C 4.7cm filter papers
2) Preparation of sample solution for exchangeable phosphate (see Plate 17)
    - a) Extractant:
        - i) Olsen's reagent : 0.5M Na HCO_3 buffered at pH 8.5
        - ii) Dissolve 210g $NaHCO_3$ in water in an aspirator and add 100ml M N_aOH
        - iii) Dilute to 5 litres and mix well
        - iv) Check that the pH is 8.5 + or - 0.05
    - b) Procedure:
        - a) Weigh 5g air- dry sieved soil into a polythene bottle
        - b) Determine moisture at time of weighing
        - c) Add 100ml Olsen's reagent
        - d) Shake for 30 minutes on a rotary shaker

Plate 17. Preparing solution to determine " P "

- e) Filter through No. 1, 9.0cm and No. GF/C 4.7cm filter paper
- f) Run blank extractions and subtract where necessary

Reagents used for the phosphate analysis.

1) Phosphorus standards
2) Ammonium molybdate
   - a) Antimony potassium tartrate
   - b) Sulphuric acid ($H_2 SO_4$)
   - c) Ascorbic acid

1) Phosphorus standards
   - a) Stock solution (1ml = 0.1mg P) - dissolve 0.4393g dry $KH_2 PO_4$ in water and dilute to 1 litre.
   - b) Working standard (1ml = 0.002mg P) - dilute the stock solution 50 times. Make up fresh at intervals.

2) i) Reagent A

Dissolve 12g of ammonium molybdate in 250ml of distilled H_2O. In 100ml of distilled H_2O dissolve 0.2908g of antimony potassium tartrate. Add both of the dissolved reagents to 1000ml of 5N $H_2 SO_4$ (148ml concentrated $H_2 SO_4$ / litter), mix thoroughly and make to 2,000ml. Store in Pyrex glass bottle in a dark and cool compartment.

ii) Reagent B

Dissolve 1.056g of ascorbic acid in 200ml of reagent A and mix. This reagent should be prepared as required as it does not keep for more than 24 hours.

Procedure:

1) Prepare the sample solution
2) Pipette 0 to 8ml of working standard range from 0 to 0.016mg P
3) Pipette 10ml sample solution into 25ml volumetric flask
4) Add 4ml ammonium molybdate reagent and mix
5) Dilute up to 25ml
6) From this point treat standards and samples in the same way
7) Measure the optical density at 700nm wavelength using Spectrophotometer (see Plate 18)
8) Prepare a calibration curve from the standards and use it to determine mg P in the sample aliquot
9) Carry out blank determinations in the same way and subtract where necessary
10) Calculation:

$$PO_4^{3-}(mg/100g) = \frac{C(mg) \times \text{Solution Volume}}{10 \times \text{aliquot(ml)} \times \text{Sample dry Wt.}} \times 10^3$$

$$PO_4^{3-} \times \frac{31}{95} = PO_4\text{-}P = \text{Phosphorus}$$

Plate 18. Measuring " P " using Spectrophotometer

APPENDIX 2

Field Data Worksheet for the CREAMS Model

I. Climatological Data

A. Location of field

State South Devon County Slapton.

B. Nearest local climate station

State South Devon City Slapton.

C. Location and name of nearest State experiment station, if any:

Slapton field centre

II. Topographic and Soils Data

A. A topographic map of the field is needed. Is a field grid survey or topographic map available? Yes (YES or NO) If yes, please provide a copy. Provided

Is a USGS topographic map available? (YES or NO) If yes, provide a copy or give name of topographic map.

B. Aerial Photo

A copy of the aerial photo with the field and soils delineated is needed. Also, designate row direction. Provided

C. Is there a county soil survey available? (YES or NO) If yes, please provide a copy with the field drawn on the appropriate soil map.

If no, please delineate and label the soils on the aerial photo. Estimate of soil boundaries is adequate.

III. Crops and Cultural Practices

A. Single crop ✓ Crop rotation

Double crop Native range Pasture

B.

Crops	Plant date or grazing start date(s)	Harvest date(s) or grazing end date(s)	Maximum active root zone (inches)
Kale	June 30	Nov 30	22

Example of field data worksheet for CREAMS (page 1 of 3).

