Water and cation movement in a tropical rainforest environment.

I. Objectives, experimental design and preliminary results.

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Abstract

The paper briefly outlines work being done on the movement of cations under a Palmetum-type rain forest near Manaus, Amazonas. It is suggested that the low cation content of river waters is concerned with the nature and dynamics of water movement in relation to soil moisture and tension as much as lack of availability of cations in the soil. Preliminary results support the idea of a 'by-pass' mechanism whereby the smaller pore spaces, saturated with water, only drain and provide cation-rich water late in the dry season.

Introduction

A commonly presented paradox of the Amazonian tropical rainforest is that soils are excessively deficient in available nutrients whilst they support some of the most dense, luxuriant forest in the world. Richards (1966) states that "It can thus be seen that in mature soil the capital of plant nutrients is mainly locked up in the living vegetation and the humus layer, between which a very nearly closed cycle is set up". This theme has been elaborated upon by Sioli (1966) and Stark (1971). Stark described this as the 'direct nutrient cycling hypothesis', where the nutrients in the Amazonian forest are held mainly in the organic phase, in living roots, wood, bark, and leaves and in dead organic matter. There are considered to be few nutrients available in the heavily leached soils which are regarded as having high percentages of silica. Stark supports the hypothesis and suggests that this state of affairs is of long standing because the deposits on which the present forest is developed were originally nutrient deficient alluvium exposed during the Miocene. Leaching from heavy rains is thought to have depleted the soil nutrients faster than additions from the atmosphere and by weathering could deliver fresh supplies.

A closer inspection of the literature reveals that statements concerning the nutrient status of the soil are based only rarely upon observation of the soil as a whole. Rather, they tend to be based on ancillary measurements only tenuously linked to soil status. For example Went & Stark (1968) comment on the distribution of feeder roots, essentially in the top 15 cm of predominantly organic material, together with what they describe as white or grey sterile sands or poor yellow clays, as indicative of a nutrient deficient soil. Further conclusions relating to the poor status of Amazonian soils have been drawn from the analyses of stream and river samples considered to be carrying the leaching products of the soils (Sioli, 1968, 1975). As the solute concentrations of many Amazonian streams and rivers have been found to be so low (e.g. Edwards and Thornes, 1970), it has been generally concluded that the soils had low sources of leachable materials. The arguments underlying these conclusions together with those for a 'nearly closed cycle' are presented by Jordan & Kline (1972). Of the limited number of soil analyses available for the region around Manaus, those of Brinkmann & Nascimento (1973) were for only the top 20 cm of the two groups of soils, yellow latosols and hydromorphic soils, but they concluded that the soils as a whole generally have a low fertility. The only detailed descriptions and analyses of whole soil profiles readily available are those of IPEAN (1969) but these are few in number because of the very low sampling density.

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It is with this background that the current study was initiated. The broad aim is to examine in greater detail the nutrient movement through the soil system, endeavouring if possible to complete some of the links in the subsystem between inputs at the organic surface and output in the stream waters. To do this, we have adopted a simple model of spatial and seasonal variations of soil water concentrations and movement which is described in the following section. In turn this was used to develop an empirical design for the experiment which takes the form of a detailed investigation of a slope segment, established as a field laboratory, in a small catchment. The water movements into and through the slope segment have been monitored, and analyses of water quality were made for incoming rainfall, the soil water in the saturated and unsautrated zones on the slope, and of the outgoing stream water. In addition detailed studies have been made of the soil over the whole slope length, though as yet no analytical results are available for this part of the investigation.

General model

The extent to which soil materials appear in stream channels relates to the relative solubility of the oxides or elements, their relative abundance in the soil and the movement of water through the soil, provided that the time required for the equilibration is relatively short compared with the residence time of the water in the soil. As we mentioned earlier, it is the second of these that has generally dominated hypotheses about nutrient cycling in the humid tropical environment. In this work the soils are to be examined in detail for the relative availability of nutrients but appreciable effort is also directed to the amounts and conditions of water movement.

In a system of pore spaces, the order of evacuation of of pores with drainage goes from the relatively large to the relatively fine pores. With abundant water content, the finer pores may undergo little activity as infiltrating water bypasses them through the coarser part of the system. This may be the case in tropical soil systems. As the finer pore spaces are bypassed concentrations of elements are higher than in the coarser pore spaces and weathering occurs at a lower rate. The pore system may be likened to a cup with ions distributed about the inner surface. When the cup is full, addition of further water leads to overflow and there is turnover of water near the brim but not at depth. Concentrations near the brim are lower and decrease more rapidly with time than at the bottom of the cup because of the higher frequency of emptying and filling (Fig. 1a). This could be regarded as the wet season situation. In the dry season the cup is gradually emptied, outward diffusion is less, because the concentration gradient is lower and only with large 'flushing' rains, towards the end of the season are the elements in the finer pore spaces evacuated. This occurs as a result of overflow with the first heavy rains. Base saturated water at the bottom of the cup is redistributed over the entire depth and this overflows. During the wet season, if only overflow from the cup is examined we may expect concentrations to be relatively low. Plants apply considerable stress and therefore can draw from the bottom of the cup. To know what elements are available to plants and in what quantity it is not enough, therefore, to examine only freely draining soil water.

In the profile as a whole (Fig. 1b) the movement of water depends on the distribution of potential and the saturated and unsaturated conductivities. The latter are heavily dependent on soil moisture which in turn is related to the pore space distribution in the soil as well as the recent history of infiltration into and drainage from the soil. During the wet season it is likely that the upper levels of the soil experience more rapid turnover and higher flow rates than at depth because of the natural distribution of potential due to head (as opposed to matric potential) and, on steeper slopes, a greater tendency to lateral movement. The lower layers are close to saturation, rates of movement are slow and turn-over of elements may be expected to be less. Consequently one may anticipate significant variations in the vertical sense in the concentrations of elements in soil water. These effects should also contrast seasonally being stronger in the wet than in the dry season.

