Gross inputs and outputs of nutrients in undisturbed forest, Taï area, Côte d'Ivoire

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Stoorvogel, J.J.

Gross inputs and outputs of nutrients in undisturbed forest, Taï area, Côte d'Ivoire / J.J. Stoorvogel. -Wageningen : The Tropenbos Foundation. - Ill. -(Tropenbos series 5)
With ref.
ISBN 90-5113-017-1
Subject headings: nutrient cycling / nutrient concentrations / tropical rain forests Côte d'Ivoire.

Cover design Diamond Communications
Printed by Veenman Drukkers, Wageningen

GROSS INPUTS AND OUTPUTS OF NUTRIENTS IN UNDISTURBED FOREST, TAÏ AREA, CÔTE D'IVOIRE

J.J. Stoorvogel

The Tropenbos Foundation
Wageningen, The Netherlands
1993

TROPENBOS SERIES

The Tropenbos Series presents the results of studies and research activities related to the conservation and wise utilization of forest lands in the humid tropics. The series continues and integrates the former Tropenbos Scientific and Technical Series. The studies published in this series have been carried out within the international Tropenbos programme. Occasionally, this series may present the results of other studies which contribute to the objectives of the Tropenbos programme.

CONTENTS

PREFACE

The Wageningen Agricultural University started to work in Côte d'Ivoire in 1954. This provided an opportunity for staff and students of the university to carry out research in the tropical lowlands of West-Africa. In 1986 a new multidisciplinary research programme was initiated: "Analysis and development of land use systems in the Taï region, Côte d'Ivoire". At that time much scientific research was carried out in Côte d'Ivoire by the Unesco Man and Biosphere programme (MAB), ORSTOM (Office de la Recherche Scientifique et Technique Outre Mer) and the University project.

Also in 1986 the Dutch government initiated the Tropenbos programme. This programme should stimulate multi-disciplinary research concerning long-term land use in regions with tropical rain forest. The Tropenbos research programme is focused on several pilot areas. The objectives of the Tropenbos programme were much in line with the objectives of the research programme from the Wageningen Agricultural University and the Taï region became one of the Tropenbos study sites.

The research described in this report was carried out in cooperation between the Wageningen University and Tropenbos. It is part of a larger research programme carried out by the Wageningen University on nutrient cycling in different types of land use in the Taï region.

The fieldwork for this research was carried out between March 1990 and March 1991. Many individuals were of great help in the research. The author would like to express special acknowledgement to the following persons:

All the Ivorian people who have been working with and for me in this year and specially the staff and employees of the Institute for Tropical Ecology.

Prof dr ir N. van Breemen and dr ir B.H. Janssen. They wrote the research proposal and were supervisors of the study. During the study they were always available for advice. Especially the visit of prof dr ir N. van Breemen to the Côte d'Ivoire was appreciated.

The "Centre Néerlandais" in Côte d'Ivoire of the Wageningen Agricultural University provided the infrastructure and atmosphere for the study. Special thanks are due to ir A.P. Vooren and ir H. van Reuler who were of great help in the organisation of this study.

- The two MSc students K. Nooren and M. Berenschot, who worked with me in the forest, and were always there to help me and give me some company.
- All the staff members of the laboratories of the department of Soil Science and Geology and of the department of Soil Science and Plant Nutrition of the Wageningen Agricultural University who were of great help in the often difficult analysis of the samples from Côte d'Ivoire. In addition I thank Ms. A. Clerx from the Technical and Physical Engineering Research Service for her work on the scanning electron microscope.
- Dr R.L.H. Poels of the department of Soil Science of the Wageningen Agricultural University gave helpful critical comments on an earlier draft of the report.
- Last but not least Marjon Oostrom for her patience and support during my stay in the Côte d'Ivoire and during the time this report was taking shape.

SUMMARY

West African rain forests have been obliterated almost completely. One of the few large remnants of a once continuous forest cover is the Taï National Park in Southwestern Côte d'Ivoire. The present study aims to contribute to the conservation of the Taï National Park. To conserve the forest, sustainable land use systems must be developed. One of the major characteristics of a Tropical Rain Forest area which determines whether the forest can be utilized on a sustainable basis or not is its nutrient balance. The nutrient balance of a 117 ha catchment area was estimated on the basis of two input fluxes and three output fluxes. The measured nutrient inputs involved total wet and dry atmospheric deposition. The outputs of nutrients included fluxes of solutes, sediment and organic debris in the stream draining the catchment.

Inputs from Harmattan dust were in the same order as inputs in rain water. Stream output of Ca and Mg was mainly in dissolved form, and mainly as sediment for P. The conspicuous stream output of organic debris represented a negligible nutrient loss. For the nutrients P, Ca, K and Mg stream output far exceeded atmospheric input. Phosphorus, which is considered to be the nutrient limiting biomass production in the Tai region, showed a net loss of 0.8 kilo per hectare per year, which is 0.6% of all phosphorus present in the vegetation. For the other elements these relative losses were of the same order: 0.5% for K, 0.6% for Ca and 3% for Mg.

If the Taï forest ecosystem were stable, these losses must be made up by inputs not measured in this study. The only substantial other input is weathering. Given the strongly weathered character of the soils, inputs from weathering of soil minerals are probably very small. However, deep sub-surface flow may cause an output of inorganic nutrients originating mainly from weatherable minerals at depths below the rooting zone, i.e. from outside the ecosystem. A calculated nutrient balance which does not include nutrients in base flow, however, remains negative for all elements except Ca.

Two conclusions emerge. First, it is likely that the Taï forest is undergoing a net loss of nutrients. This decreases the possibilities for wood harvesting, even by selective cutting, without causing damage to the capacity of the land to support the present forest ecosystem. Second, given the low

nutrient status of the soils, sustainable agriculture in the surrounding deforested areas will be possible only if fertilizers are applied.

1. INTRODUCTION

1.1 Rain forest in West-Africa

The equatorial West African rain forest with an annual rainfall of more than 1500 mm once covered an area of 1.1 million square kilometres. The landscape of the area consists of (slightly) dissected peneplains with inselbergs and mesas, over basement complex formations. The soils range from well drained and (very) deep, coarse- to medium-textured, strongly weathered Ultisols and Oxisols on the upper and middle slopes to imperfectly and poorly drained, deep and coarse-textured Ultisols, Inceptisols and Entisols in the lower slopes and valley bottoms. Mostly the soils are gravelly and have a very low inherent fertility (Andriesse and Fresco, 1991).

The distribution of forest in West Africa (Fig. 1.1) shows a high degree of destruction and fragmentation of this former vast rain forest zone by human action. Only small isolated areas, covering less than 15% of the original forested area, are still under forest. The rate of deforestation has accelerated in the last decennia. According to estimations by FAO/UNEP (cited by Martin, 1991) 179,270 km^2 of rain forest had been left in West Africa at the end of 1980.[1] At the end of 1985 this had diminished by 20% to 143,260 km^2. Deforestation is often initiated by the big timber companies, who clear part of the forests and make logging roads for timber transport. When they have left, the forest is accessible for the farmers, who start slash and burn practices. It is this combination of logging and agriculture that has contributed most to deforestation in West Africa.

1.2 Taï National Park

The Taï National Park in the south-west corner of Côte d'Ivoire contains one of the last large remains of humid tropical forest in West Africa (Fig. 1.1). The park consists of 3,400 km^2 rain forest with an adjacent protection zone comprising 660 km^2. The protection zone has been

---

Including the rain forests of Benin, Ghana, Guinea, Guinea Buissau, Côte d'Ivoire, Liberia, Nigeria, Sierra Leone and Togo.

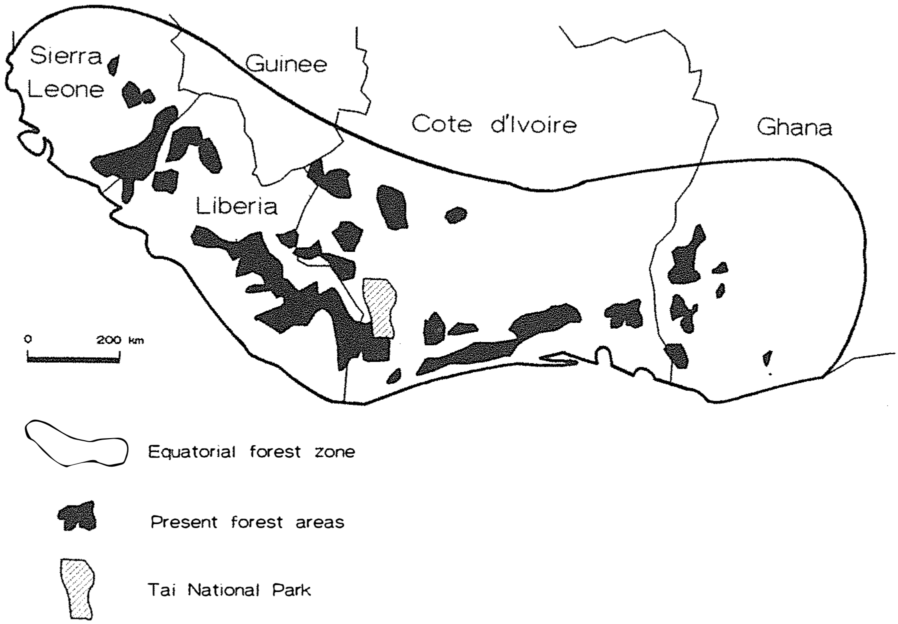


Figure 1.1 Remnants of forest in the equatorial forest zone in West Africa and the location of Taï National Park (Collins, 1990)

partially cleared before it got its present status and is not fully covered with forest. By decree (N°. 77-348 of June 1977) of the Ivorian president there is almost no difference in status between the park and the protection zone. In 1978 the park has been registered at UNESCO as a biosphere reserve giving it an international protection. Scientific research in the park area has been and is being carried out mainly in the western part of the park and in the zone between the park and the Liberian border.

The park is threatened by a relatively high pressure on agricultural land in the Taï district. De Rouw et al. (1990) show that the fallow period of the traditional shifting cultivation has been decreased to less than 10 years and that the region between the park and the Liberian border is almost devoid of primary forest. In the zone west of the park the people and their land are enclosed by the park boundary and the Liberian border. In 1990 the problem has increased by large numbers of Liberian refugees crossing the border to the Côte d'Ivoire. The high population pressure is unavoidable and the protection of the park depends on the development of more efficient land use systems that provides enough food, forest products and money to sustain the people.

1.3 The aim of the study

The Tropenbos programme is focused on forest conservation and emphasizes study of the interaction between forest ecosystems and human populations. this is a logical choice as in most cases it is the human population that threatens the forest ecosystem. By prociding alternative and sustainable forms of land use to the people the pressure on the forest can diminish. In the tropical forest zone nutrients are often in short supply and in general it can be said that land use is only sustainable if the nutrient balance is in equilibrium. This indicates the importance of nutrient cycling studies.

The present research does not consider the whole nutrient cycle under tropical rain forest but is focused mainly on the budget of inputs and outputs of nutrients on the scale of a small watershed. It was carried out in a catchment area of 117 ha in Taï National Park. The results should provide necessary elements for designing sustainable cropping systems in the zone around the national park.

A general description of the catchment is given in Chapter 2. Many observations and measurements were needed to assess the nutrient budget for the catchment. Chapter 3 describes details of the methods used. For the hydrological data results of past studies were used. For export of nutrients output of solutes, sediment and organic debris by means of a creek was considered. A hydrological model, developed to quantify the discharge of the creek, is discussed in Chapter 4. The results of the various measurements are presented and discussed in Chapter 5. The general conclusions on the nutrient balance of the catchment are described in Chapter 6. The conclusions relevant for forest conservation, are summarized in Chapter 7.

2 THE STUDY AREA

2.1 Location of the study area

Taï National Park is located in the south-west corner of Côte d'Ivoire (Fig. 1.1). The study area situated in the western part of the Taï National Park, is a catchment area of 117 ha in the upper reaches of the Audrenisrou river. The centre of the catchment lies 7° 19' 55" west and 5° 53' 30" north. Six kilometres south of the catchment area the field station of the Institute for Tropical Ecology ("Institut Ecologique Tropicale") is situated. Fig. 2.1 shows the position of the study area in Taï National Park.

2.2 Climate

The climate of the region is monsoonal with two dry spells. The long rainy season between March and December, when the Inter Tropical Convergence zone (ITCZ) lays to the north of the area, is dominated by the monsoon winds from the south-west, and is divided in two by a short dry spell in August. During the dry season between December and March, when the ITCZ lays south of the area, Harmattan winds from the north-east determine the climate. In that period, the relative humidity is low, and dust, originating from the Chad basin, is imported. The climate can be classified as an "Aw climate" according to Köppen (1936), being warm (>18°C in the coldest month) and wet with a dry period in winter.

Fig. 2.2. shows how monthly rainfall, temperature and potential evapotranspiration vary over the year. The mean annual rainfall in Taï (1944-1959 and 1969-1979) is 1833 mm with a standard deviation of 338 mm (Casenave et al., 1980). Temperatures vary seasonally between 23 and 28°C with highest values in April and October when the sun is at its highest position. The potential evapotranspiration based on pan measurements is between 80 and 120 mm/month, and is correlated with the global radiation which varies between 1200 and 1700 $Jcm^{-2}day^{-1}$. The actual evapotranspiration for the forest ecosystem, derived from the data by Casenave et al. (1984) on the water balance of the catchment is 1467 mm/year (4.0 mm/day).

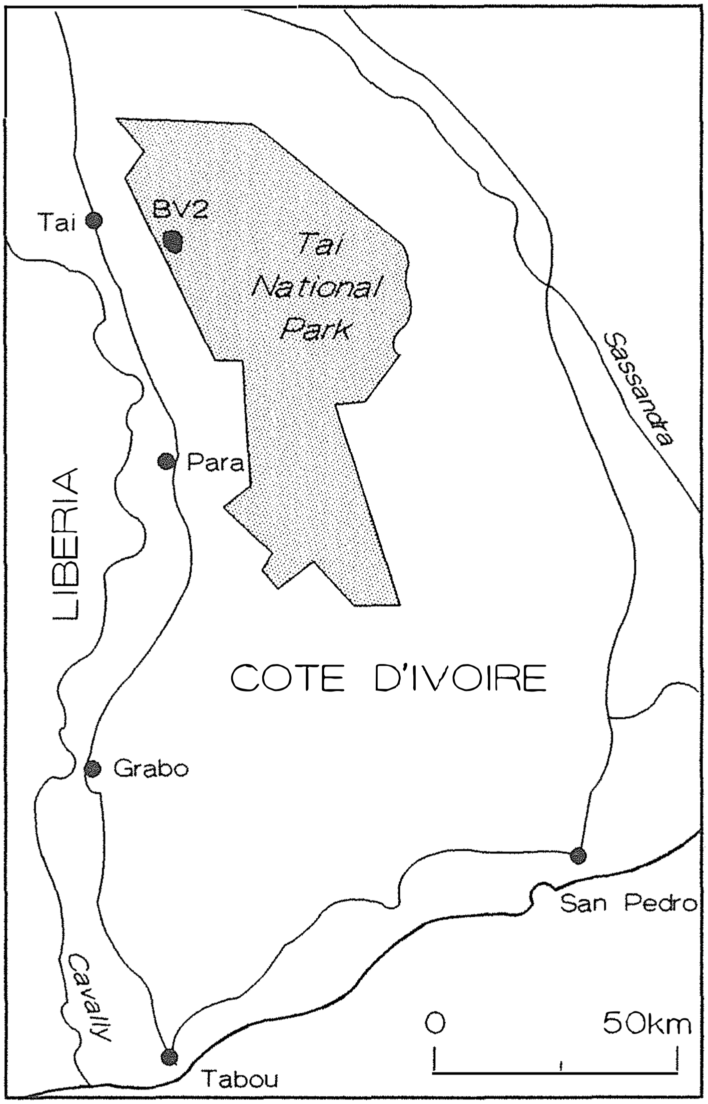


Figure 2.1 Location of the study area

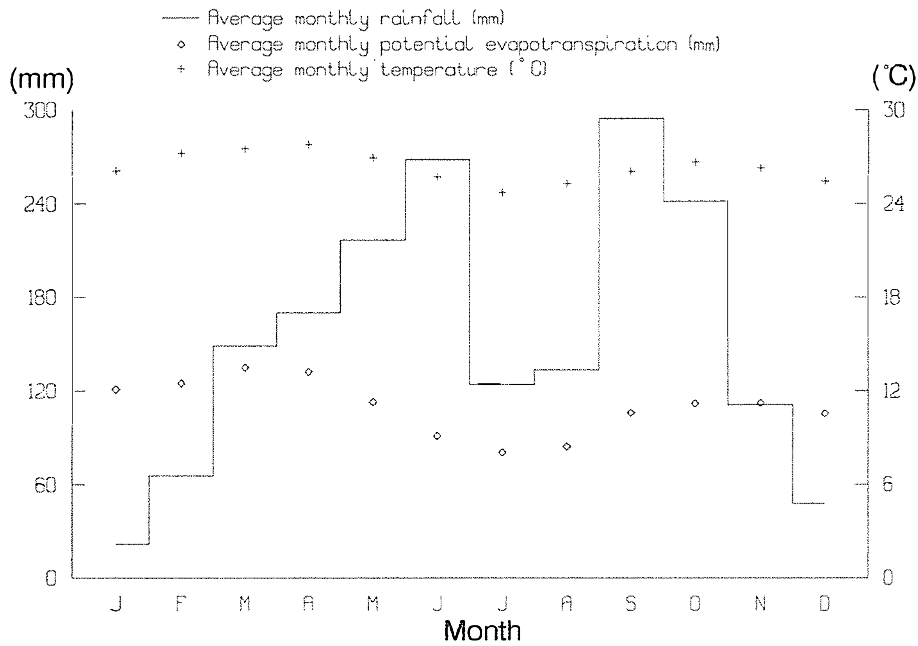


Figure 2.2 Average monthly rainfall, potential evapotranspiration and temperature (MAB station, Taï, 1978-1982, after Monteny, 1983)

2.3 Geology and geomorphology

Almost the whole National Park of Taï is underlain by the Precambrium Basement Complex, which consists of granites and associated gneissic metamorphic rocks (Papon, 1973). According to Bos (1964) the studied catchment has been developed in heterogeneous migmatites.

Over 80% of the western part of the park consists of a sissected peneplain with remnants of an ironstone cap at the highest areas, the crests (de Rouw et al., 1990). The peneplain descends from 225 meters above sea level in the north of the park to 50 meters above sea level in the south. In the studied catchment, where less than 1% of the peneplain remains, the old peneplain is at 198 meters above sea level and is dissected by 45 meters to produce a present day elevation of 153 meters above sea level in the lowest point (Casenave et al., 1980). Slopes in the area vary between 0 and 8% (Fig. 2.3).

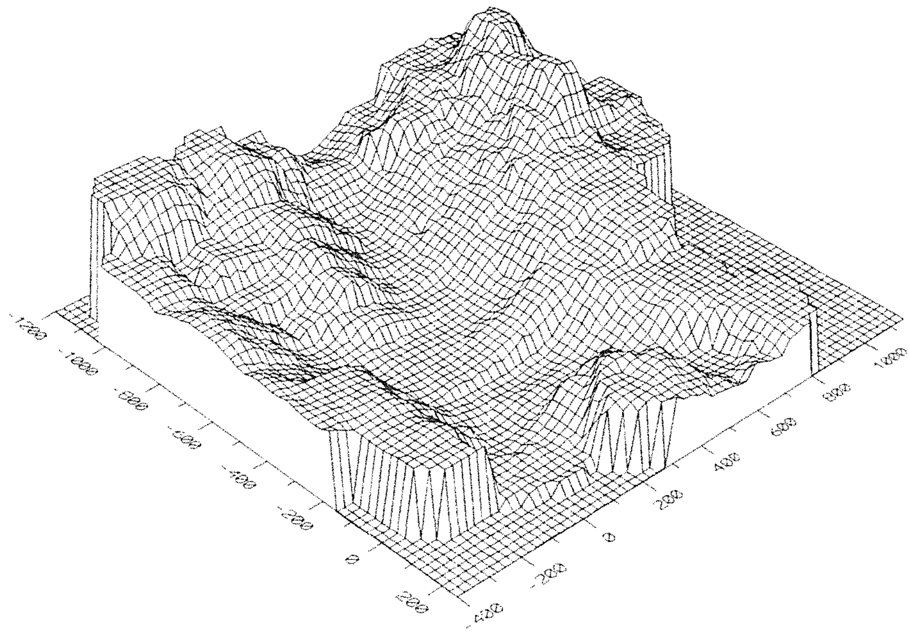
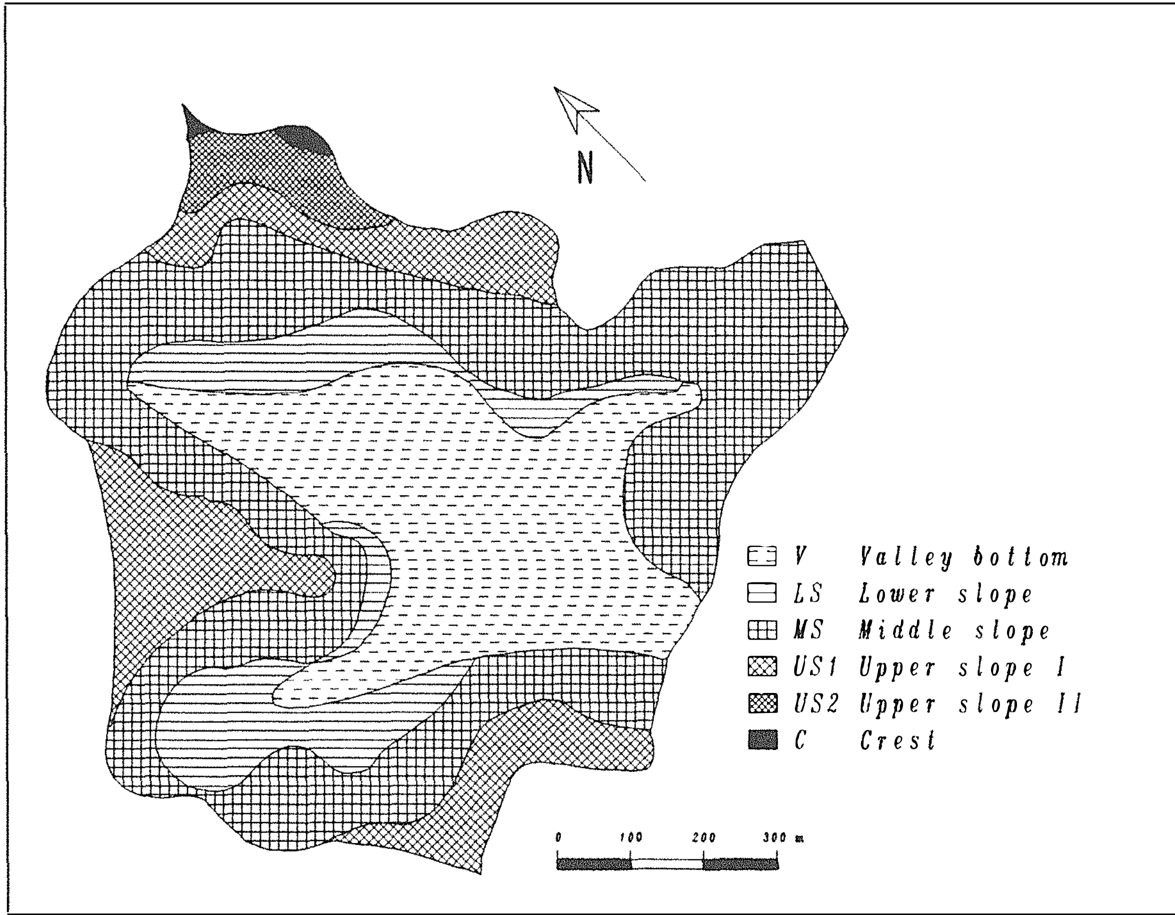


Figure 2.3 3-dimensional view on the catchment at a horizontal scale of 1:10,000 (vertical scale is exaggerated ten times)

2.4 Soils

Several pedological studies have been carried out in the area (Fritsch, 1980, Fraters, 1986 and de Rouw et al., 1990). A detailed soil survey at a scale of 1:5,000 has been carried out for the catchment (Nooren, 1991; Fig. 2.4). A total of 9 km of lines was cut through the area. On these lines the topography was measured and 180 soil augerings were made. Six soil pits were dug, described and analyzed previously as reported by Fraters, 1986 (Annex I).

There is a strong correlation between the topography and the pedology. Roughly three positions can be distinguished. The highest position (Unit C in Fig. 2.4) covers 0.3% of the area, and has an ironstone capping which is the last remnant of the peneplain that once covered large parts of West Africa. Almost 55% of the catchment is on sloping terrain, where soils can be classified (FAO, 1988) as Plinthic Acrisols and Plinthic Ferrasols (Units US_1, US_2, MS and LS). The valley bottom, comprising 40% of the



(Continued on page 21)

Unit	Physiography	Drainage	Altitude (m)	Slope form	Slope degree	Soil Characteristics
C	Crest	Well drained	185-198	Flat to convex	Flat to gently sloping	Very gravelly red (2.5 YR 4/8) clay over cemented ironstone layer
US_1	Upper slope	Well drained	180-192	Convex	Sloping	Very gravelly red (2.5 YR 4/8) clay over non gravelly red(10 R 4/8) clay
US_2	Upper slope	Well drained	170-180	Straight	Gently sloping	Very gravelly red (2.5 YR 4/8) to strong brown (7.5 YR 5/8) sandy clay loam to clay over non gravelly red (10 YR 4/8) clay
MS	Middle slope	Moderately well drained	160-175	Straight	Gently sloping	Very gravelly yellowish brown (10 YR 5/8) sandy loam to sandy clay loam over non gravelly yellowish brown (10 YR 5/8) clay
LS	Lower slope	Moderately well drained	160-170	Concave	Gently sloping	Non gravelly yellowish brown (10 YR 5/8) sandy loam to sandy clay loam over petro-plinthite or very gravelly layer
V	Valley bottom	Poorly drained	153-160	Concave to flat	Almost flat	Non gravelly light grey (10 YR 7/1) loamy sand to sandy loam

Figure 2.4 Soil map of the catchment at a scale of 1:10.000 (adapted from Nooren, 1991)

area, has hydromorphic soils classified as dystric Gleysols (Unit V). the soil map by Fritsch (1980) on a scale of 1:10,000 and covering a larger area shows that the soils of the catchment are representative for a much larger area where individual watersheds show the same typical toposequence. In fact, the soils of the catchment area are representative for large parts of the West African forest belt, which is also underlain by the Precambrium basement complex.

2.5 Vegetation

The vegetation of the survey area can be classified as a tropical evergreen seasonal lowland forest (Vooren, 1985). The canopy height reaches up to 40 m. Imbrication of the forest canopy occurs on sites with impeded drainage or superficial ironstone formations. A vegetation survey in the area was carried out by Huttel (1977). A characterisation of the major tree species with a circumference of more than 11 cm was given for six different topographic positions (Appendix II[a] and II[b]). Vegetation compositions were related to the topographical positions.

A vegetation survey with emphasis on the undergrowth has been carried out by de Rouw (1991), but she did not differentiate between vegetation zones within catchments.

2.6 Fauna

The fauna of Taï national park is very diverse and numerous. A list of the main mammals in Taï National Park is presented by Guillaumet et al. (1984). An avifaunal survey has been carried out by Gartshore (1989). At the moment the fauna of the national park, and especially the larger mammals like elephant and zebra duiker are threatened by poaching.

3 METHODS

3.1 Introduction

The gross inputs and outputs of nutrients considered in this study are illustrated in Fig. 3.1: wet and dry deposition as inputs of nutrients and solutes, sediment and particulate organic material as outputs of nutrients. To measure the nutrient balance with limited resources, some restrictions had to be made.

1) According to van Reuler and Janssen (1988), phosphorus is the limiting nutrient in the ecosystems in Taï. Therefore emphasis was placed on phosphorus, and less attention was paid to nitrogen. Another reason is that nitrogen is involved in gaseouses transfers which could not be measured with the available means.
2) The analyses were meant to obtain total nutrient contents. Therefore no distinction was made in plant available and non-available forms of nutrients in the exported sediment.
3) In spite of the spatial variation in soils, hydrology and vegetation discussed in Chapter 2, the catchment was treated as a whole for which only the gross inputs and outputs were measured and fluxes between the different units within the catchment were not considered.
4) The system is defined as the total watershed down to the (presumably) watertight basis, and including the standing biomass. Weathering is therefore not taken into account as an input factor. However, weathering and its possible importance as an input factor is discussed in Chapter 6.
5) It is assumed that all outputs of non-volatile nutrients from the catchment go through the creek. Sub-surface flow of water with solutes is assumed to be nil. A check on this assumption has been carried out, as described in Section 4.3.
6) Between December and March Taï National Park lays under the influence of the Harmattan. Dry deposition in this period is relatively high. In other parts of the year dry deposition is low due to landward wind directions and high rainfall. Therefore dry deposition outside the Harmattan season is not taken into consideration. Bertrand (cited by Baudet and Bertrand, 1988) determined the number of ice-nuclei in the air during the Harmattan and the rainy season. The number of ice-nuclei (which is a good

representation for the number of dust particles) decreases during the rainy season by a factor of 20, supporting the assumption that dry deposition during the rainy season is negligible.

All water and sediment samples were analyzed at the laboratory of the Department of Soil Science and Geology of the Wageningen Agricultural University, the Netherlands. The samples of particulate organic debris were analyzed at the laboratory of the Department of Soil Science and Plant Nutrition of the Wageningen Agricultural University. Dust samples have been analysed by scanning electron microscopy in combination with a X-ray microanalysis system at the Technical and Physical Engineering Research Service (TFDL) in Wageningen.

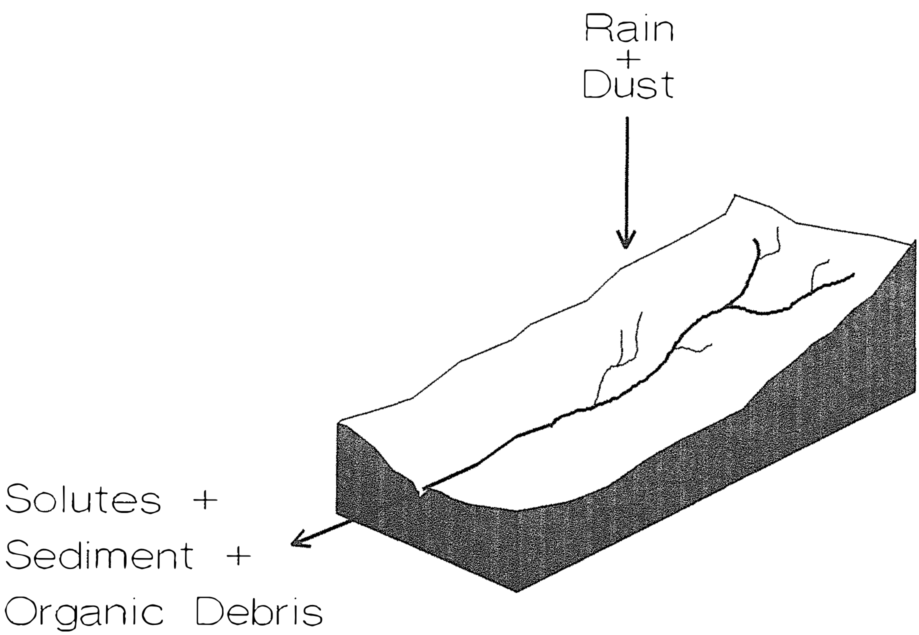


Figure 3.1 The inputs and outputs of nutrients

3.2 Rainfall

To assess the nutrient input by rainfall, rainfall and nutrient concentrations in rainwater were determined.

Daily rainfall figures were obtained from three hand-operated rain gauges (ϕ 20 cm) and one automatic rainfall recorder. Three gaps in the vegetation of the catchment (for locations see Annex III[b]) were used for the measurements (the central gap was equipped with both an automatic and an hand-operated rain gauge).