IV. Farming Operation in Field

Date	Type of operation	Tillage depth
June 17	Ploughed	
July 1	Fertilizer applied	
July 17	Seeded or planted	
December 13	Harvested.	

V. Chemical Operations

A. Fertilizer

Date of application	Quantity by formula	Method of application (injected, surface, etc.)
July 1	206 N, 109 P kg/ha.	Surface-topdress

If the farmer has a recent soils analysis, please provide copy.

B. Pesticides

Date of application	Type of pesticide	Trade or generic name	Rate of application of active ingredient (units)	Method of application

VI. Conservation Practices Applied

None

Example of field data worksheet for CREAMS (page 2 of 3).

VII. What are the recommended resource management systems for this field? (list only 2 systems)

A. Winter cover crop.

B. ____

VIII. What has been the cropping history of this field? (Brief narrative is satisfactory, unless there has been a radical change in land use or chemicals applied in the last 5 years.)

____

IX. Outlet Ditch Receiving Runoff Water from Field

A. Shape (circle one): Triangular Rectangular [✓ Naturally eroded]

B. Dimensions:

Slope of ditch banks (horizontal/vertical) 6 ft/ft

Grade of ditch (vertical/horizontal) 0.167 ft/ft

Length 600 ft Top width 800 ft

Depth ____ ft Bottom width (if rectangular) ____ ft

C. Vegetative cover conditions (circle one):

Excellent Good [✓ Fair] Poor

Very poor, primarily bare soil Bare soil

D. Soil texture Silty Loam.

E. Is there a culvert or bridge that constricts runoff? (YES or [✓ NO])
If yes, attach a sketch showing the dimensions.

X. Terraces (Present or Recommended)

A. Slope of terrace channel (vertical/horizontal) ____ ft/ft

B. For underground outlet terraces, height of fill is ____ ft and inside diameter of orifice in riser is ____ inches.

District Conservationist Date Phone Number

Example of field data worksheet for CREAMS (page 3 of 3).

APPENDIX 3

WATER SOLUBLE AND EXCHANGEABLE PHOSPHORUS CONCENTRATION DATA PRESENTED IN DUPLICATE SOIL

CEREAL LAND USE / TEMPORARY GRASS

Sample No. (Ref. from Fig. A3.1)	Water soluble $[PO_4\text{-}P]$ (ppm) in soil		Exchangeable $[PO_4\text{-}P]$ (ppm) in soil	
	1	2	1	2
1	0.07	0.07	22.1	22.0
2	0.01	0.05	18.0	22.2
3	0.09	0.05	19.1	21.5
4	0.08	0.12	16.0	16.0
5	0.003	0.003	20.0	22.0
6	0.30	0.42	22.8	26.4
7	0.33	0.39	29.2	29.2
8	0.10	0.10	22.0	26.0
9	0.10	0.10	14.4	14.3
10	0.01	0.05	10.0	10.2
11	0.13	0.13	6.0	10.0
12	0.03	0.03	7.0	7.1
13	0.11	0.15	8.5	8.0
14	0.25	0.21	27.1	31.0
15	0.42	0.42	28.9	28.0
16	0.03	0.03	5.1	5.1
17	0.03	0.03	10.0	10.2
18	0.04	0.02	5.3	5.6
19	0.08	0.06	12.0	14.0
20	0.03	0.03	9.0	9.0
21	0.10	0.16	7.2	7.3
22	0.10	0.10	6.0	8.0
23	0.13	0.07	7.5	9.6
24	0.40	0.44	24.3	28.0
25	0.005	0.001	4.0	4.0
26	0.003	0.003	5.0	7.0
27	0.09	0.05	5.1	5.0
28	0.10	0.10	5.1	5.0
29	0.15	0.11	5.2	7.2
30	0.10	0.10	6.0	6.3
31	0.03	0.03	4.0	4.0
32	0.15	0.11	8.0	8.0
33	0.10	0.10	10.1	6.3
34	0.48	0.44	29.0	25.0
35	0.10	0.10	4.0	8.0
36	0.10	0.10	4.0	4.0
37	0.09	0.17	5.5	5.2