Finally, significant variations in the concentrations of solutes may be expected on the hillslope scale (Fig. 1c) on the basis of hillslope hydrology. In the wet season one might reasonably expect the floodplain sector to be comparable to the top of the cup. Rapid and frequent response to rainfall may lead to a shunting to-and-fro of water between the floodplain and the channel. Further back, away from the saturated wedge at the foot of the slope, groundwater movement is slower and dictated in part by receipts from the overlying soil as well as the gradient of the piezometric surface itself. An exception to this occurs when a groundwater 'hump' moves downslope carrying with it the recent 'overflow' water. Such humps may be expected to have appreciably lower concentrations than the water

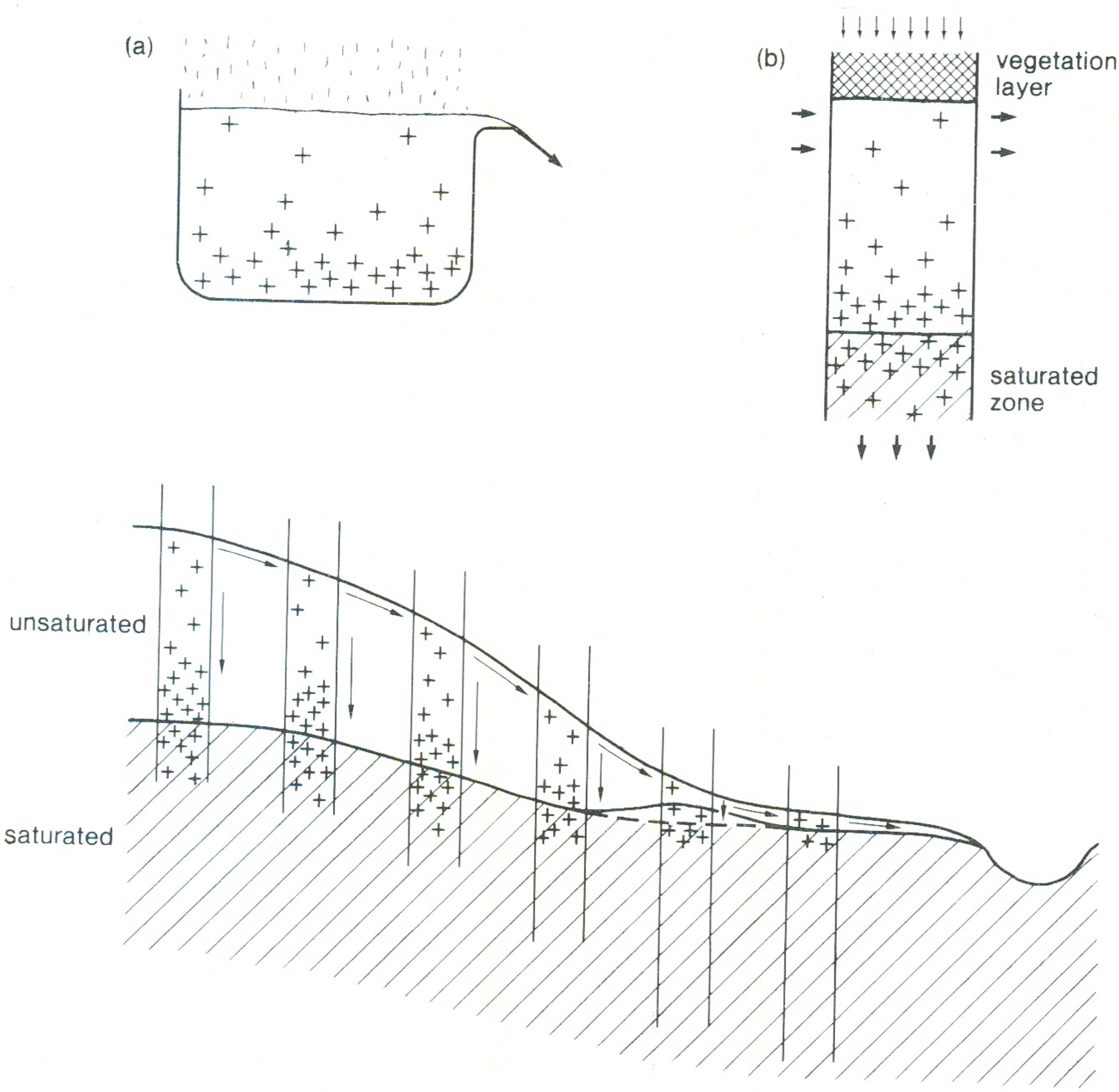

Fig. 1 — Basic simple models.

below the seasonally stationary piezometric surface. A hump of this type is shown schematically in Fig. 1c. Again, the concentrations of solutes in the stream channel may be a relatively poor indicator of their availability to plants on the hillslope since the immediate response of the river, especially in the wet season, may be largely determined by flood plain storage and response.

These considerations led us to the conclusion that a much better understanding of the relationship between soil and plants could be obtained via the soil water composition. Contrary to being in direct opposition to the closed nutrient cycle concept, whether expressed in terms of indirect or direct cycling, it might preclude the need for it, at least as far as certain elements are concerned. If this were true, more conventional processes of nutrient supply could be envisioned and this might have some implications for the management of soil resources in the Manaus area.

Area of study

The field area chosen for the investigation is in the National Forest Reserve, Reserva Ducke, 26 km east of Manaus on the road to Itacoatiara (Fig. 2). The area is underlain by Tertiary deposits of the Barreiras Series and is the centre of considerable research from the Instituto Nacional de Pesquisas da Amazonia. This research provided a useful source of background information. In addition to the general INPA research, closely related research by Dr. W. Franken (Max Planck Institute for Limnology) will provide complementary data on the hydrochemical budget of the Barro Branco catchment as a whole.

The research area has three major forest types, described by Brinkmann & Santos (1973); (1) Riverine Forest (2) Carrasco Forest (3) Terra Firme Rain Forest. The experimental site was located in the second of these types which is intermediate between the other two. It has canopy heights from 22 - 32m, is quite heterogenous, with an understory of numerous seedlings and saplings and has some herbaceous plants and palms. On the slope segment studied the soils correspond broadly with those found by Brinkmann and Santos that is, yellow and yellow/brown latosolic soils with some sand throughout the profile and generally of medium porosity, with gleyed sands at the foot of the slope. Full details of our own studies of the plants and soils on the site will be published later.