Nutrient concentrations in rainwater normally are extremely low. Therefore much attention had to be paid to possible contamination from local sources (plant debris, insects, faeces) that would be part of the internal nutrient cycle. Frequent heavy winds just before rain storms increase the risk of contamination. The gaps in the vegetation appeared to be too small (average surface of the three gaps is 134 m^2) for rainwater sampling without appreciable contamination. Therefore sampling was limited to the collector at the meteorological field of the Institute for Tropical Ecology, 3 km south of the catchment (Annex III[a]), an open surface of 2 ha. The rainfall collector consisted of a plastic funnel and a polyethylene bottle. The collector was emptied and cleaned daily by washing with demineralised water (rather than by acid, which would remove any adsorbed cations, and which would cause an underestimation of nutrient inputs by rainfall). If possible it was cleaned several times a day. Every day a new bottle was installed to avoid effects of algal growth in the moist bottle.

After sampling two drops of chloroform were added to the samples which were subsequently stored at 11°C. In all 98 samples electrical conductivity and pH were measured within 10 days after sampling. One fifth of the rainwater samples was analyzed for P, Al, Si (by Autoanalyser Technicon II), Ca, Mg, Fe, Mn (by AAS Perkin Elmer 560), K, Na (by AES Perkin Elmer 560), Cl, NO_3, SO_4 (by HPLC Waters 150), C_{total} and $C_{inorganic}$ (by TOC analyser Thermo Instruments type 555) (Further details of the analytical procedures are described by Begheijn, 1980). Statistical relations between the electrical conductivity and the pH on one hand and the solute concentrations on the other were derived to try to estimate the solute concentrations in all samples, as will be described in Section 5.2.

3.3 Harmattan dust

Two dominant and opposite wind systems determine the climate in West Africa. A south-western current is responsible for the humid air and high rainfall during the long wet season. During the dry season (December to March) it is replaced by a north-eastern current consisting of very dry air. The latter is also called the Harmattan, which distributes dust, eroded in the Chad basin, over West Africa.

McTainsh (1986) describes dust deposition measurements by means of a metal pan filled with distilled water (wet-basin method). Its rough structure probably gives the tropical rain forest canopy characteristics that are different from those of a flat water surface. To properly estimate deposition on the forest a new method has been developed. Dust deposited on the forest canopy, will probably wash from the canopy with the first rains after the dry season. Therefore dust deposition can be measured by determining the amount of dust in canopy drip. However, canopy drip will be contaminated with other substances (e.g. dead organic matter). To distinguish between dust and contamination use was made of titanium, a lithophilic element which occurs in dust but not in the vegetation. In addition, it was necessary to know the chemical composition of non-contaminated dust. Therefore dust was also sampled separately, directly from the air.

To collect canopy drip 56 collectors (ϕ 15 cm) were placed along three lines in the forest (See Annex III[b]). Canopy drip was collected during the last two rain events before the Harmattan season and during the first two rain events after the Harmattan season. The samples of each line were pooled, resulting in three different samples of the three lines respectively. Canopy drip was filtered and the residue was dried for 24 hours at 105°C. The residues were analyzed by X-ray fluorescence spectroscopy (according to Begheijn and van Schuylenborg, 1971). To check the hypotheses that all dust is washed from the canopy with the first rains, leaves were collected at 5 different heights and three different places in the forest 6 km south of the catchment area (See Annex III[a]) on a weekly basis between December 1, 1990 and February 7, 1991 and in addition after the two rainy days in February, 1991. The leaves were placed between two glass slides and stored in silica gel. The leaves were examined under the microscope at a magnification of 500 times and the number of dust particles (> 5 μm) per square centimetre was counted.

For chemical analysis, Harmattan dust was sampled using an adapted version of the Gromoz apparatus which was developed by IMG-TNO (Vrins et al., 1985). It is based on an air pump which sucks the air through a filter (Annex IV). In this study, glass-fibre filters were used.[1] They do not clog easily and have a relatively low air resistance (according to Sleicher and Schuell product information: 650 mm WS). A disadvantage is the rough structure of the filter material which collects part of the dust particles between the fibres. It is therefore almost impossible to separate the dust particles from the filters. Therefore filters with and without dust were analyzed separately, so that the dust composition could be assessed by difference. Dust was sampled 9 times in the first two weeks of January, 1991. Sampling started in the morning after the morning mist disappeared and was continued for 6 hours (±2 hours). Several chemical, mineralogical and physical properties of Harmattan dust were determined.

- Three filters with dust and two clean filters were pulverised and analyzed by X-ray fluorescence spectroscopy (according to Begheijn and van Schuylenborg, 1971) to assess the elemental chemical composition of the dust samples.
- One filter with dust was studied by X-ray diffraction to obtain more insight in the mineralogy of the dust particles.
- One filter with dust and one without dust were subjected to thermal gravimetric analysis (TGA) to estimate the contribution of organic particles.
- The particle size distribution of dust was estimated from scanning electron micrographs. On six different micrographs at three different magnifications (1000, 2500 and 5000 times) counts were made.
- The variation in chemical composition of individual dust particles was evaluated with a X-ray microanalysis system connected to the scanning electron microscope.· Point analyses were carried out in twenty dust particles of an ignited sample (for 3 hours at 600°C) and in ten dust particles of an untreated sample.

With the titani m content in dust, the amount of dust in canopy drip could be assessed. With additional information on the nutrient concentrations, the nutrient input with Harmattan dust could be calculated.

The wet-basin method for estimating dust inputs described by McTainsh was carried out too, to be able to compare the Taï situation with literature data. However, McTainsh's version was slightly adapted to the specific

[1] Schleicher & Schuell glass fibre filter No. 10 (ϕ 15 cm)

circumstances. Six round plastic pans with a diameter of 50 cm and a height of 15 cm were installed at three different sites. Two pans were placed in the tree canopy, 34 metres above ground level, close to the field station of the IET. Two pans were installed on the meteorological field of the IET (1.5 m above ground level). Finally, two pans were placed in a young coffee plantation, just outside the National Park (also 1.5 m above ground level) (Exact positions are given in Annex III[a]). The pans were installed on December 18, 1990. The water level in the pans was kept between 2 and 2.5 cm. Visible contaminations like leaves, small insects etc. were removed after rinsing them with some demineralised water above the pan. The samples from the pans were taken just after the Harmattan season on the 6th of February, 1991.
All water in the pans was filtered and the residue was dried for 24 hours at 105°C. Samples from each pair of pans on the same location were pooled because individually they were too small for accurate analysis. The samples were analyzed by X-ray fluorescence spectroscopy. All the samples had been contaminated to some extent with insect and plant debris (incl. pollen) and, presumably, droppings of birds, bats and insects. Therefore the lithophilic element titanium was used again to estimate the amount of dust collected in the pans, based on the titanium concentration in dust as determined in the dust samples collected by the Gromoz apparatus.

3.4 Solutes

In humid tropical areas with strongly weathered soils, creek waters normally have very low concentrations of solutes and sometimes resemble distilled water. However, such enormous quantities of water may be exported from watersheds under tropical rain forest that still a substantial amount of nutrients can be exported, even if the solute concentrations are very low.

The base flow of the creek was sampled daily by hand.[2] During quickflow in the creek, samples were taken by automatic water samplers at five different moments: when water level reached 25, 50 and 75 cm above the creek bed during rising of the water level and when the water level

---

The flow in the creek is divided in two different parts, the base flow and the quickflow. The definition of the two flows is given in Section 4.1.

reached 50 and 25 cm above the creek bed during lowering of the water level. In addition, if possible, hourly samples of the quickflow were taken by hand. Annex V gives a description of the automatic water samplers used. The same water samples were used to estimate the sediment concentrations. For preservation, two drops of chloroform were added to the samples and they were stored in a refrigerator at 11°C.

Creek water was filtered through Whatman 542 ashless filter paper. Residues were analyzed as sediment samples and filtrates were analyzed to estimate solute concentrations. In all water samples pH and electrical conductivity were measured. In 16% of the samples concentrations of all major solutes were analyzed in Wageningen, as described in Section 3.2. Standard water analysis does not provide data on the organic fractions of dissolved P. For analysis of total P, ten 1 litre-samples were freeze-dried and the residue was digested by 0.4 M nitric acid. Subsequently the digests were analyzed to provide total P. Organic P was calculated as the difference between total and organic P.

3.5 Sediment

Casenave et al. (1980) estimated the suspended sediment yield at 1.5 ton per ha per year. Even with low nutrient concentrations this export could contribute to an appreciable removal of nutrients. Because the sediment output is probably correlated to the outflow which is very variable, a high variability in sediment output can be expected. Frequent sampling of the sediment load was therefore necessary. The sampling scheme for the sediment was the same as for the solutes. Every two days a sample from the base flow was taken. During quickflow samples were taken at water levels of 25, 50 and 75 cm during water rise, and at 50 and 25 cm during the fall of the water level, by means of the same collectors as used for solutes (for a description of the collectors see Annex V). In addition hourly samples of 3 l were taken manually during quickflow whenever there was an opportunity to do so. In the field, three drops of chloroform were added to preserve the samples. In the laboratory two drops of a 0.2% superfloc solution were added to the samples to increase sedimentation. Subsequently the suspension was shaken for 30 minutes and left for 2 hours to settle. Next, the clean supernatant was siphoned off. After decanting 50% of the supernatant, the sample was shaken again for 30 minutes and filtered through a Whatman 542 ashless filter. The filters with the residues were dried for 24 hours at 70°C. The sediment was removed from the filter and analyzed by X-ray fluorescence spectroscopy. If the samples were smaller than 1.0 gram (the minimum quantity of a sample for X-ray fluorescence analysis) quartz sand[3] was added up to 1.0 gram. A sample of the quartz sand was analyzed to correct for any element additions by the quartz diluent.

Annex V[c] shows the places in the cross section of the creek where sampling took place. However, the location of sampling may have an effect on the sediment concentration. Therefore on September 17, 1990 and September 25, 1990 five sediment samples were taken at the same time but in different places in the creek as shown in Annex V[d]. In all these samples the sediment load has been determined.

3.6 Particulate organic debris

Nutrient export in the form of particulate organic debris in the creek water was measured where the creek leaves the catchment. At this point the valley bottom is 88 m wide, and during quickflows water levels may be up to 65 cm above the land surface, so the valley bottom becomes a flood plain. Organic material, exported during base flow has been sampled with a collector in the stream and with three collectors installed across the valley bottom. Because of the dense undergrowth in the valley bottom, the velocity of the quickflow outside the creek itself was quite low, and it was relatively easy to obtain a representative sample even during quickflow events. The set up of the collectors in the stream and in the flood plain are illustrated in Annex VI.

During the first three months of the study and during the dry season from December until March no high quickflows occurred and a simple but strongly build collector could be used. The creek was closed with 2 mm gauze supported by 5 cm mesh. During the much larger quickflows in the wet season, this construction had to be changed because of high water velocities, and large amounts of organic debris which would otherwise clog up the gauze. Therefore two bow nets with 2 mm mesh which did not completely shut off of the river-bed (as displayed in Annex VI) were used. To check the efficiency of this trap, two identical small but long bow-nets with 2 mm gauze were placed before and behind the construction. The

---

Sea sand purified by acid and calcined for analysis purposes difference between these two bow nets represent the efficiency and the values obtained from the large bow nets in the river bed could be corrected for incomplete recovery. All the bow-nets were emptied daily. The total wet mass was weighed and, if necessary, a sub-sample of circa 500 g was taken and was divided into three categories of material: (1) branches, (2) leaves and (3) flowers and fruits. These different categories were considered because differences in the nutrient contents for the different groups were expected. The samples were stored in the freezer and dried afterwards at 65°C for 24 hours. One fifth of the samples was selected for chemical analysis, after digestion, by colorimetry for N and P, by atomic emission spectrometry for Na and Ca, and by atomic absorbtion spectrometry for Mg, Mn and Zn (according to Wallinga et al., 1989).

As indicated in the beginning of this chapter, the present study dealt only with the inputs and outputs of the whole catchment and fluxes of nutrients within the catchment were not considered. Some field observations indicated, however, that transport of organic debris along the slopes is negligible. This would mean that most of the organic debris exported by the stream originated from the valley bottom. To verify the origin of organic debris two small experiments were initiated.

- The movement of leaves on the slopes of the catchment was measured. During the wet season, leaves were marked with white paint along the contours. During the following two weeks the marked leaves were checked regularly and the number of leaves which are transported and the distance over which they are transported were measured (van Zon, 1978). The experiment was carried out on five different slope positions. Results are a rough indication on the transport of organic debris along the slopes of the catchment.
- Because most trees occur on specific topographic positions (see also Annex II[a] and II[b]) the origin of the leaves in the creek could be assessed. This has been done by identifying leaves sampled in the creek to the species level.

4 HYDROLOGY

4.1 Introduction

In a humid tropical forest ecosystem the hydrology is a major factor in nutrient cycling. The hydrology of a (watertight) catchment area comprises rainfall as the only source of water import and the actual evapo-transpiration in combination with the discharge as the export of water. Rainfall and discharge are the major carriers of nutrients in the nutrient balance of a tropical forest ecosystem.
Two different types of discharge can be distinguished, base flow and quickflow. The base flow is the relatively persistent low-intensity discharge that is observed between peaks and that consists mainly of relatively deep ground water (Wanielista, 1990). The quickflow occurs only during and just after rainfall and is characterised by a relatively rapid fluctuation in water level. The hydrograph in Fig. 4.1 illustrates the marked differences between base flow only and base flow with superimposed quickflow.

The study area is one of many second-order basins, tributary to the Audrenisrou river. All second-order basins are more or less 1km^2 and have a similar geology, topography and pedology. The soils on the slopes have a low infiltration capacity ranging from 7 to 12 mm h^{-1} (Wierda et al., 1989) which results in a very peaky discharge pattern with large quickflows after rainfall.

The present study relied heavily on past hydrological studies in the region carried out between 1979 and 1981 by Casenave et al. (1984). They studied the hydrology of three catchments in the Taï region, providing data on rainfall, base flow and quickflow. The present study was done in one of these three catchments. Section 4.2 summarizes the results for the particular catchment, derived from Casenave et al. (1984).

An empirical model, based on the observations of Casenave et al. was developed to simulate the hydrological cycle for the period of 1990-1991. This was necessary because in the present study the hydrological observations only included (daily) rainfall and (continuous) creek waterlevels. The model is described in Section 4.4.

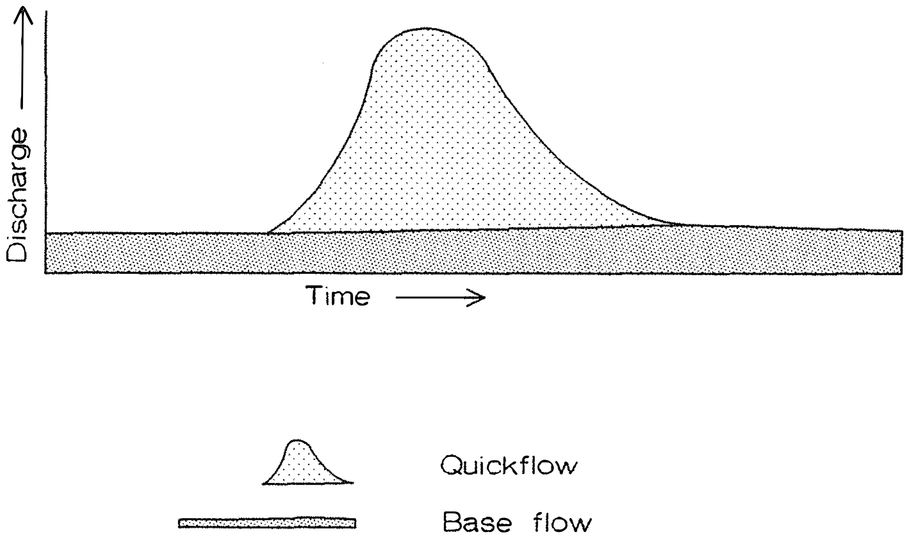


Figure 4.1 A hydrograph with the two different types of discharge, base flow and quickflow

4.2 Water balance for the catchment area

The hydrological studies by Casenave and co-workers were published in three ORSTOM publications (Casenave et al., 1980, 1981 and 1984) and summarized in a Unesco report (Guillaumet et al., 1984).

Their study was carried out in two small catchments (1.2 and 1.4 km^2), of which one is used in the present study, and one large catchment (38 km^2) which comprises the two smaller ones. For each of the three catchments a hydrological balance was set up. A multitude of hand-operated rain gauges and automatic rainfall collectors throughout the catchments provided data on rainfall patterns and characteristics. A weir in each of the three catchments was used to measure discharge.

The results for the catchment area used in this study (BV2) for 1980, the only year without missing data, are summarized in Table 4.1. By the quickflow 11% of the rainfall is directly exported from the catchment. Total base flow exceeds the quickflow by a factor of two and is responsible for a discharge of 21% of the rainfall. So, 32% of the

Table 4.1 Monthly data of rainfall and discharge in 1980 (in mm/month)

Month	Pm	OF	BF	QF
January	23.8	11.0	10.6	0.4
February	65.4	7.3	5.5	1.8
March	228.1	29.7	13.4	16.3
April	182.9	31.7	16.1	15.6
May	264.5	58.1	30.7	27.4
June	149.8	52.5	40.7	11.8
July	170.9	42.1	28.0	14.1
August	225.1	83.4	63.6	19.8
September	388.8	171.7	86.7	85.0
October	179.3	76.7	57.1	19.6
November	68.4	36.3	34.3	2.0
December	39.0	22.2	20.8	1.4
1980 (mm/yr)	1,986.0	622.7	407.5	215.2

In which: Pm rainfall, OF total discharge
BF total base flow, QF total quickflow

incoming rain water is discharged through the creek. The discharge through the creek varied between 0 and 25 l/s during base flow and between 25 and 1500 l/s during quickflow. The rain intensities responsible for the highest quickflows could mount up to 120 mm/h.

The present study used the raw data for BV2 provided by Casenave et al. (1980, 1981 and 1984) for the development of a model which describes the hydrology of the catchment (Section 4.4).

4.3 Sub-surface flow in the catchment area

Casenave et al. (1980) assumed that no water was discharged by sub-surface flow. Based on the topography and pedology of the area, this assumption seems reasonable. However, in the sandy soil of the valley bottom sub-surface flow could occur above the compact loamy layer present at one meter below the valley bottom. Because sub-surface water losses would considerably influence the results of this study a check on the sub-surface flow has been carried out.

Three times during the wet season the occurrence of sub-surface flow parallel to the stream was tested using a profile pit in the valley bottom 25 meters adjacent to the outflow point dug for previous pedological research.

First all ground water was removed from the pit after which three collectors with a width of 50 cm were installed in the wall of the pit at 50, 75 and 100 cm depth (Fig. 4.2). The flow trapped by the collectors was measured for two hours. Assuming that the soil pit is representative, the sub-surface flow for the whole valley bottom was calculated for the whole valley bottom by multiplying the flow trapped by the collector by the ratio of the widths of valley bottom and collector (88 m / 0.5 m = 176). The results are listed in Table 4.2. The estimated sub-surface flow was less then 4% of the creek flow, and is therefore considered as negligible.

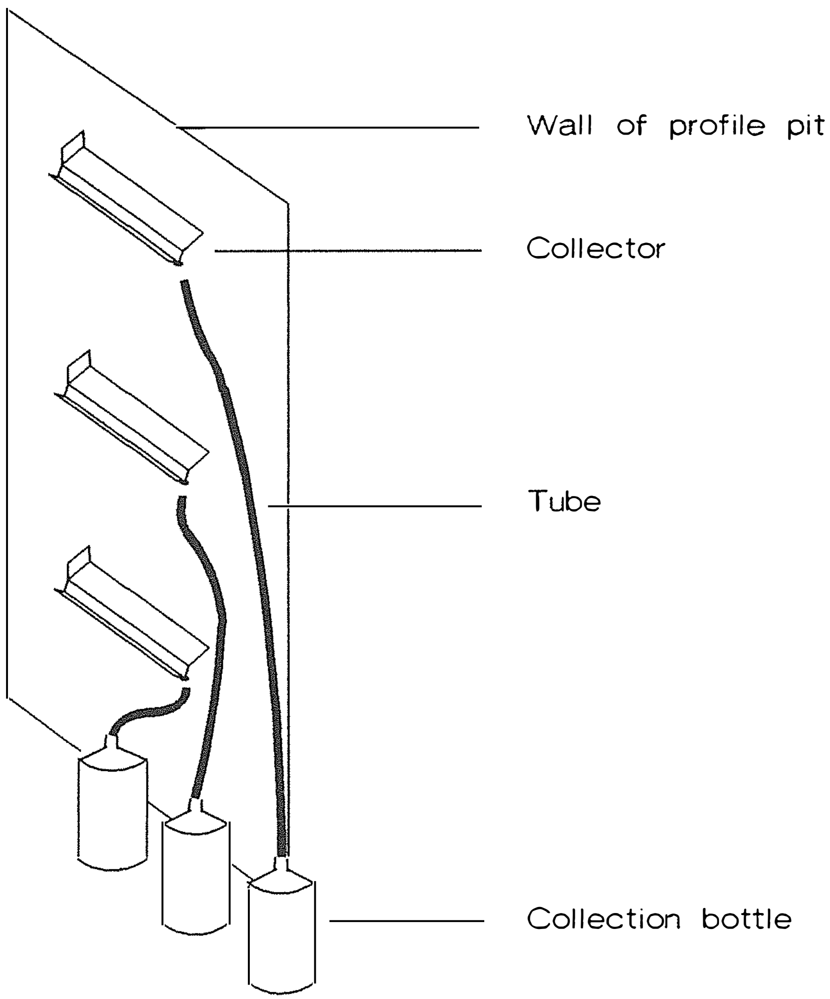


Figure 4.2 Collectors used to measure the sub-surface flow

Table 4.2 Sub-surface flow in litres per second for the catchment on August 12, August 30 and September 20

		12-8-90	30-8-90	20-9-90	Average
Depth	50 cm	0.00	0.00	0.04	0.01
	75 cm	0.05	0.02	0.10	0.06
	100 cm	0.16	0.09	0.17	0.14
Total		0.21	0.11	0.31	0.21
Creek[1]		6.0	4.2	8.2	6.1

[1] Estimates by the hydrological model

4.4 A hydrological model for the catchment area

From data collected by Casenave et al. (1984) a model describing the hydrological cycle of the catchment was developed. Its objective is the simulation of the hydrological cycle in years for which only rainfall data are known. Daily rainfall is the only input variable required to run the model. The model calculates two output flows (base flow, quickflow) and the storage of water within the ecosystem. Fluxes or processes within the system are not considered. All the other vectors are calculated with statistical relations based on the data by Casenave et al. (1980, 1981 and 1984). Annex VII gives the listing of the model, which has been programmed in Turbo Pascal Version 6.0.[1]

Rainfall intensity and distribution do play an important role in the hydrological cycle. However, only data on a daily basis were available for the calibration period between 1979 and 1982. Therefore the model involves daily time steps.

The actual evapotranspiration (AET) is very hard to measure or estimate. For the catchment the average AET can be calculated using the hydrological data collected by Casenave et al. For a period of more than 650 days, the input (rainfall) and output factors (base flow and quickflow) have been measured. If the base flow is determined wholly by the storage of ground water in the system, the storage of ground water must be the same at all moments with the same base flow. In the data by Casenave et al., the same base flow (4.0 l/s) was found on March 21, 1979 and January 12, 1981. If the storage of ground water plus soil moisture at

[1] Copyright Borland International.

those two days was indeed the same, the sum of the AET and all daily outflows between March 21, 1979 and January 12, 1981 must equal the total rainfall during that period. The unknown AET can then be solved, and it turned out to be 4.02 mm/day. Mean annual AET values of about 4 mm/day are typical for tropical forests (Bruijnzeel, 1990). For lack of data for a more dynamic approach of the AET, it was kept constant in the model.

The best estimate of the base flow was obtained if it was expressed as a function of the rainfall of the foregoing 90 days. Equation 4.1 gives this relation.

Equation 4.1

$$\text{Sum} = \sum_{d=-1}^{d=-90} \left(\frac{R_d}{(-d+0.7)} \right) \qquad \text{[Equation 4.1}^{a}\text{]}$$

$$BF_{d=0} = 0.022 * \text{Sum} + 0.43*10^{-3} * \text{Sum}^2 \qquad \text{[Equation 4.1}^{b}\text{]}$$

$(r^2 = 0.91)$

In which :	Sum	Variable representing the rainfall of the last 90 days
	BF	Base flow (mm/day)
	d	number of days prior to BF estimate
	R_d	Rainfall d days before the BF estimate (mm)

The quickflow could be described as a function of rainfall and storage in the catchment. The absolute value of the storage is very hard to measure. Therefore, the change in storage since a fixed reference point of time was used. The storage at the two days used for the assessment of the AET was set at 0. From that point on, storage was calculated on the basis of rainfall figures and AET. Once storage is known, quickflow can be calculated. Equation 4.2 gives the procedure used in the model. Casenave et al. (1984) found that if the rainfall was smaller then (6.5-0.09 * Base flow) no quickflow occurs. The fraction of the rainfall which is discharged as quickflow increases with increasing storage.

Equation 4.2

If $(R < (6.5 - 0.09 * BF))$

then $QF = 0$

else $QF = (0.93*10^{-3} * S + 8.2*10^{-3}) * R$

$(r^2 = 0.84)$

In which :	BF	Base flow (mm/day)	QF	Quickflow (mm/day)
	R	Rainfall (mm)	S	Storage in the catchment (mm)

Casenave et al. (1984) already indicated that the shape of the hydrograph is very uniform regardless the amount of rainfall. Due to changes of nutrient and sediment concentrations in the creek water during quickflow events a more dynamic approach to the quickflow is necessary. Using the shape of the hydrograph indicated by Casenave et al. the quickflow is divided in five periods of one hour with a ratio in discharge of 4.2 : 10.4 : 8.1 : 2.7 : 1.0. With the ratio the discharge (in mm/hour) can be calculated for the five hours in which quickflow occurs. In the present study relations between electrical conductivity and the discharge are based on the water level, therefore, the relation between discharge and water level during base and quickflow should be derived as presented in Equations 4.3 and 4.4.

Equation 4.3

$$WL_{BF} = 1.6 * BF$$

$(r^2 = 0.72)$

In which :	WL	Water level (cm)	BF	base flow (mm/day)

Equation 4.4

If $TD < 1.90$: $WL_{QF} = 11.4 + 49.5 * TD - 12.0 * TD^2$

If $TD \geq 1.90$: $WL_{QF} = 32.7 + 16.0 * TD + 0.49 * TD^2$

$(r^2 = 0.84)$

In which :	TD	Total discharge including base flow and quickflow (mm/day)
	WL	Water level (cm)

4.5 The hydrology in the study period

The hydrological balance between April 15, 1990 and March 15, 1991 has been simulated with the model described in Section 4.4. This resulted in simulated daily figures for storage, base flow and quickflow on the basis of the rainfall figures. Figures 4.3-4.6 show the simulated results between May 1990 and February 1991. In the study period the base and quickflow were responsible for respectively 15% (184 mm) and 10% (127 mm) of the total rainfall (1238 mm).
To check the simulated figures, water levels in the creek have been measured continuously using a water level recorder which had been installed in the creek 10 meters from the old and now malfunctioning weir. The total simulated discharge can be correlated with the measured water levels as shown in Equations 4.3 and 4.4. The high correlation coefficient between water level and simulated outflow strongly supports the validity of the model.

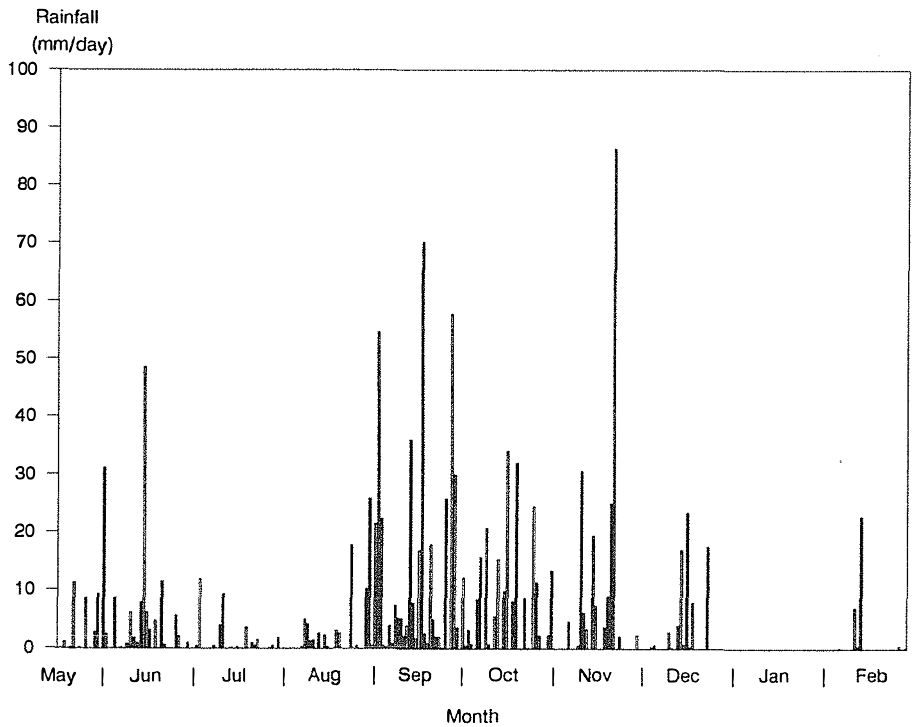


Figure 4.3 Measured daily rainfall between May 1990 and February 1991

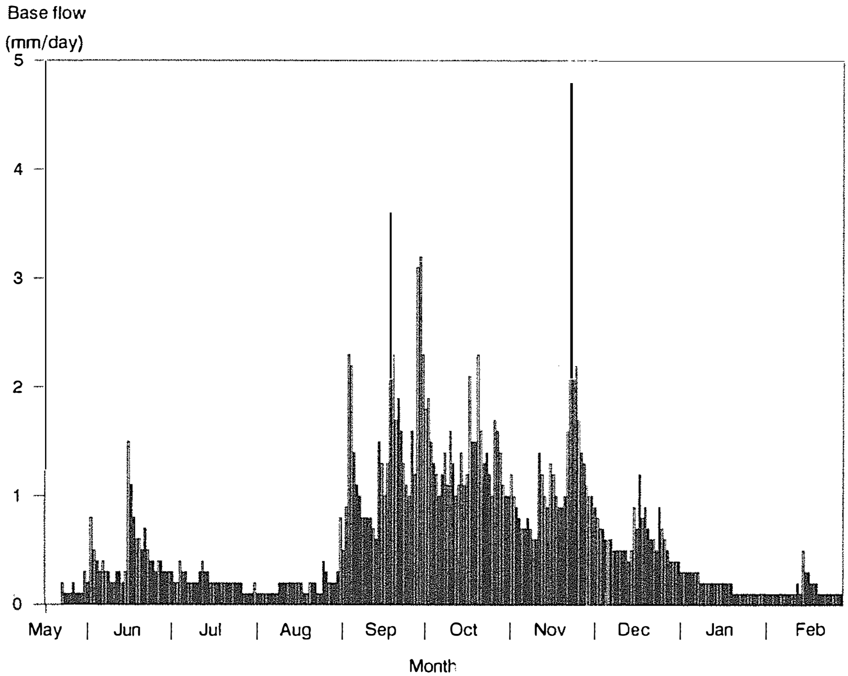


Figure 4.4 Simulated base flow between May 1990 and February 1991

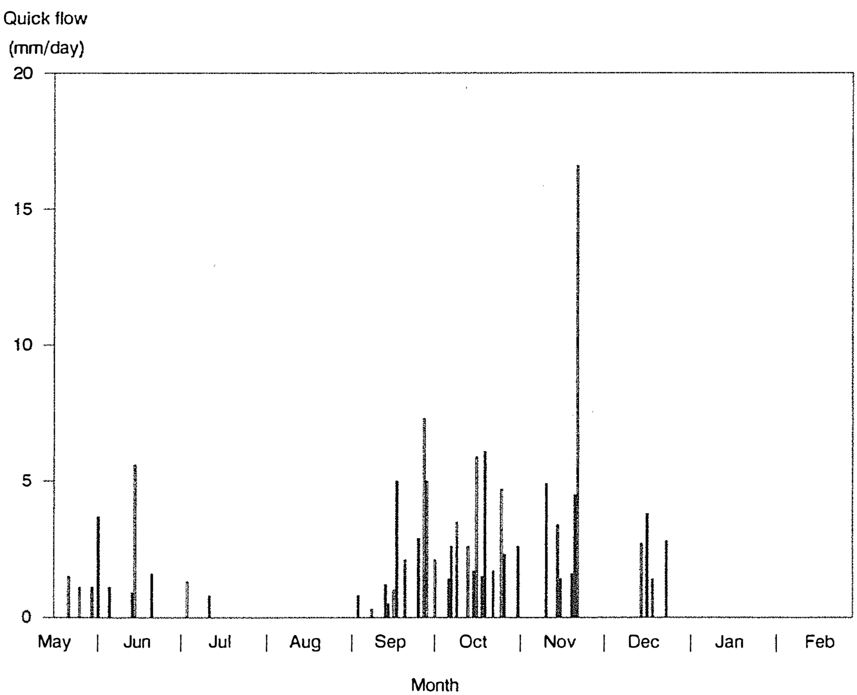


Figure 4.5 Simulated quickflow between May 1990 and February 1991

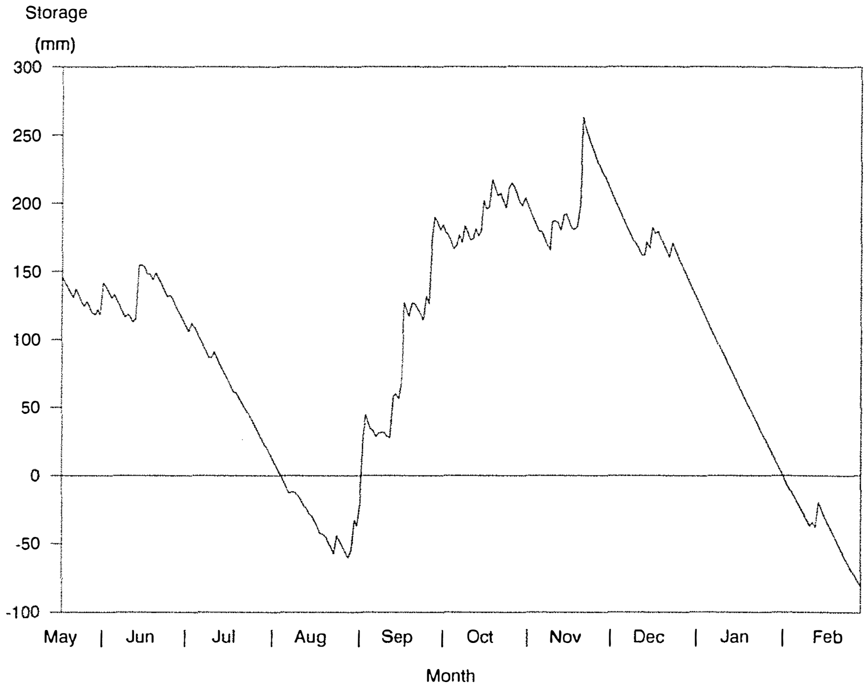


Figure 4.6 Simulated storage (in mm) between May 1990 and February 1991 relative to that on March 21, 1979.