CEREAL LAND USE / TEMPORARY GRASS

Sample No. (Ref. from Fig. A3.1)	Water soluble $[PO_4-P]$ (ppm) in soil		Exchangeable $[PO_4-P]$ (ppm) in soil	
	1	2	1	2
38	0.06	0.08	4.0	6.2
39	0.07	0.07	6.3	8.0
40	0.03	0.03	8.2	6.0
41	0.10	0.10	6.0	6.0
42	0.17	0.15	6.0	6.0
43	0.10	0.10	9.0	5.0
44	0.10	0.10	8.2	8.3
45	0.02	0.04	4.0	4.0
46	0.03	0.03	9.1	5.3
47	0.20	0.20	5.0	5.0
48	0.001	0.005	4.0	4.0
49	0.13	0.13	6.0	2.0
50	0.38	0.40	6.3	6.2
51	0.15	0.11	3.0	5.2
52	0.07	0.07	8.1	8.8
53	0.16	0.16	5.2	5.0
54	0.18	0.14	5.0	5.0
55	0.20	0.20	5.0	5.0
56	0.10	0.10	13.0	15.0
57	0.15	0.11	7.6	7.0
58	0.16	0.10	7.0	7.0
59	0.07	0.o7	4.4	8.1

ARABLE LAND USE (ROOT)

Sample No. (Ref. from Fig. A3.1)	Water soluble [PO_4-P] (ppm) in soil		Exchangeable [PO_4-P] (ppm) in soil	
	1	2	1	2
1	0.25	0.33	11.0	11.0
2	0.06	0.64	14.0	16.4
3	0.20	0.20	6.4	6.0
4	0.27	0.31	10.0	10.0
5	0.10	0.10	12.3	16.0
6	0.21	0.25	12.5	12.0
7	0.03	0.03	6.1	6.0
8	0.11	0.15	6.0	6.3
9	0.38	0.34	4.0	4.1
10	0.03	0.03	12.4	12.0
11	0.33	0.33	7.3	11.0
12	0.06	0.06	9.0	9.0
13	0.18	0.14	4.1	4.3
14	0.25	0.33	4.0	14.2
15	0.03	0.03	11.0	11.0
16	0.02	0.04	4.1	12.2
17	0.05	0.09	6.0	6.0
18	0.24	0.28	6.0	6.0
19	0.03	0.03	7.3	7.0
20	0.09	0.05	6.0	6.0
21	0.003	0.003	12.4	4.2
22	0.08	0.06	6.0	10.0
23	0.15	0.11	9.0	9.3
24	0.15	0.11	7.0	7.2
25	0.06	0.00	7.0	9.0
26	0.08	0.08	12.1	12.4
27	0.05	0.02	12.0	12.0
28	0.92	0.90	13.3	13.0
29	0.18	0.14	11.0	15.0
30	0.07	0.07	20.0	20.5
31	0.16	0.16	8.0	8.6
32	0.10	0.10	12.1	12.0
33	0.30	0.36	12.0	12.0
34	0.07	0.07	6.0	6.0
35	0.05	0.01	17.2	13.0
36	0.07	0.07	16.0	16.0
37	0.13	0.13	6.2	10.0
38	0.01	0.05	14.0	14.0
39	0.09	0.05	9.2	9.0
40	0.03	0.03	12.0	16.0
41	0.05	0.09	10.2	10.0
42	0.16	0.16	11.0	11.0
43	0.16	0.16	10.2	10.4
44	0.24	0.34	8.0	12.5
45	0.05	0.09	10.4	16.1

ARABLE (ROOT)

Sample No. (Ref. from Fig. A3.1)	Water soluble [PO_4-P] (ppm) in soil 1	2	Exchangeable [PO_4-P] (ppm) in soil 1	2
46	0.16	0.16	10.0	10.0
47	0.07	0.07	12.0	24.0
48	0.13	0.13	36.3	42.0
49	0.03	0.03	20.1	20.1
50	0.24	0.34	9.0	9.1
51	0.30	0.36	10.0	12.9
52	0.07	0.07	17.2	17.4
53	0.20	0.26	14.2	14.0
54	0.16	0.16	36.0	40.3
55	0.60	0.70	8.0	20.0
56	0.10	0.16	34.4	34.4
57	0.03	0.03	15.1	15.0
58	0.07	0.09	19.4	19.0
59	0.11	0.13	16.1	23.4
60	0.10	0.10	18.1	21.0
61	0.10	0.10	19.0	19.0