A summary of the climatological data from Reserva Ducke has recently been published by Ribeiro (1975) In the period 1965-73 the range of temperature was from 37 - 14.3°C, the average maximum daily temperature being about 33°C. A precipitation intensity of 60mm/hour appears to occur with an annual return period, the wettest months being March and April (about 400 mm) the driest being September with about 50mm.

Experimental design and measurement

The basic design comprises a hillslope section from the channel to the local divide partitioned into six approximately equal segments and five depths. The design has been based on the need to estimate vertical and downslope variations in water movement and is similar to those typically used in hillslope hydrology.

i) Water movement. Following the ideas of Freeze (1972) and Weyman (1970) the water fluxes have to be estimated from potential differences, resulting from head and matric suction variations. The latter were determined using a standard design of tensiometer (Webster, 1966) and compensating for tube size and depth in the usual fashion. Originally it was planned to determine soil moisture using a neutron probe, but due to malfunctioning this instrument was not available and soil moisture had to be estimated by conventional auger and gravimetric techniques. The locations of the tensiometers are shown in Fig. 2 The six sites and five depths were also used as the basis for soil moisture determinations. The tensiometer cups were set at depths of 20, 36, 66, 96 and 120 cm below the surface and the tensiometers were inspected at frequent intervals during and after storms (shortest interval, 10 min.) but some storms occurring at night were not observed. On the days of no rain the tensiometers were

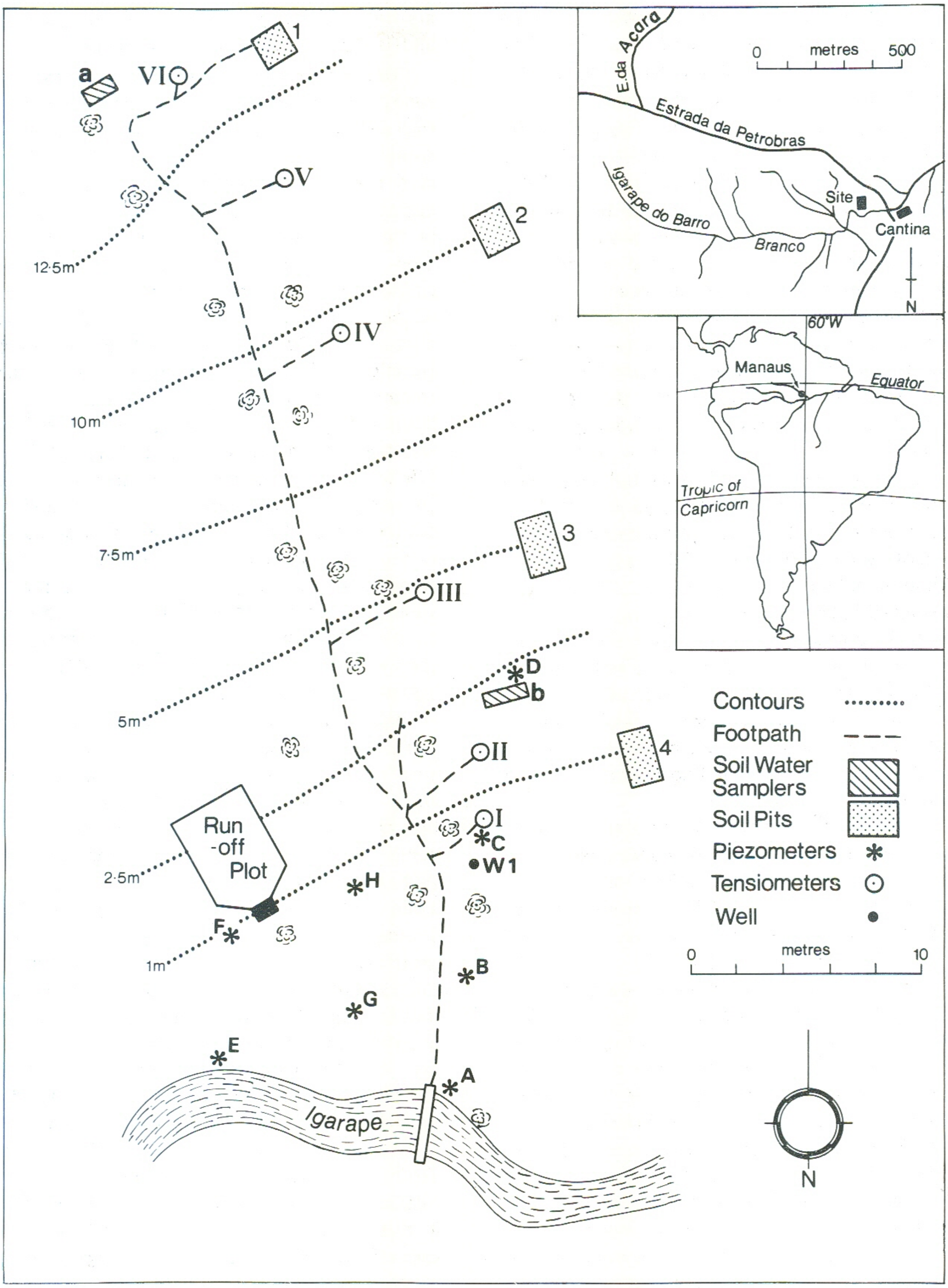

Fig. 2 — Instrumentation of hillslope.

read on a 2 hour basis. Because of the need to preserve the sites, augering could only be done on a weekly basis, and this has led to some serious loss of definition of the characteristic curve between tension and moisture.

Steady state infiltration has been determined using the standard double ring infiltrometer with a small constant head (Hills, 1970) under both saturated and unsaturated conditions for the underlying profile. These were carried out over prolonged periods and have resulted in consistent results in the various environments. Run-off was measured from a natural plot four metres in length and two mestres wide. This was bounded by plastic edge to a depth of 15 cm into the soil, and measured at the outlet by a tipping bucket raingauge.

On the floodplain and to its hillslope edge a set of eight simple wells were installed for the measurement of the piezometric surface in that region. These comprise plastic, 2 cm diameter tubes of 2 m length. These were measured four times daily and at more frequent intervals during and after major storms. Unfortunately all instruments were not read all weekends because of problems of logistics. However since our concern is essentially on water movement this is not a serious problem since a storm-based sampling scheme is more meaningful.

ii) WATER CHEMISTRY. Water samples were collected for the analysis of concentrations of the cations Ca++, Mg++, Na+ and K+ and the samples were obtained from streamwater, rainwater ,unsaturated zone in the soil and wells (saturated zone).