5 RESULTS AND DISCUSSION

5.1 Introduction

A complete listing of the results is given in the Annexes VIII-XII. Relations derived from the results are presented and discussed in this chapter. In all regression procedures linear, quadratic and exponential fits were examined. The fit with the highest correlation coefficient and within theoretical boundary conditions is presented and used for the calculations. Theoretical boundary conditions comprise for most cases that the fit within the range that it is applied, is continuously positive and does not contain a minimum or maximum. The different input and output factors are discussed separately in the different Sections. All equations presented in this chapter are implemented in a model which also comprises the hydrological model as described in Section 4.4. The model can be used to simulate the nutrient balance for the catchment and is listed in Annex XIII. In Chapter 6 the results are summarized in the form of a nutrient balance for the catchment.

5.2 Solute import: rainfall

Fig. 5.1 shows the mean monthly rainfall distribution over the period 1944-1959 and 1966-1979 with the range defined by the standard deviation (Casenave et al., 1980) as well as the rainfall measured during the study period. None of the observed monthly rainfalls is exceptionally high or low. However, in the study period, the rainy season started relatively late with a higher than average rainfall in the first months. The dry season was extremely dry with almost no rainfall. The total rainfall between May 15, 1990 and March 7, 1991 was 1238 mm which is 12% below the average rainfall for this period (1407 mm).

The automatic rainfall recorder performed inadequately, resulting in many missing data. For the sake of completeness the results of rainfall intensities are listed in Annex VIII[c] but they will not be used in further analysis.

Annex VIII[a] presents the daily rainfall figures for the study period. In addition the electrical conductivity and pH are given. For days with less then 3 mm of rain, contamination in the samples has frequently been observed and therefore only samples of more than 3 mm rain are taken into consideration for the regression procedures. A number of data with exceptionally high EC values (>11 μmho/cm) were disregarded because these samples invariably contained visible contaminants (insects, plant material). The average pH and EC for the rain water samples were respectively 5.5 (standard deviation 0.3) and 7.0 μmho/cm (standard deviation 0.3 μmho/cm). A reasonable correlation between rainfall quantity and electrical conductivity was found (Eq. 5.1). No satisfactory correlation between daily rainfall and pH was found.

Equation 5.1

$$EC = 8.01 - 0.032 * Rain$$

$(r^2 = 0.82)$

In which:
- EC — The electrical conductivity of the rain water in μmho/cm
- Rain — Daily rainfall in mm

Annex VIII[b] lists the analytical results of the rain water samples. Table 5.1 presents the average chemical composition for the major elements. The correlation between solute concentrations and the EC is generally low. For most elements concentrations were close to the detection limit which may cause the low correlation. Equations 5.2 - 5.5 give the relations found for the most important elements. For the solutes for which no satisfactory correlation could be obtained the use of an average value is proposed. The daily input of the major nutrients by rainfall can now be calculated by applying Equation 5.1 followed by Equations 5.2-5.5.

Equations 5.2 - 5.5

$$[P] = 0.034 \quad \text{(average)} \qquad \text{[Equation 5.2]}$$

$$[K] = -4.54 + 1.32 * EC \quad (r^2 = 0.58) \qquad \text{[Equation 5.3]}$$

$$[Ca] = 0.30 * EC + 0.13 * EC^2 \quad (r^2 = 0.49) \qquad \text{[Equation 5.4]}$$

$$[Mg] = -0.9 + 0.39 * EC \quad (r^2 = 0.82) \qquad \text{[Equation 5.5]}$$

In which:
- [x] — The concentration of element x in $mmol/m^3$
- EC — The electrical conductivity in μmho/cm

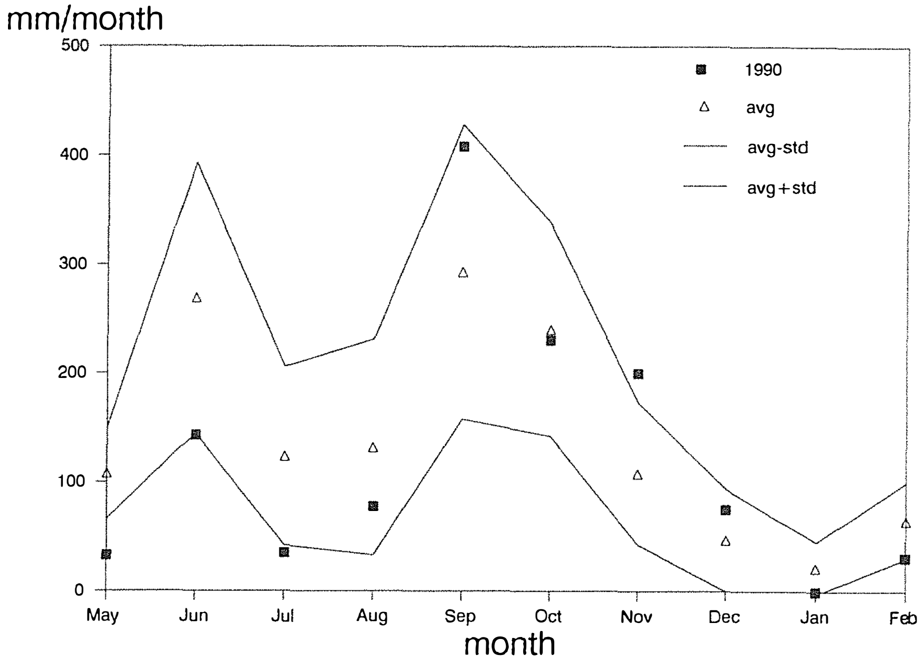


Figure 5.1 Average rainfall with the range defined by the standard deviation (STD) compared to 1990/91 rainfall distribution

Table 5.1 Average concentrations[1] for the solutes in rain water (in $mmol/m^3$)

Element	Concentration	Standard deviation
P	0.0	0.2
K	3	3
Ca	6	5
Mg	2	1
Na	4	2
Fe	1	1
Mn	1	1
Al	0	0
$N\text{-}NH_4$	5	7
$N\text{-}NO_3$	6	7
Cl	7	6
SO_4	2	4

[1] Average of 17 samples

For the study period this resulted in a total estimated input of 0.013 kg of P, 2.3 kg of K, 4.4 kg of Ca and 0.6 kg of Mg per hectare per year. Assuming that the Equations 5.1 - 5.5 which are established for 1990 are valid for the period 1966-1990, the mean input of nutrients with rainfall in Taï have been estimated at 0.019, 3.5, 6.5 and 0.9 kg/ha,yr for P, K, Ca and Mg respectively (Table 5.2). Table 5.2 also summarizes literature data

Table 5.2 Input of phosphorus, potassium, calcium and magnesium by rainfall (in kg/ha,year)

Author and Location	Rainfall (mm)	P	K	Ca	Mg
This study					
Côte d'Ivoire[1]					
Study period	1238	0.013	2.3	4.4	0.6
Average (1966-1990)	1833	0.019	3.5	6.5	0.9
(Nye, 1961)					
Ghana	1850	0.41	17.6	12.9	11.4
(Mathieu, 1976 cited by Poels, 1987)					
Côte d'Ivoire	1320	-	<6.6	<13	<1.3
(Baudet et al., 1988)					
Côte d'Ivoire, Iboke	1749	-	4.0	-	-
(Bernhard-Reversat, 1975)					
Côte d'Ivoire, Banco	1800	1.0	4.6	-	-
(Roose, 1980 cited by Pieri, 1985)					
Côte d'Ivoire, Korhogo	1350	1.3	4.1	-	-
Burkina Faso, Saria	860	2.1	3.4	-	-
(Roose, 1977)					
Côte d'Ivoire, Adiopodoumé	2130	1.0	5.2	-	-
(Pieri, 1982 cited by Pieri, 1985)					
Senegal, average of 4 sites	836	1.3	4.1	-	-
(Bille, 1977)					
Senegal	213	0.2	-	-	-
(Cooke, 1982)					
Côte d'Ivoire	-	2.3	5.7	-	-

[1] Calculated with Equations 5.1-5.5 with rainfall figures for 1966-1990

on the input of these nutrients by rainfall in the tropics. Many of the cases reported in Table 5.2 refer to areas with a lower rainfall than in Taï. Only the data by Nye in Ghana (Nye, 1961) and some data for the Côte d'Ivoire refer to areas which are climatologically similar. The nutrient input with rainfall found in this study is very low compared to the other studies. A possible explanation for the relatively low values observed in this study is methodology. Although not in every reference a thorough description of the methodology was given, in many cases the rainfall samples appear to be bulk samples collected weekly. Such a sampling procedure carries a great risk of contamination from dust and debris coming from the terrestrial ecosystem itself. In this study particular attention has been paid to prevention of contamination of the rainfall collectors by dust and organic debris, like pollen, which is considered to be part of the internal cycle of the forest and is therefore avoided to be included in the measurements. Dry deposition during the Harmattan season is measured separately.

5.3 Harmattan dust

The data on Harmattan dust will be presented together with literature data on dust inputs, mostly from Nigeria, for comparison. It should be noted that the different studies refer to different years and that the year-to-year variation in intensity of the Harmattan may influence the characteristics of the Harmattan dust.

The X-ray fluorescence spectroscopy of dust collected with the Gromoz apparatus corrected for the filter material resulted in the data presented in Table 5.3 (The complete results are given in Annex IX[a]). Due to the dilution of the samples with filter material the accuracy of the measurements diminished by a factor of ten (circa 0.1 gram dust per filter of 1 gram). The three replicates, which were carried out, nevertheless showed a variation of less then 30%. The concentration of TiO_2, which will be used as a tracer element was 0.3%. The average concentrations for P_2O_5, K_2O, CaO and MgO were respectively 0.3, 3.7, 6.1 and 0.9%.

X-ray diffraction indicated the presence of kaolinite and quartz. Quartz could also originate from the filter material. Point analysis of 30 dust particles with the X-ray microanalysis system connected to the Scanning electron microscope (Annex IX[b]), yielded only one particle consisting purely of SiO_2. The other particles were mostly Al-silicates, probably mainly kaolinite and presumably Ca and K feldspars.

Table 5.3 The chemical composition (mass fraction of oxide components) of Harmattan dust collected in the Taï region, compared to three samples from Nigeria

	This study Average	This study Range	Ibadan, Nigeria[1]	Kano, Nigeria[2]	Zaria, Kano Nigeria[3]
SiO_2	48	(44-52)	49.34	66.03	55.3
Al_2O_3	24	(19-27)	10.34	11.08	21.9
CaO	6.1	(5.3-6.6)	5.28	1.13	7.00
Fe_2O_3	1.9	(1.5-2.5)	4.14	4.45	1.72
MgO	0.9	(0.8-0.9)	2.07	0.82	0.12
K_2O	3.7	(2.4-4.9)	1.62	2.04	1.38
Na_2O	0.7	(0.5-0.9)	0.80	0.91	0.06
TiO_2	0.3	(0.2-0.3)	0.66	0.73	1.10
P_2O_5	0.3	(0.2-0.3)	N.D.	0.17	N.D.
MnO	0.1	(0.1-0.1)	N.D.	0.10	0.05
L.I.	11.4	(11.3-13.6)	24.81	12.79	11.1
Total	97.4	(96.9-98.2)	99.06	100.25	99.73

1 Doyne et al., 1938
2 McTainsh and Walker, 1982
3 Möberg et al., 1991

The particle size distribution presented in Table 5.4 is based on particle counts from six micrographs with magnifications of 1250 (4 micrographs) and 2500 (2 micrographs) times. Especially the micrographs with a magnification of 1250 times gave a good impression of the particle size distribution (Figure 5.2). Compared to the results from other areas closer to the source of Harmattan dust (Table 5.5) the dust in the Taï region is much finer. This is to be expected as the coarser particles will deposit in the more northern areas, closer to the source areas.

Table 5.4 Particle size distribution for 5 micrographs on count basis

Magnification	<2μm	2-5μm	5-10μm	10-15μm	>15μm
1250	27	21	4	1	0
1250	14	8	3	3	0
1250	76	63	4	1	0
2500	38	10	1	1	0
2500	16	8	3	2	0
Total	171	50	15	8	0
	(70%)	(20%)	(6%)	(3%)	(0%)

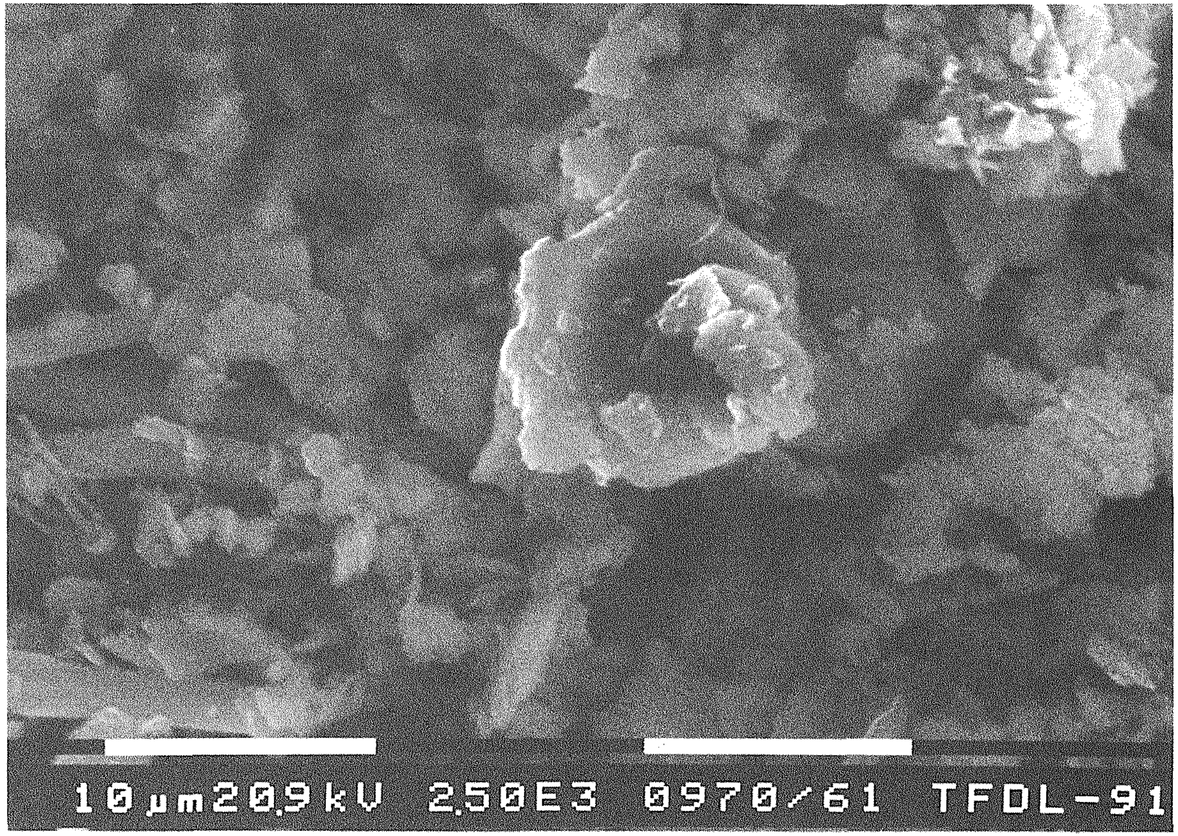


Figure 5.2 Micrograph of Harmattan dust on glass fibre filter (magnification 2500 times)

Table 5.5 Particle size distribution of Harmattan dust according to other research (mass fraction %)

	This study[1]	Zaria-Kano Nigeria[2]	Zaria Nigeria[3]
Clay (<2μm)	2	24.9	1
Fine silt (2-20 μm)	98	42.2	80
Coarse silt (20-50 μm)	0	14.5	16
Fine sand (50-125 μm)	0	16.6	3
Medium sand (125-250 μm)	0	1.2	0
Coarse sand (250-2000 μm)	0	0.7	0

1 Estimate based on particle counts
2 Möberg et al., 1991
3 Whalley and Smith, 1981

The thermal gravimetric analysis showed a 11.4% loss on ignition between 100 and 600°C progressing linearly between the two temperatures (Annex IX[c)]. No analysis has been performed above 600°C because the glass fibres would melt. Similar losses on ignition have been found during the analysis for the X-ray fluorescence spectroscopy (average loss on ignition of 12.1%).

Table 5.6 lists the amounts of titanium collected in the pans and the corresponding amount of dust assuming that the dust in the pans has the same Ti content as that sampled by the Gromoz apparatus. The amount of dust input in pans with demineralised water, estimated using titanium as an index, was very similar regardless of their position. The mass of residue collected from the pans was 70-102% higher than the input of Harmattan dust estimated on the basis of the Ti content. This indicates appreciable contamination by debris of local origin, illustrating the importance of using an index element. On average a total of 42 kg dust input per ha was found. This is about 5% of the input found in northern Nigeria (McTainsh, 1980) and 30% of the input in northern Ghana (Tiessen et al., 1991), both also measured with the wet-basin method.

Prior to estimating dust inputs to the forest canopy by analyzing canopy drip, the assumption that Ti present in canopy drip is derived from dust only, has been tested. Canopy drip sampled during the last two rains before the Harmattan arrived in Taï did not contain detectable amounts of Ti. The first rain after the Harmattan season (February 11, 1991) brought 0.21 kg of TiO_2 per ha in canopy drip. During the second rain (February 13, 1991) this had decreased to 0.02 kg of TiO_2 per ha. The leaves that were collected in the top of the canopy after the second rain contained

Table 5.6 Titanium input and calculated dust input (without contamination) estimated through pan collection compared to the canopy drip measurements

	TiO_2 (mg/m^2)	Dust (kg/ha)	Contamination (%)
Tree platform	13.8	46	93
Meteorological field	9.9	33	70
Coffee plantation	14.1	47	102
Canopy drip (Average)	23	76	78
Canopy drip (line 1)[1]	17	57	62
Canopy drip (line 2)[1]	22	73	71
Canopy drip (line 3)[1]	29	97	101

1 For location lines see Annex III[b]

only 3% of the number of dust particles per square cm found before the rains (the complete data set is listed in Annex IX[d]). The amount of Ti in canopy drip corresponds with 76 kg of Harmattan dust per ha (Table 5.6). The nutrient input of the Harmattan dust to the canopy would amount 0.05 kg of P, 1.2 kg of K, 3.4 kg of Ca and 0.4 kg of Mg (Table 5.7).

The deposition measurements with canopy drip gives a 180% higher deposition rate as the wet-basin method. The difference seems logical due to the different deposition characteristics of the basin and the forest canopy. The roughness length of a forest canopy is around 1.0 cm compared to 0.05 cm for a non-open water surface (Wieringa cited by Dop, 1990). Sehmel (1980) derives the deposition velocity of particles for different roughness lengths. Assuming a friction velocity of 10 cms^{-1} and a particle density of 2 gcm^{-3} this would result in a deposition velocity for the forest canopy of 0.11 cm/s and for the water surface of 0.06 cm/s. These differences in deposition velocity explain the measured differences in dust input in the water-filled basin and in the canopy drip quite well. This indicates that the basin method is inappropriate to measure dust deposition in a tropical forest area.

Epiphytes are known to effectively scavenge airborne dust from the atmosphere, which could lead to an underestimation of dust inputs. In view of the relatively coarse texture of the Harmattan dust, however, it is unlikely that above ground nutrient uptake from Harmattan dust, and/or occlusion by epiphytes will be quantitatively important.

Table 5.7 Average nutrient input for the four major nutrients by Harmattan dust (in kg/ha,yr)

Nutrient	P	K	Ca	Mg
Input	0.052	1.2	3.4	0.4

The procedure which has been followed has several limitations, which are difficult to overcome given the small quantities of dust in the Taï region:

- Sampling of dust with glass fibre filters diminished the analytical accuracy as the dust particles could not be separated from the filter material.
- In the procedure which has been followed to assess the nutrient input by Harmattan it is assumed that dust collected by filtering air and that collected on the canopy has the same composition. As already indicated in the discussion on the particle size distribution this is not necessarily the case because larger particles will deposit first.

5.4 Solute export: creek water

Discharge and solute concentrations determine the export of dissolved nutrients as solutes. Discharge has been estimated by simulating the hydrology with the model described in Chapter 4.

The pH and the EC values of the creek water were measured with high frequency. Daily samples of the base flow and several samples during quickflow were collected. Results for pH and EC of the creek water and the corresponding water level are listed in Annex X[a]. Although good relations with the water level are found for both pH and EC only the relation between EC and water level is used (Eq. 5.6). The EC diminishes with increasing water levels and varies between 24 and 96 μmho/cm. The pH increases with increasing water levels and varies between 6.2 and 6.8.

Equations 5.6 - 5.7

EC_{BF} = 68.5 - 8.09 * log (BF) [Equation 5.6]
(r^2 = 0.57)

EC_{QF} = 77.3 - 26.2 * log (WL) [Equation 5.7]
(r^2 = 0.63)

In which :

	EC_{BF}	The electrical conductivity of the creek water during base flow (µmho/cm)
	EC_{QF}	The electrical conductivity of the creek water during quickflow (µmho/cm)
	BF	The base flow (mm/day)
	WL	Water level in the creek during quickflow (cm)

Fifty-three samples, 16% of the total, have been completely analyzed for the concentrations of all major solutes. The analytical results are listed in Annex X[b] and the average values are presented in Table 5.8. Using the hydrological model in combination with the analytical results it is possible to calculate the average nutrient concentrations for the base flow and the quickflow separately (Table 5.9). For P the standard procedure used only yields the concentration of the inorganic fraction. The relatively high concentration of organic carbon (on average 2205 mmol/m^3) suggests that stream water export of organically bound P might be relatively important.

Table 5.8 Average concentrations for the solutes in creek water (in mmol/m^3)

Element	Concentration	Standard deviation
P	0.9	1.1
K	55	12
Ca	108	37
Mg	71	24
Na	232	77
Fe	26	13
Mn	1	1
Al	4	13
$N\text{-}NH_4$	1	2
$N\text{-}NO_3$	3	8
Cl	75	19
SO_4	4	5
C-total	2731	918
C-organic	2205	1022

Table 5.9 Average concentrations in creek water during quickflow and base flow for the four major solutes (in $mmol/m^3$)

Solute	P	K	Ca	Mg
Base flow				
- Total	1.2	53	116	76
- Organic	0.4			
- Inorganic	0.9			
Quickflow	0.1	56	67	43

To get an impression of the possible contribution of organically bound nutrients to solute export, ten large stream water samples were analyzed separately. After freeze drying the water samples, the residue was digested with 0.4 M HNO_3 for analysis of total P concentrations. Organically bound P appeared to be a significant contribution to total P in stream water (Table 5.10). The number of data on the organically bound fraction of P is too small to derive an equation and therefore a fixed contribution of organically bound P of respectively 52% of the inorganic concentration is assumed. The total analysis was not performed on samples of the quickflow as the concentrations of the different nutrients in the quickflow were already very small. Therefore only the inorganic fraction is used for the quickflow. To calculate the total nutrient output the relations between the different nutrient concentrations and the electrical conductivity are determined (Eq. 5.8 - 5.15). With the data from the hydrological model and these relations the total solute export has been calculated (Table 5.11).

Table 5.10 Concentrations of total, organic and inorganic phosphorus and organic carbon in 10 selected stream water samples ($mmol/m^3$)

Date	Total	Organic	Inorganic	C-content
20-06	1.8	0.7	1.1	1961
28-06	3.1	1.4	1.7	1553
03-07	1.5	0.5	1.0	1673
15-07	2.1	0.6	1.5	1714
15-08	4.2	1.2	3.0	1650
29-08	0.2	0.1	0.1	2339
03-09	0.3	0.1	0.2	2130
19-09	0.3	0.2	0.1	2561
20-09	0.3	0.1	0.2	2792
30-09	0.1	0.0	0.1	1611
Average	1.4	0.5	0.9	1998

$[\ ]_{BF} = -20.0*10^{-3} * EC + 0.55*10^{-3} * EC^2$ [Equation 5.8]
$(r^2 = 0.50)$

$[\ ]_{QF} = 0.14$ [Equation 5.9]
$(r^2 = 0.13)$

$[\ ]_{BF} = 37.6 + 0.037 * EC + 3.8*10^{-3} * EC^2$ [Equation 5.10]
$(r^2 = 0.55)$

$[\ ]_{QF} = 50$ [Equation 5.11]
$(r^2 = 9)$

$[\ a]_{BF} = -2.1 + 1.8 * EC$ [Equation 5.12]
$(r^2 = 0.92)$

$[\ a]_{QF} = -14.7 + 2.3 * EC$ [Equation 5.13]
$(r^2 = 0.93)$

$[\ g]_{BF} = 6.6 + 1.1 * EC$ [Equation 5.14]
$(r^2 = 0.90)$

$[\ g]_{QF} = -16.8 + 1.7 * EC$ [Equation 5.15]
$(r^2 = 0.95)$

In which:

$[x]_{BF}$	The concentration of element x in creek water during base flow ($mmol/m^3$)
$[x]_{QF}$	The concentration of element x in creek water during quickflow ($mmol/m^3$)
EC	The electrical conductivity of creek water (μmho/cm)

Comparing the average solute export with data from Bernhard-Reversat (1975), who carried out research under comparable situations, the exports especially for P, K and Ca in Taï and Banco are remarkably similar. The data from Roose differ more, which is probably due to a different type of forest as pedology and climate are more or less comparable.

5.5 Sediment export

Field observations indicated the presence of two different types of erosion: sheet erosion and gully erosion. Sheet erosion takes place in most parts of the catchment. Gully erosion is confined to the middle slopes. During the study period the sediment concentration in the creek varied between 0 and 1168 mg/l. Sediment is exported from the catchment during rain events and during the first quarter of an hour after the end of a rain storm.

Table 5.11 Nutrient output as solutes (in kg/ha,yr)

Location		Total discharge (mm)	P (	K	Ca kg/ha,yr	Mg)
This study						
Taï, Côte d'Ivoire						
Study period						
- base flow	- total	184	0.11	1.6	9.5	3.8
	- organic		0.04			
	- inorganic		0.07			
- quickflow		127	0.04	0.4	1.5	1.1
- total		311	0.15	2.0	11.0	4.9
Average for 1966-1990						
- base flow	- total	272	0.16	2.4	13.9	5.5
	- organic		0.06			
	- inorganic		0.10			
- quickflow		199	0.07	0.7	2.3	1.8
- total		471	0.23	3.1	16.2	7.3
Roose, 1977						
Adiopodoumé, Côte d'Ivoire		1000	11.0	0.9	21.1	4.4
Bernhard-Reversat, 1975[1]						
Banco, Côte d'Ivoire		630	0.2	1.3	43	4.3

[1] cited by Bruijnzeel, 1990

Although the water in the creek sometimes continues to rise until 2 hours after the end of a rain storm event, the sediment concentration has its peak much earlier. The circular path is shown in Fig. 5.3. The relationship between the water level and the sediment concentration can be described by Equation 5.16.

This circular path corresponds with the observations of Wierda et al. (1989). The high sediment concentrations at the beginning of the quickflow is mainly the result of Hortonian overland flow, which is in combination with the rainfall highly erosive. After the rainfall will cease, the discharge is more and more dominated by saturated overland flow and the sediment concentration will strongly diminish.

Two times sediment has been sampled simultaneously on 5 different places in the cross section of the creek (Annex V[d]). The sediment concentrations varied less than 5%. The low variability can be explained by the highly turbulent nature of the stream during quickflow. The samples taken close to the creek bed, did not show a higher sediment concentration than samples taken at shallower depth. Therefore bedload sediment transport was probably negligible and has been set at zero.

