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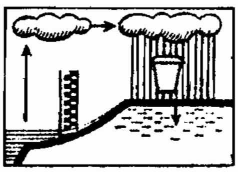

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STUDY OF HYDROLOGICAL CHARACTERISTICS OF FOREST SOILS WITH THE AID OF A RAIN-SIMULATOR

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PREFACE

This study is comprised of measuring and interpreting information which was gathered during two brief campaigns. The study lasted five months and for the author it was the first practical application of scientific methods.

The study was prepared with consent of the Direction Générale de l'Office de la Recherche Scientifique et Technique Outre-Mer and the professors ir. L. Horst and ir. D.A. Kraajenhof v.d. Leur of the Agricultural University via Jan Siemonsma.

My special thanks go to the project-leader, Mr. A. Casenave of the hydrology department, ORSTOM, Adiopodoumé, for his invaluable assistance and explanations and to Mr. J-M. Simon for his technical and organisational contributions while setting up the experiments.

Without the help of Emmanuel and Amany the work could not have bean executed. Thanks to both of you.

Furthermore my thanks and best whishesto Jan, Lies, Jean-Michel, Mariama, Mr and Mrs Chaigneau, Mr. Ranc, Mr. Flory and all those friends who have been so kind to me.

Hans Hunink

Centre Neérlandais
Adiopodoumé,

June, 1980

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ABSTRACT

After introducing the project in which he has worked, the author describes the country (Ivory Coast), the place of his work (basins of Agbeby and Nion) and the material with which he worked (a rain-simulator and apparatus to determine soil humidity). The program of simulated rains and the overal procedure are described before several raindepths and rain-and-runoff figures are given and re-worked into more comparable forms.

The obtained runoff coëfficients (5 % for Agbeby and 2 % for Nion) compared with previous studies gave a correct value for Agbeby but not for Nion. The author makes note of the difference and gives a possible explanation and a suggestion for improving the set-up of the experiment.

Soil moisture studies show that sub-surface horizons play an important part in determining the runoff of initially permeable soils. Besides this and other well-known factors no new influences or correlations have been found.

The author concludes with a list of note-worthy observations that he has made during the study.

RÉSUMÉ

Après la présentation de l'étude, l'auteur fait une description du pays (Côte d'Ivoire), des bassins étudiés (bassin de l'Agbéby et du Nion) et de la technique utilisée (simulateur de pluie et dispositif de mesure de l'humidité du sol). Le protocole des pluies-débits sont schématisés par des figures.

Les coefficients de ruissellement mesurés (5 % pour l'Agbeby et 2 % pour le Nion) sont en accord avec ceux obtenus lors des études de bassins versants antérieures pour l'Agbeby mais pas pour le Nion. L'auteur rend compte de ces différences, propose une explication et suggère des modifications de la technique de mesure.

L'étude de l'humidité des sols met en évidence l'influence des horizons supérieurs sur la genèse du ruissellement pour ces sols perméables. L'étude n'a pas permis de trouver des relations entre les caractéristiques physiques des sols et le ruissellement;

L'auteur termine par une liste des observations manquantes qu'il a pu faire au cours de cette étude.

I. INTRODUCTION

In September 1976, an agreement to make a two-year study of discharges of floods, with ten years frequency, of small river-basins (smaller than 200 km2), situated in forest regions, was signed by the Comité Interafricain d'études Hydrauliques (CIEH) and the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM). The first part of the study was to establish a quick method for calculating the maximal discharges and a method of determining the influence of the nature of the soil on the flow. The second part of the study is to apply the methods, found suitable, on different forest river-basins . This report describes a study whereby the suitability is put to the test.

In the past 20 years ORSTOM studies have indicated that runoff coefficients can vary considerably (10 to 60 %) without exactly being able to determine the causes. The different reactions of the ferralitic soils have been difficult to classify according to pedological classifications. The classical study of river basins and the study - method used in savannahs are not suitable for forest regions. The first because a classical study of river bassins with extensive discharge measurements takes several years (A quicker method was needed). The method of study of river basins used in savannah country, which takes a few months, collecting data on soil type, slope, vegetation and climatology, was not suitable either. This method can only be used in homogeneous soil conditions. Soils of tropical forests which appear as being similar, react differently to rains without a clear explanation.

Now the reason for using the rain simulator seems clear : to make a short study, to make an estimation of discharge coëfficients of tropical forest regions, possible. In the study primarily the runoff coefficients are determined and secondly through supplementary observations and measurements an explanation is sought.

In 1977 a start had been made with the mini-rainsimulateur .It facilitates determination of principle flow characteristics (depth of runoff, maximal discharge etc...) as a function of different influences (soil humidity, rain characteristics, vegetative cover etc ...) on one square - meter plots. The first basins chosen for the study were those which had been intensively studied before. A lot of information about the soil, vegetation and climatology (including interception in forests) is therfor available.

In 1977 the experiments took place at the MANSO basin at Guessigué. In 1978 followed the Tai basin and the Gboa and Loué basin of Mont Tonkoui (the last of which have been studied before in 1958 and 1959). In 1979 ORSTOM continued the study beyond the agreed two years The experimental basins of 1979 were the Agbeby bassin at Adankoua and the Nion, or Nyon, basin at Zagoue.

The final aim of the study is to use the results, obtained at the plots, for the basins and to arrive at criteria to include a basins in one of several cathegories of an existing or other classification resulting from the studies. Then it will be a simple matter to calculate discharges with a 10 years frequency.

II. THE IVORY COAST IN GENERAL (VII, VIII, IX)*

2.1. Geographic situation (fig. 1)

The Republic of the Ivory Coast in West Africa was before August 7, 1960 a territory in a federation of french West-Africa . Two neighbours, Upper Volta to the north east and Guinea to the west, also formed part of this federation. Other neighbours are Ghana to the east, Mali to the north and Liberia to the west. The Guinean Gulf (Atlantic ocean) forms its southern shore. The country covers 322 463 Km2.

2.2. Relief and rivers

The greatest part of the Ivory Coast consists of an extensive peneplain that starts in a narrow coastal plain and inland it increases in altitude to about 400 m. The monotonous weak undulating relief is occasionally interupted by granitic domes, which are particularly dominating in the Man region. In the north-west and mid-west there are extensions of the Guinean Highlands with peaks of over 1200 m , Mount Nimba (1752 m), on the border with Guinea, is the highest peak in West Africa.

Four great rivers flowing almost parallel southwards dominate the hydrological pattern of the country (fig. 1). They are the Cavally (also border with Liberia), the Sassandra (of which the Nyon - experimental site where basic material for this study was collected - is an upper tributary), the Bandama and the Comoe rivers.

In the south, between the Bandama and the Comoe basins, is situated amongst others the smaller Agneby river basin. The Agbeby (also an experimental site) is a lower tributary of the Agneby. The Agneby flows into the Ebrie lagoon.

In the rain season the rivers have large discharges (eg. 1500 m3/s) while in the dry season they are reduced to small streams that flow in broad stony river beds.

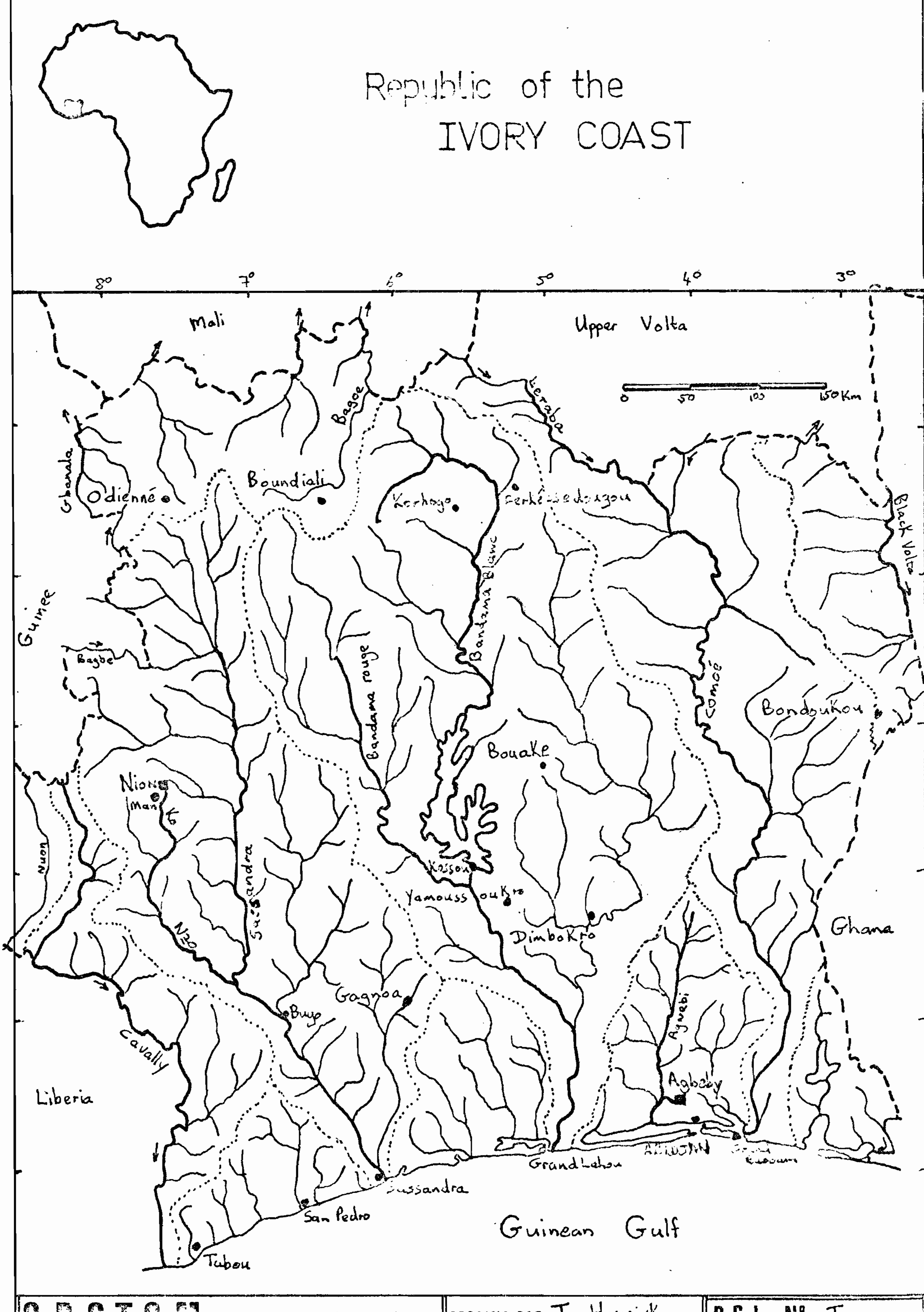
The marshy and mangrove coastal plain in the east (Fresco to Ghanian border), is bordered by lagunes and spits which open by the Bia, Comoe and Bandama rivers only. Westwards of Fresco, upto the Liberian border, the coast is steeper and rockier, with a few bays and short headlands. It is in this stretch where the Sassandra and the Cavally flow to sea.

Because of the tall surf, the numerous sandbanks and lagoons, the country was hardly accessable by ship. Expensive projects have done much to change this.

The rivers are unreliable because of changing water-levels, waterfalls and rapids.

* reference to literature used, see list on the last page.

fig. 1



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2.3. Vegetation (fig. 2)

Directly along the coastline begin the cocopalm plantations. Further inland is a wide (150-300 km) forest-belt that has largely been cultivated to produce the important export products : coffee, cocoa and pine -apple.

In the south the exploited tropical forest is becoming less dense. North-wards it transforms into open woodland and eventually savannah. Along the rivers the forest continues in so-called forest galeries. The savannah-belt is determined by climatological (long periods of drought), edaphic and anthropological factors. Through the ages the savannah has been extended (due to extensive burning) to the disavantage of the tropical forest.

In the north the vegetation changes from tree-savannah to long grass savannah.

2.4. Climate (fig. 2 and 3)

The southern part of the Ivory Coast has an Equatorial climate with high average temperatures of 26-27°, a small daily amplitude of temperature and two rain maxima yearly alternated with relatively dry periods. Rain-maxima occur from May to July and from September to November. The rainfall to the south east and to the south west are the highest while between Sassandra and Grand Lahou it's lower. Tabou in the west has a yearly rainfall of 2300 mm, Sassandra in the middle 1800 mm and Abidjan to the east has 2100 mm.

Going land inwards the precipitation decreases while the lenght of the dry period increases.

The average annual humidity decreases from south to north, but the whole country can experience extreme high degrees of humidity (towards 100 %) as wel as extreme low degrees in the time of the Harmattan* (even in the south sometimes only 15 % in January).

In the centre of the country a dry season (Nov.-March) precedes a rain season marked by two pluviometric maxima, one in June the other in September ; but the precipitations of the month of August are relatively important and this month cannot be termed dry. This climate is described by Harrison Church (VII) as semi-seasonal equatorial (see fig. 2).

The north northeast is characterised by 2 seasons and goes from a seasonal equatorial climate to a savannah climate in the north. The rain season extends from June to September with a maximum precipitation usually in August. Here the rains are very unpredictable. The dry season is marked by very little rain especially December untill February.