The stream water samples were initially collected at hourly intervals during the day, with more frequent sampling during and after storm events, but after analyses of the early samples it became evident that the stream water was relatively invariant both in storms and throughout the day. Subsequent stream water samples were collected once or twice per day with some increase in sampling intensity during and after storm events.

The rain water samples were analysed for one randomly selected rain gauge within each of the five sampling blocks (see below for description) for seven collecting periods. In addition to the collections for chemical analysis field observations were made of the colour and particulate matter in the sample.

Soil water samples (from the unsaturated zone) were collected at two positions within the segment: (Fig. 2). Porous ceramic cup samplers were used at depths of 23, 33, 63 and 102 cm for both sites, with additional samples at 180 cm at the lower site and 7 cm at the upper site. The samplers consist of a tube which can be evacuated to a known suction, tipped with a porous ceramic cup which takes in the soil water. A standard suction of 600 cm was established and the samplers left for approximately 180 minutes (exact times were noted) before the accumulated samples were extracted. Full recognition was taken of the comments of Hansen & Harris (1973), but it was considered that a standard suction was more apropriate for testing the proposed model than a variable suction related to the ambient matric suction. The soil water samples obtained by the porous cup method should be more representative of the soil solution than those obtained by lysimeters or zero tension lysimeters (Jordan, 1968) for the reasons outlined earlier.

Well water samples were extracted from wells located in the flat, frequently inundated area at the foot of the slope segment. Three wells were sampled: WI — located directly at the foot of the experimental slope segment, some 2 m from the break of slope, WF4 and WF5, located a small distance upstream on the same broad flat area at the base of the slope. During the period of sampling, the local groundwater level was above the bottom of the sampling tubes (wells), consequently these samples are representative of the soil moisture in the saturated zone.

iii) INTERCEPTION. Interception of rainfall by the forest canopy has long been recognised as important in the overall hydrological balance of tropical rainforests (Richards, 1966). Clegg 1963 investigated interception amounts in relation to forest structure and storm intensity. In this study an attempt was made to estimate the relative amounts of interception in the experimental site by randomly locating four standard raingauges (50 cm above the ground) within each of five blocks located on the slope parallel to that used for tensiometer measurements. The five blocks were approximately 10m wide and broadly correspond to positions on the main slope in the following manner: A — between the stream and tensiometer site I, B — between tensiometer sites I and III, C — between tensiometer sites III and IV, D between tensiometer sites IV and V and E between tensiometer sites V and VI. After each rainfall collection the gauges were relocated randomly. The rainfall received at each site was expressed as a percentage of the open site rainfall.

iv) RUNOFF. Dr. Franken has kindly permitted access to his run-off data for the Barro Branco for the period in question. These are based on stage records for a broad-crested weir and we were able to rate these using the Ott current meter. The recording station is about 150m downstream from our own site and stages there correlate perfectly with those at the main gauging station.

v) CLIMATOLOGICAL DATA. A full range of climatological data, but especially rainfall data is recorded at the Reserva Ducke and we have been able to abstract this data for the observation period. Rainfall is measured by standard tipping bucket raingauge with a 24 hour chart which is changed at 0700 hours. From this rainfall totals for 10 minute periods for the whole period of observation (3 months) have been obtained.

PRELIMINARY RESULTS

(i) HYDROLOGY

We present here a few general results in the belief that they will be of immediate interest to coworkers, especially those at INPA. They are intended as a background to a more detailed analysis and separate papers which will follow later. During the peroid of observation, from March to late May, 1977 there was a gradual shift from very wet to relatively much drier conditions, with associated trends in soil tension and runoff. The overall period was marked by four very pronounced storms, on the 23rd March, on 3rd April, 15-16th April and again on the 6th May. These rainfalls (fig. 3a) provided important pulsed inputs, the earliest into very wet soil, the latest into relatively dry soil. In fig. 3b we indicate three storms of comparable volume but of quite different time distributions. Early during the observation period sotrms were more sustained and of generally lower intensity than during the latter part of the period.

Throughout, we were surprised at the very sharp response of the Barro Branco to rainfall; lag to peak times were almost invariably within an hour of the cessation of rainfall and time to rise was almost instantaneous (e.g. Fig. 3c). We consider these results to indicate the very fast response of the saturated floodplain areas both here and upstream for they coincide with extensive inundation of the floodplain. The recession limbs of the hydrographs were more varied and a fuller analysis by Dr. Franken will appear later. However most revealed a considerable attenuation which might be attributable to slower drainage of the lower hillslopes or at least of the floodplain areas. Although the well data has yet to be plotted, it is evident that towards the back of the floodpalin the wells showed a rapid rise and fall throughout individual storms. This probably reflects the growth and decay of a saturated wedge at the slope base after the fashion described by Weyman (1970) and others. The rapid response of this zone may, itself, be a further indication of the by-pass mechanism.

During the entire period the overall drying produced a corresponding shift of the mean tensions within the profiles. (Fig. 4). Site 1 was almost continuously saturated at all depths below 20 cm so that the diagram of average matric suction (Fig. 4) shows that positive pressures, increasing with depth as a result of hydrostatic head, prevailed throughout the entire period. Site 2 shows the influence of proximity to the piezometric surface during a wet period (11-16/05/77). The other sites 3 and 5 show almost vertical matric suction profiles, indicating that the main driving force in water movement is differences in head potential. This can largely be attributed to the relatively high moisture content. In sites 4 and 6 however,, the latest period shows strong evidence of the effects of drainage.