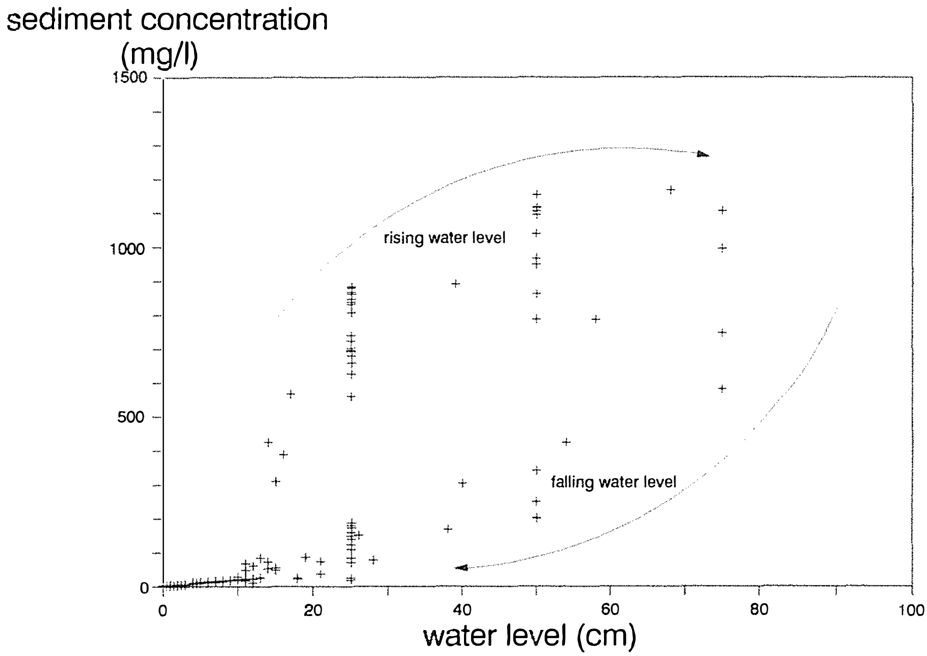


Figure 5.3 The relation between the water level (in cm) and the sediment concentration (in mg/l) (Eq. 5.16)

Equation 5.16

SC_{BF} = 2.02 * WL
if WL is rising then $SC_{QF} = -98 + 29.1 * WL - 0.17 * WL^2$
($r^2 = 0.67$)
if WL is falling then $SC_{QF} = 6.0 + 0.142 * WL^2$
($r^2 = 0.78$)

In which:
SC_{BF} Sediment concentration during base flow (mg/l)
SC_{QF} Sediment concentration during quickflow (mg/l)
WL water level in cm

A chemical elemental analysis of the sediment has been carried out on 19 samples. The average chemical composition is given in Table 5.12. The high loss on ignition and high P_2O_5 content of this material indicates that it is relatively rich in organic matter. Calculating the export of nutrients by sediment with the hydrological model and Equation 5.16 results in Table 5.13.

Table 5.12 The average chemical composition of the sediment compared to the chemical composition of the surface horizon of the soils on the lower slopes (Fraters, 1986) (mass fraction of oxide compounds, %)

Element	Sediment		Top soil
	Average	Standard deviation	
LI[1]	28	4	3.8
SiO_2	51.4	4.3	88.4
TiO_2	0.9	0.1	0.31
Al_2O_3	13.4	1.6	3.41
Fe_2O_3	3.7	0.6	2.17
MnO	0.1	0.0	0.01
MgO	0.2	0.0	0.05
CaO	0.5	0.1	0.00
K_2O	0.6	0.2	0.03
P_2O_5	0.2	0.0	0.01
Tot	98.7		98.1

1 LI: Loss on ignition

Table 5.13 Average nutrient output for the four major nutrients by erosion (in kg/ha,yr)

Nutrient	Sediment	P	K	Ca	Mg
Study period	$1.2*10^3$	0.51	2.9	4.2	1.4
Average (1966-1990)	$1.8*10^3$	0.80	4.6	6.5	2.2

The cause of the high organic matter content (presumably more than 20% by mass) in the stream sediment is not quite clear. The topsoils in the area have an organic matter content ranging from 0.9 and 3.5% and can not explain the organic matter levels in stream matter. In the area earthworms are very active and production figures of casts up to 3.2 kg/m^2,yr have been measured. However, loss on ignition of these casts does not exceed 5% which therefore cannot be responsible for the organic matter levels in sediment. Very fine particulate organic debris, however, is probably measured as sediment and must be responsible for the high nutrient concentrations in the sediment. The erosion of top soil material is therefore lower than the 1.8 ton/ha,yr mentioned above, presumably by about 20%. The output of nutrients presented in Table 5.13 is still valid, however, but does include particulate organic debris (as well as plankton), that is too fine to be sampled by means of the collectors for organic debris described in Section 3.6.

5.6 Export of particulate organic debris

Organic material has been collected on a daily basis and divided into three fractions: (i) fruit and flowers, (ii) leaves and (iii) branches. All the results are presented in Annex IX[a]. Output of organic debris is highly correlated with the flow in the creek. A total of 0.575 kg of organic debris per hectare has been exported in the study period. For an average year the output can be estimated to be 0.724 kg of organic debris per ha. This consists for 39% out of leaves, 33% out of branches and 27% out of fruit and flowers. So, the output of (coarse) particulate organic debris, although visually impressive, appears to be insignificant compared to the approximately 360 kg of fine particulate organic matter included in the sediment export (Table 5.13)

Ten percent of the samples of organic debris has been analyzed (Annex X[b]). Variation in the chemical composition occurred for all categories but most explicitly for the fruit and flower material. Fruit and flower material constituted a small quantity, consisting in many cases out of two or three fruits. Due to seasonal variations of fruiting trees the samples became highly variable. Leave fall is strongly seasonal too, but leaf samples comprised a large number of different species resulting in an average chemical composition which shows relatively little variation. Table 5.14 lists the average chemical compositions and their range. With a total output of 0.575 kg organic debris per ha and the nutrient concentrations from Table 5.14, the output of nutrients in (coarse) organic debris is clearly negligible (Table 5.15).

Table 5.14 The average chemical composition of organic debris (mmol/kg)

	P	K	Ca	Mg
Branches	10	19	369	57
Leaves	19	38	175	49
Fruit and flowers	18	27	303	71

Table 5.15 Average nutrient output for the four major nutrients by particulate organic debris (in g/ha,yr)

Nutrient	P	K	Ca	Mg
Export	0.3	1.2	7.8	0.9

The point-marked leaves in the watershed showed hardly any sign of transport on any of the five slope positions. Less than 1% of the leaves was transported and these leaves moved less than 1 m away. The identification of leaves in the creek supported the earlier finding of little lateral transport of leaves overland; almost all the identifiable leaves from the creek belonged to species that grow mainly in the valley bottom.

6. THE NUTRIENT BALANCE

In this study two input flows and three output flows have been considered as described in Chapter 5. In this Chapter the contributions of these flows to the nutrient balance will be discussed. Although three separate outputs of nutrients have been studied it must be realized that the division between these flows is not as distinct as it appears. Decomposition of organic material in the creek e.g. leads to an increased export of solutes and a decreased export of particulate organic debris.

Table 6.1 summarizes the data from Chapter 5 and gives the totals of the balances for the four major elements for the study period as well as a long-term average extrapolated from the 1990-1991 data based on long-term rainfall data only. The relations derived from the data for 1990-1991 have been used to estimate the input or output of nutrients based on daily rainfall figures. All the equations were added to the hydrological model described in Chapter 4 resulting in a new model, which simulates the nutrient balance on the basis of the daily rainfall figures, which are available for the period between 1966 and 1990. This procedure involves the implicit assumption that all relationships between nutrient levels and hydrological parameters are uniform for that period. Because the climate in the study period was rather typical and fairly close to the average, and because the ecosystem is probably close to a steady state, this assumption may be reasonable. At any rate it is very unlikely that the true nutrient balance would deviate greatly from the extrapolated values shown in Table 6.1. The nutrient balance for the watershed is negative of all elements considered; a net export takes place. For P and K erosion is largely responsible for the negative balance. For Ca and Mg solute export mainly causes the negative balance. However, an appreciable part of the nutrient export in Table 6.1 may consist of solutes released by weathering of the deep-seated migmatitic parent material. It is unlikely that trees can derive an appreciable fraction of those nutrients from the weathering zone. Some large roots may penetrate 5-10 m below the surface (Poels, 1987) but they are probably more important for water than for nutrient supply. In particular, uptake of P, which has a very low mobility in the soil, requires an extensive fine root system, augmented by mycorrhyzal hyphen. Such a root system is probably confined to the surface soil only. So inclusion of nutrient export from deep weathering zones may give a misleading impression of ecosystem functioning, and a nutrient budget for the surface soil-vegetation zone may be ecologically more relevant. Such a budget has been drawn up by assuming that all solutes exported in base flow, exceptorganic P, are derived from weathering of migmatite (Table 6.2). The dominance of Na, Ca, Mg, K and Si, and their ratio's in the base flow water are fairly similar to those typical of water enriched by weathering of granite (Table 6.2). This strongly supports the assumption about deep weathering as the main source of solutes in base flow. The (organically-bound) phosphorus in base flow can hardly be derived from deep weathering, it may largely represent stream biota including diatoms, which probably derive their P mainly from mineralized organic debris, and thus would indeed represent export from the soil-vegetation stratum. The new budget (Table 6.3) is positive for Ca, but still shows a net output for the other elements. The actual nutrient depletion from the surface soil-vegetation zone may be higher than that indicated by the nutrient balance of Table 6.3. Several processes occur in addition to weathering below the active root zone which contribute nutrients to the base flow. Nutrients from litter decomposing in the creek may leave the system as solutes in base flow. Base flow water will also contain nutrients leached from the top soil and the nutrients originating from rainfall. The nutrient balance for at least P, K and Mg may therefore be more negative than indicated by Table 6.3.

Table 6.1 The nutrient balance for the catchment (in kg/ha,yr)

	P	K	Ca	Mg
Study Period				
Rain water	0.01	2.3	4.4	0.6
Dust	0.05	1.2	3.4	0.4
Base flow	-0.11	-1.7	-9.5	-3.8
Quickflow	-0.04	-0.4	-1.5	-0.6
Sediment	-0.40	-2.3	-3.3	-1.4
Organic debris	-0.00	-0.0	-0.0	-0.0
Total	-0.48	-0.8	-6.5	-4.8
Average (1966-1990)				
Rain water	0.02	3.5	6.5	0.9
Dust	0.05	1.2	3.4	0.4
Base flow	-0.16	-2.5	-13.9	-5.5
Quickflow	-0.07	-0.7	-2.3	-1.8
Sediment	-0.64	-3.7	-5.3	-2.2
Organic debris	-0.00	-0.0	-0.0	-0.0
Total	-0.80	-2.1	-11.6	-8.2

Table 6.2 Concentration of solutes (mmol/litre) in Taï base flow, compared to concentrations in Sierra Nevada spring water from granite weathering (Garrels and Mackenzie, 1971)

	Na	K	Ca	Mg	Si
a. Taï base flow	0.27	0.058	0.125	0.082	0.73
b. Ephemeral springs, Sierra Nevada (USA)	0.11	0.020	0.068	0.022	0.27
c. Ratio of a : b	2.5	2.9	1.8	3.7	2.7

Table 6.3 The nutrient input by weathering and the resulting nutrient balance (in kg/ha,yr)

	P	K	Ca	Mg
Rainfall	0.02	3.5	6.5	0.9
Harmattan	0.05	1.2	3.4	0.4
Organic P, base flow	-0.06			
Quickflow	-0.07	-0.7	-2.3	-1.8
Sediment	-0.64	-3.7	-5.3	-2.2
Organic debris	-0.00	-0.0	-0.0	-0.0
Total	-0.70	-0.3	+2.3	-2.7

The effect of these net losses on the ecosystem depends mainly on the availability of the different elements. Table 6.4 (Bernhard-Reversat et al., 1975) gives a rough estimate of the total nutrient pool of the vegetation. Comparing Tables 6.3 and 6.4 shows that 0.8% of the phosphorus, 0.1% of the potassium, and 0.6% of the magnesium present in the vegetation is exported every year. Only the calcium pool is gaining yearly by 0.2%.

As indicated in Chapter 3 the catchment is considered to be homogeneous. This is, however, a gross simplification, and the nutrient balance probably varies across the soil-vegetation toposequence. For some of the exports it is possible to trace the origin. Leaching may predominate on the higher parts where the soils are relatively fertile. Erosion takes place especially on the middle slopes. The atmospheric input is distributed homogeneously over the catchment, but is small compared to the output. Therefore, even with large differences in export between sites within the catchment, the nutrient cycle for all elements but Ca is probably negative for almost all soil-vegetation types in the catchment.

Table 6.4 Nutrient pool of undisturbed forest (kg/ha)

	P	K	Ca	Mg
Vegetation [1]	90	520	1000	430
Soil[2]	2539	6210	535	4500
Total	2629	6730	1535	4930
Nutrient balance[3]	-0.7	-0.3	+2.3	-2.7

1 Bernhard-Reversat et al., 1975

2 Total nutrient content in the soil to 20 cm depth (available + unavailable) (derived from appendix 1)

3 Data from Table 6.3

7 CONCLUSIONS

One of the original objectives in specifying the nutrient balance was to help policy decisions for the conservation of tropical rain forests and especially the conservation of Taï National Park. The nutrient balance is an important characteristic of a tropical rain forest as in most cases the nutrients are limiting. The nutrient balance sets boundary conditions for sustainable management systems which are developed for a tropical forest zone.

What are the implications of different outcomes of a nutrient balance study? Three different cases can be identified, a negative, a neutral and a positive balance.

A negative nutrient balance implies that the forest is degrading to an ecosystem with less nutrients. Under such conditions harvesting will cause accelerated nutrient depletion with concomitant severe degradation. Normally one can expect that the ecosystem will degrade to a new equilibrium. If exploitation would cause an accelerated depletion of nutrients, the whole system will collapse eventually.

A neutral nutrient balance is the kind of nutrient balance that one would expect for a humid tropical climate forest. The tight nutrient cycle keeps the export of nutrients to the same level as the import of nutrients. This type of forest is still not very suitable for sustainable management. Most management types increase the export of nutrients at constant inputs, thus resulting in a negative nutrient balance.

A positive nutrient balance provides good possibilities for sustainable harvesting. In theory one could export the difference between imports and exports of nutrients resulting in a neutral nutrient balance.

As shown by Bruijnzeel (1990) a large number of nutrient balance studies have been carried out in tropical forest areas. Almost all studies, however, use a different methodology and a comparison between the studies is difficult. The general statement how the results of a nutrient balance study must be interpreted is, therefore, not so clear.
In Taï National Park the nutrient balance of the watershed appears to be negative for at least P, K and Mg. In Chapter 6 some aspects of the reliability were touched upon. Two general statements of the measured nutrient balance are of importance, (i) weathering has not been measured

directly and the effect of weathering is therefore disputable, but does not seem to change the negative balance for most nutrients, (ii) the present study is catchment based and does not provide information on differences in the nutrient balance within the area. Some remarks can be made on the reliability of the assessments for the separate input and output factors:

- **Wet deposition**
  The nutrient input with wet deposition is, as also indicated by Bruijnzeel (1990), very hard to assess. For K, Ca and Mg differences in the nutrient concentration may change the nutrient balance. For P the input with rainfall seems negligible in comparison with the amount of P exported with sediment.
- **Dry deposition**
  Looking at literature data from Nigeria and Ghana one can see that the amount of dust and the chemical composition measured in this study fit the same line. The fact that measurements were carried out only during the dry season will have led to a, presumably slight, underestimation (See also Point 6 in Section 3.1).
- **Solutes**
  The hydrological model seems to give good results and over a longer period the total output should be a good estimate. For a short period a more dynamic estimation of the actual evapotranspiration would be necessary. However, even a static approach used to estimate solute concentrations will probably cause small deviations from those shown by a more realistic approach.
- **Sediment**
  Neglecting the bedload export causes an underestimation of the nutrient outputs. However, measurements as presented in Section 5.5 support the assumption that bedload is negligible. It must be realized that in the measurements also fine particulate organic debris is included. This increases the nutrient concentrations and the total amount of sediment. The total amount of sediment is almost equal to the measurements of Casenave et al. (1980).
- **Organic debris**
  Although there seems to be a complete lack of exported organic debris, very fine particulate organic debris is measured as sediment.

The nutrient balance in Table 6.3 shows that the negative nutrient balance is a result of the high export of sediment, which is not compensated by the inputs. It is not clear whether the present nutrient balance is a temporal situation part of a certain fluctuation or that the ecosystem is degrading towards a new equilibrium. Rainfall figures for the last decades do not indicate a decreasing or increasing trend. Visibility figures during the

Harmattan season for the last decades provided by Guiglo airport also do not show an increase or decrease of the length or intensity of the Harmattan season. A temporal increase of the erosion rate may be caused by the fact that after a lowering of the erosion basis the hard ironstone capping covering the original peneplain stagnated the erosion for a certain period. Now, as the erosion finally removed the ironstone capping, erosion takes place at an increased rate.

For conservation the negative nutrient balance means that one should be very careful with management in order to avoid depletion of the nutrient pool in the ecosystem. The tropical forestry action plan (Committee on forest development in the tropics, 1985) indicates for Côte d'Ivoire:

"*Place 3 million ha of natural forest under more effective management and protection; complete forest inventories ....*"

Effective management of the natural forests requires regulation of the nutrient balance to be sustainable, which should lead to ultimate protection.

If the nutrient balance, estimated in this study, is indeed representative for a long time period it will be difficult to define sustainable forest management systems. Even under present-day undisturbed conditions the pool of several essential nutrients seems to decline. Because inputs are not very likely to change for a forest under management, management systems should minimize the outputs, a difficult task if one wants to conserve the present forest type.

REFERENCES

Andriesse, W. and Fresco, L.O. (1991). A characterization of rice-growing environments in West-Africa. Agriculture, Ecosystems and Environment, 33:377-395.

Baudet, G.J.R. (1991). Personal communication.

Baudet, G.J.R. and Bertrand, J.J. (1988). Circulation atmosphérique, composition et propriétés physico-chimiques de l'aérosol de Côte d'Ivoire. In: Le climat de la savane de Lamto (Côte d'Ivoire) et sa place dans les climats de l'Ouest africain, eds. M. Lamotte and J.L. Tireford, Trav. cherch. Lamto (RCI) 8: 117-146.

Begheijn, L.T. (1980). Methods of chemical analyses for soils and waters. Agricultural University, Wageningen, The Netherlands.

Begheijn, L.T. and van Schuylenborg, J. (1971). Methods for analysis of soils used in the laboratory of Soil Genesis of the Department of Regional Soil Science. Agricultural University, Wageningen.

Bernhard-Reversat, F. (1975). Recherches sur l'écosystème de la fôret subéquatoriale de basse Côte d'Ivoire. IV. Les cycles de macroéléments. La Terre et la Vie, 29: 229-254.

Bille, J.C. (1977). Etude de la production primaire nette d'un écosystème Sahélien. Travaux et documents de l'ORSTOM no. 65, ORSTOM, Paris, France.

Bos, J. (1964). Rapport de fin de levé des coupures Taï 4A-4C. B.R.G.M., Abidjan, SODEMI, Côte d'Ivoire.

Bruijnzeel, L.A. (1990). Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. Free University, Amsterdam, The Netherlands.

Casenave, A., Flory, J., Mathieux, A. and Simon, J.M. (1984). Etude hydrologique des bassins de Taï. Campagne 1981. ORSTOM, Adiopodoumé, Côte d'Ivoire.

Casenave, A., Flory, J., Ranc, N. and Simon, J.M. (1981). Etude hydrologique des bassins de Taï. Campagne 1980. ORSTOM, Adiopodoumé, Côte d'Ivoire.

Casenave, A., Flory, J., Guiguen, N., Ranc, N., Simon, J.M., Toilliez, J. and Tourne, M. (1980). Etude hydrologique des bassins de Taï. Campagnes 1978-1979. ORSTOM, Adiopodoumé, Côte d'Ivoire.

Collins, M. (Ed.) (1990). De laatste regenwouden. Zomer & Keuning boeken B.V., Ede, The Netherlands.

Committee on forest development in the tropics (1985). Tropical forestry action plan. FAO, Rome, Italy.

Cooke, G.W. (1982). Fertilizing for maximum yield. English Language Book Society/Collins, London, United Kingdom.

Doyne, H.C., Hartley, K.T. and Watson, W.A. (1938). Soil type and manurial experiments in Nigeria. In: Proceedings of the Third West African Agricultural Conference, Vol 3 (1): 227-298.

FAO (1988). FAO-Unesco soil map of the world. Revised legend. World Soil Resources Report 60. FAO, Rome, Italy.

Fraters, D. (1986). A study of a catena in the Taï forest, Ivory Coast. MSc Thesis, Department of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands.

Fritsch, E. (1980). Etude pédologique et représentation cartographique au 1/15.000e d'une zone de 1.600 ha représentative de la région forestière du Sud-Ouest Ivorien. Rapport ORSTOM, Adiopodoumé, Côte d'Ivoire.

Garrels, R.M. and Mackenzie, F.T. (1971). Evolution of sedimentary rocks. W.W. Norton & Company Inc., New York, U.S.A.

Gartshore, M.E. (1989). An avifaunal survey of Tai National Park Ivory Coast. Study Report 39. ICBP, Cambridge, United Kingdom.

Guillaumet, J.-L., Couturier, G. and Dosso, H. (1984). Recherche et aménagement en milieu forestier tropical humide: Le projet Taï de Côte d'Ivoire. MAB 15, UNESCO, Paris, France.

Huttel, Ch. (1977). Etude de quelques caractéristique structurales de la vegetation du bassin versant de l'Audrenisrou. ORSTOM, Adiopodoumé, Côte d'Ivoire.

Köppen, W. (1936). Das geographische system der klimate. In: Handbuch der klimatologie, Bd. I, Teil C, eds. W. Köppen and R. Geiger. Berlin: 1-44.

Martin, C. (1991). The rain forests of West Africa: ecology - threats - conservation. Birkhauser Verlag, Basel, Switzerland.

McTainsh, G. (1980). Harmattan dust deposition in northern Nigeria. Nature 286: 587-588.

McTainsh, G.H. (1986). A dust monitoring programme for desertification control in West Africa. Environmental Conservation 13: 17-25.

McTainsh, G.H. and Walker, P.H. (1986). Nature and distribution of Harmattan dust. Z. Geomorph. N.F. 26(4): 417-435.

Möberg, J.P., Esu, I.E. and Malgwi, W.B. (1991). Characteristics and constituent composition of Harmattan dust falling in Northern Nigeria. Geoderma 48: 73-81.

Monteny, B.A. (1983). Observations climatiques à la station écologique de Taï dans le Sud-Ouest ivorien, 1978-1982. Importance de la superficie de la défriche sur les parametres climatiques mésurés. Rapport ORSTOM, Adiopodoumé, Côte d'Ivoire.

Nooren, C.A.M. (1991). A soil survey of a 117 ha catchment in Taï National Park. (In prep.) MSc report, Agricultural University Wageningen, The Netherlands.

Nye, P.H. (1961). Organic matter and nutrient cycles under moist tropical forest. Plant & Soil 13 (4): 333-346.

Nye, P.H. and Greenland, D.J. (1960). The soil under shifting cultivation. Technical communication No. 51 Commonwealth Agricultural Bureau, Bucks, United Kingdom.

Papon, A. (1973). Géologie et minéralisations du Sud-Ouest de la Côte d'Ivoire; synthèse des travaux de l'opération SASCA 1962-1986. SODEMI, Abidjan, Côte d'Ivoire.

Pieri, C. (1985). Bilans minéraux des systèmes de cultures pluviales en zones arides et semi-arides. l'Agronomie tropical 40-1: 1-20.

Poels, R.L.H. (1987). Soils, Water and Nutrients in a Forest Ecosystem in Suriname. Doctoral thesis, Agricultural University, Wageningen, The Netherlands.

Reuler, H. van and Janssen, B.H. (1988). Soil fertility aspects of upland rice in shifting cultivation systems in south-west Côte d'Ivoire. In: Proc. 2nd Int. Tropenbos Seminar, October 5-7, Amsterdam, Tropenbos, Ede, The Netherlands.

Roose, E.J. (1977). Erosion et ruisselement en Afrique de l'Ouest. Travaux et documents de l'ORSTOM no. 78. ORSTOM, Paris, France.

Rouw, A. de, Vellema, H.C. and Blokhuis, W.A. (1990). Land unit survey of the Taï region, south-west Côte d'Ivoire. Tropenbos Technical Series 7. The Tropenbos Foundation, Ede, The Netherlands.

Rouw, A. de (1991). Rice, weeds and shifting cultivation in a tropical rain forest. A study of vegetation dynamics. Doctoral thesis, Agricultural University, Wageningen, The Netherlands.

Sehmel, G.A. (1980). Particle and gas dry deposition: A review. Atmospheric environment 14: 983-1011.

Tiessen, H., Hauffe, H.-K. and Mermut, A.R. (1991). Deposition of Harmattan dust and its influence on base saturation of soils in Northern Ghana. Geoderma, 49: 285-299

Vooren, A.P. (1985). Patterns in tree and branch fall in a West African rain forest. Wageningen Agricultural University, Department of Silviculture. Report D 85-05.

Vrins, E.L.M., Hofschreuder, P., Kuile, W.M. ter, Oeseburg, F. and Alderliesten, P.T. (1985). Het vangstrendement voor grof stof van de mens en van meetinstrumenten in de buitenlucht. Vakgroep Luchthygiëne en -verontreiniging. Landbouwhogeschool Wageningen, The Netherlands.

Wallinga, I., Vark, W. van, Houba, V.J.G. and Lee, J.J. van der (1989). Plant analysis procedures. Soil and plant analysis, Part 7. Department of Soil Science and Plant Nutrition, Agricultural University, Wageningen, The Netherlands.

Wanielista, M.P. (1990). Hydrology and water quantity control. John Wiley & Sons Inc, New York, U.S.A.

Whalley, W.B. and Smith, B.J. (1981). Mineral content of harmattan dust from northern Nigeria examined by scanning electron microscopy. Journal of Arid Environments 4: 21-29.

Wierda, A., Veen, A.W.L. and Hutjes, R.W.A. (1989). Infiltration at the Tai rainforest (Ivory Coast): Measurements and modelling. Hydrological Processes 3: 371-382.

Zon, H.J.M. van (1978). Litter transport as a geomorphic process (a case study in the grand-duchy of Luxembourg). Publicaties van het Fysisch-Geografisch en Bodemkundig Laboratorium van de Universiteit van Amsterdam, No. 24. Universiteit van Amsterdam, Amsterdam, The Netherlands.

Annex I Soil profile descriptions (Fraters, 1986)

Profile CI.1

I Information on the site:

a. Profile number: CI-1
b. Soil Name: IC (Fritsch 1980)
c. Higher category clasification:
   FAO ferric Acrisol
   USDA Orthoxic Palehumult, clayey-skeletal,
   kaolinitic isohyperthermic
   CPCS Sol Ferrallitique fortement désaturé,
   rémanié modal sur migmatites
d. Date of examination: February 29, 1984, beginning of the rainy season, rain previous night
e. Author: B. Fraters, field description by A.J. van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, near hilltop (5°53' N and 7°20' W)
g. Elevation: 177 meters
h. Landform:
   - surrounding landform: gently undulating to rolling
   - slope: length = 500m; shape = convex; pattern: regular
   - microtopography: termite mounds <60 cm high, few fallen treeroot holes and mounds (up to 3 m)
i. Slope on which the profile is sited: sloping (10%), with south-west exposure
j. Land-use: primary forest, 100% cover
k. Climate: Aw (Köppen, 1936)

II General information on the soil (CI-1)

a. Parent material: migmatite rich in biotite
b. Drainage: well drained
c. Moisture conditions in profile: moist throughout
d. Depth of groundwater: very deep
e. Presence of surface stones, rock outcrops: ironstone gravel
f. Evidence of erosion: none
g. Presence of salts or alkali: none
h. Human influence: none

III Brief description of the profile (CI-1)

Deep, well drained, red profile, very gravelly clay (115 cm) over slightly gravelly clay. Moderate fine to medium (sub)angular blocky structure throughout, sticky and plastic when wet and friable when moist. Well developed argillic B. Roots concentrated in the top 20 cm. Very strongly acid.

IV Profile description (CI-1)

O 3 to 4 layers of leaves in various stages of decomposition.

Ahcs 0-7 cm
Dark brown (7.5 YR 3/4, moist), very gravelly sandy loam; moderate fine and medium subangular blocky; slightly sticky, slightly plastic when wet and friable when moist; very frequent medium and large hard spherical ironstone concretiones; very few medium quartz fragments; many very fine to fine interstitial and few micro to fine tubular pores; many fine to coarse roots; clear smooth boundery; medium acid, pH 5.9.

BAcs 7-20 cm
Dark reddish brown (5 YR 3/4, moist), very gravelly sandy clay loam; structure as above; sticky, plastic when wet and friable when moist; concretions, fragments and pores as above; common fine to coarse roots; gradual smooth boundery; very strongly acid, pH 4.9.

Btcs 1 20-45 cm
Red (2.5 YR 4/8, moist), very gravelly clay; moderate medium angular blocky; skeletans; consistence, concretions, fragments and pores as above; few fine roots; diffuse smooth boundery; extremely acid, pH 4.4.

Btcs 2 45-115 cm
Red (2.5 YR 4/8, moist), very gravelly clay; structure, cutans, consistence, fragments as above; common very fine to fine interstitial and few micro to very fine roots; gradual smooth boundary; very strongly acid, pH 4.6.

2Btcs 3 115-135 cm
Red (2.5 YR 4/6, moist), slightly gravelly clay; moderate fine subangular blocky; cutans and consistence as above; few medium and large hard spherical ironstone concretions; common very fine and many fine tubular pores; very few very fine roots; clear smooth boundary; very strongly acid, pH 4.6.

2Bws 135-160 cm
Slightly gravelly clay; moderate very fine angular blocky; thin clay-iron cutans; consistence as above; few medium hard spherical ironstone concretions; few very fine tubular pores; very few very fine roots; very strongly acid pH 4.7.

V Analysis results (CI-1)

Depth	0-7	7-20	20-45	50-70	80-100	115-135	135-150
Gravel (> 2mm)	76	75	77	75	71	8	7
Sand(1.0-2.0 mm)	4.9	3.0	3.5	4.8	5.4	1.3	0.9
(0.5-1.0 mm)	2.9	1.8	2.5	1.5	1.6	1.1	0.6
(0.25-0.50 mm)	17.0	11.6	7.5	4.0	3.9	3.9	3.3
(0.10-0.25 mm)	29.2	22.6	12.5	6.6	6.4	6.3	5.7
(0.05-0.10 mm)	12.7	11.2	7.6	4.4	4.2	4.2	4.3
Silt (20-50 um)	8.5	9.5	9.3	6.4	5.8	9.9	9.5
(2-20 um)	5.3	6.9	7.0	7.5	10.2	16.0	18.3
Clay(< 2 um)	19.4	33.4	50.1	64.8	62.5	57.2	57.5
Water disp.	5.3	14.5	27.2	0.5	0.5	0.0	0.0
pH (1:2.5)H_2O	5.9	4.9	4.4	4.6	4.7	4.6	4.7
KCl	4.8	3.8	3.6	3.7	3.8	3.8	3.8
SpS ($m^2 \cdot g^{-1}$)						75	
Org. Matter (% C)	3.11	1.32	1.05	0.68	0.40	0.26	0.21
Exchangeable cations (meq/100g)							
Ca	5.3	0.8	0.0	0.0	0.0	0.0	0.0
Mg	1.0	0.5	0.2	0.2	0.1	0.1	0.0
Na	0.0	0.1	0.1	0.0	0.0	0.2	0.0
K	0.1	0.0	0.0	0.0	0.0	0.0	0.0
sum	6.5	1.4	0.3	0.2	0.1	0.3	0.1
CEC	8.9	5.1	5.9	5.3	3.9	3.9	3.5
B.S. (%)	73	28	6	4	3	7	2
EC (1:2.5) in mS/cm	0.16	0.05	0.03	0.02	0.02	0.02	0.02
Na-Dit extr. (%)							
Fe	2.66	3.67	4.37	5.53	5.30	5.21	5.44
Al	0.36	0.57	0.79	0.92	0.82	0.69	0.74
Si	0.07	0.09	0.08	0.11	0.11	0.11	0.15
Mn	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Amm-Ox Extr. (%)							
Fe	0.23	0.36	0.22	0.18	0.18	0.13	0.13
Al	0.07	0.09	0.11	0.12	0.12	0.09	0.10
Si	0.01	0.01	0.01	0.02	0.02	0.02	0.03
Na-Pos Extr. (%)							
Fe						7.29	
Al						0.87	
elemental composition (weight %)							
SiO_2	75.93	70.09	59.95	49.19	49.41	48.26	49.37
Al_2O_3	7.21	11.82	18.15	23.27	23.84	26.03	25.91
Fe_2O_3	7.66	8.59	11.52	14.18	13.86	12.47	11.89
CaO	0.22	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.08	0.08	0.10	0.09	0.11	0.10	0.10
K_2O	0.04	0.05	0.06	0.05	0.05	0.08	0.09
Na_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.78	1.05	1.36	1.50	1.44	1.47	1.44

MnO	0.03	0.02	0.03	0.03	0.03	0.03	0.03
P_2O_5	0.06	0.05	0.07	0.08	0.06	0.05	0.06
BaO	0.00	0.00	0.00	0.00	0.00	00.0	00.00
ign. loss	8.34	7.48	9.51	11.13	10.66	10.91	10.86
Σ	100.35	99.24	100.75	99.52	99.46	99.40	99.75
Kaolinite	+++	+++	+++	+++	+++	+++	+++
Vermiculite	tr-+	tr	0-tr				
Chlorite	tr	tr-+	tr-+	+	+	+	tr-+
Gibbsite	tr-+	tr-+	tr-+	tr-+	tr-+	tr-+	tr-+
Goethite	+	+	+	+	+	+	+
Hemathite						tr	

Profile CI.2

I **Information on the site:**

a. Profile number: CI-2

b. Soil Name: IIB (Fritsch 1980)

c. Higher category clasification:
FAO ferric Acrisol
USDA Orthoxic Palehumult, clayey-skeletal,
kaolinitic isohyperthermic
CPCS Sol Ferrallitique fortement désaturé,
rémanié, faiblement appauvri sur migmatites

d. Date of examination: February 29, 1984, beginning of the rainy season, rain previous night

e. Author: B. Fraters, field description by A.J. van Kekem

f. Location: Taï forest, parcel of A.P. Vooren, on shoulder below summit (5°53' N and 7°20' W)

g. Elevation: 173 meters

h. Landform:
- surrounding landform: gently undulating to rolling
- slope: length = 500m; shape = convex; pattern: regular
- microtopography: some small termite mounds (<60 cm), irregular forest floor

i. Slope on which the profile is sited: gently sloping (5%), with south-west exposure

j. Land-use: primary forest, 100% cover

k. Climate: Aw (Köppen, 1936)

II General information on the soil (CI-2)

a. Parent material: migmatite rich in biotite
b. Drainage: well drained
c. Moisture conditions in profile: 0-80 cm moist and below 80 cm slightly moist
d. Depth of groundwater: very deep
e. Presence of surface stones, rock outcrops: ironstone gravel
f. Evidence of erosion: very slight sheet erosion
g. Presence of salts or alkali: none
h. Human influence: none

III Brief description of the profile (CI-2)

Deep, well drained red profile, very gravelly clay (80 cm) over slightly gravelly clay. Weak to moderate fine (sub)angular blocky structure, sticky and plastic when wet, friable when moist. Argillic B. Roots concentrated in the top 20 cm. Very strongly acid.