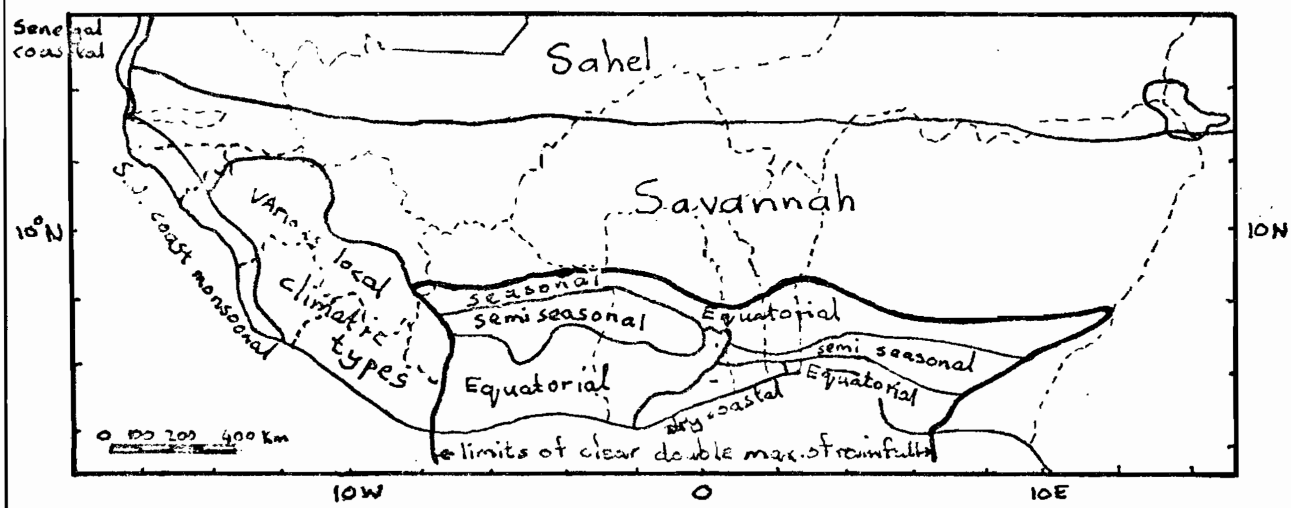
The westerly mountainous region of Man receives a greater yearly precipitation, due to ascending air, than other areas in the country with the same latitude.

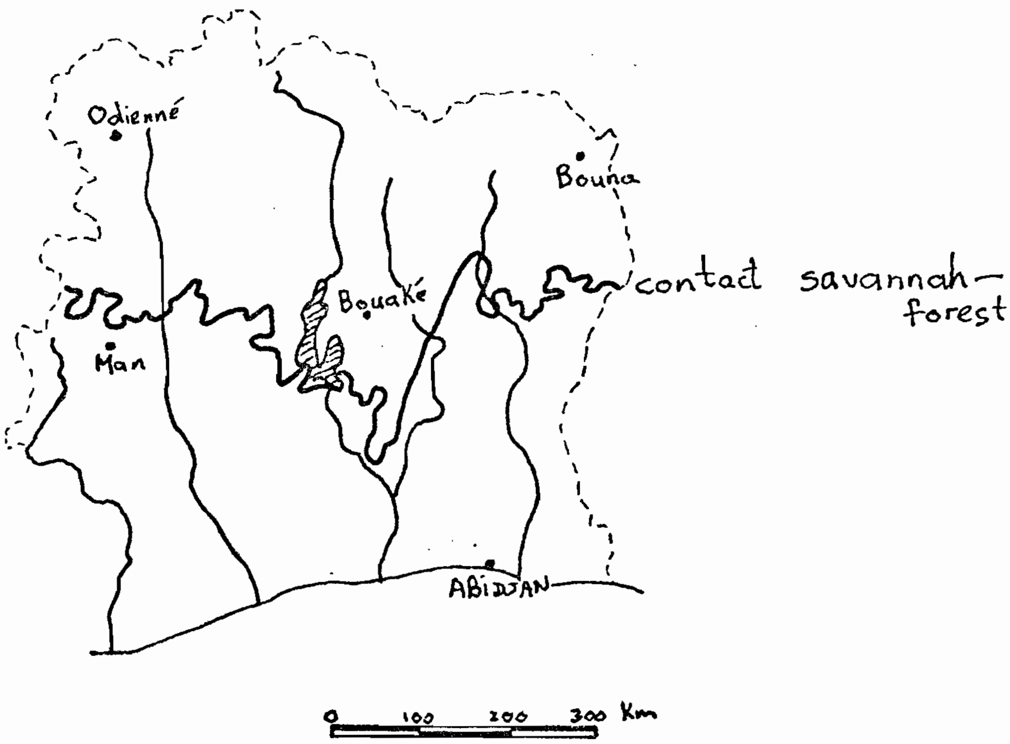
* dry sandladen northeast mousoon wind

fig. 2

Climatic types of Western Africa

according to Harrison Church (VII)





The coinciding climatic and vegetative boundary

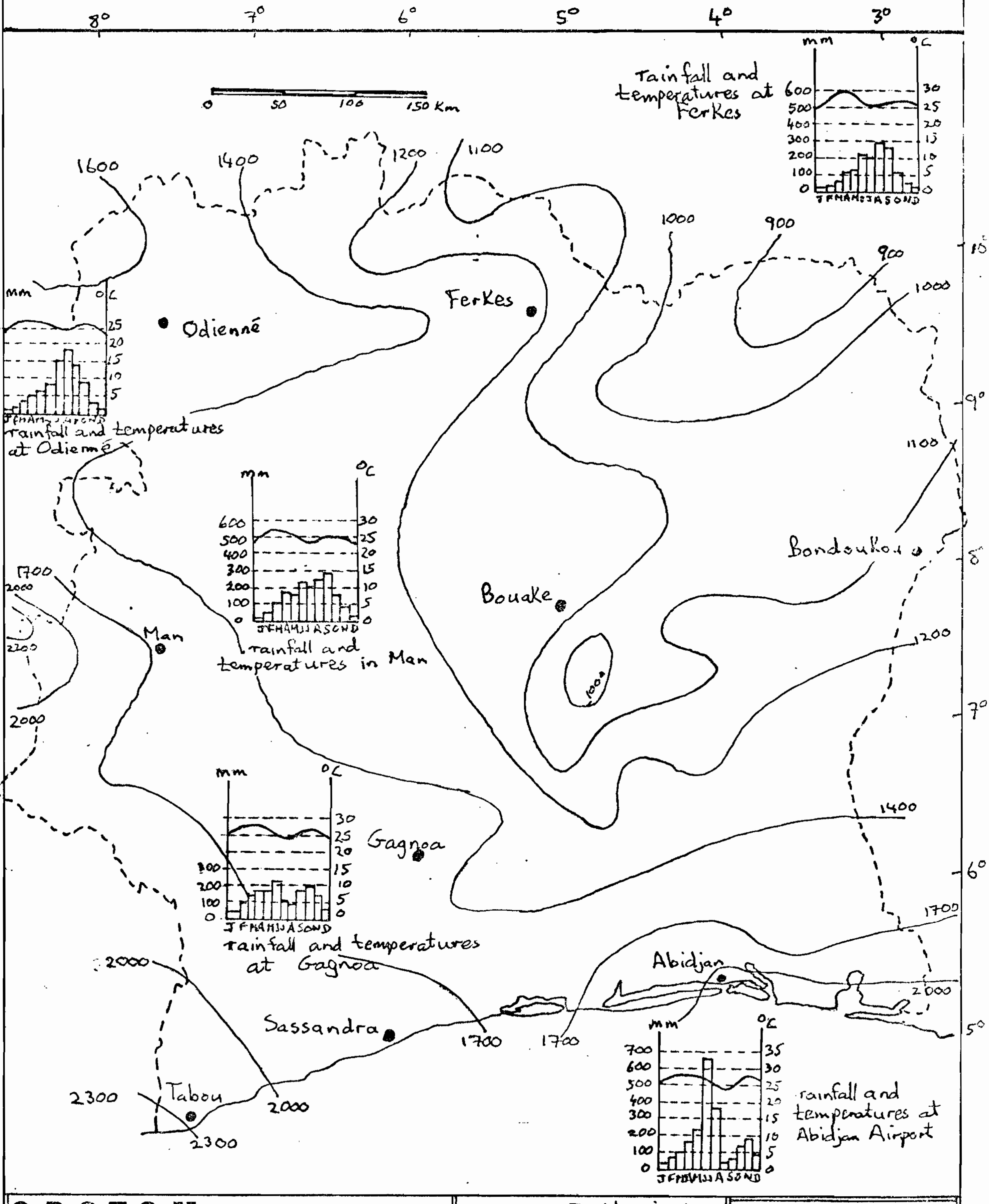
fig. 3

Climate

precipitation (in mm) and average monthly temperatures (in°c)

Isohyets: average yearly rainfall (in mm)

Histograms: average monthly rainfall (in mm)



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III. THE SITES AND THE MATERIAL

3.1. The river basins (fig. 4 and 5)

The requirements were to choose a site which was in a small forest river basin, smaller than 200 km2, which had been studied before. It is in forest regions that runoff forespelling presents problems as pedologists cannot find a one-to-one correspondance between soil properties and the influence they have on discharges.

For basins smaller than 50 km2 the Instantaneous Unit Hydrograph method can be used as rains can be found to extend uniformly over such small areas. For basins greater than 200 km2 the effect of a geographically limited rainstorm is diffused.

The criterium that the basin had been studied before was to make a comparison of results possible.

Three such basins have been studied with the rain simulator and a list of the remaining basins which have been classically studied by ORSTOM before is available in Cah. ORSTOM, ser. Hydrol., vol XIII, N° 4, 1976.

For this campaign were chosen the Agbeby basin (situated about 16 km northwest of Adiopodoumé) and the Nyon river basin (situated about 15 km north northeast of Man).

Here are some characteristics of the basins :

Table 1		Agbeby	Nyon
main hydrographic basin	:	Agneby	Sassandra
tributary of	:	Nieky	N'Zo
geographical co-ordinates	:	5° 25'N 4° 13'W	7° 29'N 7° 30'W
period of previous study	:	1961-1962	1957-1959
surface area	:	11 km2	75 km2
altitude	:	50 m	330-630 m
general slope index	:	10	19,7
drainage density	:	2,27	2,37
climate	:	equatorial (2 rain maxima)	seasonal equatorial (1 rainy season)
average precipitation	:	2000	1170
nature of the soil	:	argillic sand	ferralitic