Fig. 5 shows the distribution of total hydraulic potential with reference to the top

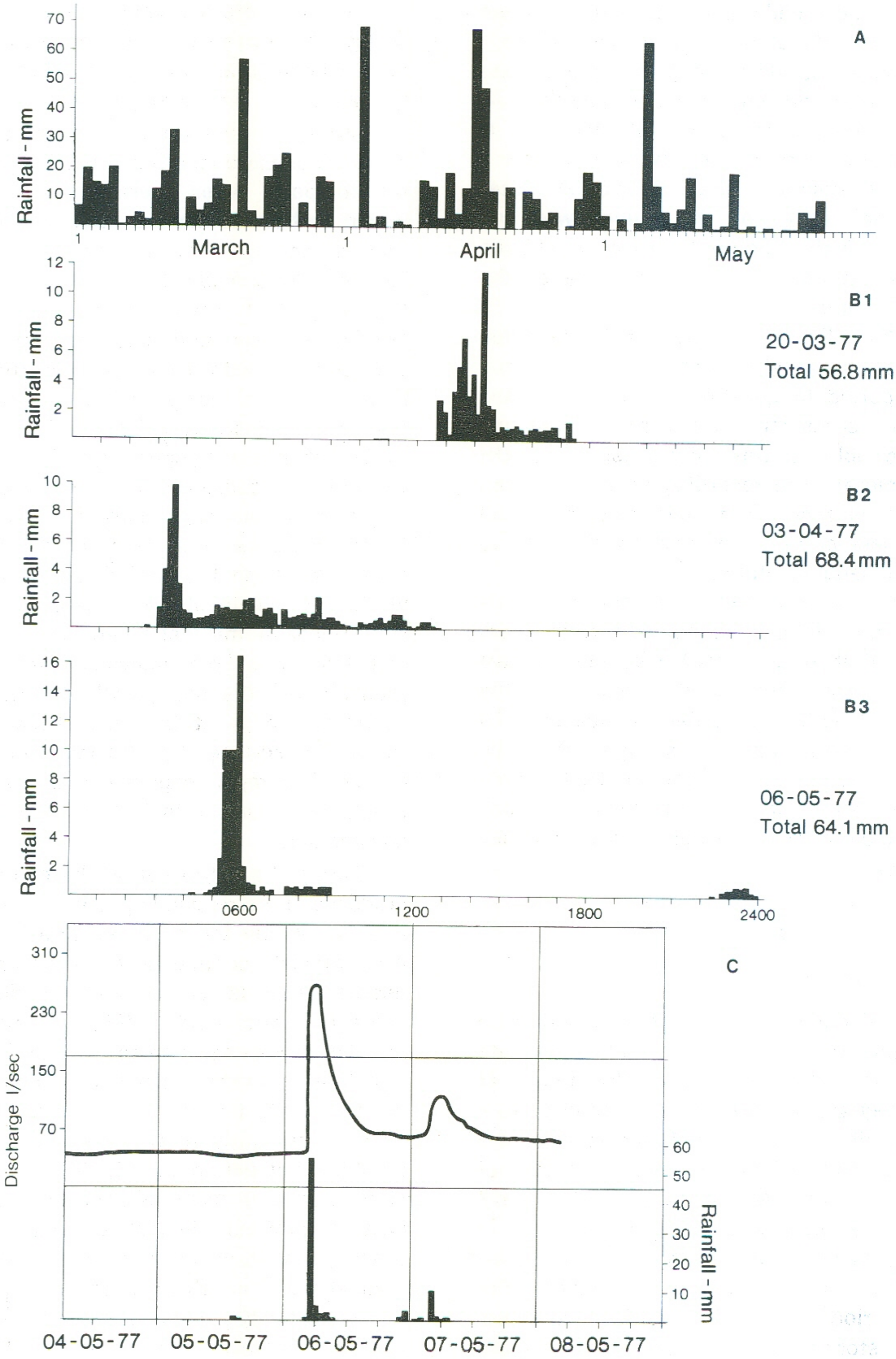

Fig. 3 — (a) Plot of daily rainfall totals during period of observation. (b) Plot of hourly rainfall totals for three different storms to show distribution types. (c) Hydrograph for storm of 6th June 1977, Barro Branco.