IV Profile description (CI-2)

O 2 to 3 layers leaves, rapidly decomposing.

Ahcs 0-10 cm
Dark brown (7.5 YR 5/6, moist), very gravelly sandy loam; weak fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; very frequent medium and large hard spherical ironstone concretions with black patina; many micro interstitial and medium tubular pores; many fine, medium and coarse roots; clear smooth boundary; medium acid, pH 5.6.

Bcs 10-30 cm
Yellowish red (5 YR 5/6, moist), very gravelly sandy clay loam; moderate fine subangular blocky; sticky, plastic when wet and friable when moist; concretions as above with dark reddish brown (5 YR 3/2) inside colour; common fine and medium exped intertitial and many micro to fine inped and exped tubular pores; few fine roots; gradual smooth boundary; very strongly acid, pH 4.6.

Btcs 30-80 cm
Red (2.5 YR 4/8, moist), very gravelly clay; structure, consistence and concretions as above; many very fine and fine discontinuous interstitial and tubular pores; very few fine roots; diffuse smooth boundary; very strongly acid, pH 4.6.

2Bt 80-150 cm

Red (2.5 YR 4/6, moist), slightly gravelly clay; few fine prominent clear brownish yellow (10 YR 6/8) mottles; moderate fine and medium angular blocky; broken and continuous moderately thick clay-iron cutans; sticky, plastic when wet and friable to firm when moist; few medium slightly hard angular clay and iron concretions with red (2.5 YR 4/6) colour; common very fine tubular and interstitial pores; very few fine roots; very strongly acid, pH 4.6.

V Analysis results (CI-2)

Depth	0-10	10-30	40-70	80-100	110-150
Gravel (> 2mm)	75	71	63	5	2
Sand(1.0-2.0 mm)	8.5	12.1	6.8	3.8	12.0
(0.5-1.0 mm)	3.4	4.2	2.8	3.0	1.5
(0.25-0.50 mm)	17.2	10.0	6.0	5.0	4.1
(0.10-0.25 mm)	27.0	21.3	10.3	9.1	8.5
(0.05-0.10 mm)	12.4	10.1	5.8	5.5	5.0
Silt (20-50 um)	8.9	9.1	9.3	12.2	13.0
(2-20 um)	5.2	4.7	6.0	15.6	17.2
Clay(< 2 um)	17.2	28.6	52.8	45.8	48.7
Water disp.	2.4	13.4	0.5	0.5	0.0
pH (1:2.5)H_2O	5.6	4.7	4.6	4.6	4.5
KCl	4.2	3.8	3.8	3.8	3.7
Exch. Acid (H+Al)	0.4	1.4	2.0	2.1	2.3
Exch Al in KCl	0.2	1.1	1.8	1.8	1.8
Org. Matter (% C)	3.45	1.08	0.79	0.43	0.22
Exchangeable cations (meq/100g)					
Ca	3.3	0.2	0.0	0.0	0.0
Mg	1.3	0.3	0.1	0.1	0.1
Na	0.3	0.2	0.2	0.2	0.1
K	0.2	0.1	0.0	0.0	0.0
sum	5.0	0.8	0.3	0.4	0.2
CEC	9.6	5.4	5.1	5.1	4.8
B.S. (%)	53	15	6	8	5
EC (1:2.5) in mS/cm	0.14	0.06	0.03	0.03	0.03
Na-Dit extr. (%)					
Fe	3.50	3.72	5.69	6.14	5.87
Al	0.31	0.42	0.70	0.65	0.53
Si	0.06	0.06	0.10	0.08	0.10
Mn	0.02	0.01	0.02	0.01	0.01
Amm-Ox Extr. (%)					
Fe	0.23	0.37	0.22	0.15	0.14
Al	0.08	0.14	0.18	0.15	0.17
Si	0.01	0.02	0.03	0.02	0.03

elemental composition (weight %)					
SiO_2	75.32	70.54	52.59	48.39	49.75
Al_2O_3	7.38	11.47	20.94	24.73	25.65
Fe_2O_3	8.65	9.78	14.11	14.89	14.22
CaO	0.07	0.00	0.00	0.00	0.00
MgO	0.09	0.07	0.10	0.06	0.07
K_2O	0.04	0.04	0.04	0.07	0.08
Na_2O	0.0	0.0	0.0	0.0	0.0
TiO_2	0.75	0.94	1.34	1.42	1.44
MnO	0.04	0.02	0.03	0.02	0.02
P_2O_5	0.05	0.04	0.05	0.03	0.03
BaO	0.00	0.00	0.00	0.00	0.00
ign. loss	9.03	6.97	10.19	10.99	10.79
Σ	101.42	99.87	99.39	100.60	102.05
Kaolinite	+++	+++	+++	+++	+++
Vermiculite	tr	0-tr			
Chlorite	tr	tr-+	tr-+	tr-+	tr-+
Gibbsite	tr-+	tr-+	tr-+	tr-+	tr
Goethite	+	+	+	+	+

Profile CI.3

I **Information on the site:**

a. Profile number: CI-3

b. Soil Name: III (Fritsch 1980)

c. Higher category clasification:
FAO plintic Acrisol
USDA Plinthudult, clayey-skeletal, kaolinitic isohyperthermic
CPCS Sol Ferrallitique fortement désaturé, rémanié à recouvrement plus ou moins appauvri sur les alterations de migmatites en place

d. Date of examination: March 1, 1984, beginning of the rainy season, dry

e. Author: B. Fraters, field description by A.J. van Kekem

f. Location: Taï forest, parcel of A.P. Vooren, upper slope below shoulder (5°53' N and 7°20' W)

g. Elevation: 165 meters

h. Landform:
- surrounding landform: gently undulating to rolling
- slope: length = 500m; shape = concave; pattern: regular
- microtopography: few small termite mounds, irregular forest floor with earthworm casts

i. Slope on which the profile is sited: gently sloping (5%), with south-west exposure
j. Land-use: primary forest, 100% cover
k. Climate: Aw (Köppen)

II General information on the soil (CI-3)

a. Parent material: migmatite rich in biotite
b. Drainage: moderately well drained, mainly superficially and laterally
c. Moisture conditions in profile: slightly moist throughout
d. Depth of groundwater: unknown (deep?)
e. Presence of surface stones, rock outcrops: ironstone gravel, fairly to slightly gravelly
f. Evidence de erosion: moderate splash erosion, slight deposition
g. Presence of salts or alkali: none
h. Human influence: none

III Brief description of the profile (CI-3)

Deep moderately well drained yellowish brown profile, very gravelly sandy clay over clay; moderate fine (sub)angular blocky structure; from non-sticky and non plastic to sticky and plastic when wet, and from very friable to friable when moist. Argillic B on plinthite. Roots concentrated in the upper 10 cm; very strongly to strongly acid.

IV Profile description (CI-3)

O Fast decomposing leaves (±1/2 cm)

Ah 0-10 cm

Dark brown (10 YR 4/3, moist), slightly gravelly loamy sand; weak fine subangular blocky; non sticky, non plastic when wet and very friable when moist; few medium hard ironstone spherical concretions with black patina coating; many micro tubular and medium interstitial pores; many fine, medium and coarse roots; clear smooth boundary; very strongly acid, pH 4.5.

BAcs 10-20/28 cm

Yellowish brown (10 YR 5/6, moist), very gravelly sandy loam; moderate fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; very frequent medium hard spherical dark reddish brown (2.5 YR 3/4) ironstone concretions with black patina; many very fine and fine continuous tubular and inped interstitial pores; very few fine roots; gradual irregular boundary; very strongly acid, pH 4.7.

Btcs 20/28-50/80 cm

Yellowish brown (10 YR 5/8, moist), very gravelly sandy clay; moderate very fine and fine angular to subangular blocky; sticky and plastic when wet and friable when moist; concretions as above; very few small weathered quartz fragments; many very fine discontinuous tubular and fine inped and exped interstitial pores; roots as above; clear irregular boundary; strongly acid, pH 5.1.

2Bs 50/80-150 cm

Yellowish brown (10 YR 5/8, moist), clay; many coarse distinct clear dark red (2.5 YR 3/6) mottles; weak to moderate fine falling apart to very fine angular blocky; clay-iron cutans around gravel; consistance as above; very frequent medium and large slightly hard irregular clay-iron nodules (plinthite); at 120 cm quartz vein, broken 2-4 mm; many very fine and fine discontinuous inped and exped tubular and interstitial pores and few medium and coarse exped interstitial pores; roots as above; strongly acid, pH 5.0 (the big pores are lined with humus and clay cutans).

V Analysis results (CI-3)

Depth	0-10	10-20	30-60	100-130
Gravel (> 2mm)	3	56	70	
Sand (1.0-2.0 mm)	3.3	6.1	7.7	2.6
(0.5-1.0 mm)	4.2	3.1	4.1	2.6
(0.25-0.50 mm)	21.2	16.0	9.1	5.8
(0.10-0.25 mm)	36.6	32.2	15.8	9.9
(0.05-0.10 mm)	13.9	13.8	8.3	4.7
Silt (20-50 um)	8.8	9.2	6.7	9.3
(2-20 um)	3.0	4.0	6.6	16.6
Clay (< 2 um)	9.2	15.7	41.7	48.4
Water disp.	2.4	5.8	28.1	0.5
pH (1:2.5)H_2O	4.5	4.7	5.1	5.0
KCl	3.6	3.8	3.9	3.9
Exch. Acid (H+Al)	1.1	1.3	1.1	1.3
Exch Al in KCl	0.7	0.9	0.7	0.9
Org. Matter (% C)	1.78	0.89	0.91	0.43
Exchangeable cations (meq/100g)				
Ca	0.6	0.4	1.4	0.4
Mg	0.2	0.0	0.1	0.2
Na	0.1	0.1	0.1	0.1
K	0.1	0.0	0.0	0.0
sum	1.0	0.5	1.7	0.6
CEC	6.2	4.7	7.5	6.2
B.S. (%)	16	11	22	10
EC (1:2.5) in mS/cm	0.29	0.03	0.03	0.02

Na-Dit extr. (%)				
Fe	1.80	1.39	3.85	5.43
Al	0.16	0.20	0.56	0.64
Si	0.05	0.04	0.07	0.11
Mn	0.00	0.00	0.00	0.01
Amm-Ox Extr. (%)				
Fe	0.11	0.21	0.26	0.23
Al	0.05	0.07	0.12	0.14
Si	0.01	0.01	0.01	0.03
elemental composition (weight %)				
SiO_2	88.35	84.43	64.84	52.48
Al_2O_3	3.41	6.04	16.51	22.88
Fe_2O_3	2.17	3.99	8.55	11.99
CaO	0.00	0.00	0.02	0.00
MgO	0.05	0.06	0.09	0.08
K_2O	0.03	0.03	0.07	0.06
Na_2O	0.0	0.0	0.0	0.0
TiO_2	0.31	0.49	0.96	1.11
MnO	0.01	0.01	0.01	0.01
P_2O_5	0.01	0.02	0.02	0.02
BaO	0.00	0.00	0.00	0.00
ign. loss	3.78	4.03	8.18	9.93
Σ	98.12	99.10	99.25	98.56
Kaolinite	+++	+++	+++	+++
Vermiculite	tr	tr	tr	0-tr
Chlorite	tr	tr-+	tr	tr
Gibbsite	tr-+	tr-+	tr-+	tr
Goethite	tr-+	tr-+	tr-+	tr-+

Profile CI.4

I Information on the site:

a. Profile number: CI-4

b. Soil Name: IVA (Fritsch 1980)

c. Higher category clasification:
FAO xantic Ferralsol
USDA Tropeptic Haplortox, fine loamy over loamy-skeletal, mixed, isohyperthermic
CPCS Sol Ferrallitique fortement désaturé, induré, appauvri, hydromorphe, sur colluvions recouvrant les alterations migmatites

d. Date of examination: March 1, 1984, beginning of the rainy season, dry

e. Author: B. Fraters, field description by A.J. van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, lower slope (5°53' N and 7°20' W)
g. Elevation: 160 meters
h. Landform:
   - surrounding landform: gently undulating to rolling
   - slope: length = 500m; shape = rectilinear; pattern: regular
   - microtopography: very many earthworm casts, 5 cm high
i: Slope on which the profile is sited: gently sloping (5%), with south-west exposure
j: Land-use: primary forest, 100% cover
k: Climate: Aw (Köppen)

II General information on the soil (CI-4)

a. Parent material: colluvium on altered migmatite rich in biotite
b. Drainage: moderately well drained, mainly superficially and laterally
c. Moisture conditions in profile: moist throughout
d. Depth of groundwater: highest 80 cm, lowest very deep
e. Presence of surface stones, rock outcrops: none
f. Evidence of erosion: moderate splash erosion, some white sand deposition
g. Presence of salts or alkali: none
h. Human influence: none

III Brief description of the profile (CI-4)

Moderately deep, yellowish brown, moderately well drained profile, Sandy clay loam over very gravelly clay loam. Moderate medium angular falling apart into weak very fine subangular blocky structure over massive strongly coherent; sticky, plastic and friable over very firm, very compact Oxic B over petro-plinthite. Roots concentrated in the upper 30 cm. Extremely acid.

IV Profile Desciption (CI-4)

O 2 to 3 layers of leaves, rapidly decomposing.

Ah 0-8 cm

Yellowish brown (10 YR 5/4, moist), sandy loam; moderate very fine and fine subangular blocky; non-sticky, non-plastic when wet and very friable when moist; many micro interstitial and many fine tubular pores; many fine, medium and coarse roots; gradual smooth boundary; extremely acid, pH 4.3.

Bwsl 8-30 cm

Yellowish brown (10 YR 5/6, moist), sandy clay loam; weak fine subangular blocky; slightly sticky, plastic when wet and friable when moist; many fine interstitial and many very fine tubular pores; few fine and medium roots; gradual smooth boundary; extremely acid, pH 4.4.

Bws2 30-50 cm

Yellowish brown (10 YR 5/8, moist), sandy clay loam; sticky, plastic when wet and friable when moist; moderate fine and medium angular falling apart into weak very fine subangular blocky; pores and roots as above; diffuse smooth boundary; extremely acid, pH 4.4.

Bws 3 50-70/90 cm

Yellowish brown (10 YR 5/8, moist), few fine faint clear yellowish red (5 YR 4/6) mottles; sandy clay; moderate medium angular falling apart into weak very fine subangular blocky; consistence as above; few small soft and hard spherical ironstone nodules; many very fine and common fine tubular and interstitial pores; roots as above; abrupt irregular boundary; very strongly acid, pH 4.7.

Bms 70/90-110 cm

Yellowish brown (10 YR 5/8, moist), very gravelly clay loam; massive, strongly coherent, slightly cemented; sticky, plastic when wet and very firm, very compact when moist; very frequent medium and large irregular ironstone concretions (inside colour: dark reddish brown (2.5 YR 3/4); few fine and fine discontinuous vesicular pores; few fine and medium roots; very strongly acid, pH 4.7.

Petro-plinthite,

In the field described by Van Kekem as having only 20% soil, the rest being ironstone breaking up in hundreds of gravels (2-10 mm), irregular formed, strongly coherent iron concretions (porous) massive, not continuously indurated.

V Analysis results (CI-4)

Depth	0-8	8-30	30-50	50-80	80-110
Gravel (> 2mm)					54
Sand(1.0-2.0 mm)	0.5	0.8	0.9	1.8	4.9
(0.5-1.0 mm)	3.5	2.7	2.4	2.6	2.9
(0.25-0.50 mm)	22.3	16.5	13.2	11.7	8.5
(0.10-0.25 mm)	37.7	29.5	23.9	19.7	15.1
(0.05-0.10 mm)	12.8	11.6	10.5	9.8	8.2
Silt (20-50 um)	8.0	10.5	11.2	11.6	12.8
(2-20 um)	4.8	5.7	6.2	6.4	9.2
Clay(< 2 um)	10.5	22.8	31.7	36.5	38.3

Water disp.	3.8	11.2	18.9	4.6	0.0
pH (1:2.5)H_2O	4.3	4.4	4.4	4.5	4.7
KCl	3.8	3.8	3.8	3.8	4.0
SpS m^2,g^{-1}	18	33	42	48	63
Org. Matter (% C)	0.93	0.65	0.50	0.47	0.38
Exchangeable cations (meq/100g)					
Ca	0.2	0.0	0.0	0.0	0.0
Mg	0.2	0.2	0.1	0.1	0.1
Na	0.0	0.0	0.0	0.0	0.0
K	0.1	0.0	0.0	0.0	0.0
sum	0.5	0.2	0.1	0.1	0.1
CEC	2.3	3.0	3.2	2.8	3.0
B.S. (%)	23	6	4	5	4
EC (1:2.5) in mS/cm	0.13	0.05	0.03	0.03	0.02
Na-Dit extr. (%)					
Fe	0.7	1.2	1.6	1.8	4.3
Al	0.2	0.3	0.4	0.4	0.6
Si					
Mn	0.0	0.0	0.0	0.0	0.0
Amm-Ox Extr. (%)					
Fe	0.1	0.1	0.1	0.1	0.1
Al	0.0	0.1	0.1	0.1	0.1
Si	0.0	0.0	0.0	0.0	0.0
elemental composition (weight %)					
SiO_2	91.36	84.90	78.29	76.34	64.23
Al_2O_3	3.75	8.18	11.12	13.39	17.44
Fe_2O_3	1.26	2.37	3.08	3.95	8.36
CaO	0.00	0.00	0.00	0.00	0.00
MgO	0.06	0.07	0.07	0.08	0.08
K_2O	0.03	0.04	0.05	0.05	0.05
Na_2O	0.0	0.0	0.0	0.0	0.0
TiO_2	0.33	0.57	0.71	0.83	1.03
MnO	0.00	0.00	0.00	0.00	0.01
P_2O_5	0.00	0.01	0.01	0.01	0.02
BaO	0.00	0.00	0.00	0.00	0.00
ign. loss	2.97	4.39	5.35	6.11	7.93
Σ	99.76	100.53	98.68	100.76	99.15
Kaolinite	+++	+++	+++	+++	+++
Vermiculite	tr	tr	-	-	-
Chlorite	tr-+	tr-+	+	+	+
Gibbsite	tr-+	tr-+	tr-+	tr-+	tr-+
Goethite	tr-+	tr-+	tr-+	tr-+	tr-+
Hematite	-	-	-	-	tr

Profile CI.5

I Information on the site:

a. Profile number: CI-5
b. Soil Name: VA (Fritsch 1980)
c. Higher category clasification:
FAO dystric Gleysol
USDA Tropaquent, coarse loamy mixed isohyperthermic
CPCS Sol Hydromorphe peu humifére, à amphi-gley, à nappe phréatique profonds sur colluvions
d. Date of examination: January 26, 1985, the dry season, rain once a week.
e. Author: B. Fraters, field description by A.J. van Kekem
f. Location: Taï forest, parcel of A.P. Vooren, Valley bottom (5°53' N and 7°20' W)
g. Elevation: 155 meters
h. Landform:
- surrounding landform: gently undulating to rolling
- slope: length = 500m; shape = rectilinear; pattern: regular
- microtopography: irregular forest floor
i. Slope on which the profile is sited: gently sloping (4%), with north-east exposure
j. Land-use: primary forest, 100% cover
k. Climate: Aw (Köppen)

II General information on the soil (CI-5)

a. Parent material: colluvium on altered migmatites rich in biotite
b. Drainage: poorly drained
c. Moisture conditions in profile: moist throughout
d. Depth of groundwater: high = 40 cm, low = 80 cm
e. Presence of surface stones, rock outcrops: none
f. Evidence of erosion: moderate splash erosion and rainwash, some depositions
g. Presence of salts or alkali: none
h. Human influence: none

III Brief description of the profile (CI-5)

Deep, poorly drained, light yellowish brown over light gray profile. Sandy loam, porous massive, weakly coherent structure, slightly sticky, slightly plastic when wet and very friable when moist. Strong brown mottling. Water table between 40 and 80 cm. Roots concentrated in the upper 20 cm. Very strongly acid.

IV Profile Description (CI-5)

O Few leaves, rapidly decomposing.

Ah 0-5/20 cm
Dark brown (10 YR 4/3, moist), sandy loam; moderate very fine to medium subangular blocky; non-sticky, non-plastic when wet and very friable when moist; many micro tubular and fine interstitial pores; many very fine and coarse roots; gradual irregular boundary; extremely acid, pH 4.2.

Bws 5/20-37 cm
Light yellowish brown (10YR 6/4, moist), sandy loam; mottling increases with depth to few fine faint diffuse strong brown (7.5 YR 5/8) mottles; weak fine subangular blocky; slightly sticky, slightly plastic when wet and very friable when moist; many micro and fine tubular pores; common fine, medium and coarse roots, along them often organic matter mottles; gradual smooth boundary; extremely acid, pH 4.4.

BCg 37-50 cm
Very pale brown (10 YR 7/3, moist), sandy loam; from common fine distinct diffuse yellow (5 Y 7/7) to many fine distinct clear strong brown (7.5 YR 5/8) mottles; porous massive; weakly coherent; consistence as above; common micro and fine tubular pores; few fine and medium roots; clear smooth boundary; very strongly acid, pH 4.4.

Cr 1 50-75 cm
Light gray (5 Y 7/1, moist), sandy loam; common fine prominent clear strong brown (7.5 YR 5/8) mottles; structure, consistence and roots as above; common micro and very fine tubular pores; gradual smooth boundary; very strongly acid, pH 4.7.

Cr 2 75-100 cm
White (10 Y 8/1, moist), sandy loam; few very fine distinct diffuse brownish yellow (10 YR 6/6) mottles; structure and consistence as above; few micro and very fine tubular pores; very few very fine and fine roots; clear smooth boundary; very strongly acid, pH 4.7.

2Cr 100-120
White (10 Y 7/1, moist) sandy clay loam; very few very fine orange mottles and few organic mottles; structure and consistence as above; at 100-105 cm a layer of coarse (1-5 cm) quartz gravel, subangular; common very fine and fine tubular pores; no roots; very strongly acid, pH 4.7.

V Analysis results (CI-5)

Depth	0-10	10-40	40-50	50-75	75-100	100-120
Gravel (> 2mm)	0	0	0	0	0	0
Sand (1.0-2.0 mm)	0.3	0.4	0.8	1.2	1.6	2.2
(0.5-1.0 mm)	4.5	6.7	5.5	7.7	9.2	8.3
(0.25-0.50 mm)	24.7	25.8	24.6	27.3	27.6	21.1
(0.10-0.25 mm)	33.4	28.5	29.0	27.8	25.8	16.7
(0.05-0.10 mm)	14.5	12.0	11.9	10.2	8.8	5.9
Silt (20-50 um)	8.0	6.8	6.7	6.3	6.1	5.7
(2-20 um)	4.8	5.1	6.5	5.0	5.0	15.6
Clay (< 2 um)	9.8	14.8	15.0	14.4	16.0	24.6
Water disp.	1.8	5.3	8.2	10.9	12.9	19.9
pH (1:2.5) H_2O	4.2	4.4	4.7	4.6	4.7	4.7
KCl	3.7	3.9	4.0	3.9	3.9	3.8
Exch. Acid (H+Al)	1.1	1.2	0.8	0.8	0.8	1.6
Exch Al in KCl	0.7	0.7	0.4	0.4	0.4	1.1
Org. Matter (% C)	1.57	1.18	0.82	0.25	0.27	0.23
Exchangeable cations (meq/100g)						
Ca	1.2	1.4	1.0	1.0	1.0	1.4
Mg	0.2	0.2	0.2	0.1	0.1	0.3
Na	0.3	0.1	0.3	0.1	0.1	0.2
K	0.1	0.0	0.1	0.0	0.0	0.0
sum	1.7	1.7	1.6	1.2	1.2	2.0
CEC	4.7	3.2	3.0	1.6	4.0	3.3
B.S. (%)	37	55	54	74	29	59
EC (1:2.5) in mS/cm	0.14	0.08	0.06	0.04	0.03	0.03
Na-Dit extr. (%)						
Fe	0.10	0.16	0.15	0.16	0.01	0.01
Al	0.04	0.05	0.03	0.02	0.01	0.02
Si	0.00	0.02	0.00	0.01	0.02	0.03
Mn	0.00	0.00	0.00	0.00	0.00	0.00
Amm-Ox Extr. (%)						
Fe	0.10	0.18	0.18	0.05	0.02	0.02
Al	0.04	0.06	0.04	0.03	0.03	0.03
Si	0.00	0.01	0.00	0.00	0.00	0.00
elemental composition (weight %)						
SiO_2	93.13	88.88	90.98	91.61	89.36	76.55
Al_2O_3	3.42	5.39	5.84	5.54	6.72	15.71
Fe_2O_3	0.36	0.54	0.56	0.38	0.40	0.73
CaO	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.04	0.04	0.04	0.03	0.04	0.05
K_2O	0.05	0.05	0.05	0.05	0.04	0.06
Na_2O	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.17	0.23	0.26	0.24	0.27	0.43
MnO	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.01	0.01	0.01	0.00	0.00	0.01

BaO	0.00	0.00	0.00	0.00	0.00	0.00
ign. loss	3.60	3.58	3.15	2.53	2.88	6.13
Σ	100.78	98.72	100.89	100.38	99.71	99.67
Kaolinite	+++	+++	+++	+++	+++	+++
Mi/Ill	0-tr	-	-	-	-	-
Chlorite	tr-+	tr-+	tr-+	tr-+	tr-+	tr-+
Quartz	tr	tr	tr	tr	tr	0-tr

Annex II Floristic composition of the vegetation

Annex II[a] Trees of more than 40 cm circumference on different topographic positions. (Numbers of trees per ha) (Huttel, 1977)

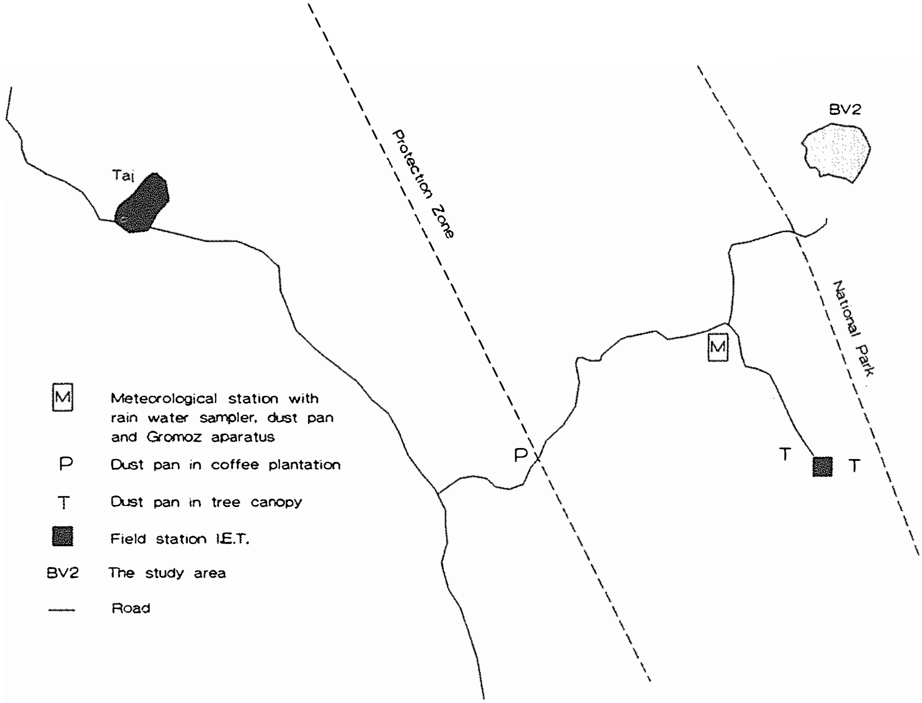
Name	S	H	M	B	BF	FP
Gilbertiodendron splendidum	.	.	.	.	58.0	.
Uapaca paludosa	0.6	9	33.9	7.4	.	.
Strephonema pseudocola	4.5	0.5	3.9	6.9	19.0	1.2
Trichoscypha arborea	.	.	3.4	4.0	0.9	8.7
Calpocalyx brevibracteatus	13.4	10.2	16.5	11.4	2.8	45.9
Scottellia coriacea	1.0	4.4	4.4	5.5	2.3	6.2
Bussea occidentalis	1.0	2.0	0.5	1.0	.	9.9
Diospyros soubreana	5.4	3.9	3.9	3.5	.	9.9
Scottellia chevalieri	6.9	4.4	4.4	5.5	2.3	6.2
Enantia polycarpa	3.0	4.9	1.5	6.4	0.5	7.4
Dialium aubrevillei	3.0	4.9	6.3	10.9	0.5	7.4
Coula edulis	16.3	15.1	13.6	25.3	3.2	16.1
Memecylon lateriflorum	9.9	5.9	11.2	11.9	0.9	3.7
Carcinia afzelii	.	.	5.3	3.5	1.4	3.7
Galpocalyx aubrevillei	.	2.0	9.2	3.5	0.5	.
Corynanthe pachyceras	26.7	22.9	31.5	15.4	.	18.6
Xylopia quintasii	4.0	10.7	10.7	4.5	1.9	5.0
Scytopetalum tieghennii	6.9	3.	0.9	32.8	8.7	.
Strombosia glaucescens	10.9	14.6	8.2	5.9	0.5	6.2
Diospyros mannii	23.8	26.3	18.4	17.3	1.9	7.4
Diospyros sanza-minika	21.8	15.1	11.2	10.9	3.2	2.5
Diospyros canaliculata	7.9	2.9	1.0	.	0.5	.
Funtumia elastica	5.9	0.5	.	.	0.5	.
Erythroxylon mannii	9.9	2.4	0.5	.	.	1.2
Octoknema borealis	10.4	3.9	6.3	3.5	.	8.7
Chrysophyllum taiense	12.4	8.8	9.2	3.5	.	6.2
Total	205.5	175.6	193.7	183.6	234.9	204.5
Total density	269	250	252	252	293	253