fig. 4

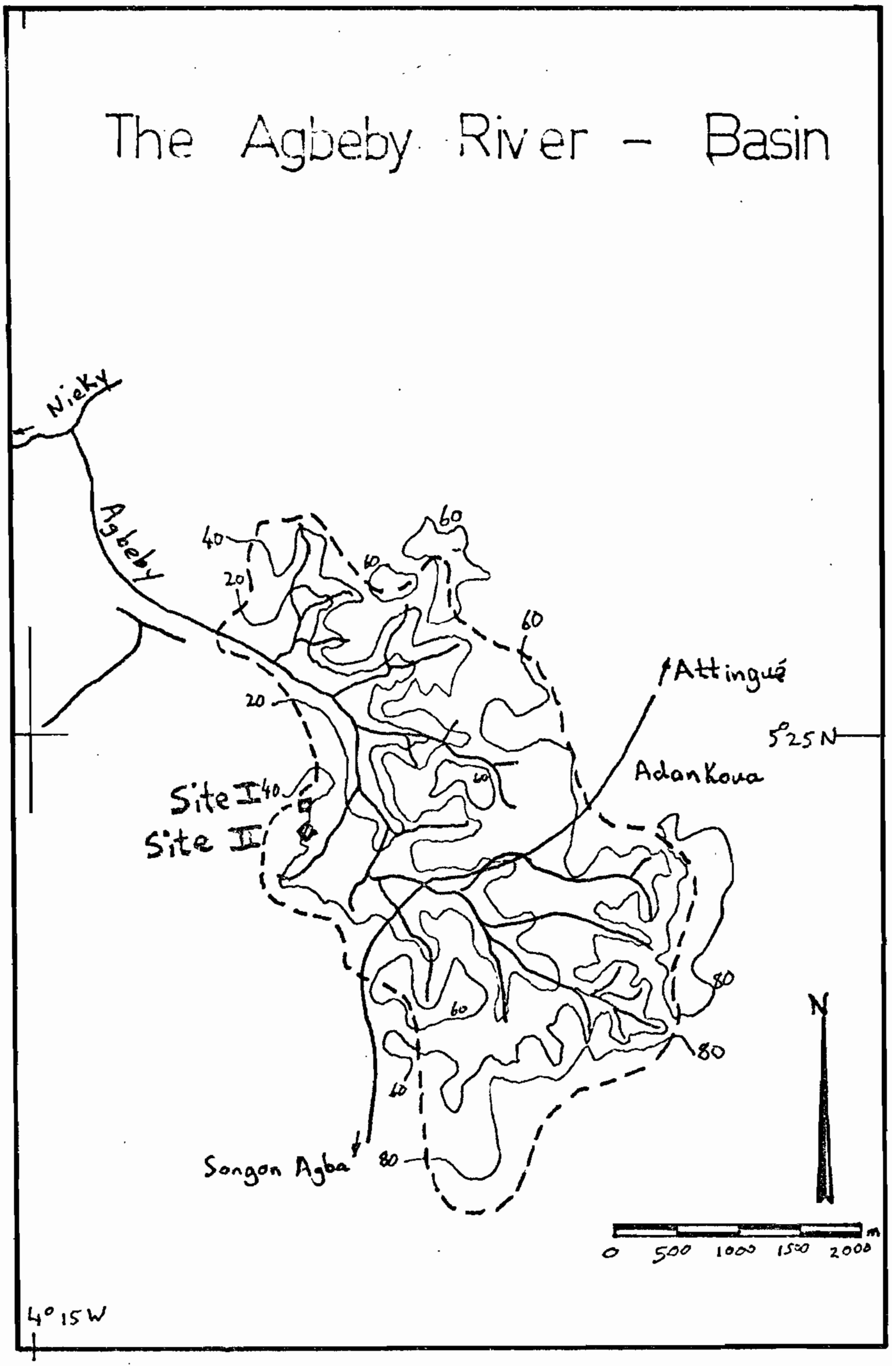
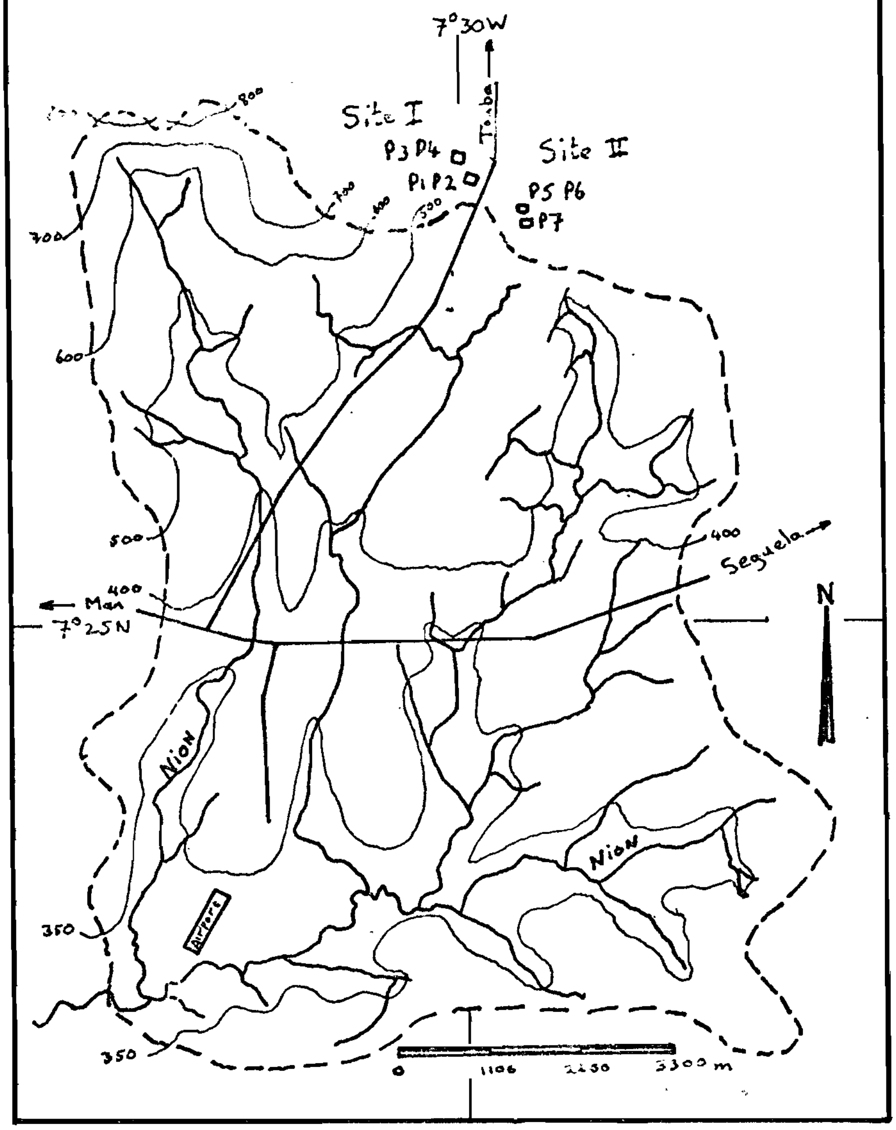

The Agbeby River - Basin
Nieky
Agbeby
Attingué
Adankoua
5°25 N
4°15 W
Site I
Site II
Songon Agba
N
0 500 1000 1500 2000 m
20
40
60
80

fig. 5

The Nion River - Basin



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3.2. The sites

In both basins 2 sites were chosen, where possible under forest and one site situated relatively high and one relatively low.

Limits were the availability of water for the rain simulations and reasonable accessability from a nearby roadsite or pathway. After choosing fairly representative sites the borders (cadre in fig. 4 appendix I) were installed a month befor the experiments started, to give the lower vegetation a chance to revive.

In the basin of the Nyon most streams had run dry. The solution was found by situating the sites for the study of this basin on the edge of a bordering basin. Soil, vegetative and climatic conditions were similar.

Under the forests (secondary) of sites I and II of Agbeby and site II of Nyon were coffee plantations.

3.3. The material

For basic information on the apparatus concerning construction and utilisation of the rain simulator see Appendici I and II.

Supplementary materials used were an earth drill, a neutron source and thermic shock apparatus* (II).

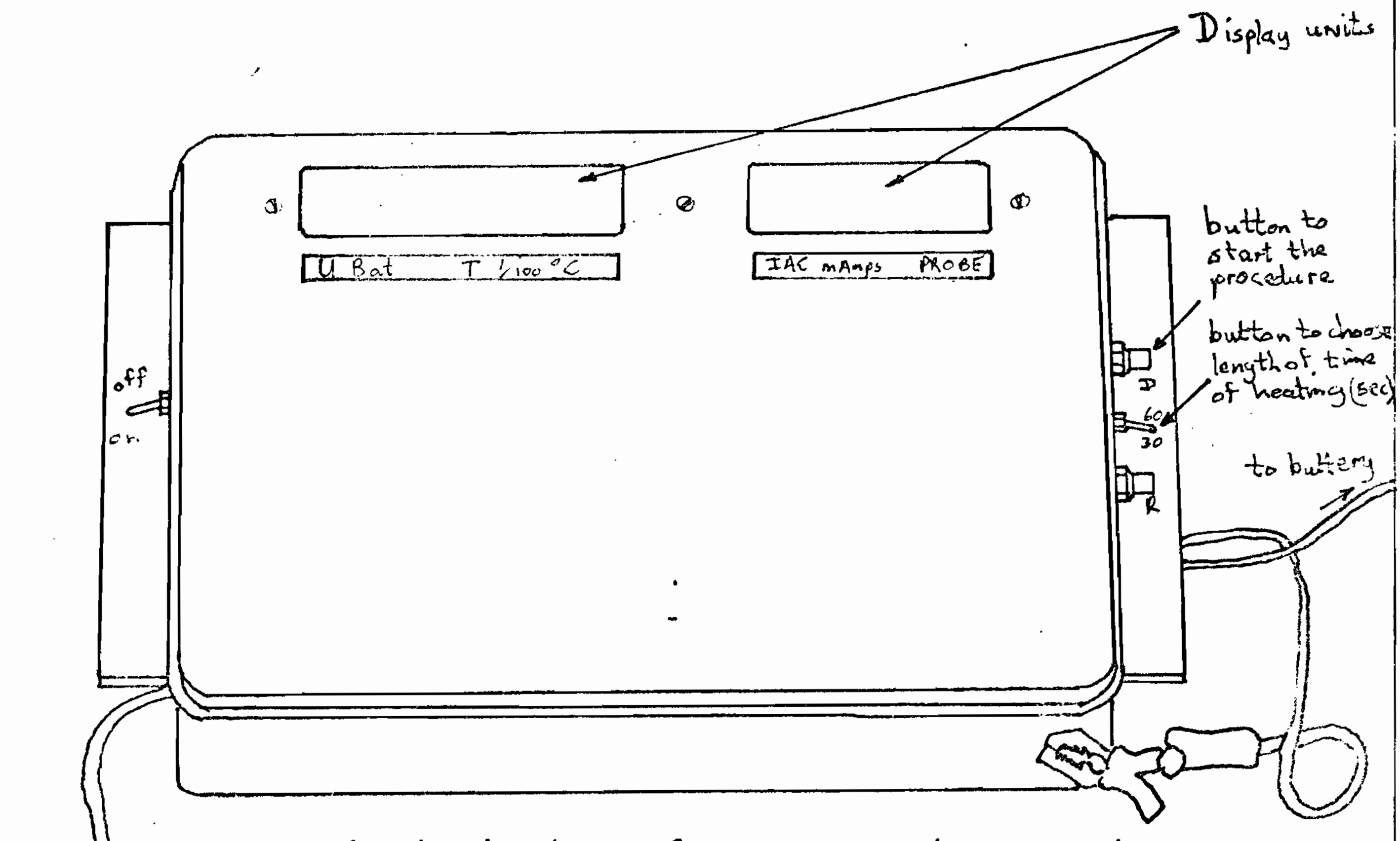
The neutron source was manipulated by an assistant from the isotopic laboratorium, Adiopodoumé.

The thermic shock apparatus was an experimental method to use thermic differences (before and after heating of the soil) to determine the humidity percentages of the soil (see fig. 6 and 7).

These apparatus and the earthdrill were used to gain insight in the passage of infiltrating water in the soil.

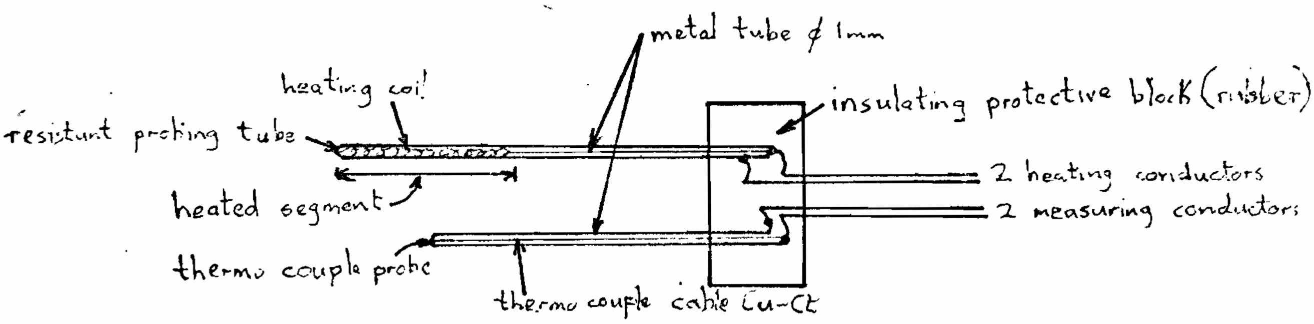
* for manipulation see chapter IV : Experimental procedure.

fig. 6



The electonic box for measuring and producing the thermic shock

fig. 7



scematic representation of the thermic probe

IV. THE EXPERIMENTAL PROCEDURE

4.1. Introduction

The same program has been used as that used at Tai - and Mount Tonkoui. This is a modification of the program used before at Guessigue (for the program used there see the rapport of the 1978 campaign, I*).

This year one change has been made in simulated rain of type A. It has been modified with an extra 10 min. rain period of 40 mm/hr. at the beginning. This is more like a natural rain than before.

4.2. The program

The program for the Nyon and Agbeby basins was the following.

table 2

Plot / Day	P1 denuded	P2 veg.	P3 veg.	P4 veg.
D	A	A		
D+1	A	A		
D+2	A	A		
D+3			A	A
D+4	A	A		
D+5	A+B	A+B		
D+6			B+B+B	B+B+B
D+15	B+B	B+B		

rain of type A : 40 mm/h during 10 min
140 mm/h " 15 "
100 mm/h " 15 "
80 mm/h " 10 "
60 mm/h " 10 "
40 mm/h " 10 "

rain of type B : 140 mm/h during 15 min
50 mm/h " 15 "

* N° in bibliography

The vegetation of plots 2, 3 and 4 is cut without disturbing the topsoil befor the rain type B begins. The time between rains of type A and B of the day D + 5 and between rains of type B is 30 minutes.

The rain of type B on always denuded soils allows for determining the influence of the soil differences. The influence of the vegetation is deduced from the results of rains A on plots 1 and 2 on the days D until D+5 with a control for the plots 3 and 4 with the rain of day D+3. The serie of rains A on days D until D+5 on plots 1 and 2 allow for a study of the influence of the soil humidity preceding a rainfall on soils under vegetation and denuded soils.

4.3. Further procedures

Rain intensity control, discharge rate and raindepth were all measured with a waterlevel-recorder placed at the lower end of the plot (see Appendix I fig 4).

Before each rain, soil samples were taken around the plot with the easthdrill to determine the soil humidity proceding rains. This was done again after the rain. Each time 3 profiles were made which tend to vary considerably. The average or the median values were used.