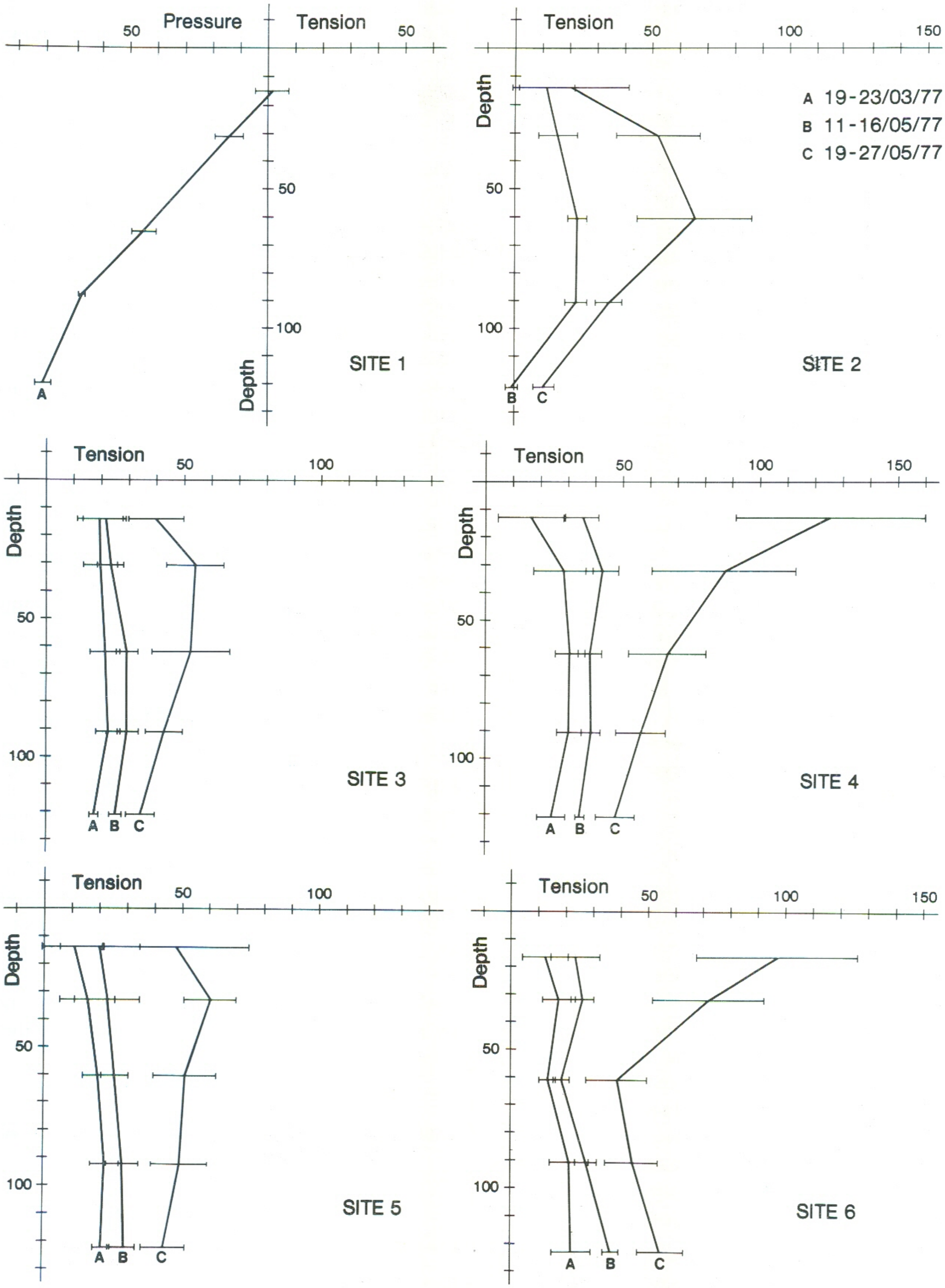

Fig. 4 — Distribution of matric potential at depth. Averages calculated for selected periods. Horizontal bars show one standard deviation.

profile indicating that during periods A and B the potential was distributed more or less according to head (depth), the matric potential being constant. In period C the effects of drainage in producing high matric potentials in the upper horizons are much more evident.

A preliminary inspection of the moisture data reveals similar fairly uniform profiles. The tension-moisture curves are almost vertical near the saturation limit, there is a wide range of tension values for moisture contents near $27cm^3/cm^3$, the average saturation. These characteristics are to be expected of fairly permeable material. Steady infiltration rates ranged from 0.0976mm/sec on the latosols to 0.0384 for the floodplain. Average rates on the root mat at the top of the soils was 0.3152 mm/sec which is very high. A comparable order of magnitude is observed for migration of the wetting front under saturating conditions. Regression of the data for times when the soil was already very wet yield an average of 0.075 mm/sec, so that typically after a lag of up to 45 minutes for saturation of the rootmat, infiltration into the latosols was very swift. This, together with the very fast river response, appear to confirm the by-pass mechanism described earlier and should help to explain the low concentrations of river water mentioned earlier.

ii) CHEMICAL ANALYSES

Water samples were collected during each week and analysed at the end of each week using a Perkins Elmer Atomic Absorption Spectrophotometer (AAS). Selected examples were examined after longer storage periods and showed no significant changes in recorded concentrations. At this stage, results presented are mean values, with some introductory comments on the variance characteristics of the throughfall, further analyses of variance characteristics and patterns related to climatic conditions and antecedent soil moisture conditions will be presented later.

a. **River Samples**. The river samples collected throughout the period show exceptionnally low concentrations in respect of all four cations examined (Table 1). The mean value for Ca++ was 0.01 mg/1, with a maximum value of 0.04 and minimum of 0.00. Given the sensitivity of the AAS, it may be more correct to consider all these values as zero or very close to zero. The mean value for Mg++ is slightly higher at 0.03 mg/1, with a range from 0.10 to 0.00, but as with the Ca++ a relatively low variance. Further analysis of the changes in Mg++ is progress in relation to stream discharge and long and short term antecedent climatic conditions. Na+ concentrations are considerably higher than for the other three cations, but are low when compared with published results. The mean concentration for Na+ during the period was 0.19mg/1 with a range from 0.48 to 0.00. Values for K+ are again very low with a mean of 0.06mg/1 and a range of 0.45 to 0.00.

With the exception of the low mean for Na+ these results agree in general with those obtained for the same catchment by Dr. Franken and are within the range of values presented in other studies (see Sioli, 1968). The intensive sampling at the start of the observation period both during a day and throughout storms suggested no clear patterns, but further analysis is in progress to investigate relationships at longer time scales.

b. **Throughfall Samples**. Analyses of throughfall samples show markedly higher concentrations for all four cations than those obtained for stream water samples (Table 1). The overall mean concentration for Ca++ is 0.32 mg/1 with a range of 0.88 to 0.10, Mg++ as 0.20mg/1 with a range of 0.40 to 0.04, Na+ as 0.42mg/1 with a range of 1.58 to 0.05, and K+ as 1.33mg/1 with a range of 7.47 to 0.22. Preliminary tabulation of mean concentrations by rainfall events and by blocks for all rainfall events is given in Table II.

TABLE I — Mean Chemical Results : Barro Branco and Rainfall, March — May 1977 (mg/1)