Annex II[b] Trees between 11 and 40cm circumference on different topographic positions. (Numbers of trees per ha) (Huttel, 1977)

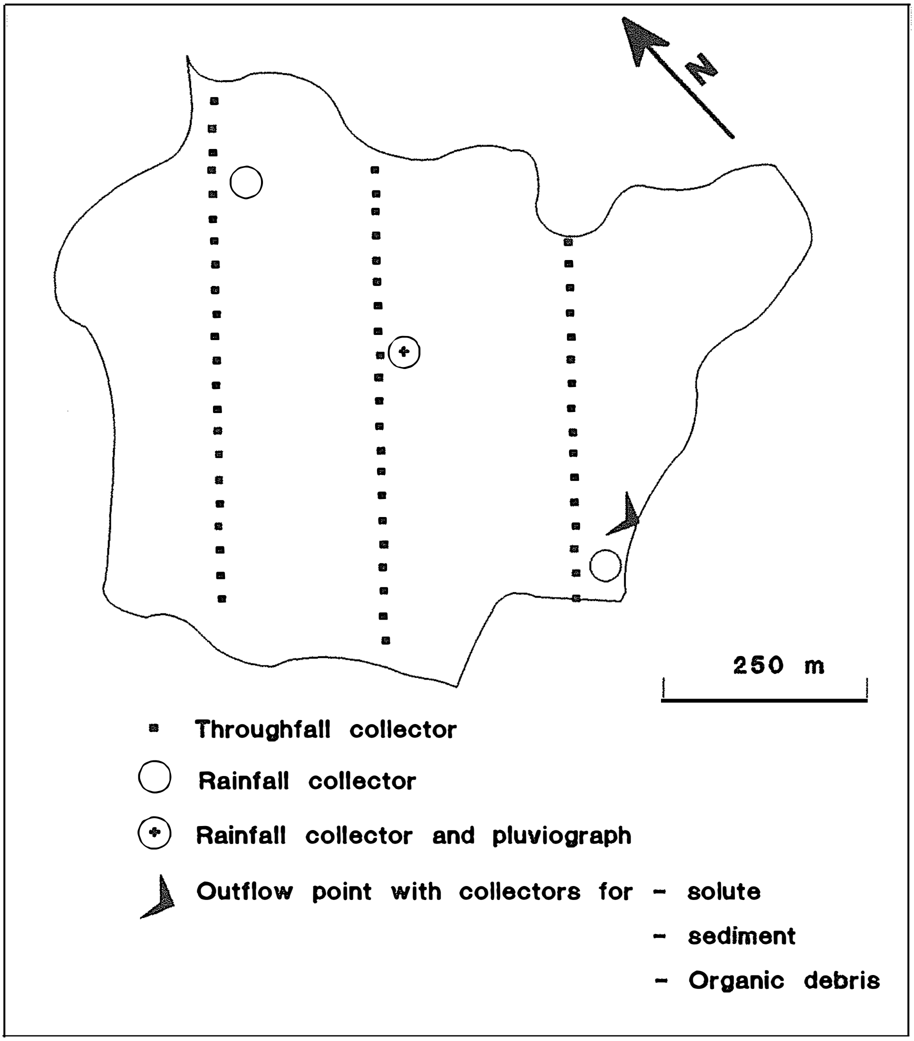
Name	S	H	M	B	BF	FP
Acioa dinklagei	.	.	.	.	10.4	.
Carapa procera	.	.	.	.	7.6	.
Gaertnera cooperi	.	.	.	0.7	11.6	.
Gilbertiodendron splendidum	.	.	.	0.2	14.9	.
Tarrietia utilis	.	.	.	0.4	18.4	9.0
Pauridiantha hirtella	0.2	.	.	.	5.8	1.0
macaranga heterophylla	0.5	0.2	0.4	.	8.7	0.5
Napoleona leonensis	4.0	7.0	5.3	1.6	17.3	20.5
Diospyros soubreana	17.1	15.5	17.1	17.3	2.9	20.0
Maesobotrya barteri	3.1	2.0	3.8	7.6	0.4	9.5
Rinorea longicuspis	0.7	3.2	8.7	0.9	.	9.5
Calpocalyx brevibracteatus	3.1	5.2	4.0	4.4	.	6.2
Octoknema borealis	2.9	2.3	2.0	1.3	.	7.1
Strephonema pseudocola	1.0	0.5	1.8	10.7	8.0	0.7
Xylopia parviflora	4.5	4.3	2.2	7.3	4.4	2.4
Memecylon lateriflorum	4.0	11.1	5.8	14.2	0.2	9.4
Polyalthia oliveri	5.0	4.8	6.2	14.2	0.2	5.0
Diospyros mannii	20.0	23.6	37.3	24.2	5.6	23.8
Memecylon guineense	8.6	6.6	17.6	14.2	.	3.8
Drypetes gilgiana	9.3	10	7.3	4.4	0.2	4.8
Xylopia quintasii	14.5	11.1	3.1	5.1	4.4	5.7
Strombosia glaucenscens	7.9	6.1	6.2	4.2	0.2	5.7
Memecylon golaense	9.0	4.8	9.3	2.0	.	5.7
Craterispermum caudatum	13.3	8.0	8.0	8.9	.	7.1
Total	127.8	128.3	146.1	143.8	121.2	157.4
Total density	175	196	186	187	179	201

Annex III Locations of the equipment

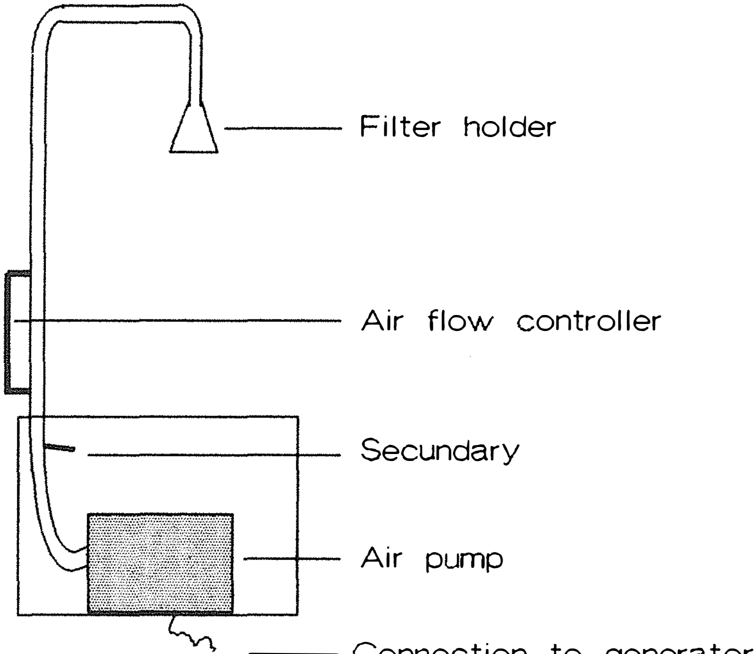
Annex III[a] Locations of equipment outside the catchment area



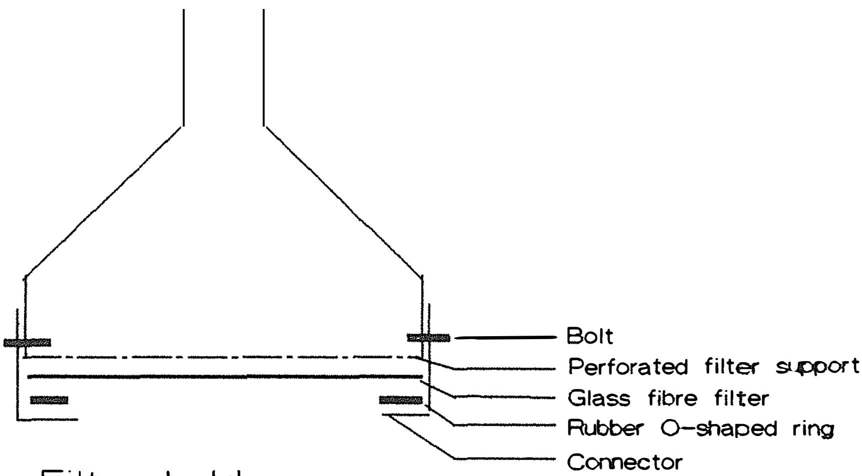
Annex III[b] Locations of equipment within the catchment area



Annex IV Gromoz aparatus for dust sampling



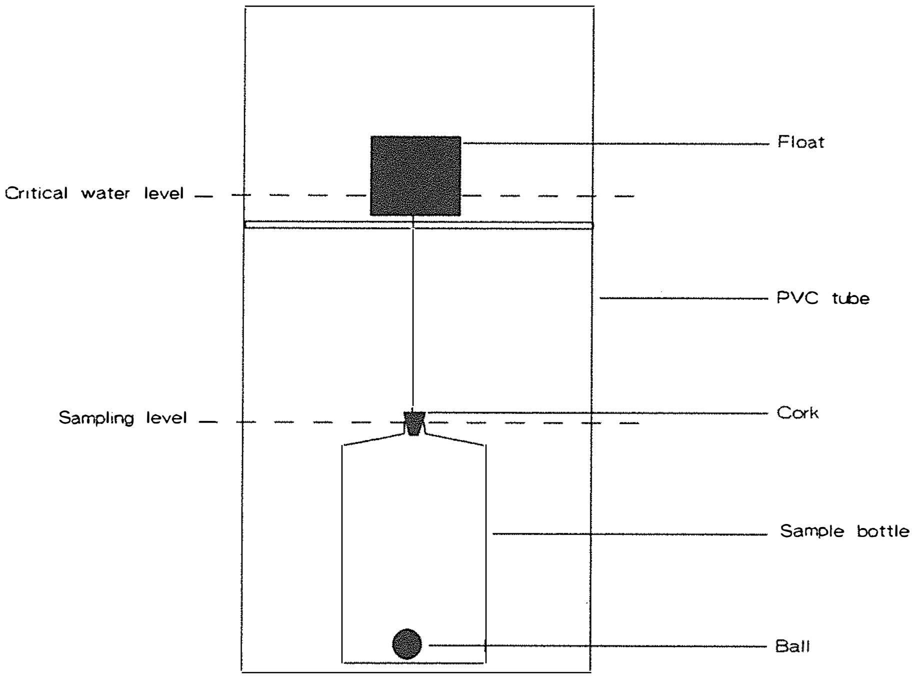
Gromoz aparatus



Filter holder

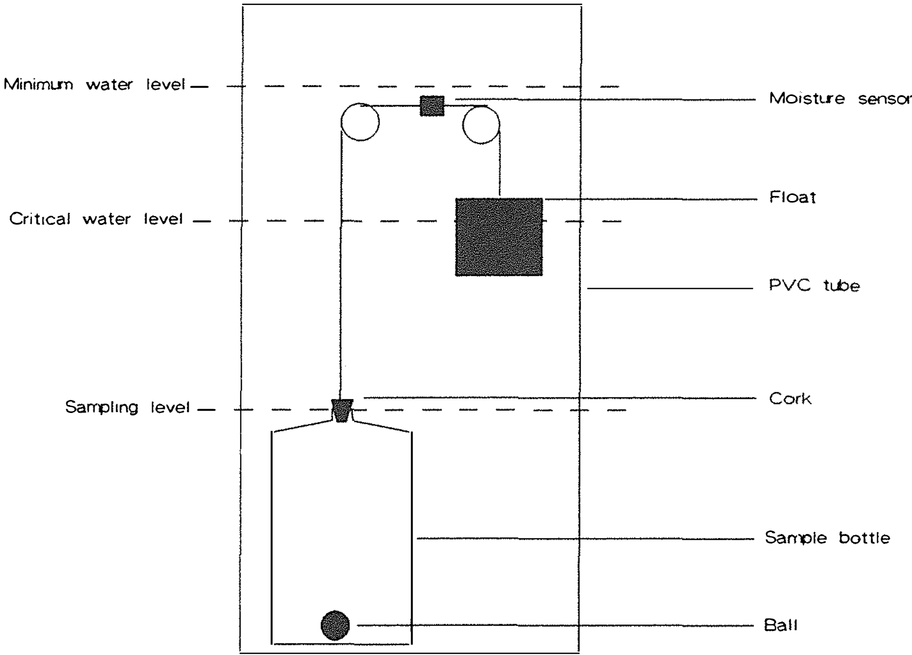
Annex V Water samplers and the location of sampling in the cross section of the creek

Annex V[a] Automatic water sampler for sampling during rising water levels



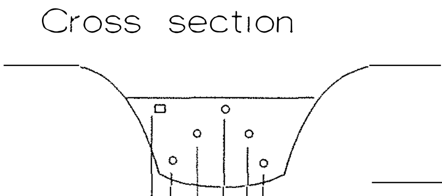
The water level in the creek will rise until the critical water level. At that level the float will open the sample bottle, which will be filled with creek water. To avoid mixing of the sample afterwards, the bottle will be closed with the ball which will float on top of the sample.

Annex V[b] Automatic water sampler for sampling during falling water levels



The float is carried by the moisture sensor, which is based on a lump of sugar. When rising water reaches the critical water level, the weight will be taken over by the water. When the water reaches the moisture sensor the sugar is dissolved and removed by the stream. When the water level drops and reaches the critical water level again the moisture sensor can not take over the weight of the float and the sample bottle will be opened. The bottle will fill up until it is full closed by the ball.

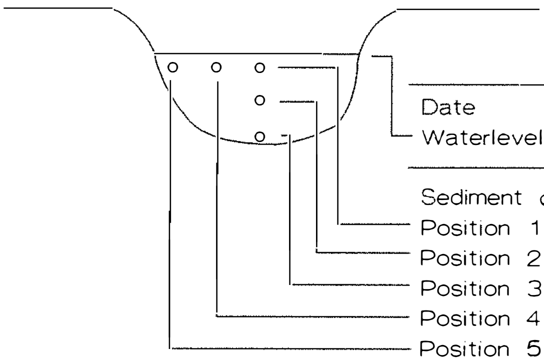
Annex V[c] Location of sampling in the cross section of the creek



Sample type	Sampling depth
Automatic:	
rising water 25cm	13cm
rising water 50cm	25cm
rising water 75cm	37cm
lowering water 50cm	25cm
lowering water 25cm	13cm
Manual	
all samples	5cm

Annex V[d] Sampling for the variability of the sediment concentration over the cross section of the creek

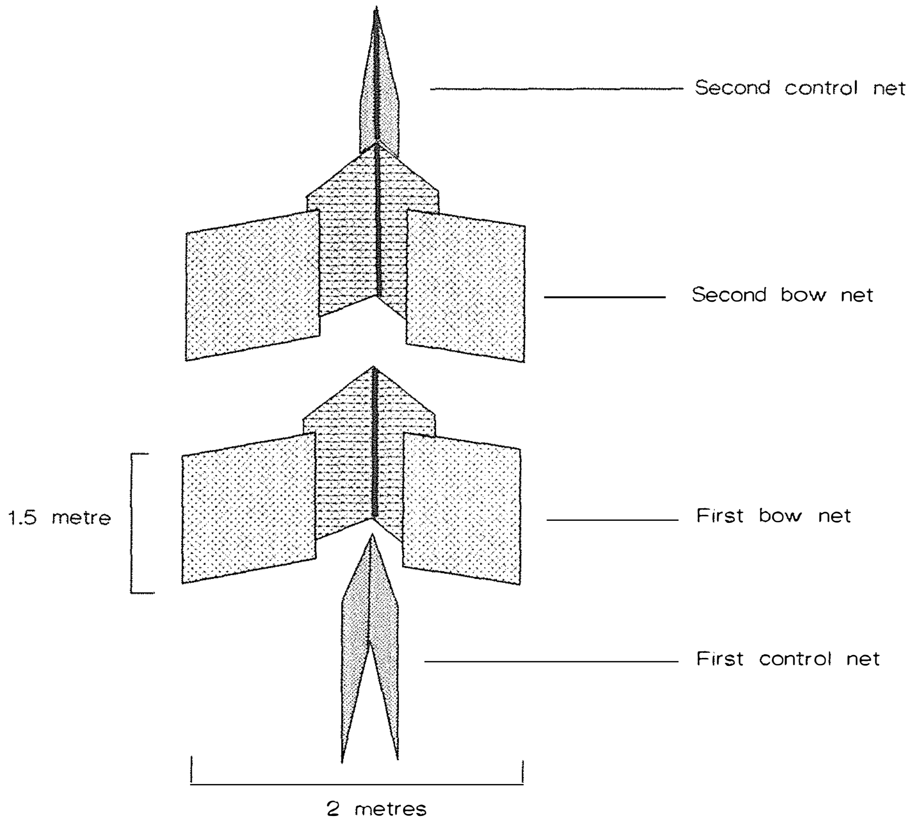
Cross section



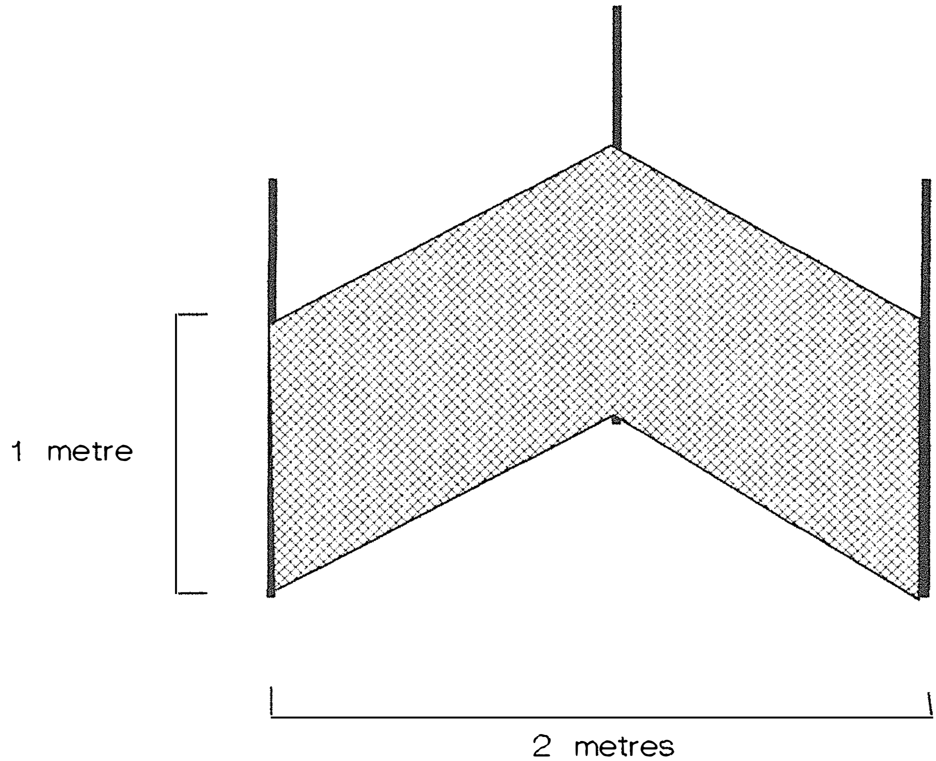
Date	17-09-92	25-09-92
Waterlevel	58	40
Sediment concentrations in mg/l		
Position 1	778	309
Position 2	764	314
Position 3	803	328
Position 4	771	287
Position 5	788	306

Annex VI Organic debris collectors

Annex VI[a] Collector for organic debris in the creek



Annex VI[b] Collector for organic debris in the valley bottom



Annex VII Listing of the hydrological model

```
Program HydroModel (Input,Output,Infile,Outfile);

{  HydroModel
   Author:     Ir J.J. Stoorvogel
               Agricultural University Wageningen
   Function:   Simulation of the hydrological balance of a catchment in
               Taï National Park, Côte d'Ivoire based on daily rainfall
               figures
   Interface:  The input consists of a file with daily rainfall figures. The
               output file is a file with data on the nutrient balance. During
               the calculation the storage of water in the catchment will be
               graphically displayed on the terminal.                       }

Uses Crt, Graph;

Const
      AET =4.018;

Var
      Day,I,X1,X2,Y,
      GraphDriver, GraphMode                        : Integer;
      Rain,BaseFlow,PeekFlow,Store1,Store2,
      SumRain                                       : Real;
      Infile1,Infile2,Outfile                       : Text;
      Rainfall                                      : Array[1..1100]
of Real;

Begin
GraphDriver:=detect;
InitGraph(GraphDriver, GraphMode,'C:\TP6\BGI');
SetGraphMode(GraphMode);
OutTextXY(25,25,'Water Storage ');
Rectangle(160,75,600,275);
Line(155,225,605,225);
Line(155,175,605,175);
Line(155,125,605,125);
Line(155,275,605,275);
OutTextXY(120,223,'   0');
OutTextXY(120,173,' 200');
OutTextXY(120,123,' 400');
OutTextXY(120,273,'-200');
      Assign(InFile1,'c:\dat\rain9091.dat');
      Reset(InFile1);
      Store1:=0;
```

```
        X2:=540;
        For Day:=1 to 434 do
                Begin
                Readln(Infile1,I,rainfall[Day]);
                End;
        Close(InFile1);
        Assign(OutFile,'c:\dat\flow90.out');
        rewrite(OutFile);
        Store2:=150;
        X2:=540;
        Day:=136;
        Writeln(Outfile,'Daynr   Rain   AET    Qo    Qp    Store');
        writeln(Outfile,'(All data in mm/dag)');
        Repeat
                Begin
                Day:=Day+1;
                X2:=X2+1;
                X1:=Round(0.6*X2)-150;
                SumRain:=0;
                For I:=1 to 90 do
                        SumRain:=SumRain+Rainfall[Day-I]/(I+0.7);
                Rain:=RainFall[day];
                BaseFlow:=0.0217*SumRain+0.000433*Sqr(SumRain);
                If Rain<(6.5-0.09*BaseFlow) then
                        PeekFlow:=0
                Else
                        PeekFlow:=(+0.000926*Store2*Rain+0.00816*Rain);
                If BaseFlow<0 then BaseFlow:=0;
                If PeekFlow<0 then PeekFlow:=0;
                Store2:=Store2+Rain-AET-BaseFlow-PeekFlow;
                Y:=Trunc(225-0.25*Store2);
                Writeln(OutFile,Day:7,Rain:6:1,AET:6:1,BaseFlow:6:1,
                        PeekFlow:6:1,Store2:8:1);
                PutPixel(X1,Y,1);
                End;
        Until day=434;
        Close(InFile1);
        Close(OutFile);
Readln;
CloseGraph;
End.
```

Annex VIII Rainfall quantities and composition

Annex VIII[a] Daily rainfall with EC and pH

Day	Rain (mm)	EC (µmho/cm)	pH	Month	Date
136	0.0			May	16
137	0.0				17
138	0.0				18
139	1.1	9.3	6.2		19
140	0.0				20
141	0.2				21
142	11.3	8.7	5.9		22
143	0.0				23
144	0.1				24
145	0.0				25
146	8.6	8.8	5.6		26
147	0.0				27
148	0.0				28
149	2.7	9.7	6.0		29
150	9.5	5.5	6.0		30
151	0.0				31
152	31.1	5.6	5.2	June	1
153	2.5	7.0	5.3		2
154	0.0				3
155	0.0				4
156	8.6	8.1	5.6		5
157	0.0				6
158	0.1				7
159	0.0				8
160	0.8				9
161	6.2	8.3	5.9		10
162	1.8	12.9	6.1		11
163	0.9				12
164	7.9	9.0	6.1		13
165	48.6	5.7	6.2		14
166	6.1	5.7	6.2		15
167	3.2	8.1	5.8		16
168	0.0				17
169	4.8	5.2	6.2		18
170	0.0				19
171	11.6	7.1	5.6		20
172	0.6				21
173	0.0				22
174	0.0				23
175	0.0				24
176	5.7	6.4	5.5		25
177	2.1	6.5	5.7		26

Continuation Annex VIII[a]

Day	Rain (mm)	EC (μmho/cm)	pH	Month	Date
178	0.0				27
179	0.0				28
180	1.0	8.1	5.4		29
181	0.0				30
182	0.0			July	1
183	0.4				2
184	11.9	6.9	5.6		3
185	0.0				4
186	0.0				5
187	0.0				6
188	0.0				7
189	0.4				8
190	0.0				9
191	3.9	6.4	5.7		10
192	9.3	7.5	5.3		11
193	0.0				12
194	0.0				13
195	0.1				14
196	0.0				15
197	0.3				16
198	0.0				17
199	0.0				18
200	3.6	23.0	4.8		19
201	0.0				20
202	0.9				21
203	0.5				22
204	1.5	7.5	5.3		23
205	0.0				24
206	0.0				25
207	0.0				26
208	0.1				27
209	0.5				28
210	0.0				29
211	1.8	8.6	5.6		30
212	0.0				31
213	0.0			August	1
214	0.0				2
215	0.0				3
216	0.0				4
217	0.0				5
218	0.0				6
219	0.3				7
220	5.0	6.8	5.7		8
221	4.2	7.1	5.7		9

Day	Rain (mm)	EC (µmho/cm)	pH	Month	Date
222	1.3	8.5	5.5		10
223	1.4	7.1	5.4		11
224	0.0				12
225	2.6	8.5	5.3		13
226	0.0				14
227	2.2	6.7	5.3		15
228	0.2				16
229	0.0				17
230	0.0				18
231	3.1	7.5	5.6		19
232	2.6	7.9	5.5		20
233	0.0				21
234	0.0				22
235	0.0				23
236	17.8	15.0	5.1		24
237	0.0				25
238	0.5				26
239	0.0				27
240	0.0				28
241	10.3	7.1	5.3		29
242	25.9	5.0	5.0		30
243	0.5				31
244	21.6	5.7	5.5	September	1
245	54.8	5.0	5.0		2
246	22.4	4.3	5.4		3
247	0.4				4
248	0.3	14.2	4.6		5
249	3.9	9.3	4.8		6
250	0.7				7
251	7.4	6.6	4.7		8
252	5.3	9.2	6.1		9
253	5.1	8.4	5.4		10
254	2.0	9.0	4.8		11
255	3.9	5.4	5.1		12
256	36.1	6.8	5.0		13
257	7.8	6.0	5.1		14
258	1.7	6.2	5.6		15
259	16.9	7.3	5.4		16
260	70.2	6.2	5.2		17
261	2.6	6.3	5.5		18
262	0.9				19
263	17.9	7.8	5.5		20
264	5.0	6.9	5.2		21
265	2.0	7.3	5.4		22

Continuation Annex VIII[a]

Day	Rain (mm)	EC (µmho/cm)	pH	Month	Date
266	2.0	7.3	5.7		23
267	0.1				24
268	25.8	6.0	5.3		25
269	0.0				26
270	57.8	4.0	5.1		27
271	30.0	3.0	5.2		28
272	3.6	5.6	5.6		29
273	0.0				30
274	12.2	6.3	5.2	October	1
275	0.5				2
276	3.2	7.9	5.6		3
277	0.8				4
278	0.0				5
279	8.5	7.7	5.8		6
280	15.7	6.8	5.6		7
281	0.0				8
282	20.8	6.0	5.6		9
283	0.8				10
284	0.0				11
285	5.5	6.8	5.7		12
286	15.4	6.0	5.7		13
287	0.0				14
288	9.9	6.3	5.6		15
289	34.1	6.0	5.4		16
290	0.0				17
291	8.1	7.8	5.4		18
292	32.1	6.7	5.4		19
293	0.0				20
294	0.0				21
295	8.7	7.1	5.2		22
296	0.1				23
297	0.0				24
298	24.6	4.0	5.4		25
299	11.4	6.4	5.6		26
300	2.2	6.5	5.3		27
301	0.0				28
302	0.0				29
303	2.3	7.6	5.3		30
304	13.4	7.0	5.3		31
305	0.0			November	1
306	0.0				2
307	0.0				3
308	0.0				4
309	0.0				5

Day	Rain (mm)	EC (µmho/cm)	pH	Month	Date
310	4.6	8.1	5.5		6
311	0.0				7
312	0.0				8
313	0.4				9
314	30.6	6.8	5.7		10
315	6.0	7.2	5.5		11
316	3.3	7.6	5.6		12
317	0.0				13
318	19.5	6.9	5.4		14
319	7.4	6.8	5.2		15
320	0.0				16
321	0.0				17
322	3.7	7.7	5.2		18
323	9.0	8.3	5.7		19
324	25.1	6.2	5.2		20
325	86.4	5.0	5.1		21
326	0.0				22
327	2.1	7.3	5.2		23
328	0.0				24
329	0.0				25
330	0.0				26
331	0.0				27
332	0.0				28
333	2.2	8.2	5.8		29
334	0.0				30
335	0.0			December	1
336	0.0				2
337	0.0				3
338	0.3				4
339	0.6				5
340	0.0				6
341	0.0				7
342	0.0				8
343	0.0				9
344	2.8	8.3	5.3		10
345	0.1				11
346	0.0				12
347	4.0	7.9	5.4		13
348	17.1	10.0	6.1		14
349	0.7				15
350	23.6	8.0	5.5		16
351	0.3				17
352	7.9	7.0	5.6		18
353	0.0				19

Continuation Annex VIII[a]

Day	Rain (mm)	EC (μmho/cm)	pH	Month	Date
354	0.0				20
355	0.0				21
356	0.0				22
357	17.7	4.0	5.1		23
358	0.0				24
359	0.0				25
360	0.0				26
361	0.0				27
362	0.0				28
363	0.0				29
364	0.0				30
365	0.0				31
366	0.0			January	1
367	0.0				2
368	0.0				3
369	0.0				4
370	0.0				5
371	0.0				6
372	0.0				7
373	0.0				8
374	0.0				9
375	0.0				10
376	0.0				11
377	0.0				12
378	0.0				13
379	0.0				14
380	0.0				15
381	0.0				16
382	0.0				17
383	0.0				18
384	0.0				19
385	0.0				20
386	0.0				21
387	0.0				22
388	0.0				23
389	0.0				24
390	0.0				25
391	0.0				26
392	0.0				27
393	0.0				28
394	0.0				29
395	0.0				30
396	0.0				31
397	0.0			February	1

Day	Rain (mm)	EC (µmho/cm)	pH	Month	Date
398	0.0				2
399	0.0				3
400	0.0				4
401	0.0				5
402	0.1				6
403	0.0				7
404	0.0				8
405	0.0				9
406	0.0				10
407	7.0	7.6	5.3		11
408	0.5				12
409	22.8	10.0	5.0		13
410	0.0				14
411	0.0				15
412	0.0				16
413	0.0				17
414	0.0				18
415	0.0				19
416	0.0				20
417	0.0				21
418	0.0				22
419	0.0				23
420	0.0				24
421	0.0				25
422	0.5				26
423	0.0				27
424	0.1				28
425	21.9	5.0	5.3	March	1
426	0.8				2
427	0.0				3
428	1.5				4
429	0.0				5
430	0.0				6
431	0.0				7
432	0.0				8
433	0.0				9
434	0.0				10