GRASS LAND USE

Sample No. (Ref. from Fig. A3.1)	Water soluble [PO_4-P] (ppm) in soil		Exchangeable [PO_4-P] (ppm) in soil	
	1	2	1	2
1	0.45	0.54	37.0	37.0
2	0.13	0.13	27.0	31.0
3	0.05	0.09	30.2	34.3
4	0.39	0.39	50.0	54.2
5	0.15	0.11	27.2	27.0
6	0.03	0.03	37.2	41.0
7	0.02	0.04	20.0	20.5
8	0.42	0.30	28.0	30.6
9	0.05	0.01	24.2	24.0
10	0.24	0.28	21.1	27.0
11	0.10	0.10	23.1	29.3
12	0.16	0.10	29.1	21.0
13	0.07	0.07	28.5	28.1
14	0.10	0.10	30.3	32.1
15	0.18	0.14	37.0	37.0
16	0.16	0.16	48.2	50.2
17	0.14	0.12	39.0	39.0
18	0.17	0.15	30.4	30.2
19	0.07	0.07	36.0	32.0
20	0.07	0.07	25.0	25.0
21	0.18	0.22	22.6	22.0
22	0.03	0.03	27.0	31.0
23	0.14	0.18	16.3	14.5
24	0.13	0.13	13.0	17.0
25	0.22	0.18	11.0	11.0
26	0.20	0.20	12.1	12.2
27	0.11	0.09	17.4	15.0
28	0.03	0.03	18.1	16.5
29	0.26	0.20	16.0	16.0
30	0.003	0.003	27.3	23.2
31	0.16	0.10	35.0	35.0
32	0.07	0.07	16.0	16.0
33	0.003	0.003	14.4	12.0
34	0.10	0.10	20.1	20.1
35	0.08	0.12	18.0	14.9
36	0.003	0.003	14.0	18.0
37	0.03	0.03	12.0	12.3
38	0.10	0.10	6.0	6.0
39	0.18	0.22	4.4	4.1
40	0.12	0.08	6.0	8.0
41	0.01	0.05	19.2	15.0
42	0.79	0.85	17.0	17.0
43	0.07	0.07	13.3	13.3
44	0.33	0.33	20.0	20.0

GRASS LAND USE

Sample No. (Ref. from Fig. A3.1)	Water soluble [PO_4-P] (ppm) in soil		Exchangeable [PO_4-P] (ppm) in soil	
	1	2	1	2
45	0.07	0.07	16.3	20.2
46	0.07	0.07	19.0	19.0
47	0.07	0.07	10.0	10.0
48	0.10	0.16	6.0	10.0
49	0.20	0.20	4.0	4.0
50	0.16	0.10	8.0	10.0
51	0.07	0.07	11.2	11.3
52	0.10	0.10	9.0	9.0
53	0.05	0.09	15.0	19.4
54	0.05	0.09	13.0	13.0
55	0.07	0.07	12.4	14.6
56	0.07	0.07	17.0	17.0
57	0.07	0.07	11.0	11.0
58	0.18	0.14	11.3	15.0
59	0.10	0.10	13.2	13.6
60	0.10	0.10	13.0	13.0
61	0.10	0.10	19.4	15.2
62	0.16	0.10	14.0	16.0
63	0.08	0.12	10.1	12.0
64	0.16	0.10	12.2	16.3
65	0.16	0.16	22.0	20.6
66	0.10	0.10	13.3	13.0
67	0.16	0.10	11.0	11.0
68	0.10	0.10	11.0	15.0
69	0.18	0.14	10.0	12.0
70	0.08	0.12	8.3	8.0