	Ca++	Mg++	Na+	K+
Barro Branco	0.01	0.03	0.19	0.06
Rainfall	0.32	0.20	0.42	1.33

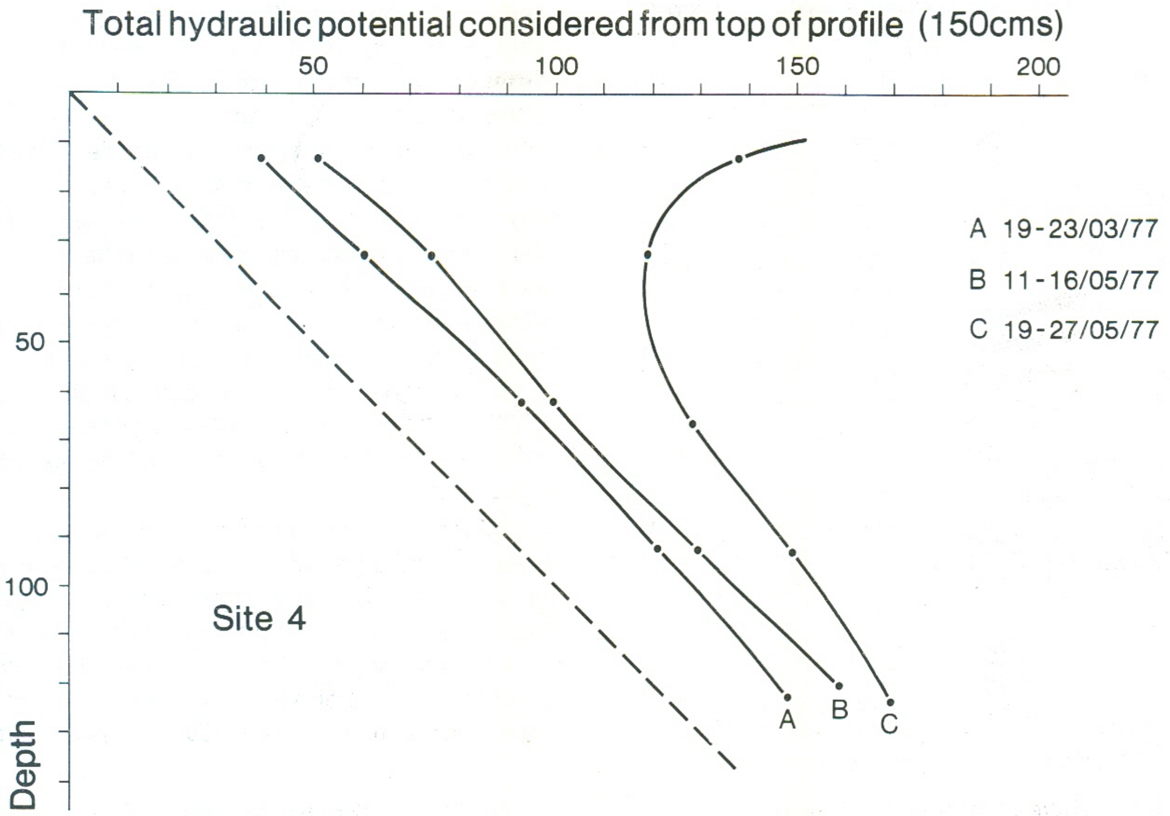

Fig. 5 — Distribution of total hydraulic potential with reference to top of profile.

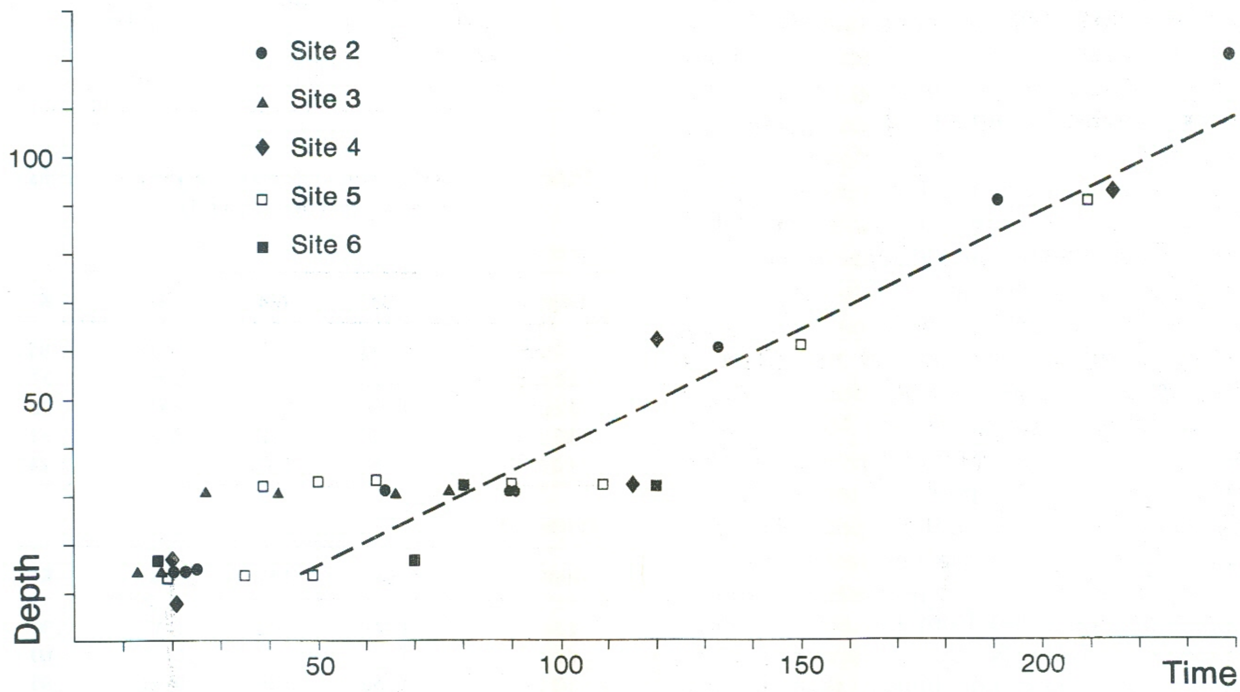

Fig. 6 — Travel times for wetting fronts plotted against depth; the regression line is computed only for the cases where the soil was initially at or very close to saturation.

TABLE II — Means for chemical analysis of throughfall samples (mg/1)

(1) By Events

Date	Ca	Mg	Na	K
220477	0.33	0.14	0.40	1.08
250477	0.59	0.30	0.59	1.81
280477	0.40	0.25	0.45	1.52
060577	0.13	0.07	0.15	0.84
110577	0.28	0.16	0.20	0.67
160577	0.24	0.23	0.71	2.29
270577	0.26	0.21	0.43	1.10

(2) By Blocks

Block	Ca	Mg	Na	K
A	0.35	0.17	0.35	1.22
B	0.35	0.17	0.20	0.81
C	0.37	0.18	0.23	0.93
D	0.28	0.26	0.78	2.77
E	0.25	0.19	0.53	0.92
Overall Mean	0.32	0.20	0.42	1.33

Initial investigations to elucidate patterns in the data has been undertaken using a 2-way analysis of variance model without replication. The sources of variation incorporated in the model were (i) the storm effect (variations between throughfall collecting periods for all blocks), (ii) the block effect (variations between blocks for all collecting periods) and (iii) the interaction effect. Mean squares are computed for each of the effects and the existence of storm or block effects are tested by dividing their mean squares by the interaction mean squares and comparing with the F-distribution for the appropriate degrees of freedom. Initial results are given in Table III, where the significance level of the effect is listed (N.S. indicates not significant). These results suggest that Ca^{++} and Mg^{++} inputs vary in relation to storm intensity and duration while Na^{+} and K^{+} inputs are more strongly influenced by spatial location, probably, as a result of variations in the vegetative cover.

c. **Soil Samplers**. The preliminary results for samples collected from the soil samplers are given in Table IV, by site and depth. In general the values are higher than for the throughfall and stream samples, the throughfall exceptions being Ca^{++}, Lower Site 33cm and K^{+}, Lower Site 33 and 63cm. The relationship between depth and concentration are different for the two sites and with respect to different cations. Further analyses relating soil water concentration to antecedent rainfall and matric suction are in progress to elucidate any relationships. One significant feature of the results is with respect to the 180cm sample at the Lower Site which, from field observations, appeared to be sampling the saturated zone during the period of observation, but the concentrations are consistently higher than those obtained for the Well Samples (Table VI), also considered to be sampling the saturated zone.