Annex VIII[b] Composition of rain water

Date	Rain (mm)	pH	EC (μmho/cm)	Ct (	Cin	Si	H	K	Na	Ca mmol/m3	Mg	Fe	Mn	Al	NH_4	Cl	NO_3	S	P)
14-06	48.6	6.2	5.7	363	138		2	0	0	8	2	0	0	0	5	10	0	0	.7
15-06	6.1	6.2	5.7	314	107		3	1	0	7	2	1	0	0	5	8	0	0	.5
29-08	10.3	5.3	7.1	781	69	1	10	2	7	3	1	0	1	0	2	21	13	0	.1
02-09	54.8	5.0	5.0	591	48	0	11	2	3	1	1	0	0	0	1	14	11	0	.1
17-09	70.2	5.2	6.2	2590	100	2	10	0	1	1	1	6	1	0	0	9	0	3	.1
22-09	2.0	5.4	7.3	1810	286	3	7	5	7	7	2	4	1	0	1	11	0	14	.0
25-09	25.8	5.3	6.0	2430	102	0	5	2	7	7	2	4	2	0	0	11	1	14	.0
27-09	57.8	5.1	4.0	386	108	0	7	1	3	2	1	1	0	0	3	0	0	0	.0
28-09	30.0	5.2	3.0	298	72	0	0	1	2	3	1	0	0	0	1	0	1	0	.0
09-10	20.8	5.6	6.0	549	159	0	3	2	4	3	1	0	0	0	8	14	22	0	.0
16-10	34.1	5.4	6.0	456	183	0	4	5	6	10	2	0	0	0	23	5	22	0	.0
25-10	24.5	5.4	4.0	150	45	0	4	1	3	4	1	0	1	0	0	0	0	0	.0
21-11	86.4	5.1	5.0	225	57	0	8	3	2	5	2	1	1	0	0	1	5	0	.0
16-12	23.5	5.5	8.0	338	131	0	1	5	7	7	3	1	0	0	1	3	10	0	.0
23-12	17.7	5.1	4.0	305	42	0	7	3	3	7	1	1	0	0	0	0	0	0	.0
13-02	22.8	5.0	10.0	296	51	6	9	15	7	26	3	1	1	0	11	14	10	.5	.1
01-03	21.9	5.3	5.0	347	94	0	5	3	3	8	2	1	1	0	18	1	12	0	.0
AVG		5.4	5.8	719	105	1	6	3	4	6	1	1	0	0	5	7	6	2	.1
STD		.3	1.6	748	60	2	3	3	2	5	1	2	0	0	7	6	7	4	.2
samples with suspected contamination:																			
30-05	9.4	5.9	16.0	318	104		1	57	19	6	2	0	0	0	7	71	3	0	1.0
19-07	3.6	4.8	23.0	869	32	0	17	18	100	12	13	1	1	0	9	123	39	19	.6
24-08	17.8	5.1	15.0	1110	85	0	8	10	44	7	6	0	1	0	39	48	33	17	1.2

Annex VIII[c] Rainfall intensities

Day	Rain (mm)	Duration (min)	Intensity (mm/hr)		Date	
			Average	Maximum		
191	4.9	30	10	10	July	10
192	10.3	45	14	25		11
236	21.5	90	14	28	August	24
242	25.5	420	4	20		30
260	71	600	7	144	September	17
263	19.8	120	10	57		20
268	24.2	75	19	20		25
270	56.7	480	7	45		27
271	30.5	120	15	98		28
282	21.5	45	29	45	October	9
298	17.5	65	16	29		25
299	11.1	60	11	80		26
304	12.9	15	52	124		31
318	21.6	60	22	58	November	14
319	6.7	25	16	48		15
323	11.1	10	67	72		19
324	22.7	90	15	42		20
325	96.7	335	17	103		21
348	15.7	45	21	27	December	14
350	24.2	85	17	35		16
352	9.5	10	57	76		18
357	16.7	25	40	90		23

Annex IX Analysis results for harmattan dust

Annex IX[a] Chemical composition (mass fraction, %)

	Average	Sampling day 5-1-91	7-1-91	10-1-91
SiO_2	48	46	44	52
Al_2O_3	24	26	27	19
CaO	6.1	5.3	6.6	6.4
Fe_2O_3	1.9	1.5	1.8	2.5
MgO	0.9	0.9	0.9	0.8
K_2O	3.7	2.4	3.8	4.9
Na_2O	0.7	0.8	0.9	0.5
TiO_2	0.3	0.3	0.2	0.3
P_2O_5	0.3	0.2	0.3	0.3
MnO	0.1	0.1	0.1	0.1
L.I.	12.1	13.6	11.3	11.4
Total	97.4	97.1	96.9	98.2

Annex IX[b] X-ray microanalysis for 30 dust particles (Peak/Background) on dust sample from 9-1-1991

	Na	Mg	Al	Si	S	Cl	K	Ca	Ti	Fe
Ignited sample										
1	.64	1.10	15.07	30.28	.20	.37	2.69	.87		4.56
2	.92	.75	15.84	31.57		.37	1.26	4.32		1.74
3	.93	.57	8.93	31.36		.15	1.79	1.64	.46	4.60
4	.91	1.07	11.63	26.01		.73	2.62	1.41	.71	5.92
5	.73	1.17	10.89	30.32		.71	3.79	1.00		5.34
6	1.18	1.13	15.69	30.09		.76	1.97	2.06	1.06	5.52
7	.61	.72	14.38	26.23		.36	1.46	2.42	.85	5.39
8	.88	.89	11.05	21.17		.56	1.54	1.11	1.22	18.13
9	1.32	1.32	9.39	26.47		.85	2.41	1.73	.64	13.93
10	1.75	.97	17.76	34.62		.52	1.92	1.84	1.08	5.14
Untreated sample										
1	1.16	.98	15.11	32.53			4.52	3.17	1.28	4.98
2	1.25	.74	15.99	30.10			3.16	1.90	1.55	5.61
3	.94	1.05	13.26	27.51			4.61	3.58	1.07	6.41
4	1.49	.97	13.36	35.93			6.54	1.65	1.18	2.86
5	1.27	1.00	12.61	32.35			3.72	1.35	.75	5.73
6	1.63	1.61	13.58	38.17		.40	2.50	6.07	4.13	10.13
7		.42	3.19	69.78			.78			1.30
8	1.13	.83	12.52	30.33			2.58	2.16	1.10	12.31
9	1.52	.60	6.70	60.16			1.17	1.42		1.77
10	2.08	.85	13.64	32.10			3.46	2.24	.93	3.99
11	1.05	2.80	7.34	25.22			2.24	1.30		11.17
12			21.79	32.96			.95	.81		1.23
13	1.05	.66	15.72	28.57			1.82	1.06		5.12
14	1.07	.85	9.74	27.08			4.14	1.83		7.35
15	1.49	.56	10.90	31.05	.47		3.42	2.73		5.33
16	1.42		8.80	24.22	1.66		1.93	3.25		2.36
17	1.00		12.90	31.70			2.99	1.87		7.15
18			2.09	66.30						
19	.80		21.22	30.18			1.03	1.00		8.19
20	2.98		10.89	34.82			3.05	2.15		3.94

Annex IX[c] Thermal gravimetric analysis of Harmattan dust sampled on 9-1-1991

Temperature (°C)	Mass Loss (in %)	Cumulative mass loss (in %)
0-100	2.2	2.2
100-200	0.6	2.8
200-300	2.0	4.8
300-400	3.4	8.2
400-500	2.6	10.8
500-600	1.4	12.2
600-650	0.6	12.8

Annex IX[d] Dust particle counts for canopy leaves expressed as the number of particles per cm^2 based on a total count of 6 cm^2 on 3 leaves

Height (m)	Tree (number)[1]	3-1	10-1	17-1	22-1	2-2	12-2	14-2
		(			No of aerosols/10 cm^2			)
4	1	0	0	0	2	2	1	0
4	2	0	0	0	1	1	0	0
5	1	0	0	0	0	0	0	0
6	3	1	1	4	10	13	3	1
9	2	2	0	8	19	21	5	2
11	2	1	0	0	56	62	11	2
14	2	0	2	16	11	45	4	4
20	3	3	4	23	25	23	16	8
21	3	2	2	14	32	38	8	5
26	1	5	3	21	38	34	7	4
32	1	8	6	17	26	68	3	6
37	2	2	9	25	55	62	8	2
38	2	3	8	21	61	71	6	7
38	1	1	8	19	23	34	24	10
42	2	6	3	23	92	101	15	3
Total (150 cm^2)		34	46	191	451	575	111	54

[1] Tree numbers are given in Annex III[a]

Annex X Creek water levels and composition

Annex X[a] Creek water levels with the EC and pH

Day	Water level (cm)[1]	EC (µmho/cm)	pH	Month	Date
136	3	72.1	7.3	May	16
137	3	73.1	6.7		17
138	2	77.3	6.7		18
139	2	78.2	6.7		19
140	1.5	81.7	6.7		20
141	1	84.7	6.7		21
142	2	74.3	6.7		22
143	1	76.7	6.8		23
144	1.5	78.8	6.8		24
145	1	84.9	6.8		25
146	1.5	74.6	6.8		26
147	1	78.9	6.7		27
148	.5	85.0	6.7		28
149	.5	89.1	6.7		29
150	1.5	73.2	6.8		30
151	.5	79.8	6.7		31
152	17	48.7	6.4	June	1
153	2	51.3	6.6		2
154	1	72.0	6.7		3
155	1	71.8	6.7		4
156	1.5	71.5	6.7		5
157	.5	76.2	6.7		6
158	.5	78.5	6.7		7
159	.5	79.1	6.7		8
160	.5	83.6	6.7		9
161	1	75.3	6.8		10
162	1	76.4	6.5		11
163	1	77.2	6.8		12
164	3	71.8	6.7		13
165	16	48.2	6.4		14
166	7	60.2	6.6		15
167	5	66.0	6.6		16
168	4	70.0	6.6		17
169	4.5	70.6	6.6		18
170	4	75.8	6.7		19
171	9	61.4	6.6		20
172	6	66.5	6.6		21
173	3	69.1	6.6		22
174	3	69.6	6.7		23
175	2.5	70.2	6.7		24
176	2	75.8	6.7		25
177	3	74.7	6.7		26

Day	Water level (cm)[1]	EC (μmho/cm)	pH	Month	Date
178	2	77.3	6.7		27
179	2	77.6	6.8		28
180	2	77.9	6.7		29
181	2	78.1	6.7		30
182	2	78.1	6.7	July	1
183	2	79.9	6.7		2
184	4	70.1	6.7		3
185	4	73.4	6.7		4
186	3	74.5	6.7		5
187	2.5	76.4	6.7		6
188	2.5	78.0	6.7		7
189	2.5	78.9	6.7		8
190	2	78.6	6.7		9
191	3	73.3	6.7		10
192	4.5	68.3	6.7		11
193	3	71.7	6.7		12
194	2	76.1	6.7		13
195	2	71.6	6.7		14
196	2	77.6	6.8		15
197	2	77.4	6.8		16
198	2	77.7	6.8		17
199	2	77.9	6.7		18
200	3	73.6	6.7		19
201	3	74.2	6.7		20
202	3	74.4	6.7		21
203	3	75.9	6.7		22
204	3	75.0	6.7		23
205	2	76.1	6.7		24
206	2	77.4	6.8		25
207	2	77.7	6.8		26
208	2	77.8	6.8		27
209	2	77.6	6.7		28
210	2	77.8	6.7		29
211	2	76.3	6.7		30
212	2	76.5	6.7		31
213	1	79.2	6.8	August	1
219	1	80.7	6.8		7
220	2	78.6	6.7		8
221	2	78.9	6.7		9
222	2	79.5	6.7		10
223	2	80.0	6.7		11
224	2	80.7	6.7		12
225	2	81.9	6.7		13
226	2	82.7	6.7		14

Continuation Annex X[a]

Day	Water level (cm)[1]	EC (μmho/cm)	pH	Month	Date
227	2	82.3	6.7		15
228	0	85.3	6.8		16
229	0	85.5	6.8		17
230	0	85.4	6.8		18
231	.5	79.9	6.7		19
232	2	79.7	6.7		20
233	1	80.9	6.7		21
234	0	82.8	6.8		22
235	0	84.3	6.8		23
236	2	79.3	6.7		24
237	1	79.2	6.7		25
238	1	79.3	6.7		26
239	1	80.2	6.8		27
240	0	81.8	6.8		28
241	2	76.3	6.7		29
242.1	8	62.9	6.6		30
242.2	6	67.5	6.6		30
243	2	72.5	6.7		31
244	9	61.4	6.6	September	1
245.1	25	46.0	6.4		2
245.2	50	40.6	6.2		2
245.3	25	45.3	6.4		2
245.4	14	56.4	6.5		2
246.1	25	48.0	6.4		3
246.2	25	45.6	6.4		3
246.3	11	62.0	6.5		3
247	8	63.0	6.6		4
248	7	65.8	6.6		5
249	5	68.7	6.6		6
250	4	74.1	6.7		7
251	5	68.1	6.7		8
252	5	69.2	6.6		9
253	5	69.6	6.6		10
254	4	73.0	6.6		11
255	4	66.1	6.7		12
256	11	56.3	6.5		13
257	8	60.7	6.5		14
259	10	52.9	6.5		16
260.1	14	48.9	6.5		17
260.2	54	37.4	6.2		17
260.3	58	36.5	6.2		17
260.4	68	36.5	6.2		17
260.5	75	38.8	6.2		18
260.6	38	33.9	6.3		18

Day	Water level (cm)[1]	EC (µmho/cm)	pH	Month	Date
260.7	21	41.7	6.4		18
261	11	49.2	6.4		18
262	8	55.1	6.5		19
263.1	25	40.1	6.3		20
263.2	25	42.2	6.4		20
263.3	12	51.6	6.5		20
264	11	52.1	6.5		21
265	8	55.3	6.6		22
266	7	56.5	6.6		23
267	5	61.5	6.6		24
268.1	5	65.2	6.6		25
268.2	15	51.6	6.5		25
268.3	39	32.7	6.2		25
268.4	40	32.7	6.2		25
268.5	28	38.2	6.3		26
268.6	12	53.9	6.5		26
269	6	60.3	6.6		26
270.1	25	40.0	6.4		27
270.2	50	33.4	6.2		27
270.3	75	41.5	6.2		27
270.4	50	30.8	6.2		27
270.5	25	36.8	6.3		28
270.6	21	39.8	6.4		28
271.1	25	38.0	6.4		28
271.2	50	32.1	6.2		28
271.3	50	31.5	6.2		28
271.4	25	34.6	6.3		28
271.5	15	43.3	6.5		29
272	7	48.9	6.5		29
273	7	51.1	6.6		30
274.1	25	37.0	6.4	October	1
274.2	7	52.8	6.6		1
275	8	54.4	6.5		2
276	8	56.3	6.6		3
277	6	59.3	6.6		4
278	6	60.5	6.6		5
279	11	53.7	6.5		6
280.1	25	41.4	6.3		7
280.2	19	44.0	6.4		7
281	7	55.8	6.6		8
282.1	25	39.9	6.4		9
282.2	50	32.1	6.2		9
282.3	25	37.3	6.4		9
282.4	10	50.3	6.5		9

Continuation Annex X[a]

Day	Water level (cm)[1]	EC (µmho/cm)	pH	Month	Date
283	5	57.2	6.6		10
284	4	59.3	6.6		11
285	6	59.7	6.6		12
286.1	25	41.8	6.4		13
286.2	10	52.2	6.5		13
287	5	59.1	6.6		14
288	12	49.2	6.5		15
289.1	25	39.2	6.3		16
289.2	50	30.1	6.2		16
289.3	25	38.2	6.3		16
289.4	18	43.1	6.4		16
290	7	55.1	6.6		17
291	11	50.3	6.5		18
292.1	25	39.6	6.3		19
292.2	50	31.7	6.2		19
292.3	75	39.7	6.2		19
292.4	50	30.8	6.2		19
292.5	25	37.8	6.3		20
292.6	15	44.6	6.5		20
293	12	47.9	6.5		20
294	10	50.8	6.5		21
295	13	46.0	6.5		22
296	9	50.2	6.5		23
297	6	52.7	6.6		24
298.1	25	37.5	6.4		25
298.2	50	30.0	6.2		25
298.3	25	36.2	6.3		25
298.4	11	47.6	6.5		25
299.1	25	37.7	6.3		26
299.2	13	48.4	6.5		26
300	7	54.7	6.6		27
301	7	56.8	6.6		28
302	7	56.7	6.6		29
303	8	55.7	6.5		30
304	9	54.1	6.5		31
305	7	57.9	6.6	November	1
306	5	61.9	6.6		2
307	5	64.3	6.6		3
308	4	66.0	6.6		4
309	4	64.6	6.6		5
310	6	61.3	6.6		6
311	5	63.6	6.6		7
312	5	65.3	6.6		8
313	4	67.4	6.6		9

Day	Water level (cm)[1]	EC (μmho/cm)	pH	Month	Date
314.1	25	44.5	6.4		10
314.2	50	38.2	6.2		10
314.3	25	42.8	6.4		10
314.4	9	55.4	6.5		10
315	8	58.7	6.6		11
316	7	61.2	6.6		12
317	6	63.1	6.6		13
318.1	25	46.5	6.4		14
318.2	25	44.2	6.4		14
318.3	10	55.2	6.5		14
319	13	50.6	6.5		15
320	5	60.4	6.6		16
321	4	63.6	6.7		17
322	6	61.0	6.7		18
323	8	57.1	6.6		19
324.1	25	40.4	6.3		20
324.2	25	38.9	6.3		20
324.3	14	46.4	6.4		20
325.1	25	38.0	6.4		21
325.2	50	29.2	6.2		21
325.3	75	38.6	6.2		21
325.4	50	26.0	6.2		21
325.5	26	31.6	6.3		22
326.1	25	31.8	6.3		22
326.2	12	43.9	6.5		22
327	8	48.8	6.5		23
328	6	51.9	6.6		24
329	5	54.0	6.6		25
330	5	56.6	6.6		26
331	4	58.9	6.6		27
332	4	59.7	6.6		28
333	7	54.9	6.6		29
334	4	59.1	6.6		30
335	2	62.5	6.7	December	1
336	2	63.4	6.6		2
337	0	66.2	6.7		3
338	0	66.0	6.7		4
339	0	66.0	6.7		5
340	1.5	65.5	6.7		6
341	2	65.1	6.7		7
342	2	65.8	6.7		8
343	2	66.5	6.7		9
344	4	62.1	6.6		10
345	4	63.5	6.6		11

Continuation Annex X[a]

Day	Water level (cm)[1]	EC (μmho/cm)	pH	Month	Date
346	4	63.5	6.6		12
347	6	62.1	6.6		13
348	12	53.3	6.5		14
349	6	59.9	6.6		15
350	18	47.5	6.4		16
351	10	58.2	6.5		17
352	12	55.4	6.5		18
353	7	63.0	6.6		19
354	4	66.7	6.7		20
355	3	68.1	6.7		21
356	3	68.3	6.7		22
357	6	60.2	6.6		23
358	5	61.7	6.6		24
359	4	64.2	6.6		25
360	3	70.8	6.7		26
361	3	67.4	6.7		27
362	3	69.7	6.7		28
363	2	70.9	6.7		29
364	2	71.8	6.7		30
365	2	72.6	6.7		31
366	2	73.4	6.7	January	1
367	2	73.3	6.7		2
368	2	73.3	6.7		3
369	2	73.7	6.7		4
370	2	73.5	6.7		5
371	2	74.0	6.7		6
372	2	74.1	6.7		7
373	2	73.9	6.7		8
374	2	74.4	6.7		9
375	2	74.1	6.7		10
376	2	74.3	6.7		11
377	2	75.5	6.7		12
378	4	70.1	6.7		13
379	2	72.3	6.7		14
380	2	74.4	6.7		15
381	2	75.7	6.7		16
382	2	76.3	6.7		17
383	2	77.2	6.7		18
384	2	79.4	6.7		19
385	2	79.6	6.7		20
386	2	80.6	6.7		21
387	2	80.4	6.7		22
388	2	80.9	6.7		23
389	2	80.6	6.7		24

Day	Water level (cm)[1]	EC (μmho/cm)	pH	Month	Date
390	2	80.8	6.7		25
391	2	81.2	6.7		26
392	2	80.6	6.7		27
393	2	80.2	6.7		28
394	2	81.2	6.7		29
395	2	82.2	6.7		30
396	1	82.4	6.7		31

[1] All samples taken at water level 25, 50 and 75 cm were taken automatically.

Annex X[b] Creek water analysis

Date	WL (cm)	pH	EC (μmol/cm)	Ct (	Can	Si	H	K	Na	Ca	Mg mmol/m³	Fe	Mn	Al	NH_4	Cl	NO_3	S	P)
Base flow:																			
01-06	17	6.29	55	3580	410		1	71	234	92	65	28	0	0		81	0	3	2.5
06-06	1	6.25	81	2340	706		1	71	332	145	97	23	0	1		91	0	0	3.7
09-06	1	6.67	96	2740	850		0	74	348	186	114	29	0	3		92	0	0	5
18-06	5	6.76	80	2910	582		0	67	341	141	95	29	0	4		100	0	0	2.5
20-06	9	6.76	68	2600	639	709	0	56	303	125	86	10	1	1	1	86	6	13	1.1
26-06	3	7.45	76	2480	680	828	0	62	349	154	100	24	1	1	0	102	0	0	1.6
28-06	2	7.14	85	2350	797	939	0	59	369	158	102	8	1	0	0	90	6	0	1.7
30-06	2	7.49	79	2500	722	903	0	60	298	160	103	19	1	1	1	102	0	0	1.5
03-07	4	7.08	74	2370	697	850	0	61	340	128	83	12	1	1	0	93	3	1	1
08-07	3	7.43	78	1950	813	938	0	61	302	165	105	19	1	1	0	102	0	0	2
14-07	2	7.39	76	2440	727	907	0	59	247	154	98	18	1	1	1	101	0	0	1.8
15-07	2	6.99	83	2490	776	934	0	59	338	149	96	6	1	0	0	88	13	2	1.5
08-08	2	6.82	63	2460	646	753	0	79	255	101	65	19	1	1	1	106	0	5	1.8
14-08	2	7.08	82	2190	803	923	0	71	260	163	97	16	1	0	0	106	0	9	4.1
15-08	2	6.87	83	2450	800	996	0	70	361	142	89	4	1	0	0	96	5	0	3
29-08	2	6.49	62	2830	491	621	0	62	318	106	66	12	1	1	1	100	5	13	.1
30-08	6	6.71	59	4370	421	612	0	64	240	111	70	42	1	2	3	108	0	14	1.1
02-09	14	6.16	47	6400	314	320	1	60	202	82	50	50	1	6	1	84	0	16	1.2
03-09	13	7.01	49	2430	327	458	0	47	197	96	68	31	1	3	1	76	3	0	.2
04-09	8	6.96	58	3950	355	556	0	57	268	112	70	26	1	9	0	90	0	19	.28
17-09	14	6.28	47	4320	396	454	1	51	208	97	56	45	1	13	8	60	1	10	.11
25-09	5	6.77	64	4000	661	595	0	53	208	136	92	44	1	10	0	75	0	3	.34
25-09	15	6.31	37	2250	498	301	0	45	143	74	45	35	1	7	0	46	1	11	.31
25-09	12	6.38	49	3960	492	415	0	51	209	104	69	74	1	15	1	73	0	3	.12
01-10	7	6.43	43	3070	371	466	0	40	191	73	51	20	1	2	1	72	7	3	.1
23-10	9	6.99	50	1900	415	546	0	38	207	87	62	15	0	1	1	72	7	0	.1
31-10	9	6.65	45	2310	392	529	0	40	186	91	66	28	1	1	0	60	0	1	.2

01-11	7	6.93	61	1960	540	634	0	53	251	110	76	22	1	1	1	82	58	0	.1
08-11	5	6.81	62	1980	615	776	0	44	246	116	81	29	1	1	0	67	0	0	.6
02-12	2	6.88	51	1490	488	639	0	41	212	91	64	16	1	0	0	62	0	0	.1
09-12	2	7.01	58	1690	597	741	0	45	234	100	73	17	1	0	0	63	0	1	.2
24-12	5	7.01	57	2160	534	610	0	42	235	106	73	22	1	1	0	71	0	0	.1
11-01	2	7.12	73	1580	807	960	0	55	288	129	89	14	0	0	0	65	0	0	.7
21-01	2	7.07	89	1880	943	1113	0	71	328	164	106	17	1	0	0	71	0	1	.8
25-01	2	7.07	88	1790	958	1122	0	70	323	164	107	17	1	0	0	70	4	5	1.6
08-02	1	6.92	97	2080	1060	1195	0	88	343	183	113	18	1	0	0	77	0	0	2
AVG	5	6.85	67	2674	620	729	0	58	270	125	82	24	0	3	1	83	3	4	1.3
STD	5	.35	16	978	192	234	0	12	60	31	19	14	0	4	2	16	10	5	1.2
Quickflow:																			
17-09	54	6.17	37	4490	308	233	1	62	145	73	44	32	1	12	1	52	1	9	.03
17-09	58	6.16	35	3790	251	202	1	64	132	68	41	38	1	11	1	44	5	11	.06
17-09	68	5.99	29	3930	237	159	1	56	107	52	31	26	0	11	0	39	1	6	0
17-09	75	5.97	24	2720	218	113	1	58	78	38	24	23	0	9	0	29	2	8	.09
17-09	25	6.17	36	2970	243	260	1	55	141	65	43	38	0	12	1	60	2	11	.09
20-09	25	6.91	49	2920	359	445	0	55	216	99	67	31	1	5	1	82	9	0	.1
20-09	25	6.81	46	3030	238	370	0	57	206	96	64	39	1	8	2	76	2	0	.2
25-09	39	6.12	33	3020	418	212	1	53	117	64	40	29	1	9	1	52	5	12	0
25-09	40	6.11	34	2750	418	220	1	52	125	68	43	30	0	10	2	48	0	10	0
25-09	28	6.15	37	3190	418	264	1	51	142	74	48	37	0	11	3	56	0	9	.09
27-09	50	5.84	31	2360	241	160	1	44	117	54	38	25	0	7	9	42	0	0	.5
01-10	25	6.93	42	1890	279	388	0	43	167	81	57	30	1	4	1	76	8	0	.1
09-10	25	6.28	43	3290	447	319	1	41	185	93	64	40	0	7	0	55	0	0	.3
16-10	25	6.35	42	2260	412	311	0	39	172	84	59	32	0	4	0	62	0	0	.3
14-11	25	6.79	48	2710	387	534	0	42	214	90	62	27	0	3	1	78	5	0	.2
14-11	25	7.01	47	1650	431	508	0	37	193	83	60	20	1	1	1	71	6	0	.1
22-11	25	6.49	32	1540	245	363	0	33	129	55	41	16	1	1	0	54	3	0	.2
AVG	37	6.37	38	2854	326	298	1	50	152	73	48	30	0	7	1	57	3	4	.14
SRD	17	.37	7	761	84	119	0	9	39	17	12	7	0	4	2	15	3	5	.13

Annex XI Sediment concentrations and compositions

Annex XI[a] Suspendent sediment concentrations

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
136	3	7	May	16
137	3	5		17
138	2	7		18
139	2	7		19
140	2	5		20
141	1	4		21
142	2	7		22
143	1	5		23
144	2	5		24
145	1	4		25
146	2	4		26
148	1	2		28
150	2	5		30
152	17	569	June	1
153	2	4		2
155	1	4		4
157	1	4		6
159	1	4		8
161	1	5		10
163	1	5		12
165	16	389		14
166	7	13		15
168	4	9		17
170	4	11		19
171	9	18		20
172	6	13		21
174	3	7		23
176	2	4		25
178	2	4		27
180	2	5		29
182	2	5	July	1
184	4	11		3
186	3	7		5
188	3	5		7
190	2	5		9
192	5	9		11
194	2	7		13
196	2	5		15
198	2	5		17
200	3	7		19

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
202	3	7		21
204	3	5		23
206	2	7		25
208	2	5		27
210	2	5		29
212	2	5		31
214	0	0	August	2
216	0	2		4
218	0	0		6
220	2	5		8
222	2	5		10
224	2	7		12
226	2	5		14
228	0	2		16
230	0	4		18
232	2	5		20
234	0	0		22
236	2	7		24
238	1	4		26
240	0	2		28
242.1	8	18		30.1
242.2	6	13		30.2
243	2	5		31
244	9	20	September	1
245.1	25	626		2.1
245.2	50	967		2.2
245.3	25	149		2.3
245.4	14	52		2.4
246.1	25	868		3.1
246.2	25	20		3.2
246.3	11	68		3.3
247	8	18		4
248	7	16		5
249	5	11		6
251	5	11		8
253	5	13		10
255	4	9		12
256	11	18		13
257	8	16		14
259	10	20		16
260.1	14	427		17.1
260.2	54	425		17.2
260.3	58	788		17.3
260.4	68	1168		17.4

Continuation Annex XI[a]

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
260.5	75	581		17.5
260.6	38	169		17.6
260.7	21	38		17.7
261	11	49		18
262	8	14		19
263.1	25	693		20.1
263.2	25	160		20.2
263.3	12	11		20.3
264	11	22		21
265	8	16		22
266	7	14		23
267	5	13		24
268.1	5	9		25.1
268.2	15	310		25.2
268.3	39	893		25.3
268.4	40	306		25.4
268.5	28	77		25.5
268.6	12	61		25.6
269	6	12		26
270.1	25	680		27.1
270.2	50	1096		27.2
270.3	75	995		27.3
270.4	50	250		27.4
270.5	25	25		27.5
270.6	21	73		27.6
271.1	25	831		28.1
271.2	50	1117		28.2
271.3	50	203		28.3
271.4	25	84		28.4
271.5	15	55		28.5
272	7	16		29
273	7	16		30
274.1	25	696	October	1.1
274.2	7	14		1.2
276	8	18		3
278	6	12		5
279	11	21		6
280.1	25	808		7.1
280.2	19	86		7.2
281	7	14		8
282.1	25	862		9.1
282.2	50	948		9.2
282.3	25	180		9.3
282.4	10	28		9.4

Continuation Annex XI[a]

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
319	13	25		15
320	5	108		16
322	6	12		18
324.1	25	723		20.1
324.2	25	124		20.2
324.3	14	72		20.3
325.1	25	739		21.1
325.2	50	862		21.2
325.3	75	747		21.3
325.4	50	201		21.4
325.5	26	151		21.5
326.1	25	189		22.1
326.2	12	23		22.2
327	8	16		23
328	6	12		24
330	5	10		26
332	4	9		28
334	4	9		30
336	2	5	December	2
338	0	0		4
340	2	3		6
342	2	7		8
344	4	9		10
346	4	7		12
347	6	14		13
348	12	23		14
349	6	14		15
350	18	25		16
351	10	19		17
352	12	23		18
353	7	16		19
355	3	7		21
357	6	12		23
359	4	9		25
361	3	7		27
363	2	5		29
365	2	5		31
367	2	5	January	2
369	2	5		4
371	2	3		6
373	2	5		8
375	2	5		10
377	2	7		12
379	2	7		14

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
283	5	10		10
285	6	10		12
286.1	25	838		13.1
286.2	10	21		13.2
287	5	10		14
288	12	23		15
289.1	25	883		16.1
289.2	50	1155		16.2
289.3	25	72		16.3
289.4	18	23		16.4
290	7	16		17
291	11	21		18
292.1	25	658		19.1
292.2	50	1107		19.2
292.3	75	1108		19.3
292.4	50	342		19.4
292.5	25	109		19.5
292.6	15	48		19.6
293	12	23		20
294	10	19		21
295	13	27		22
296	9	18		23
297	6	10		24
298.1	25	880		25.1
298.2	50	1040		25.2
298.3	25	124		25.3
298.4	11	23		25.4
299.1	25	702		26.1
299.2	13	84		26.2
300	7	16		27
302	7	16		29
304	9	18		31
306	5	10	November	2
308	4	9		4
310	6	12		6
312	5	9		8
314.1	25	561		10.1
314.2	50	788		10.2
314.3	25	174		10.3
314.4	9	18		10.4
315	8	16		11
317	6	14		13
318.1	25	847		14.1
318.2	25	140		14.2

Day	Water level (cm)	Sediment load (mg/l)	Month	Date
381	2	5		16
383	2	5		18
385	2	3		20
387	2	5		22
389	2	3		24
391	2	7		26
393	2	3		28
395	2	5		30
396	1	3		31

Annex XI[b] Composition of sediment (mass fraction of oxide components, %)