On one site in the Agbeby basin it was possible to insert a tube for neutron probe measurements. This was done on plots 5 and 6 of site II where soil conditions were favorable to at least 120 cm.

A new method of determining the soil humidity was experimented : the thermic shock (see fig. 5 and 6). In brief the procedure is as follows :

Four probes of combined potential heat source and thermal detector were inserted in the soil at 5 cm intervals starting at 5 cm from the surface. On a digital counter the temperature of the soil (with zero gauge other than 0°C) was alluminated in 1/100°C. Simultaneously the battery potential was alluminated as control measure. After a command to start heating the first probe is warmed and the current intensity, with which this is done, shows on another digital counter. The values given by the thermal detector before heating and at maximum soil temperature after heating, are noted. The inverse of the difference in temperatures has a linear relation with the thermal volume capacity which has a direct relation with the humidity of the soil.

The apparatus was built to continue sequentially on demand the heating and measuring of the 4 probes. The observer simply notes the results after initiating the procedure. For further information see article n° II of the bibliography.

V. THE MEASUREMENTS

5.1. Introduction

It seems useless to produce lists of obtained results in this report. A few will be given complete but of others Examples will simply be given to indicate values and form and format of the noted results.

During the 2 campaigns 92 rain simulations took place, 48 rains fell on 8 plots in the Agbeby basin and 44 rains fell on 7 plots in the Nion basin .

Similar tabulation to those, used in the 1978 campaign have been used again.

In general the measurements can be divided in those of the rain charactéristics, those of flow characteristics and those of soil humidity determinations.

5.2. Rain characteristics

The following characteristics of the rains are noted in tables Nos 3-17.

Collumn N° 1 :	simulated rain n° on the plot
Collumn N° 2 :	date of simulation
Collumn N° 3 :	time of starting the rain
Collumn N° 4 :	raindepth Pu (pluie utile) in mm
Collumn N° 5 :	effective raindepth Pe (Pluie efficace) in mm
Collumn N° 6 :	type of rain, A or B
Collumn N° 7 :	duration of the rain tu in minutes
Collumn N° 8 :	duration of effective rain, te in minutes and seconds
Collumn N° 9 :	initital rain, raindepth used for primary saturation pi (pluie d'imbibition) Pi = Pu - Pe

AGBEBY Site I

Table : 3 plot 1

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	16-1-80	9^H 28	97,8	87,5	A	70	58,40	10,3
2	17-1-80	13^H 17	94,8	81,3	A	70	57,00	13,5
3	18-1-80	9^H 27	99,5	89,3	A	70	58,50	10,2
4	20-1-80	9^H 25	97,4	79,6	A	70	55,30	17,8
5	21-1-80	13^H 19	96,1	85,8	A	70	58,30	10,3
6	21-1-80	14^H 59	46,7	45,5	B	30	29,30	1,2
7	17-2-80	8^H 36	46,9	45,0	B	30	29,10	1,9
8	17-2-80	9^H 36	46,9	44,6	B	30	29,00	2,3

Table : 4 plot 2

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	16-1-80	13^H 56	99,1	91,1	A	70	59,30	8,0
2	17-1-80	9^H 27	98,3	89,7	A	70	59,30	8,6
3	18-1-80	11^H 55	96,5	88,0	A	70	59,20	8,5
4	20-1-80	11^H 47	96,6	86,4	A	70	58,30	10,2
5	21-1-80	9^H 00	97,2	89,4	A	70	59,30	7,8
6	21-1-80	10^H 40	47,9	44,4	B	30	28,00	3,5
7	17-2-80	10^H 38	47,5	45,6	B	30	29,10	1,9
8	17-2-80	11^H 38	47,2	45,2	B	30	29,00	2,3

AGBEBY Site I

Table : 5 plot 3

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	19-1-80	9^H 28	95,7	87,1	A	70	59,10	8,6
2	22-1-80	9^H 36	44,8	42,6	B	30	29,00	2,2
3	22-1-80	10^H 36	44,8	43,0	B	30	29,10	1,8
4	22-1-80	11^H 36	44,8	41,2	B	30	28,20	3,6

Table : 6 plot 4

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	19-1-80	11^H 59	96,4	87,8	A	70	59,20	8,6
2	22-1-80	13^H 19	45,4	42,1	B	30	28,30	3,3
3	22-1-80	14^H 19	45,4	40,6	B	30	27,50	4,8
4	22-1-80	15^H 19	45,4	38,7	B	30	26,50	6,7

AGBEBY Site II

Table : 7 plot 5

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	10-2-80	9H 24	96,2	86,4	A	70	58,40	9,8
2	11-2-80	11H 54	96,5	88,3	A	70	59,20	8,2
3	12-2-80	9H 01	95,5	88,3	A	70	59,20	8,2
4	14-2-80	8H 44	96,7	88,9	A	70	59,30	7,8
5	15-2-80	12H 06	96,7	82,7	A	70	56,50	14,0
6	15-2-80	13H.46	47,5	41,7	B	30	27,30	5,8
7	26-2-80	9H 05	45,6	43,0	B	30	28,50	2,6
8	26-2-80	10H 05	45,6	41,9	B	30	28,20	3,7

Table : 8 plot 6

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	10-2-80	12H 02	96,0	86,2	A	70	58,40	9,8
2	11-2-80	9H 24	96,9	87,9	A	70	59,00	9,0
3	12-2-80	11H 00	112,2	102,0	A	70	58,30	10,2
4	14-2-80	11H 01	96,0	81,2	A	70	56,40	14,8
5	15-2-80	8H 54	96,5	89,1	A	70	59,40	7,4
6	15-2-80	10H 34	47,1	42,1	B	30	28,10	4,3
7	26-2-80	11H 24	47,2	43,5	B	30	28,40	3,7
8	26-2-80	12H 24	47,2	45,3	B	30	29,10	1,9

AGBEBY Site II

Table : 9 plot 7

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	13-2-80	9^{H} 02	97,2	88,7	A	70	59,20	8,5
2	16-2-80	11^{H} 44	45,3	33,2	B	30	24,30	12,1
3	16-2-80	12^{H} 44	45,3	40,9	B	30	28,00	4,4
4	16-2-80	13^{H} 44	45,3	42,0	B	30	28,30	3,3

Table : 10 plot 8

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	13-2-80	11^{H} 21	96,7	87,7	A	70	59,00	9,0
2	16-2-80	8^{H} 27	47,5	44,8	B	30	28,50	2,7
3	16-2-80	9^{H} 27	47,5	44,0	B	30	28,30	3,5
4	16-2-80	10^{H} 27	47,5	42,4	B	30	27,50	5,1

NION Site I

Table : 11 plot 1

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	18-3-80	8^{H} 51	96,5	95,7	A	70	68,50	0,78
2	19-3-80	11^{H} 15	96,7	94,0	A	70	66,00	2,67
3	20-3-80	8^{H} 25	96,7	94,0	A	70	66,00	2,67
4	22-3-80	12^{H} 24	96,7	93,9	A	70	65,50	2,77
5	23-3-80	11^{H} 10	96,6	92,6	A	70	64,00	4,00
6	23-3-80	12^{H} 50	47,2	45,3	B	30	29,10	1,94
7	2-4-80	7^{H} 47	47,5	43,6	B	30	28,20	3,89
8	2-4-80	8^{H} 47	47,5	44,8	B	30	28,50	2,72

Table : 12 plot 2

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Tyepe of rain	tu min	te min/sec	Pi mm
1	18-3-80	12^{H} 07	96,6	54,9	A	70	20,00	41,7
2	19-3-80	8^{H} 30	97,1	74,9	A	70	28,30	22,2
3	20-3-80	10^{H} 46	97,9	88,9	A	70	39,20	9,0
4	22-3-80	14^{H} 03	96,6	-	A	70	-	96,6
5	23-3-80	8^{H} 14	96,7	73,7	A	70	32,40	23,0
6	23-3-80	9^{H} 54	47,5	39,3	B	30	10,10	8,2
7	2-4-80	9^{H} 45	47,5	-	B	30	-	47,5
8	2-4-80	10^{H} 45	47,5	24,2	B	30	5,00	23,3

NION Site I

Table : 13 plot 3

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	22-3-80	8^H 05	96,8	90,1	A	70	39,00	6,7
2	25-3-80	8^H 13	47,5	-	B	30	-	47,5
3	25-3-80	9^H 13	47,5	28,8	B	30	7,00	18,7
4	25-3-80	10^H 13	47,5	28,8	B	30	7,00	18,7

NION Site I

Table : 14 plot 4

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	22-3-80	10^H 17	96,8	88,4	A	70	12,30	8,4
2	25-3-80	11^H 14	45,3	-	B	30	-	45,3
3	25-3-80	12^H 14	45,3	29,5	B	30	8,00	15,8
4	25-3-80	13^H 14	45,3	29,5	B	30	14,1	13,1

NION Site II

Table : 17 plot 7

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	29-3-80	8^H 00	47	93,0	A	70	5,00	30,5
2	1-4-80	8^H 09	47,3	35,6	B	30	10,00	11,7
3	1-4-80	9^H 09	47,3	38,0	B	30	11,00	9,3
4	1-4-80	10^H 09	47,3	40,3	B	30	12,00	7,0

NION Site II

Table : 15 plot 5

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	26-3-80	8^H 58	96,3	95,6	A	70	52,30	0,7
2	27-3-80	10^H 48	86,2	79,7	A	70	50,00	6,5
3	28-3-80	8^H 15	95,7	88,6	A	70	59,10	7,1
4	30-3-80	9^H 53	96,1	88,2	A	70	55,00	7,9
5	31-3-80	8^H 15	96,0	87,4	A	70	49,10	8,6
6	31-3-80	9^H 55	44,4	40,6	B	30	28,10	3,8
7	7-4-80	10^H 49	47,5	40,5	B	30	12,10	7,0
8	7-4-80	11^H 49	47,5	42,4	B	30	12,50	5,1

Table : 16 plot 6

Rain N°	Date	Time hrs/min	Pu mm	Pe mm	Type of rain	tu min	te min/sec	Pi mm
1	26-3-80	11^H 17	96,5	79,9	A	70	31,00	16,6
2	27-3-80	8^H 23	96,6	89,2	A	70	44,30	7,4
3	28-3-80	10^H 07	95,7	87,1	A	70	49,00	8,6
4	30-3-80	8^H 01	103,0	95,2	A	70	60,00	7,8
5	31-3-80	11^H 04	96,7	87,3	A	70	43,50	9,4
6	31-3-80	12^H 44	47,5	41,7	B	30	25,00	5,8
7	7-4-80	12^H 40	47,5	44,4	B	30	13,40	3,1
8	7-4-80	13^H 40	47,5	44,0	B	30	13,10	3,5

5.3. Flow measurements

Tables, like the following, were made from measurements taken from the hydrographs made by the water-level recorder (recording the waterdepths which had flowed from the plots with the duration of the simulated rain).

Nion Site I 1^{st} rain date : 18.3.80

Table 18

t	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Pu	3,3	6,6	18,3	29,9	41,6	49,9	58,3	66,6	73,3	80,0	84,9	89,9	93,2	96,5
Lr	0,2	0,4	1,4	2,2	4,1	5,3	6,7	8,1	9,1	10,0	10,7	11,4	11,8	12,1

Table 19

I	Rx	Fn
39,7	3,6	36,1
140,0	19,5	120,5
100,0	18,8	81,2
80,0	13,6	66,4
60,0	8,5	51,5
39,7	4,4	35,3

Kru = 12,5 %

Kre = 12,6 %

Whereby
Pu = raindepth in mm
Lr = runoff depth in mm
I = rain intensity in mm/hr
Rx = max. runoff intensity in mm/hr
Fn = infiltration intensity in mm/hr
Kr = Runoff percentage measured against Pu

$$Kru = \frac{Lr}{Pu} \times 100 \quad \%$$

Kre = Runoff percentage measured against Pe

$$Kre = \frac{Lr}{Pe} \times 100 \quad \%$$

5.4. Soil humidity measurements

There were 3 types of soil humidity measurements. Samples were taken with the earth drill to determine humidity by weight, the neutron probe was used in combination with the γ-probe density-determination to give humidity by volume, and the new thermic shock was put to the test.

5.4.1. The earth drill

The following samples were taken : 3 repetitions of profile upto 100 cm (where possible) before the first rains on all plots, upto 50 cm (where possible) before and after each rain on all plots and upto 100 cm after the last rain on all plots. Here is an example from Agbeby, site II.