WOOD LAND USE

Sample No. (Ref. from Fig. A3.1)	Water soluble [PO_4-P] (ppm) in soil 1	2	Exchangeable [PO_4-P] (ppm) in soil 1	2
1	0.10	0.10	18.3	12.0
2	0.12	0.10	14.2	12.1
3	0.18	0.22	14.0	16.0
4	0.10	0.10	12.1	12.1
5	0.09	0.05	17.2	19.0
6	0.08	0.06	10.1	10.3
7	0.46	0.51	19.0	18.3
8	0.19	0.13	16.0	16.0
9	0.10	0.16	16.0	14.0
10	0.16	0.16	14.2	14.2
11	0.10	0.10	15.3	15.0
12	0.10	0.16	16.1	14.4
13	0.05	0.09	10.4	14.3
14	0.20	0.20	9.0	7.0
15	0.08	0.12	8.4	6.4
16	0.05	0.09	7.0	7.3
17	0.10	0.10	7.2	7.6
18	0.07	0.07	4.2	6.0
19	0.01	0.05	14.0	10.0
20	0.16	0.16	10.3	10.7
21	0.09	0.05	7.0	7.1
22	0.26	0.26	5.1	7.8
23	0.10	0.10	12.0	12.0
24	0.28	0.24	5.2	5.6
25	0.10	0.10	3.0	5.0

FIG. A3·1 Location of soil sampling

APPENDIX 4

SOLUBLE AND EXCHANGEABLE PHOSPHORUS CONCENTRATION DATA PRESENTED FOR POINT WATER SAMPLES

Sample No.	Soluble [PO_4-P] (mg l^{-1}) in water	Exchangeable [PO_4-P] (ppm) in sediment
1	0.34	140.85
2	0.41	130.65
3	0.10	110.89
4	0.26	200.10
5	0.06	120.15
6	0.06	130.18
7	0.16	240.99
8	0.28	240.65
9	0.32	140.38
10	0.23	130.28
11	0.10	130.81
12	0.13	120.15
13	0.51	150.10
14	0.14	130.18
15	0.71	160.46
16	0.15	140.14
17	0.17	180.25
18	0.29	130.19
19	1.40	240.12
20	0.27	140.24
21	0.10	220 18
22	0.07	230.15
23	0.08	130.24
24	0.35	230.80
25	0.12	240.60
26	0.25	140.17
27	0.24	130.24
28	0.24	200.10
29	0.30	240.25
30	0.20	130.22
31	0.56	250.18
32	0.32	140.14
33	0.10	150.19
34	0.21	130.90
35	0.90	180.12
36	2.90	190.15
37	2.80	180.12
38	1.10	180.30
39	0.90	170.30
40	0.90	160.16
41	3.20	180.12
42	3.20	190.14

Sample No.	Soluble $[PO_4\text{-}P]$ (mg l^{-1}) in water	Exchangeable $[PO_4\text{-}P]$ (ppm) in sediment
43	2.80	180.12
44	6.00	200.15
45	4.60	180.12
46	1.90	190.18
47	2.50	170.15
48	3.10	150.12
49	3.80	180.13
50	4.00	160.16
51	2.40	190.20
52	4.10	180.12
53	2.60	160.12
54	4.80	190.13
55	3.20	140.10
56	1.40	180.12
57	1.80	190.17
58	1.90	160.24
59	4.20	180.10
60	3.20	180.25
61	0.80	170.10
62	2.00	180.12
63	1.20	180.39
64	3.60	160.12
65	4.60	170.14
66	2.40	160.12
67	2.40	100.11
68	1.50	120.13
69	4.90	180.19
70	5.90	170.12
71	0.70	160.12
72	3.20	150.10
73	3.80	140.10
74	3.60	180.16
75	3.20	190.21
76	0.09	100.12
77	0.10	120.13
78	0.61	100.10
79	0.08	80.91
80	0.14	110.16
81	0.11	100.14
82	0.04	110.91
83	0.05	100.18
84	0.04	120.12
85	0.32	190.27
86	0.09	180.32
87	0.09	160.40
88	0.25	240.00
89	0.15	220.16
90	0.21	110.14

Sample No.	Soluble [PO_4-P] (mg l^{-1}) in water	Exchangeable [PO_4-P] (ppm) in sediment
91	0.23	220.16
92	0.16	110.11
93	0.03	160.30
94	0.03	110.80
95	0.06	170.14
96	0.08	180.91
97	0.08	190.14
98	0.05	110.89
99	0.05	190.99
100	0.06	90.26
101	0.05	180.18
102	0.06	140.19
103	0.03	120.16
104	0.15	110.84
105	0.02	40.11
106	0.03	160.17
107	0.02	160.90
108	0.15	180.14
109	0.06	100.12
110	0.04	200.00
111	0.03	200.00
112	0.04	120.25
113	0.02	220.10
114	0.02	210.16
115	0.03	180.12
116	0.06	40.56
117	0.05	190.18
118	0.06	220.16
119	0.03	210.18
120	0.04	190.00
121	0.04	30.16
122	0.04	20.25
123	0.05	180.40
124	0.06	160.13
125	0.16	170.50
126	0.36	40.04
127	0.03	40.90
128	0.06	40.23
129	0.06	170.20
130	0.08	30.84
131	0.05	30.15
132	0.06	40.24
133	0.06	30.16
134	0.06	150.14
135	0.06	120.68
136	0.08	120.96
137	0.08	130.16
138	0.10	130.90
139	0.03	20.19