	LI	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	P_2O_5	Total
14-06	26	56.7	0.72	10.8	2.4	0.10	0.18	0.67	0.76	0.15	98.5
02-09	28	51.7	0.87	12.1	3.3	0.06	0.16	0.71	0.49	0.17	97.5
16-09	29	46.8	1.07	16.7	3.1	0.04	0.18	0.36	0.94	0.16	98.5
24-09	25	55.7	1.00	12.0	4.2	0.05	0.12	0.34	0.65	0.17	99.1
24-09	34	48.1	0.89	12.8	3.4	0.08	0.15	0.57	0.61	0.17	100.7
24-09	31	50.2	0.84	12.7	3.4	0.05	0.15	0.34	0.55	0.21	99.5
24-09	32	49.2	0.73	12.2	4.2	0.07	0.22	0.48	0.44	0.11	99.6
27-09	28	53.1	0.90	11.7	3.9	0.06	0.14	0.28	0.45	0.19	98.8
28-09	20	61.3	0.99	13.3	2.4	0.01	0.09	0.45	0.71	0.19	99.3
18-10	27	50.0	0.90	15.5	3.8	0.05	0.15	0.42	0.60	0.17	98.5
18-10	23	54.3	0.91	12.2	4.0	0.02	0.14	0.61	0.78	0.15	96.1
02-11	32	48.2	0.93	12.1	3.8	0.02	0.21	0.49	0.89	0.16	98.7
09-11	26	55.8	0.92	12.4	3.7	0.06	0.18	0.45	0.48	0.17	100.1
09-11	24	51.9	0.93	13.8	3.7	0.12	0.12	0.52	0.63	0.16	95.8
09-11	29	49.2	0.83	15.2	4.1	0.04	0.13	0.55	0.70	0.17	99.9
09-11	33	45.8	0.95	13.8	4.2	0.08	0.11	0.43	0.38	0.18	98.8
21-11	32	45.0	0.84	15.2	4.3	0.04	0.14	0.43	0.46	0.19	98.6
21-11	21	56.7	1.05	14.5	4.3	0.03	0.12	0.68	0.72	0.19	99.3
16-12	29	47.5	0.85	15.3	4.5	0.06	0.16	0.44	0.47	0.19	98.5

Annex XII Organic debris: quantities and composition

Annex XII[a] Output of organic debris (dry weights)

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
138	May	18	25.70	12.60	5.70	7.50
139		19	25.40	6.90	4.90	13.60
140		20	61.30	14.90	15.60	30.80
141		21	18.60	5.30	8.20	5.10
142		22	47.90	21.20	10.20	16.50
143		23	33.30	7.30	13.20	12.80
144		24	11.30	3.00	4.60	3.70
145		25	8.90	2.20	3.50	3.20
146		26	34.20	5.20	14.50	14.50
147		27	14.20	5.00	3.60	5.60
148		28	7.40	2.40	2.10	2.90
149		29	19.20	7.30	6.20	5.70
150		30	42.20	5.00	15.00	22.20
151		31	17.20	12.60	1.50	3.10
152	June	1	154.50	42.70	62.20	49.60
153		2	36.20	22.40	12.30	1.50
154		3	29.60	9.60	9.10	10.90
155		4	40.70	13.30	11.40	16.00
156		5	56.20	44.60	7.30	4.30
157		6	22.70	7.30	7.30	8.10
158		7	12.10	2.10	7.00	3.00
159		8	8.30	2.30	2.80	3.20
160		9	19.60	3.80	5.00	10.80
161		10	37.90	12.80	13.40	11.70
162		11	18.90	5.60	7.10	6.20
163		12	22.50	1.40	16.30	4.80
164		13	41.30	11.00	12.90	17.40
165		14	185.40	27.30	146.60	11.50
166		15	115.70	24.10	76.50	15.10
167		16	56.10	11.90	33.50	10.70
168		17	68.00	26.70	21.60	19.70
169		18	70.10	25.10	18.80	26.20
170		19	48.80	18.20	17.50	13.10
171		20	58.60	21.70	17.00	19.90
172		21	35.20	11.60	14.80	8.80
173		22	35.10	10.30	13.20	11.60
174		23	33.80	16.30	11.90	5.60
175		24	35.10	14.60	9.80	10.70
176		25	61.40	31.00	17.80	12.60
177		26	63.40	17.20	11.00	35.20

Continuation Annex XII[a]

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
178		27	52.50	19.10	5.60	27.80
179		28	51.30	17.30	11.30	22.70
180		29	29.70	12.70	5.60	11.40
181		30	51.40	24.50	9.60	17.30
182	July	1	48.50	14.40	10.10	24.00
183		2	49.50	13.20	12.10	24.20
184		3	78.90	31.80	21.60	25.50
185		4	37.80	13.00	12.30	12.50
186		5	57.30	9.90	16.20	31.20
187		6	18.60	6.90	7.20	4.50
188		7	15.20	4.20	3.20	7.80
189		8	45.70	32.40	6.70	6.60
190		9	18.70	6.30	5.30	7.10
191		10	52.90	12.10	35.00	5.80
192		11	68.40	20.40	32.70	15.30
193		12	25.20	7.10	12.30	5.80
194		13	20.80	4.20	13.70	2.90
195		14	29.40	8.00	18.20	3.20
196		15	18.60	7.90	8.30	2.40
197		16	14.00	3.70	6.60	3.70
198		17	9.90	5.30	3.00	1.60
199		18	6.60	3.20	2.80	0.60
200		19	13.90	3.60	8.50	1.80
201		20	1.90	0.90	1.00	0.00
202		21	3.80	1.20	2.10	0.50
203		22	3.20	1.10	1.90	0.20
204		23	11.20	0.80	10.10	0.30
205		24	4.70	1.40	2.50	0.80
206		25	0.90	0.20	0.50	0.20
207		26	2.30	1.00	1.20	0.10
208		27	5.40	0.40	4.80	0.20
209		28	2.80	1.10	1.30	0.40
210		29	5.20	1.60	3.50	0.10
211		30	12.40	2.10	6.20	4.10
212		31	2.30	0.90	1.20	0.20
213	August	1	4.80	0.90	3.10	0.80
214		2	3.30	0.70	2.60	0.00
215		3	6.50	1.40	4.80	0.30
216		4	8.20	1.80	5.70	0.70
217		5	4.80	0.90	3.40	0.50
218		6	12.60	1.10	11.50	0.00
219		7	2.10	0.10	2.00	0.00
220		8	12.30	1.20	7.40	3.70
221		9	8.80	1.80	6.00	1.00

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
222		10	4.30	0.60	3.30	0.40
223		11	3.20	1.00	1.50	0.70
224		12	4.00	0.80	1.70	1.50
225		13	6.00	1.20	1.80	3.00
226		14	5.60	2.50	1.70	1.40
227		15	2.70	0.60	1.30	0.80
228		16	4.40	0.60	3.00	0.80
229		17	1.30	0.30	0.40	0.60
230		18	2.80	0.60	2.00	0.20
231		19	3.90	1.80	1.00	1.10
232		20	4.10	0.90	2.80	0.40
233		21	4.00	1.50	1.50	1.00
234		22	1.90	0.50	0.80	0.60
235		23	0.80	0.40	0.20	0.20
236		24	71.30	35.00	24.90	11.30
237		25	19.10	3.10	11.60	4.40
238		26	16.00	3.00	7.50	5.50
239		27	6.40	2.30	2.30	1.80
240		28	6.10	2.50	2.70	0.90
241		29	5.70	2.30	1.80	1.60
242		30	132.40	93.30	29.60	9.50
243		31	32.00	10.70	14.00	7.30
244	September	1	38.80	17.60	18.70	2.50
245		2	-1	-1	-1	-1
246		3	-1	-1	-1	-1
247		4	30.40	11.10	13.30	6.00
248		5	43.34	5.20	32.84	5.30
249		6	48.13	6.00	41.83	0.30
250		7	33.81	5.10	26.01	2.70
251		8	26.40	11.60	9.70	5.10
252		9	31.90	16.70	7.90	7.30
253		10	24.50	13.70	10.00	0.80
254		11	21.00	4.70	11.10	5.20
255		12	45.10	29.90	8.50	6.70
256		13	-1	-1	-1	-1
257		14	-1	-1	-1	-1
258		15	-1	-1	-1	-1
259		16	-1	-1	-1	-1
260		17	1,041.47	695.16	331.15	15.17
261		18	63.57	26.10	37.47	0.00
262		19	184.87	89.74	82.04	13.09
263		20	873.87	222.38	519.94	131.55
264		21	252.85	94.07	97.08	61.71
265		22	54.98	32.18	13.64	9.16

Continuation Annex XII[a]

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
266		23	19.60	3.30	13.20	3.10
267		24	27.90	14.10	11.50	2.30
268		25	3,035.99	838.67	2,175.12	22.20
269		26	85.70	37.00	38.90	9.80
270		27	2,076.20	836.60	730.00	509.60
271		28	1,135.20	251 10	884.10	0.00
272		29	132.30	9.20	123.10	0.00
273		30	54.46	3.40	44.56	6.50
274	October	1	61.83	7.00	44.23	10.60
275		2	36.80	9.10	6.30	21.40
276		3	36.46	4.40	21.86	10.20
277		4	35.87	13.60	19.67	2.60
278		5	14.80	5.10	9.50	0.20
279		6	31.10	12.80	10.30	8.00
280		7	118.10	31.30	82.80	4.00
281		8	52.37	11.30	40.67	0.40
282		9	113.60	55.40	55.70	2.50
283		10	60.50	17.60	39.60	3.30
284		11	58.11	24.70	20.51	12.90
285		12	53.01	18.80	34.21	0.00
286		13	112.61	24.40	48.71	39.50
287		14	88.30	21.78	58.63	7.90
288		15	57.73	7.50	45.93	4.30
289		16	381.40	146.20	172.80	62.40
290		17	91.20	29.40	43.70	18.10
291		18	83.60	37.90	40.00	5.70
292		19	403.20	171.20	208.90	23.10
293		20	78.10	8.30	61.60	8.20
294		21	63.70	18.30	33.00	12.40
295		22	65.20	13.20	47.30	4.70
296		23	68.30	12.20	52.20	3.90
297		24	45.10	18.90	21.10	5.10
298		25	253.60	36.50	166.90	50.20
299		26	91.10	19.70	71.40	0.00
300		27	17.00	4.30	12.40	0.30
301		28	34.70	18.10	12.40	4.20
302		29	18.30	6.00	12.30	0.00
303		30	25.00	9.60	15.40	0.00
304		31	67.30	27.40	33.30	6.70
305	November	1	16.40	9.50	6.80	0.10
306		2	30.20	10.50	17.10	2.60
307		3	68.90	18.20	41.90	8.80
308		4	58.90	27.30	28.40	3.20
309		5	73.99	21.79	51.69	0.50

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
310		6	68.35	29.05	20.40	18.90
311		7	71.08	34.08	30.60	6.40
312		8	52.40	12.40	28.90	11.10
313		9	54.70	13.80	26.20	14.70
314		10	703.60	268.00	195.40	240.20
315		11	42.32	24.99	16.33	1.00
316		12	61.29	11.10	22.70	27.49
317		13	52.65	5.20	43.25	4.20
318		14	190.40	50.30	28.40	111.90
319		15	143.39	33.39	59.00	51.00
320		16	55.03	18.02	32.31	4.70
321		17	66.23	14.30	32.23	19.70
322		18	75.14	11.20	42.04	21.90
323		19	450.03	215.60	154.57	79.86
324		20	7,431.09	970.23	992.09	5,468.77
325		21	17,725.00	10,111.00	4,005.00	3,609.00
326		22	34.03	10.70	15.43	7.90
327		23	69.93	36.83	26.80	6.30
328		24	38.70	7.40	13.00	18.30
329		25	44.03	6.00	29.63	8.40
330		26	40.13	12.20	23.53	4.40
331		27	42.73	9.60	30.13	3.00
332		28	19.63	6.60	13.03	0.00
333		29	49.25	33.80	15.45	0.00
334		30	22.05	8.30	12.95	0.80
335	December	1	40.62	7.90	29.22	3.50
336		2	29.90	22.40	7.50	0.00
337		3	42.79	5.00	29.49	8.30
338		4	39.24	7.95	31.30	0.00
339		5	30.57	12.10	18.27	0.20
340		6	33.66	11.00	22.26	0.40
341		7	28.90	10.20	18.40	0.30
342		8	21.30	2.10	12.10	7.10
343		9	24.20	8.60	15.60	0.00
344		10	12.30	0.00	12.30	0.00
345		11	7.50	0.00	7.50	0.00
346		12	14.00	2.40	8.20	3.40
347		13	24.70	11.10	9.60	4.00
348		14	129.20	21.20	63.80	44.20
349		15	25.80	3.40	17.30	5.10
350		16	510.10	264.40	168.50	77.20
351		17	185.67	11.10	14.70	159.87
352		18	37.51	25.51	12.00	0.00
353		19	25.00	0.00	9.00	16.00

Continuation Annex XII[a]

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
354		20	28.20	2.10	13.10	13.00
355		21	12.00	1.40	10.60	0.00
356		22	12.80	1.50	7.50	3.80
357		23	170.40	24.80	85.60	60.00
358		24	25.20	1.60	12.70	10.90
359		25	11.70	2.90	8.80	0.00
360		26	15.20	4.40	5.80	5.00
361		27	15.20	5.70	9.50	0.00
362		28	12.20	3.30	8.90	0.00
363		29	12.00	2.2	7.40	2.4
364		30	9.40	6.1	3.30	0
365		31	24.50	7.80	11.90	4.80
366	January	1				
367		2				
368		3	23.70	14.10	9.60	0.00
369		4				
370		5				
371		6				
372		7				
373		8				
374		9				
375		10				
376		11				
377		12				
378		13				
379		14				
380		15				
381		16				
382		17	23.50	0.70	8.90	13.90
383		18				
384		19				
385		20				
386		21	12.10	1.00	6.30	4.80
387		22	14.80	2.80	9.00	3.00
388		23	22.90	2.50	9.50	10.90
389		24	17.50	2.80	9.00	5.70
390		25	16.50	2.80	10.10	3.60
391		26				
392		27				
393		28	20.90	4.70	8.60	7.60
394		29	17.10	2.20	9.40	5.50
395		30	18.70	4.90	7.70	6.10
396		31	10.60	3.80	6.80	0.00

Day	Month	Date	Total	Branches	Leaves	Fruit and flowers
397	February	1	19.10	2.00	5.60	0.00
398		2	5.10	3.20	7.60	12.80
399		3	4.40	3.10	10.40	5.60
400		4	4.40	0.00	5.10	0.00
401		5	8.20	0.00	4.40	0.00
402		6	8.20	0.00	4.40	0.00
403		7	0.00	1.80	6.40	0.00
404		8	0.00	0.00	8.20	0.00

Annex XII[b] Chemical composition of organic debris

Analysis results for branch material

Collector	Date	N	P	Na	K	Ca	Mg	Mn	Zn
		(		mmol/kg			)	(mg/kg	)
O1	24-05	598	12	8	14	372	48	223	111
O1	24-05	575	11	8	13	369	47	203	109
O1	06-06	604	12	7	8	457	61	225	73
O1	06-06	563	12	7	9	532	58	160	61
O1	13-06	643	12	7	8	267	68	293	131
O1	13-06	642	14	8	14	257	66	285	125
O1	14-06	547	11	7	34	330	56	188	32
O1	14-06	539	12	14	34	338	55	187	37
O1	26-06	695	8	14	8	262	59	242	87
O1	30-06	657	7	8	9	217	44	175	89
O1	17-07	751	12	15	26	301	53	209	181
O1	29-07	699	13	7	22	278	66	505	38
O1	13-08	818	16	14	16	300	58	649	43
O1	24-08	419	5	7	17	279	37	211	21
O1	04-09	541	13	15	22	400	45	225	40
O3	04-09	423	6	7	26	577	65	57	26
O4	04-09	532	8	0	27	485	34	105	42
O1	17-09	350	5	7	31	449	51	194	46
OF	27-09	944	22	15	40	431	78	840	64
O1	27-09	358	8	7	17	503	37	109	26
O2	27-09	619	9	7	34	296	147	133	50
O3	27-09	385	6	14	8	458	50	73	16
O4	27-09	426	8	7	13	449	38	123	33
OF	13-10	824	14	15	17	482	66	388	183
O1	13-10	222	4	7	13	144	33	124	9
Average		575	10	9	19	369	57	245	67
Standard deviation		164	4	4	10	108	22	177	48

Analysis results for leaf material

Collector	Date	N	P	Na	K	Ca	Mg	Mn	Zn
		(mmol/kg					)	(mg/kg	)
O1	24-05	850	20	7	9	210	42	319	83
O1	24-05	852	20	7	9	219	43	330	91
O1	06-06	716	18	7	8	156	35	268	21
O1	13-06	825	21	7	9	214	48	408	37
O1	13-06	828	20	7	9	214	45	372	37
O1	14-06	895	21	7	13	202	49	286	26
O1	14-06	857	20	8	14	199	46	285	27
O1	26-06	489	8	7	12	101	26	117	24
O1	30-06	975	20	36	13	242	68	455	87
O1	17-07	939	19	16	23	223	58	383	239
O1	29-07	1074	26	9	30	246	70	778	31
O1	13-08	1205	29	15	22	293	75	1237	53
O1	24-08	428	7	7	20	144	42	185	10
O1	04-09	261	4	7	17	64	15	52	10
O3	04-09	622	11	7	21	151	50	65	29
O1	17-09	1005	30	21	99	187	78	197	111
OF	27-09	938	28	7	92	266	78	191	45
O1	27-09	252	7	7	13	24	15	40	15
O3	27-09	412	44	57	329	56	47	15	9
O4	27-09	519	10	14	13	169	58	101	14
OF	13-10	1118	35	15	60	195	73	449	46
O1	13-10	4	4	7	4	70	27	80	12
Average		730	19	13	38	175	49	301	48
Standard deviation		308	10	12	68	71	19	270	51

Analysis for fruit and flower material

Collector	Date	N	P	Na	K	Ca	Mg	Mn	Zn
		(		mmol/kg			)	(mg/kg	)
O1	24-05	898	17	7	29	264	66	403	92
O1	24-05	919	17	7	30	273	68	426	95
O1	06-06	860	16	7	47	314	52	443	36
O1	06-06	908	17	8	46	299	56	504	42
O1	13-06	957	24	14	13	269	65	768	77
O1	13-06	991	23	14	8	280	63	778	72
O1	14-06	828	16	7	17	306	61	395	26
O1	14-06	806	15	7	17	311	62	409	27
O1	26-06	1070	19	22	13	342	69	594	74
O1	30-06	1001	17	7	13	306	61	570	133
O1	17-07	1039	18	14	12	279	69	674	394
O1	29-07	942	20	7	42	326	67	985	36
O1	13-08	1184	35	14	21	333	88	2725	63
O1	24-08	952	19	7	30	375	64	1262	30
O1	04-09	935	14	15	26	348	68	502	27
O3	04-09	910	14	14	34	277	61	105	17
O4	04-09	1146	9	7	43	226	60	461	121
O1	17-09	781	13	7	26	276	73	312	53
OF	27-09	919	22	14	46	440	137	411	47
O1	27-09	892	14	15	13	314	58	382	39
O2	27-09	709	12	7	39	250	105	318	39
O3	27-09	901	19	22	34	208	88	175	26
O4	27-09	1089	17	7	26	357	78	195	45
OF	13-10	1004	21	14	21	293	82	745	45
O1	13-10	818	15	22	17	298	64	532	43
Average		938	18	11	27	303	71	603	68
Standard deviation		10	5	5	12	47	18	500	73

Annex XIII Listing of the model describing the nutrient balance

```
Program NutModel
   (input,output,infile,outfile,outfileP,OutfileK,OutfileCa,OutfileMg);

{ NutModel
   Author:     Ir J.J. Stoorvogel
               Agricultural University Wageningen
   Function:   Simulation of the nutrient balance of a catchment in Taï
               National Park, Côte d'Ivoire based on daily rainfall figures
   Interface:  The input file contains daily rainfall figures. Five output files
               are generated which contain respectively the hydrological
               balance and the balances for P, K, Ca and Mg.              }

Uses Crt;

Const
   AET=4.018;      { Actual evapotranspiration in mm/day                    }
   Nrdays=434;     { Total number of days in input file                     }

Var
   Day,            { Day number                                             }
   Day1,           { First day for calculation                              }
   YearDay,        { Day number within year                                 }
   I,              { Loop controller                                        }
   Flow,           { Number of input or output factor                       }
   Hour            { Hour of peak flow                                      }
              : Integer;

   Rain,           { Rainfall in mm/day                                     }
   BaseFlow,       { Base Flow in mm/day                                    }
   Peakflow,       { Peak flow in mm/day                                    }
   Store,          { Relative storage in mm                                 }
   WatLev,         { water level in the creek in cm                         }
   Sediment,       { Sediment quantity in kg/ha,day                         }
   SC,             { Sediment concentration in mg/l                         }
   sumrain,        { Sum of factorial rainfall for base flow calculation    }
   EC              { Electrical conductivity in micromho/cm                 }
              : Real;
```

```
    Infile,         { Input file with rainfall data                      }
    Outfile,        { Output file with hydrological data                 }
    OutfileP,       { Output file with P balance                         }
    OutfileK,       { Output file with K balance                         }
    OutfileCa,      { Output file with Ca balance                        }
    OutfileMg       { Output file with Mg balance                        }
              : Text;

    Rainfall        { Array with rainfall data                           }
              : Array[1..Nrdays] of Real;

    PBal,           { P balance                                          }
    KBal,           { K balance                                          }
    CaBal,          { Ca balance                                         }
    MgBal           { Mg balance                                         }
              : Array[1..6,1..2] of Real;

    Peak            { Average Peak flow, water level and EC during five
                      hours of peak                                      }
              : Array[1..5,1..3] of Real;

    Directory,      { Directory with data files                          }
    Inname,         { Name of input file                                 }
    HydroOut,       { Name of output file with hydrological data         }
    POut,           { Name of output file with P-balance                 }
    KOut,           { Name of output file with K-balance                 }
    CaOut,          { Name of output file with Ca-balance                }
    MgOut           { Name of output file with Mg-balance                }
              : String[15];

Begin

Directory := 'c:\';
Inname := 'rain9091.dat';
HydroOut := 'flow.avg';
POut := 'P_Bal.avg';
KOut := 'K_Bal.avg';
CaOut := 'Ca_Bal.avg';
MgOut := 'Mg_Bal.avg';
```

```
Store := 150;
Day1 := 136;

    Assign(Infile,Directory+Inname);
    Reset(Infile);
    For Day:=1 to NrDays do
                Readln(Infile,I,rainfall[Day]);
    Close(Infile);
    Assign(Outfile,Directory+HydroOut);
    rewrite(outfile);
    Assign(OutfileP,Directory+POut);
    rewrite(outfileP);
    Assign(OutfileK,Directory+KOut);
    rewrite(outfileK);
    Assign(OutfileCa,Directory+CaOut);
    rewrite(outfileCa);
    Assign(OutfileMg,Directory+MgOut);
    rewrite(outfileMg);
    Day:=Day1;
    For Flow:=1 to 6 do
                Begin
                PBal[Flow,2] :=0;
                KBal[Flow,2] :=0;
                CaBal[Flow,2]:=0;
                MgBal[Flow,2]:=0;
                End;
    Repeat
                Begin

    { Hydrological balance   }
                Day:=Day+1;
                Writeln('Calculation for day number:',Day:5);
                Sumrain:=0;
{Eq. 4.1a}      For I:=1 to 90 do
                    Sumrain:=Sumrain+Rainfall[day-I]/(I+0.7);
                Rain:=Rainfall[day];
{Eq. 4.1b}      Baseflow:=0.022*sumrain+0.00043*sqr(sumrain);
{Eq. 4.2}       If rain<(6.5-0.09*baseflow) then
                    Peakflow:=0
                Else
                    Peakflow:=(+0.00093*Store*Rain+0.0082*rain);
```

```
              If Baseflow<0 then Baseflow:=0;
              If Peakflow<0 then Peakflow:=0;
              Store:=Store+Rain-AET-Baseflow-Peakflow;
              Writeln(Outfile,Day:7,Store:6:1,Rain:6:1,AET:6:1,
                   Baseflow:6:1,Peakflow:6:1);

   { Rain }
{Eq. 5.1}     EC:=8.01-0.032*Rain;
{Eq. 5.2}     PBal[1,1]:=Rain*0.034                     *31.0*10*0.001;
{Eq. 5.3}     KBal[1,1]:=Rain*(-4.54+1.32*EC)           *39.1*10*0.001;
{Eq. 5.4}     CaBal[1,1]:=Rain*(0.30*EC+0.13*Sqr(EC)) *40.1*10*0.001;
{Eq. 5.5}     MgBal[1,1]:=Rain*(-0.9+0.39*EC)           *24.3*10*0.001;

   { Dust }
              YearDay:=Day-365*Trunc(Day/365);
              If YearDay<31 then
                   Begin
{Table 5.3}        PBal[2,1] :=(76*0.003*31.0/141.9)*1000/30;
                   KBal[2,1] :=(76*0.037*39.1/94.20)*1000/30;
                   CaBal[2,1]:=(76*0.061*40.1/56.08)*1000/30;
                   MgBal[2,1]:=(76*0.009*24.3/40.31)*1000/30;
                   End
              Else
                   Begin
                   PBal[2,1] :=0;
                   KBal[2,1] :=0;
                   CaBal[2,1]:=0;
                   MgBal[2,1]:=0;
                   End;

   { Base Flow }
              If BaseFlow>0 then
                   Begin
{Eq. 5.6}          EC:=68.5-8.09*(ln(BaseFlow)/ln(10));
{Eq. 5.8}          PBal[3,1] :=Baseflow*(-0.020*EC+0.00055*sqr(EC))
                        *31.0*10*0.001;
                   PBal[3,1]:=PBal[3,1]*1.9/1.2;
{Eq. 5.10}         KBal[3,1] :=Baseflow*(37.6+0.037*EC+0.0038*sqr(EC))
                        *39.1*10*0.001;
                   KBal[3,1]:=KBal[3,1]*1.9/4.7;
{Eq. 5.12}         CaBal[3,1]:=Baseflow*(-2.1+1.8*EC)*40.1*10*0.001;
```

```
{Eq. 5.14}          MgBal[3,1]:=Baseflow*( 6.6+1.1*EC)*24.3*10*0.001;
                    End
               Else
                    Begin
                    PBal[3,1] :=0;
                    KBal[3,1] :=0;
                    CaBal[3,1]:=0;
                    MgBal[3,1]:=0;
                    End;

  { Peak Flow }
               PBal[4,1] :=0;
               KBal[4,1] :=0;
               CaBal[4,1]:=0;
               MgBal[4,1]:=0;
               If Peakflow>0 then
                    Begin
                    Peak[1,1]:=Peakflow * 4.2  /26.4;
                    Peak[2,1]:=Peakflow * 10.4 /26.4;
                    Peak[3,1]:=Peakflow * 8.1  /26.4;
                    Peak[4,1]:=Peakflow * 2.7  /26.4;
                    Peak[5,1]:=Peakflow * 1.0  /26.4;
                    For Hour:=1 to 5 do
                         Begin
                         Peak[Hour,1]:=Peak[Hour,1]+BaseFlow/24;
{Eq. 4.4}                If Peak[Hour,1]<1.90 then
                              Peak[Hour,2]:=11.4+49.5*Peak[Hour,1]
                                   -12.0*Sqr(Peak[Hour,1])
                         else
                              Peak[Hour,2]:=32.7+16.0*Peak[Hour,1]
                                   +0.49*Sqr(Peak[Hour,1]);
{Eq. 5.7}                Peak[Hour,3]:=77.3-26.2*ln(Peak[Hour,2])/ln(10);
                         End;
                    For Hour:=1 to 5 do
                         Begin
                         EC:=Peak[Hour,3];
{Eq. 5.9}                     PBal[4,1]:=Pbal[4,1]
                                   +Peak[Hour,1]*0.14*31.0*10*0.001
                                   -PBal[3,1]/24;
                         If PBal[4,1]<0 then PBal[4,1]:=0;
```

```
{Eq. 5.11}              KBal[4,1]:=KBal[4,1]
                                   +Peak[hour,1]*50*39.1*10*0.001
                                   -KBal[3,1]/24;
                        If KBal[4,1]<0 then KBal[4,1]:=0;
{Eq. 5.13}              CaBal[4,1]:=KBal[4,1]
                                   +Peak[hour,1]*(-14.7+2.3*EC)
                                   *40.1*10*0.001-KBal[3,1]/24;
                        If CaBal[4,1]<0 then CaBal[4,1]:=0;
{Eq. 5.15}              MgBal[4,1]:=MgBal[4,1]
                                   +Peak[hour,1]*(-16.8+1.7*EC)
                                   *24.3*10*0.001-MgBal[3,1]/24;
                        If MgBal[4,1]<0 then MgBal[4,1]:=0;
                        End;
                PBal[4,1]:=PBal[3,1]*1.9/1.2;
                KBal[4,1]:=KBal[3,1]*4.9/4.7;
                End;

  { Sediment }
{Eq. 4.3}   If BaseFlow<(12.7) then
                WatLev:=1.6*Baseflow
{Eq. 5.16}  Sediment:=2.02*WatLev*0.01;
            If PeakFlow>0 then
                Begin
                Sediment:=Sediment*19/24;
                For Hour:=1 to 2 do
                        Begin
{Eq. 5.16}              SC:=(-98.0+29.1*Peak[hour,2]
                                -0.17*Sqr(Peak[Hour,2]))*0.01;
                        Sediment:=Sediment+SC*Peak[Hour,1];
                        End;
                For Hour:=3 to 5 do
                        Begin
{Eq. 5.16}              SC:=(6.0+0.142*Sqr(Peak[Hour,2]))*0.01;
                        Sediment:=Sediment+SC*Peak[Hour,1];
                        End;
                End;
{Table 5.12} PBal[5,1] :=(Sediment*2*31.0/141.9);
             KBal[5,1] :=(Sediment*6*39.1/94.20);
             CaBal[5,1]:=(Sediment*5*40.1/56.08);
             MgBal[5,1]:=(Sediment*2*24.3/40.31);
```

```
{ Calculation of totals }
        PBal[6,1] :=0;
        KBal[6,1] :=0;
        CaBal[6,1]:=0;
        MgBal[6,1]:=0;
        For Flow:=1 to 2 do
            Begin
            PBal[6,1] :=PBal[6,1] +PBal[flow,1];
            KBal[6,1] :=KBal[6,1] +KBal[flow,1];
            CaBal[6,1]:=CaBal[6,1]+CaBal[flow,1];
            MgBal[6,1]:=MgBal[6,1]+MgBal[flow,1];
            End;
        For Flow:=3 to 5 do
            Begin
            PBal[6,1] :=PBal[6,1] -PBal[flow,1];
            KBal[6,1] :=KBal[6,1] -KBal[flow,1];
            CaBal[6,1]:=CaBal[6,1]-CaBal[flow,1];
            MgBal[6,1]:=MgBal[6,1]-MgBal[flow,1];
            End;
        For Flow:=1 to 6 do
            Begin
            PBal[Flow,2] :=PBal[Flow,2] +PBal[Flow,1];
            KBal[Flow,2] :=KBal[Flow,2] +KBal[Flow,1];
            CaBal[Flow,2]:=CaBal[Flow,2]+CaBal[Flow,1];
            MgBal[Flow,2]:=MgBal[Flow,2]+MgBal[Flow,1];
            End;

{ Output data }
        Write(OutfileP,Rain:7:1);
        Write(OutfileK,Rain:7:1);
        Write(OutfileCa,Rain:7:1);
        Write(OutfileMg,Rain:7:1);

        For Flow:=1 to 6 do
            Begin
            Write(OutfileP,PBal[Flow,1]:7:1);
            Write(OutfileK,KBal[Flow,1]:7:1);
            Write(OutfileCa,CaBal[Flow,1]:7:1);
            Write(OutfileMg,MgBal[Flow,1]:7:1);
            End;
```

```
        Writeln(OutfileP);
        Writeln(OutfileK);
        Writeln(OutfileCa);
        Writeln(OutfileMg);
        End;
        Until day=NrDays;

  { Output data }
        For Flow:=1 to 6 do
            Begin
            Write(OutfileP,PBal[Flow,2]:7:1);
            Write(OutfileK,KBal[Flow,2]:7:1);
            Write(OutfileCa,CaBal[Flow,2]:7:1);
            Write(OutfileMg,MgBal[Flow,2]:7:1);
            End;
        Writeln(OutfileP);
        Writeln(OutfileK);
        Writeln(OutfileCa);
        Writeln(OutfileMg);

    Close(outfile);
    Close(outfileP);
    Close(outfileK);
    Close(outfileCa);
    Close(outfileMg);
End.
```