Agbeby Site II plot 6 2nd rain date : 11.2.80

Table 20

	Depth cm	Weights in grams			Humidity as % soil weight
		Empty tin	tin + humid soil	tin + dry soil	
Befor the rain	10	44,3	283,34	256,70	12,5
	20	45,2	302,30	270,31	14,2
	30	44,5	325,68	288,52	15,2
	40	44,3	309,32	271,30	16,8
	50	44,7	315,36	276,07	17,0
	10	45,7	301,42	274,98	11,5
	20	44,3	308,92	277,00	13,7
	30	45,6	303,32	267,78	16,0
	40	45,0	329,70	289,32	16,3
	50	44,7	298,03	261,46	16,9
	10	45,0	259,02	239,40	10,1
	20	44,8	282,40	253,76	13,7
	30	44,9	302,47	268,08	15,4
	40	44,4	310,60	272,74	16,6
	50	45,7	306,75	270,77	16,0
After the rain	10	43,9	262,50	241,79	10,5
	20	44,2	293,84	258,47	16,5
	30	44,9	315,43	272,99	18,6
	40	44,7	337,50	290,98	18,9
	50	44,6	325,96	280,87	19,1
	10	44,6	264,30	235,23	15,3
	20	44,9	312,30	267,95	19,9
	30	44,4	314,80	273,68	17,9
	40	45,6	283,62	244,71	19,5
	50	44,2	331,31	285,67	18,9
	10	44,2	286,22	258,84	12,8
	20	44,1	315,50	280,07	15,0
	30	44,5	293,94	256,27	17,8
	40	45,2	342,31	296,34	18,3
	50	44,7	329,55	285,63	18,2

5.4.2. The neutron probe

The neutron probe measurements were recorded as follows

Agbeby Site II plot 5 1st rain date : 10.2.80

table 21 : No. of digital counts on the alluminated counter.

Depth cm \ Time	7H 10	7H 20	7H 35	7H 50	8H 00	8H 10	8H 20
10	13909	21245	23343	24296	25164	25166	24203
20	17306	18669	22332	24826	24629	26230	26519
30	18290	18473	18697	20473	22435	23529	24248
40	17900	17600	17596	18432	19211	20121	21147
50	16734	16900	16511	17059	16979	17382	18070
60	16037	16000	16012	16179	16145	16089	16142
80	15493	15693	15584	15728	15326	15208	15510
100	15454	15428	15525	15398	15473	15388	15280
Reference count in protective cover : 14295							

The measurements at a depth of 10 cm are frequently neglected as this method is not reliable at or near the surface.

5.4.3. The thermic shock

Here an example of the thermic shock measurement.

Nion Site I plot 1 2nd rain date : 19.3.80

	Probe No	Probe Depth	Voltage range	temp before 1/100°C	Max. temp after 1/100°C	ΔT 1/100°C	Current intensity of shock m Amps m Amps
Before the rain	0	5 cm	117-120	310	897	587	777 - 779
	1	10 "	120-123	270	587	317	796 - 799
	2	15 "	117-119	-1335 *	-1081	254	794 - 796
	3	20 "	-	-	-	-	-
After the rain	0	5 "	116-119	321	836	515	777 - 798
	1	10 "	116-119	241	521	280	795 - 780
	2	15 "	-	- *	-	-	-
	3	20 "	-	- *	-	-	-

* here no stabilisation took place

It frequently occurred that one or more probes malfunctioned. This is an indication of the weakness of such fragile, electric instruments in field work.

VI. PREPARING BASIC RESULTS

6.1. Basic runoffdepths and runoff-intensities

With the results as found in tables 18 and 19, I drew the lines of runoffdepths (Lr) as a function of raindepths (Pu), and of the maximum runoff-intensity (Rx) as a function of the rain intensity (I). From these cuves, each one corresponding to an initial state of soil humidity for the plot, were tabulated the runoffdepths corresponding with raindepths of 100, 75 and 50 mm and its state of initial soil humidity (IK). I also tabulated the runoff intensitues corresponding with the same initial state of soil humidity and with the rain intensities of 100 mm/h, 75 mm/h and 50 mm/h.

Examples of these results amongst others, one finds tabulated here-after.The collumns give the following values

Collumn 1 : simulated rain no for that plot
Collumn 2 : Index of initial soil humidity, IK

$$IK = \Sigma P e^{-\alpha t}$$

with P = previous precipitation (in mm)
t = time since previous precipitation (in days)
α = an adjustment coëfficient, here equal to 0,5

For further details see report of 1978 campaign(I)

Collumn 3 : total runoffdepths (in mm), Lr
Collumn 4 : Infiltration depths Li = Pu - Lr, in mm
Collumn 5 : Runoff coëfficient Kru as function of Pu, Kru = 100 x Lr/Pu in %
Collumn 6 : Runoff coëfficient Kre as a function of Pe, Kre = 100 x Lr/Pe in %
Collumn 7 to 9 : Runoffdepth (in mm) corresponding with raindepths of 100, 75 and 50 mm, taken from above mentioned curves
Collumn 10 to 12 : Maximal runoff intensities (mm/h), corresponding with the rainintensities of 100, 75, and 50 mm/h taken from above mentioned curves
Collumn 13 : total raindepth, Pu in mm

AGBEBY Site I

Table : 23 plot I

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	3,2	94,6	3,3	3,7	4,9	3,6	2,2	4,2	1,3	0	97,8
2	56	1,2	93,6	1,7	1,5	1,4	1,0	0,7	2,6	0,6	0	94,8
3	101	2,0	97,5	2,0	2,2	2,7	2,0	1,2	2,6	0,8	0	99,5
4	76	0,8	96,6	0,8	1,0	1,1	0,8	0,4	1,6	1,0	0	97,4
5	99	1,5	94,6	1,6	1,8	2,1	1,5	0,9	2,0	0,8	0	96,1
6	188	2,0	44,7	4,3	4,4	5,2	3,9	2,6	0	0	0	46,7
7	1	7,2	39,7	15,4	16,0	9,7	8,6	7,5	27,2	13,9	0,5	46,9
8	48	2,2	44,7	4,7	4,9	5,6	4,2	2,8	0	0	0	46,9

Table : 24 plot 2

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	2,5	96,6	2,5	2,7	2,8	2,1	1,3	2,9	2,1	1,2	99,1
2	68	1,8	95,5	1,8	2,0	2,1	1,5	0,9	2,4	1,8	1,2	98,3
3	98	1,2	95,3	1,2	1,4	1,6	1,1	0,7	1,8	1,2	0,6	96,5
4	74	0,7	95,9	0,7	0,8	0,9	0,6	0,4	0,9	0,6	0,3	96,6
5	112	1,1	96,1	1,1	1,2	1,4	1,0	0,7	1,3	0,8	0,3	97,2
6	202	1,5	46,4	3,1	3,4	4,1	3,0	1,9	0	0	0	47,9
7	1	3,1	44,4	6,5	6,8	7,6	5,7	3,8	7,4	4,2	1,1	47,5
8	48	2,9	44,6	6,1	6,4	7,2	5,3	3,4	6,6	4,0	1,5	47,5

AGBEBY Site I

Table : 25 plot 3

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	2,4	93,3	2,5	2,8	3,0	2,3	1,6	3,2	1,7	0,2	95,7
2	22	3,0	41,8	6,7	7,0	7,0	5,3	3,6	8,8	5,6	2,3	44,8
3	66	3,3	41,5	7,4	7,7	9,3	6,8	4,3	10,7	6,7	2,8	44,8
4	110	2,8	42,0	6,3	6,8	7,4	5,5	3,6	7,8	5,0	2,2	44,8

Table : 26 plot 4

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	0,8	93,6	0,8	0,9	1,1	0,9	0,6	0,7	0	0	96,4
2	20	0,5	44,9	1,1	1,2	1,4	1,1	0,8	0	0	0	45,4
3	65	0,4	45,0	0,9	1,0	1,1	0,8	0,5	0	0	0	45,4
4	109	0,4	45,0	0,9	1,0	1,1	0,8	0,5	0	0	0	45,4

AGBEBY Site II

Table : 27 plot 5

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	2,6	93,6	2,7	2,7	3,4	2,5	1,7	3,2	1,6	0	96,2
2	57	1,6	94,9	1,7	1,8	2,3	1,6	0,8	2,8	1,2	0	96,5
3	101	2,1	94,4	2,2	2,4	3,2	2,4	1,5	2,5	0,7	0	96,5
4	75	1,7	95,0	1,8	1,9	2,4	1,8	1,1	1,9	0,4	0	96,7
5	99	1,5	95,2	1,6	1,8	1,9	1,4	0,8	1,9	1,0	0	96,7
6	189	0,8	46,7	1,7	1,9	2,5	1,9	1,2	0	0	0	47,5
7	2	1,5	44,1	3,3	3,5	3,5	2,8	2,0	0	0	0	45,6
8	47	0,5	45,1	1,1	1,2	1,6	1,2	0,8	0	0	0	45,6

Table : 28 plot 6

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	2	94,0	2,1	2,3	2,1	1,5	0,9	2,5	2,3	0	96,0
2	63	1,5	95,4	1,6	1,7	1,7	1,2	0,8	1,6	1,5	0	96,9
3	96	4,3	107,9	3,8	4,2	3,6	2,5	1,4	5,7	5,2	0	112,2
4	78	0,4	95,6	0,4	0,5	0,6	0,4	0,2	1,1	0,8	0	96,0
5	115	1,4	95,1	1,5	1,6	1,8	1,3	0,8	2,2	0,8	0	96,5
6	204	0,9	46,2	1,9	2,1	2,6	1,9	1,2	2,4	1,1	0	47,1
7	55	1,8	45,4	3,8	4,1	3,4	2,8	2,1	0	0	0	47,2
8	2	0,4	46,8	0,9	0,9	1,0	0,8	0,6	0	0	0	47,2

AGBEBY Site II

Table : 29 plot 7

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	2,6	94,6	2,7	2,9	4,3	3,3	2,3	1,4	0,4	0	97,2
2	21	0,5	44,8	1,1	1,5	1,7	1,3	0,8	0	0	0	45,3
3	66	0,7	44,6	1,6	1,7	2,3	1,7	1,0	0	0	0	45,3
4	110	0,9	44,4	2,0	2,1	2,3	1,7	1,1	2,3	1,6	0,8	45,3

Table : 30 plot 8

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	0	1,3	95,4	1,3	1,5	2,5	1,8	1,1	1,0	0	0	96,7
2	24	2,9	44,6	6,1	6,5	4,7	3,9	3,1	0	0	0	47,5
3	70	1,3	46,2	2,7	3,0	2,4	1,9	1,4	0	0	0	47,5
4	117	3,4	44,1	7,2	8,0	6,3	5,0	3,7	0	0	0	47,5

NYON Site I

Table : 31 plot 1

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	6	12,1	84,4	12,5	12,6	13,4	9,4	5,4	19,2	12,8	5,3	96,5
2	61	5,8	90,9	6,0	6,2	6,7	4,8	3,0	16,7	8,2	1,8	96,7
3	104	6,4	90,3	6,6	6,8	6,7	5,0	3,3	12,1	4,4	2,2	96,7
4	89	8,4	88,3	8,7	8,9	10,0	7,3	4,7	9,7	6,7	3,6	96,7
5	119	6,4	90,2	6,6	6,9	7,7	5,6	3,5	7,5	4,5	2,2	96,6
6	213	4,0	43,2	8,5	8,8	8,9	6,6	4,3	9,0	6,7	4,3	47,2
7	4	2,2	45,3	4,6	5,0	5,3	4,0	2,6	6,2	4,3	1,4	47,5
8	51	2,8	44,7	5,9	6,2	6,7	5,0	3,3	8,8	6,2	3,7	47,5

Table : 32 plot 2

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	6	0,2	96,4	0,2	0,3	0,2	0,1	0,1	1,0	0,6	0,2	96,6
2	69	0,3	96,8	0,3	0,4	0,3	0,3	0,2	0,4	0	0	97,1
3	98	0,8	97,1	0,8	0,9	1,2	0,9	0,6	0,8	0,4	0,2	97,9
4	88	0	96,6	0	0	0	0	0	0	0	0	96,6
5	130	0,3	96,4	0,3	0,4	0,3	0,2	0,1	0	0	0	96,7
6	224	0,7	46,8	1,5	1,8	1,5	1,1	0,7	0	0	0	47,5
7	4	0	47,5	0	0	0	0	0	0	0	0	47,5
8	51	0,1	47,4	0,2	0,4	0,1	0,1	0,1	0	0	0	47,5

NYON Site I

Table : 33 plot 3

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	16	0,6	96,2	0,6	0,7	0,6	0,5	0,4	0,7	0,6	0,5	96,8
2	26	0,0	47,5	0	0	0	0	0	0	0	0	47,5
3	73	0,2	47,3	0,4	0,7	0,3	0,3	0,2	0	0	0	47,5
4	119	0,2	47,3	0,4	0,7	0,4	0,3	0,2	0	0	0	47,5

NYON Site I

Table : 34 plot 4

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	16	0,2	96,6	0,2	0,2	0,3	0,2	0,1	0,1	0	0	96,8
2	25	0	45,3	0	0	0	0	0	0	0	0	45,3
3	70	0,2	45,1	0,4	0,7	0,5	0,4	0,3	0	0	0	45,3
4	114	1,3	44,0	2,9	4,4	2,5	2,0	1,4	0	0	0	45,3

NYON Site II.