Sample No.	Soluble [PO_4-P] (mg l^{-1}) in water	Exchangeable [PO_4-P] (ppm) in sediment
140	0.045	120.24
141	1.22	120.41
142	0.02	130.18
143	0.03	120.16
144	0.34	170.08
145	0.51	200.12
146	0.52	210.23
147	0.64	140.10
148	0.43	190.18
149	0.42	190.26
150	0.51	210.54
151	0.42	210.25
152	0.55	220.12
153	0.31	170.14
154	0.62	220.19
155	0.21	140.10
156	0.10	150.12
157	0.26	190.10
158	0.14	140.16
159	0.12	140.20
160	0.10	140.26
161	0.20	170.12
162	0.34	200.90
163	0.52	200.12
164	0.61	230.19
165	0.01	40.36
166	0.25	200.16
167	0.02	30.15
168	0.36	180.10
169	0.62	220.14
170	0.54	200.14
171	0.41	120.00
172	0.34	220.50
173	0.51	240.15
174	0.20	120.11
175	0.25	120.22

APPENDIX 5

THE ACTUAL GROUP AND THE HIGHEST PROBABILITY GROUP FOR THE RECONSIDERATION OF FOUR MAIN GROUPS OF PHOSPHORUS SOURCES IN THE SLAPTON LEY CATCHMENT

Case No.	Actual Group	Highest Probability Group
1	4***	3
2	4	4
3	5	5
4	5	5
5	5	5
6	4	4
7	4***	3
8	4	4
9	3	3
10	4	4
11	4***	3
12	4***	3
13	1	1
14	3***	4
15	1	1
16	4***	3
17	5***	4
18	5***	3
19	4	4
20	4***	3
21	5***	4
22	5***	4
23	4***	3
24	4***	3
25	4***	3
26	1***	2
27	2	2
28	2	2
29	2	2
30	2	2
31	2***	3
32	2	2
33	2	2
34	2	2
35	2	2
36	2	2
37	2	2
38	2	2
39	2	2
40	2	2

Case No.	Actual Group	Highest Probability Group
41	2	2
42	2	2
43	2	2
44	2	2
45	2	2
46	2	2
47	2	2
48	2	2
49	2	2
50	2	2
51	2	2
52	2	2
53	2	2
54	2	2
55	2	2
56	2	2
57	2	2
58	2***	5
59	2***	5
60	2	2
61	2	2
62	2***	3
63	2	2
64	2	2
65	2	2
66	2	2
67	5	5
68	5	5
69	5	5
70	5	5
71	5	5
72	4***	5
73	4***	5
74	4***	5
75	4***	5
76	2***	1
77	2***	1
78	2***	3
79	4***	5
80	4***	5
81	2***	1
82	2***	1
83	3***	1
84	4***	5
85	6	6
86	2***	3
87	2***	3

Case No.	Actual Group	Highest Probability Group
88	2***	1
89	4***	5
90	4***	5
91	1	1
92	1	1
93	1	1
94	1	1
95	1	1
96	6	6
97	6	6
98	2***	1
99	2***	3
100	6	6
101	6	6
102	6	6
103	6	6
104	6	6
105	6	6
106	6	6
107	5***	4
108	5***	4
109	5***	4
110	5***	3
111	6	6
112	4***	5
113	4***	5
114	4***	3
115	4***	5
116	2***	3
117	1	1
118	1	1
119	1	1
120	1	1
121	1	1
122	2***	3
123	3	3
124	3	3
125	3	3
126	3	3
127	3	3
128	2***	3
129	1	1
130	6	6
131	6	6
132	1	1
133	5	5
134	1	1
135	4***	5
136	4***	5