Means for all samples and for the four sample depths common to both sites are given in Table V. Taking results for all samples, there are distinct differences with respect to Ca^{++} and Mg^{++} for the two sites, with consistently higher values at the Lower Site. When the samples from 180cm (Lower Site)

TABLE III — Summary of analysis of variance : throughfall chemical data.

Cation	Blocks	Storms
Ca^{++}	NS	0.001
Mg^{++}	NS	0.001
Na^{+}	0.001	0.01
K^{+}	0.01	NS

TABLE IV — Mean values of chemical data by depths for soil samplers. (mg/1)

Uper Site

Depths	Ca	Mg	Na	K
7 cm	0.34	0.47	6.00	2.85
23 cm	0.85	0.75	2.68	1.37
33 cm	0.68	0.44	2.63	1.32
63 cm	1.08	0.66	3.54	2.39
102 cm	0.57	0.48	5.47	2.28

Lower Site

Depths	Ca	Mg	Na	K
23 cm	0.49	0.53	1.13	1.30
33 cm	0.25	0.30	0.57	0.69
63 cm	0.56	0.21	0.65	0.85
102 cm	0.84	0.63	1.96	1.53
180 cm	11.45	35.51	3.13	4.87

TABLE V — Mean Concentrations: Soil Samplers. (mg/1)

		Ca^{++}	Mg^{++}	Na^{++}	K^{+}
All Samples:	Uper	0.77	0.57	3.72	1.90
	Lower	1.64	4.05	1.26	1.46
Four Depths:	Uper	0.78	0.58	3.63	1.86
(23, 33, 63, 102)	Lower	0.50	0.40	1.04	1.05

TABLE VI — Mean values of chemical data for well samples. (mg/1)

	Ca	Mg	Na	K
W1	0.31	0.11	2.83	1.85
WF4	0.84	0.08	0.74	0.86
WF5	0.48	0.07	0.61	0.94
All Wells	0.55	0.09	1.33	1.19

TABLE VII — Raw interception data

Date	Time Off	Rf. mm	% Rain Received
29.03	0820	8.0	73.0%
31.03	0833	35.5	80.5%
04.04	1200	69.7	81.9%
06.04	1200	3.3	107.0%
11.04	0825	27.5	96%
11.04	1505	5.0	42.8%
12.04	1005	2.2	35%
14.04	0850	19.65	75%
14.04	1530	4.45	52.7%
20.04	0840	142.2	67%
20.04	1400	8.4	82.1%
22.04	1500	13.9	64.0%
25.04	1200	16.7	94.1%
27.04	1035	5.4	53.5%
28.04	1200	10.32	73.4%
02.05	0830	39.6	99.5%
03.05	1455	3.25	58.5%
06.05	1300	62.3	78.9%
09.05	0940	24.6	82.4%
09.05	1340	2.5	72.2%
10.05	1515	7.1	84.4%
11.05	1535	12.7	75%
13.05	0950	6.0	82.7%
16.05	1400	27.45	102.9%
24.05	0950	10.45	45.0%
26.05	0820	4.28	72.9%
27.05	0840	10.13	85.7%

Mean Rainfall received 74.7%.

and 7cm (Upper Site) are not considered, the pattern is reversed. With respect to both Na+ and K+ the Top Site has higher average concentrations for both data sets.

d. **Well Samples**. The mean concentrations for well samples are given in Table VI. The values obtained from the three wells are within the range of values obtained for the soil samplers with the exception of Mg++, which has recorded concentrations within the range of values obtained for incoming rainfall and outgoing streamwater. Analysis is in progress to relate the concentration at WI to the throughflow of water from the slope segment, and at all sites to changing stream discharge conditions.

iii) INTERCEPTION

Interception results are presented in Table VII and VIII, in terms of the percentage of open site rainfall received at the forest sites. Table VII gives the summary results for each event (means of 20 gauges), with detailed results for selected rainfall events presented in Table VIII. Initial analysis of the variation in rain

TABLE VIII — Percentage rain received by Blocks

1104	**1505**	**5.0 mm**
	A	18.5%
	B	43.0%
	C	25.5%
	D	46.0%
	E	81.0%
2504	**1200**	**16 7 mm**
	A	92.1%
	B	230.7%
	C	49.4%
	D	61.5%
	E	36.8%
0905	**0940**	**24.6 mm**
	A	123.4%
	B	89.5%
	C	88.2%
	D	50.2%
	E	60.9%
0605	**1300**	**62.3 mm**
	A	75.2%
	B	73.1%
	C	134.4%
	D	46.6%
	E	65.3%

TABLE IX — Percentage of rainfall received related to rainfall amounts (mean for all events)

Rainfall	% Rain received
0 — 10 mm	68.1
10 — 20 mm	72.9
20 mm +	86.0

received suggests a broad relationship with rainfall amounts as indicated in Table IX, intensity and duration. A two-way analysis of variance test has been undertaken to investigate the existence of storm and block effects on the interception values. The effects were found to be not significant.

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Resumo

Relata-se um trabalho feito sobre o movimento de cátions sob uma floresta úmida do tipo "Palmetum" perto de Manaus, Amazonas. Sugere-se que o baixo teor de cátions das águas dos rios está ligado à natureza e dinâmica do movimento da água em relação ao teor e tensão da umidade do solo, assim como à falta de disponibilidade de cátions no solo. Os resultados preliminares apoiam a hipótese de haver um mecanismo tipo "by pass" pelo qual os micropóros, saturados com água, somente drenam e fornecem água rica de cátions no fim da estação seca.

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