Table : 37 plot 7

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	5	0,1	92,9	0,1	0,2	0,1	0,1	0,1	0	0	0	93,0
2	22	0,2	47,1	0,4	0,6	0,4	0,3	0,2	0	0	0	47,3
3	69	0,3	47,0	0,6	0,8	0,6	0,5	0,4	0	0	0	47,3
4	115	0,5	46,8	1,1	1,2	1,2	0,9	0,6	0	0	0	47,3

NYON Site II

Table : 35 plot 5

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	23	4,1	92,2	4,2	4,3	6,0	4,4	2,9	4,1	2,0	1,3	96,3
2	72	2,4	83,8	2,8	3,0	3,2	2,4	1,6	3,2	2,8	0	86,2
3	103	2,8	92,9	2,9	3,2	3,5	2,6	1,7	4,4	1,6	1,4	95,7
4	73	2,6	93,5	2,7	2,9	3,3	2,4	1,5	4,4	2,4	0,8	96,1
5	108	2,3	93,7	2,4	2,6	3,1	2,2	1,3	5,3	2,7	2,1	96,0
6	202	1,5	42,9	3,4	3,7	3,8	2,8	1,8	4,7	3,2	1,7	44,4
7	11	0,5	47,0	1,1	1,2	1,4	1,0	0,6	0	0	0	47,5
8	36	1,2	46,3	2,5	2,8	2,7	2,0	1,3	3,5	1,9	0,4	47,5

Table : 36 plot 6

Rain N°	IK	Lr	Li	Kru	Kre	Lr 100	Lr 75	Lr 50	Rx 100	Rx 75	Rx 50	Pu
1	22	0,4	96,1	0,4	0,5	0,4	0,3	0,2	0,6	0,5	0	96,5
2	78	0,7	95,9	0,7	0,8	0,9	0,6	0,4	0,8	0,6	0	96,6
3	105	1,0	94,7	1,0	1,1	1,1	0,8	0,5	1,6	0,9	0,2	95,7
4	79	1,5	101,5	1,5	1,6	1,6	1,2	0,9	1,5	1,1	0,7	103,0
5	106	1,0	95,7	1,0	1,1	1,1	0,8	0,6	2,0	1,0	0	96,7
6	201	0,6	46,9	1,2	1,4	1,7	1,2	0,7	1,9	1,2	0,5	47,5
7	11	0,4	47,1	0,8	0,9	1,1	0,8	0,5	0	0	0	47,5
8	58	0,8	46,7	1,7	1,8	1,4	1,1	0,7	2,6	1,7	1,0	47,5

6.2. Calculating soil humidity

Examples of the results of earth drill samples are given in table 20. These were then graphed in soil humidity profiles.

The results of the Neutron probe were transformed as follows :

under table 23 one finds the reference count in the protective cover which was equal to 14295. Gauging in 100 % water at the laboratory gave a count of 74483. Transforming linearly to pro-mille with "n" the no of counts gives

$$n/74483 \times 1000$$

Table 21 now looks as follows :

AGBEBY SITE II Plot 5 1st rain date : 10.2.80

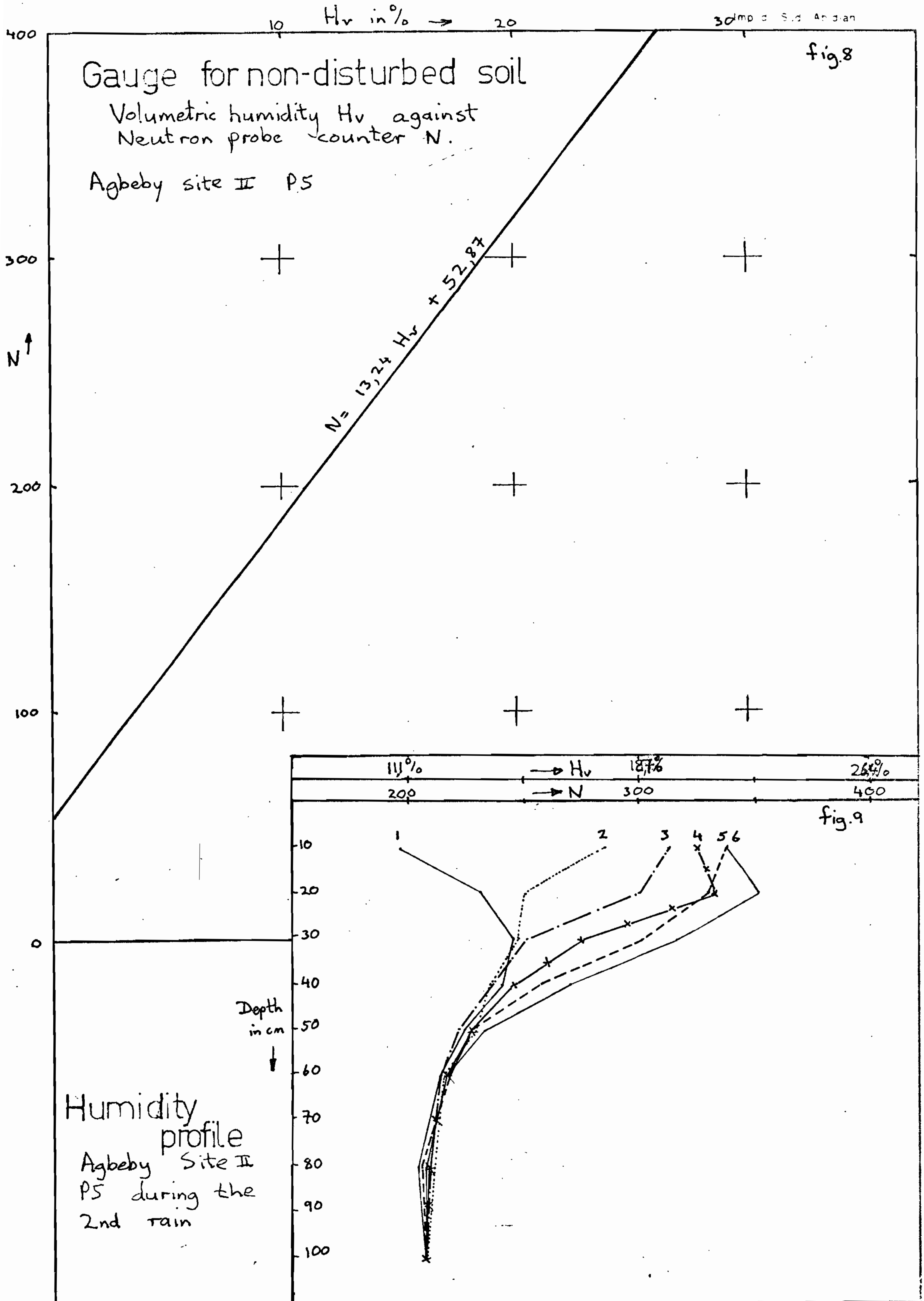
Table 21c digital count equivalent

Depth cm \ Time	7h10	7h20	7h35	7h50	8h00	8h10	8h20
10	187	285	313	326	338	338	325
20	232	251	300	333	331	352	356
30	246	248	251	275	301	316	326
40	240	236	236	247	258	270	284
50	225	227	222	229	228	233	243
60	215	215	215	217	217	216	217
80	208	211	209	211	206	204	208
100	207	207	208	207	208	207	205

After having taken α-probe measurements at different depths to determine the soil density, the proton-lab was able to deliver a guaging curve giving the volumic soil humidity corresponding with a certain transformed counter no. (see fig 8). With the aid of this curve it was possible to determine soil humidities and draw humidity profiles. For an example see fig 9.

The thermal shock measurements being in their experimental stage were only of limited use. The measurements did deliver a reasonable trend - i.e higher humidity percentages after rains than before rains and higher percentages after several rains - but clarity on relation constants was limited by a large percentage of fallout. One guaging was possible with the humidity weight percentages obtained by soil sampling at equal depths. In 2 cases, both in Agbeby, a relation could be found with the aid of at least 5 points and a correlation coefficient with $r^2 > 0,60$. For a relation, between the inverse of the temperature (1/Tm) and the humidity weight percentage (Hp), was found that in

$$Hp = a \times (1/Tm) + b$$



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Similar results for a and b were obtained for Agbeby plot 1 at 5 cm depth and plot 6 at 20 cm depth.

Agbeby 1 : $Hp \simeq 54{,}16 \times (1/Tm) - 9{,}25$

Agbeby 6 : $Hp \simeq 55{,}5 \times (1/Tm) - 12{,}13$

With these relations it is possible to estimate the soil humidity in one point in the profile of each plot. With one assumption, that the soils are homogeneous, it is possible to extend the usefulness of the relations. Then one can use the relation for the whole profile and it is possible to calculate soil humidity profiles, from the thermic shock measurements. Unfortunately the no. of depths at which the humidity could be determined is insufficient to draw a humidity profile or to be used for explanation. Here follows one example, however, to show that results can be very good.

AGBEBY Plot 6 depth : 20 cm

humidity percentages Hp

method \ Before rain	1	2	3	4	5
thermic shock	9,0	-	12,8	14,5	14,5
soil sampling	8,7	-	13,4	14,1	14,8

VII. ANALYSIS OF THE RESULTS

7.1. Introduction

As has been mentioned by A. Casenave in the report on the campaign of 1978 (I), the determination of the humidity of the soil is not a simple matter. Again this year the results of the earth drill samples were widely spread. This year an attempt has been made to determine soil humidities near the surface, i.e. soil samples of 0-5 cm and 5-10 cm, but because of the high organic matter content this presents problems. Neutron probe measurements near the surface are not representative either. In general an estimation of the humidity of the soil based on point measurements (e.g. ground drill, neutron probe, thermic shock) is very dependant on the place of the measurement and often not representative of the soil horizon as a whole.

As an estimation of the humidity of the soil in greater context, use has been made of the distribution of the rain with concern to time. Again this year this has been done using the IK index (see 6.1). This is also done because it is favourable to use the same method as used in previous studies. This index will be used in the analysis.

The initial soil humidity index halfway through the rain season (equal to the value generally present when calculating the maximum discharge with ten years frequency) is around the 50.

After determining the IK-runoffdepths and the IK-runoff intensity relations, the humidity profiles are discussed.

7.2. Study of the runoff depths

One site (site II of Nyon) will be dealt with in full to explain the method of interpreting the results. There-after the results of the other sites will be discussed.

7.2.1. Nyon site II

7.2.1.1. The runoffdepth-raindepth humidity index relations

In tables 35-37 one finds, for different rains, values of runoff depths (Lr) in relation to IK. These have been plotted for raindepths (Pu) of 100, 75 and 50 mm for rains 1-5 on plot 6 with vegetation and for plots 5 and 7 under denuded conditions (see fig. 10).

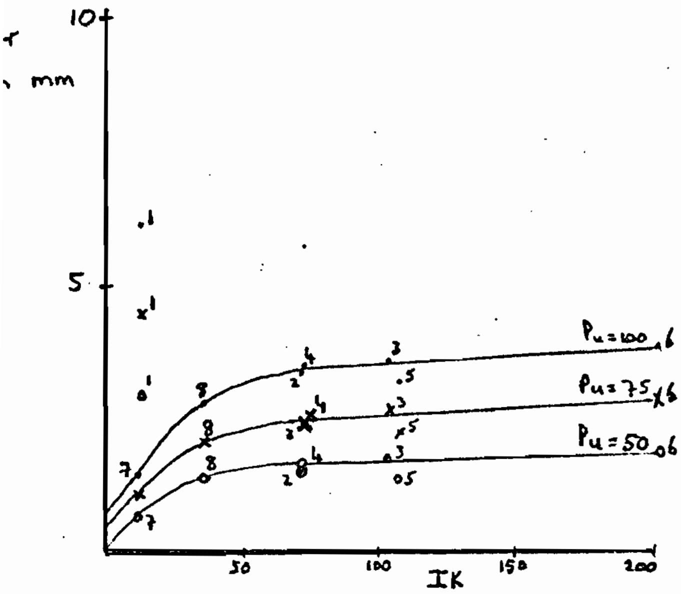
7.2.1.2. The influences of the soil differences

It is now possible to find the relation between the runoff depths of the different plots taking into account the raindepths and the humidity index.

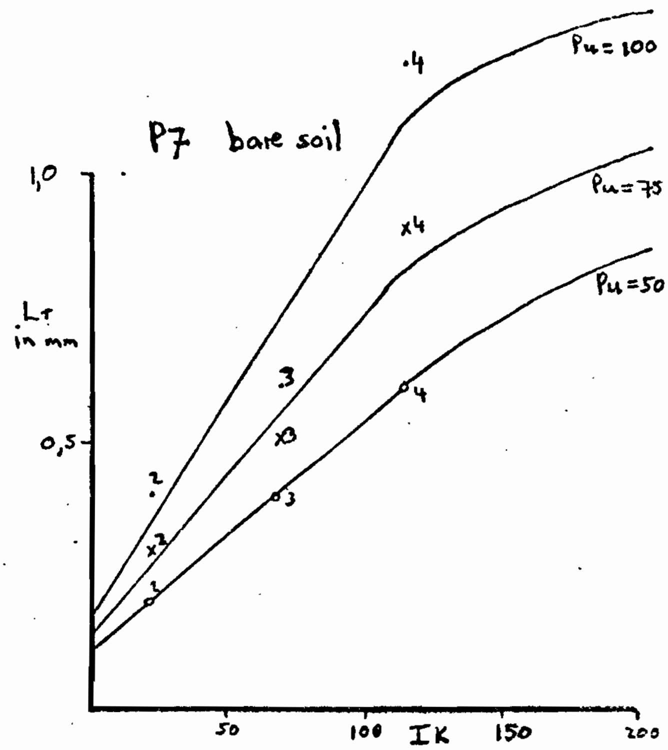
fig. 10

Nyon Site II

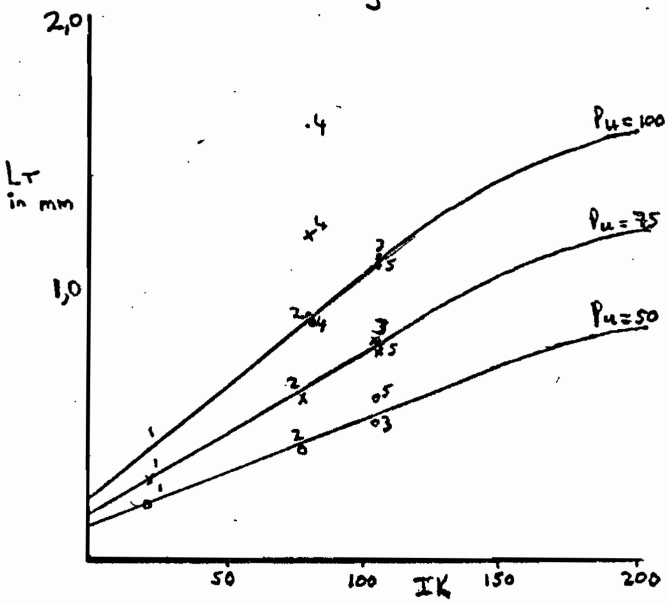
P5 bare soil



P7 bare soil



P6 vegetated soil



For the raindepth of 100, 75 and 50 mm one now compares the runoff depths occuring on different plots at equal initial soil humidity condition (IK). Here this is done for IK values of 0,30, 50,100,150 and 200.

Table 38 : - Lr in mm -

Pu mm	Plot N° IK	0	30	50	100	150	200
100	P5 P7	0,7 0,2	2,3 0,4	3,0 0,6	3,5 1,0	3,7 1,2	3,8 1,3
75	P5 P7	0,4 0,1	1,8 0,3	2,3 0,5	2,5 0,7	2,7 0,9	2,8 1,0
50	P5 P7	0,1 0,1	1,2 0,2	1,5 0,3	1,6 0,5	1,7 0,7	1,8 0,8

Bringing into a graph these runoff depths gives an influence curve of how soil of plot 7 transforms rain to runoff in comparison to how the soil of plot 5 (taken as reference plot for denuded soil for site II) does this. Examination of the graph, see fig. 11, makes apparent that the runoff of plot 7 is nearly always about 33% of that of plot 5. This indicates how important the soil and soil conditions can be with regard to determining the runoff.

If one looks at the slopes of plots 5 and 7 they are 14% and 18% respectively. The influence of the slope on the infiltration rate is small in this limited range and may be disregarded. This has been shown in previous experiments.

The graph thus indicates that maximum runoffs on soil types of plot 5 and 7, under similar conditions other than soil properties, occur on soil of plot 5. It is also possible to transform runoffs of plot 5 (or 7) to runoffs of plot 7 (or 5) if the climatic conditions have been the same for these plots.

7.2.1.3. The influence of the vegetation

Similarly, as for soil differences, one now compares runoff depth of plots 5 and 6 with similar climatic and initial soil conditions i.e for raindepth values of 100, 75 and 50 mm and initial soil humidity index values of 0, 50, 100, 150 and 200. The values of the following table, obtained from the graphs in fig. 10, are plotted against each other in the graph of fig. 12.

Table 39 : - Lr in mm -

Pu mm	Plot N° IK	0	50	100	150	200
100	P5 (bare soil) P6 (vegetated)	0,7 0,2	3,0 0,6	3,5 1,1	3,7 1,4	3,8 1,6
75	P5 P6	0,4 0,2	2,3 0,5	2,5 0,7	2,7 1,0	2,8 1,2
50	P5 P6	0,1 0,1	1,5 0,3	1,6 0,5	1,7 0,7	1,8 0,9

fig. 11

Nyon Site II

influence of the soil

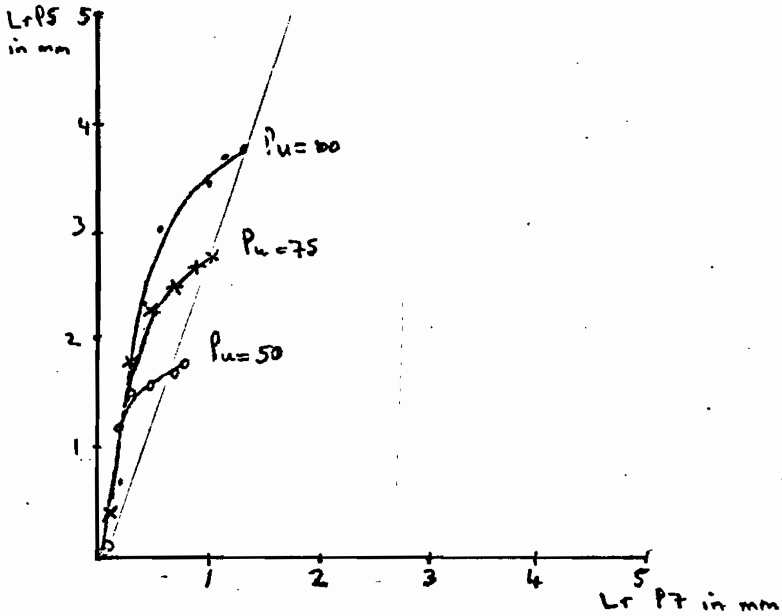
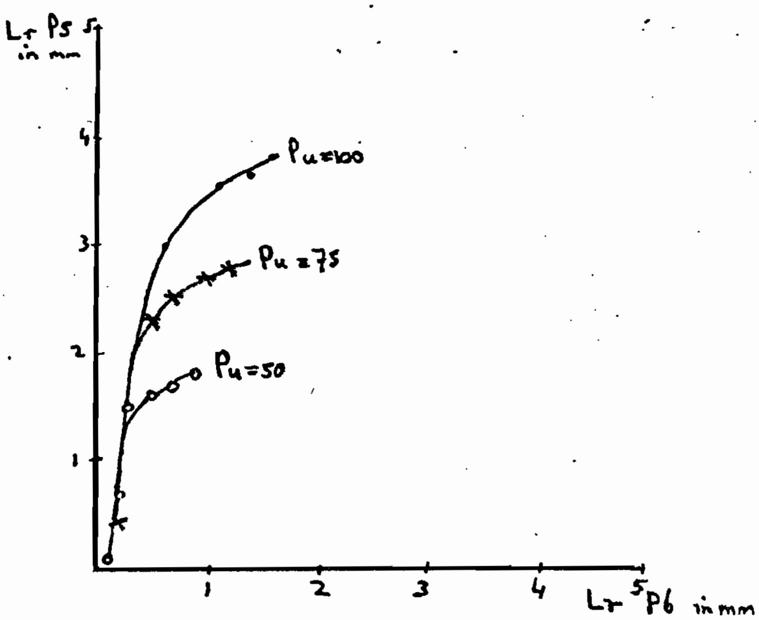


fig.12

influence of the vegetation



From the graph it is clear that the vegetation has a retaining interceptive function with a minimum of 60% retention at humidity indici < 150 (which is in nearly all cases). If the IK values remain < 100 then runoff depths are < 1 mm. With IK values > 150 the vegetation seems to be drenched and approaching its maximum interceptive capacity. The remaining runoff depths differences must then be attributed to influences of the soil type.

7.2.1.4. Site representative curves

With the curves giving the influence of the soil type and the influence of the vegetation, one can now produce curves which represent the runoff of the site in general. The values found in tables 35-37 are corrected for by the influence curves. In tabulated form this gives the following results. (table 40).

Table 40 : - IK values -

Plot N°	rain N°	IK	Ir 100	Lr 75	Lr 50	denuded			vegetation		
						Lrc 100	Lrc 75	Lrc 50	Lrc 100	Lrc 75	Lrc 50
P5	1	23	6,0	4,4	2,9						
	2	72	3,2	2,4	1,6				0,7	0,6	0,5
	3	103	3,5	2,6	1,7				1,1	0,8	0,6
	4	73	3,3	2,4	1,5				0,8	0,6	0,3
	5	108	3,1	2,2	1,3				0,7	0,4	0,2
	6	202	3,8	2,8	1,8				1,6	1,2	0,8
	7	11	1,4	1,0	0,6				0,2	0,2	0,2
	8	36	2,7	2,0	1,3				0,5	0,3	0,2
P6	1	22	0,4	0,3	0,2	2,5	1,8	0,7			
	2	78	0,9	0,6	0,4	3,4	2,4	1,5			
	3	105	1,1	0,8	0,5	3,5	2,6	1,6			
	4	79	1,6	1,2	0,9	3,9	2,9	1,8			
	5	106	1,1	0,8	0,6	3,5	2,6	1,7			
	6	201	1,7	1,2	0,7	3,7	2,7	1,6			
	7	11	1,1	0,8	0,5	1,5	1,1	0,2			
	8	58	1,4	1,1	0,7	3,0	2,4	1,6			
P7	1	5	0,1	0,1	0,1						
	2	22	0,4	0,3	0,2	2,4	1,9	1,2			
	3	69	0,6	0,5	0,4	2,9	2,3	1,5			
	4	115	1,2	0,9	0,6	3,4	2,7	1,7			

The graphs of fig. 13 represents these influences of the initial soil humidity on runoff depth for site II in general with plot 5 as reference for denuded soils and plot 6 as reference for plots with vegetation.

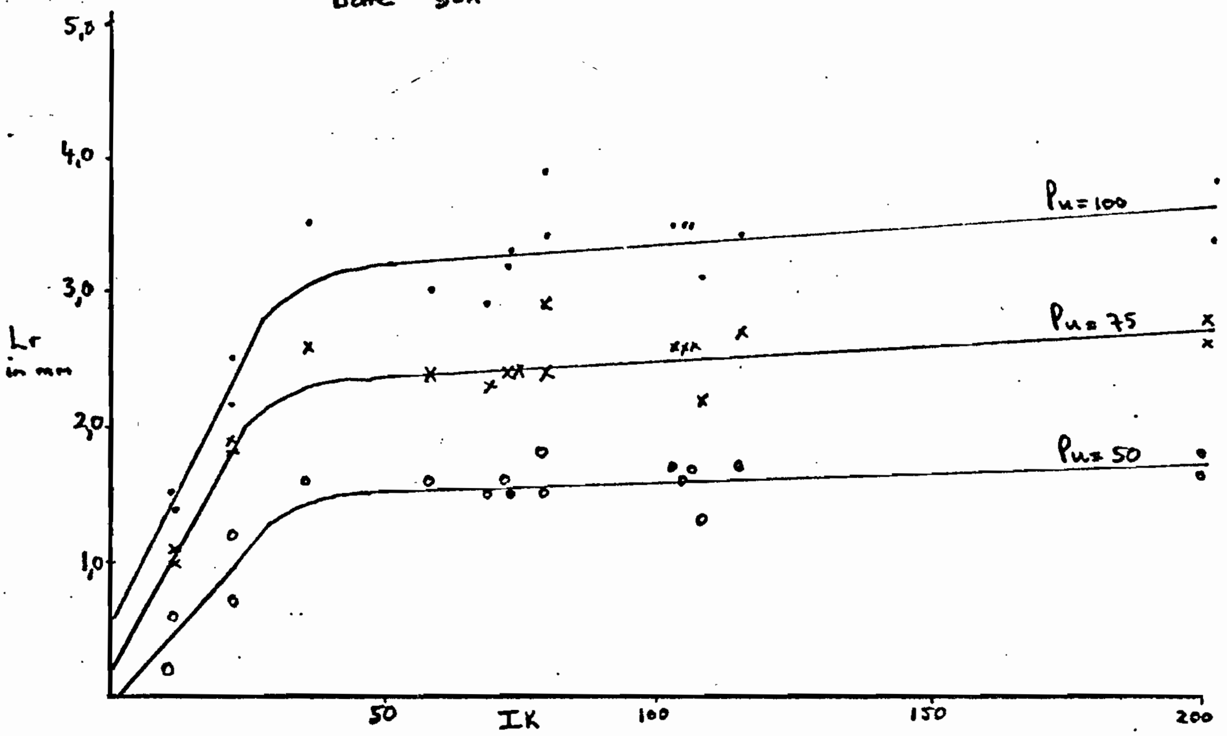
The curves show that soils at this site have a strong infiltration capacity and runoff is not more than 4% for denuded soils and not more than 2% for soils with vegetative cover.

Runoff from a dry surface, i.e. IK = 0, is < 1%.

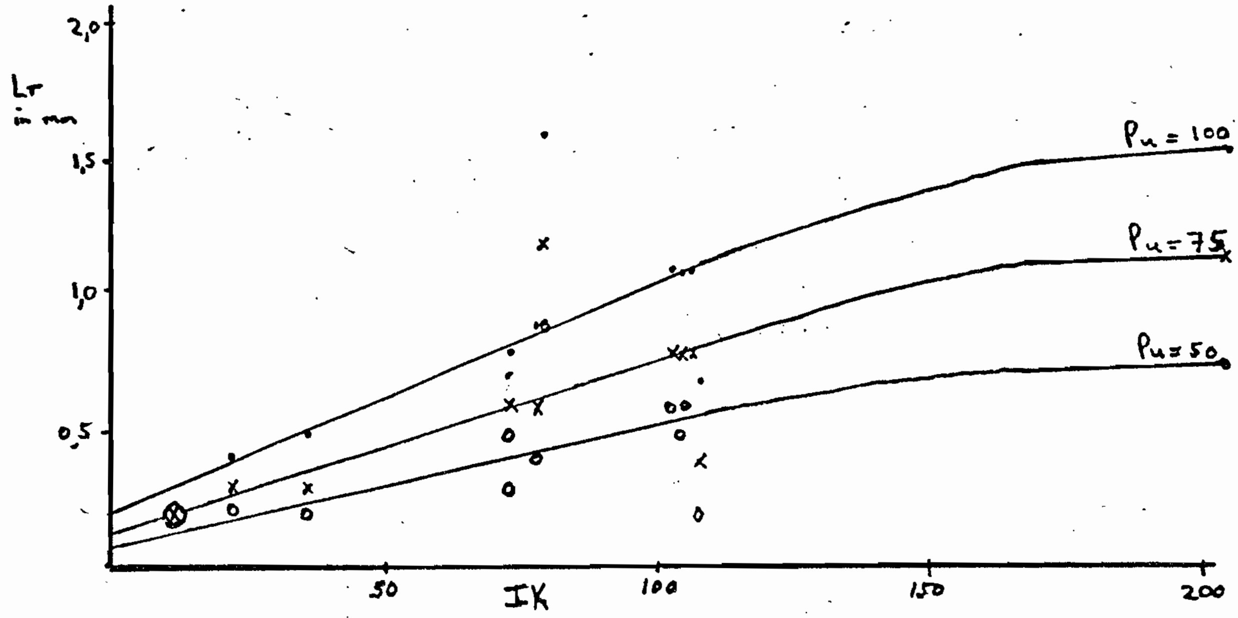
Nyon Site II

fig. 13

Site representative curve for bare soil



Site representative curve for plots with vegetation



7.2.2. Nyon Site I

7.2.2.1. The runoffdepth-raindepth humidity index relations

As is described in 7.2.1., the values of tables 31-34 have also been plotted to find soil humidity-runoff relations. From these graphs were taken values at soil humidity indici of 0,30,50, 100,150 and 200 to give tables similar to those of tables 38 and 39.

From these tables runoffs are again comparable as raindepths and soil humidity conditions are similar.

7.2.2.2. The influence of the soil differences (fig. 14)

The above mentioned graphs,e.g. for soil type of plot 1 (reference plot), indicate an increased runoff with in creasing initial soil humidity. This trend leads to a maximum of 10 mm, 7 mm and 5 mm for raindepths of 100, 75 and 50 mm respectively. There occurs one exception, with a runoff of 13,4 mm, on plot 1 which was during the first rain of the season. Here a possible crust or cake, forming during the dry season, could have increased the resistance to infiltration. This case is not representative of a runoff in the middle of the rainy season (IK = 6 is also not representative).

The relation between runoffs of plots 1-2* and of plots 1-4 are given in graphs in figure.14. Immediately one observes that runoff of plots 2 and 4 commences** only after plot 1 has had runoffs of 6,3 mm, 4,5 mm and 3,0 mm for raindepths of 100, 75 and 50 mm respectively. After this initial difference, which occurs at IK values < 50 at both plots 2 and 4, the soil influences no longer the same for plots 2 and 4. For soil type of plot 2 the runoff there after is about 200% of that of plot 1 and for soil type of plot 4 the runoff is about 50% that of plot 1.

For plot 3 a runoffdepth relation with plot 1 could not be defined as a curve of the runoff of plot 3 did not exceed 0,5mm. This is in the magnitude of possible errors. One can simply state that infiltration in soil types of plot 3 is 99% and runoff is negligable.

7.2.2.3. The influence of the vegetation

About the influence of the vegetation can only be concluded that for soils of type of plot 2 the runoffdepths remain less than 1,2 mm for all tested conditions, i.e. IK < 130 and raindepth (Pu) equal to 100 mm. Here the values are again so small that the error margin makes the determination of a relation between runoffdepths of P1 and P2, uncertain.

7.2.2.4. Site representative curves

Using the curves of the influence of the soil differences (fig. 14), one can again find corresponding values for plots 1 and 2 and for plots 1 and 4..

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* for plot 2 results are taken from rains 6, 7 and 8 only, when vegetation has been cut.

** IK = 0

Nyon Site I

fig.14

influence of the soil

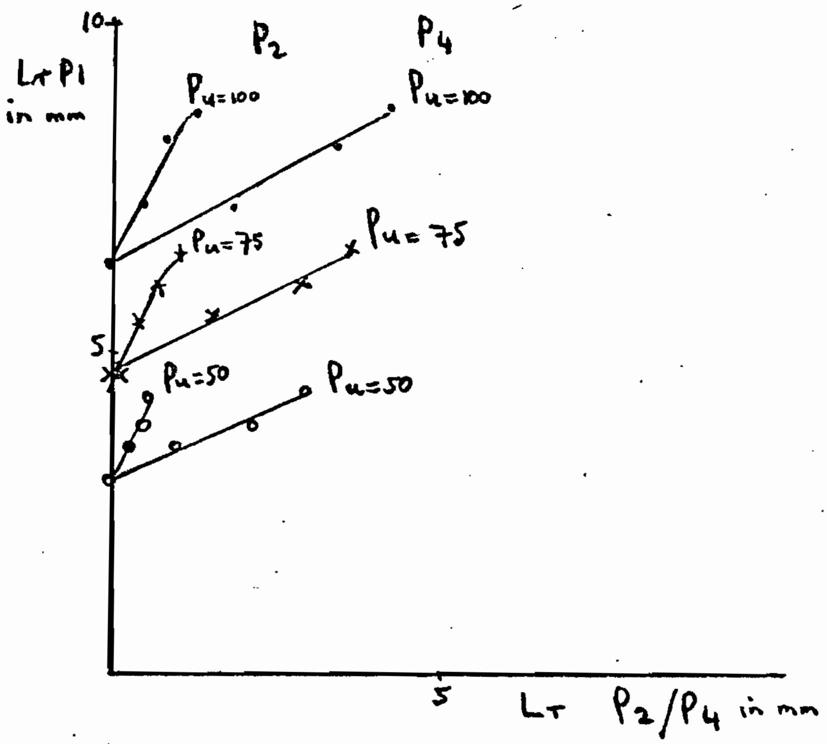
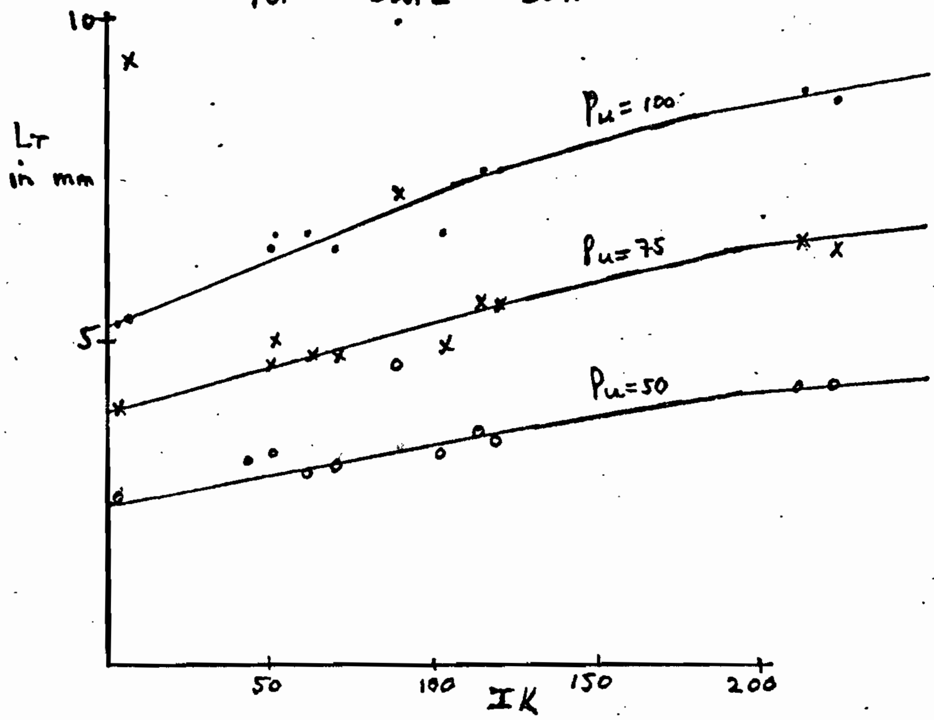


fig.15

Site representative curve for bare soil



The results one finds in table 41 and the graph of fig. 15.

Table 41 : - Corrected runoffdepths in mm -

Plot N°	Rain N°	IK	Lr 100	Lr 75	Lr 50	denuded soil			vegetation		
						Lrc 100	Lrc 75	Lrc 50	Lrc 100	Lrc 75	Lrc 50
	1	23	6,0	4,4	2,9						
	2	72	3,2	2,4	1,6				0,7	0,6	0,5
P5	3	103	3,5	2,6	1,7				1,1	0,8	0,6
	4	73	3,3	2,4	1,5				0,8	0,6	0,3
	5	108	3,1	2,2	1,3				0,7	0,4	0,2
	6	202	3,8	2,8	1,8				1,6	1,2	0,8
	7	11	1,4	1,0	0,6				0,2	0,2	0,2
	8	36	2,7	2,0	1,3				0,5	0,3	0,2
	1	22	0,4	0,3	0,2	2,5	1,8	0,7			
	2	78	0,9	0,6	0,4	3,4	2,4	1,5			
	3	105	1,1	0,8	0,5	3,5	2,6	1,6			
	4	79	1,6	1,2	0,9	3,9	2,9	1,8			
	5	106	1,1	0,8	0,6	3,5	2,6	1,7			
	6	201	1,7	1,2	0,7	3,7	2,7	1,6			
	7	11	1,1	0,8	0,5	1,5	1,1	0,2			
	8	58	1,4	1,1	0,7	3,0	2,4	1,6			
	1	5	0,1	0,1	0,1						
	2	22	0,4	0,3	0,2	2,4	1,9	1,2			
	3	69	0,6	0,5	0,4	2,9	2,3	1,5			
	4	115	1,2	0,9	0,6	3,4	2,7	1,7			

This in a graph gives practically the same result for the site as was obtained for plot 1 (7.2.2.2.). Again a maximum of 10% runoff with one exception of 13,4% for a first rain (which is not representative), was found.

7.2.3. Agbeby Site I

7.2.3.1. The runoffdepths-raindepths humidity index relatic

The soil humidity-runoff relations only gave a clear picture for plot 1 (base soil) and for plot 2 with vegetation.

7.2.3.2. The influence of soil differences

For all tested soils runoffdepths were less than 10% of raindepths. As no curves can be found, one can only describe relations between groups of points.

It is noted that for rains 2,3,4 and 5 the raindepths only exceeded the 3 mm for plot 3. Here it reached a maximum of 9,3 mm for IK = 66 and Pu = 100 for the 3rd rain.

Besides this one exception, a 5 mm runoff was only exceeded during rains 6,7 and 8. They all remained smaller than 10 mm however.

7.2.3.3. The influence of the vegetation

For this site the influence of the vegetation has been found to be little dependent of the raindepths. The relation found (see fig. 16) indicates that on plots with vegetation the runoff is about 50% of that on plots without vegetation.

7.2.3.4. Site representative values

With the relation of the influence of the vegetation one can now correct the obtained values of Lr (Lrc) of tables 23-26, with result the list below.

Table 42 : - Corrected runoffdepths in mm -

Plot N°	Rain N°	IK	Lr 100	Lr 75	Lr 50	denuded soil			vegetation		
						Lrc 100	Lrc 75	Lrc 50	Lrc 100	Lrc 75	Lrc 50
1	1	0	4,9	3,6	2,2				2,2	1,7	1,2
	2	56	1,4	1,0	0,7				0,8	0,6	0,5
	3	101	2,7	2,0	1,2				1,3	1,1	0,7
	4	76	1,1	0,8	0,4				0,7	0,6	0,3
	5	99	2,1	1,5	0,9				1,1	0,8	0,6
	6	188	5,2	3,9	2,6				2,3	1,8	1,3
	7	1	9,7	8,6	7,5				5,0	3,6	3,2
	8	48	5,6	4,2	2,8				2,5	1,9	1,3
2	1	0	2,8	2,1	1,3	6,5	4,6	2,6			
	2	68	2,1	1,5	0,9	4,6	3,2	1,7			
	3	98	1,6	1,1	0,7	3,3	2,2	1,3			
	4	74	0,9	0,6	0,4	1,8	1,0	0,5			
	5	112	1,4	1,0	0,7	2,9	1,9	1,2			
	6	202	4,1	3,0	1,9						
	7	1	7,6	5,7	3,8						
	8	48	7,2	5,3	3,4						

These values in graph do not give a curve relation.

For denuded soils the corrected values give a maximum value of 6,9 mm for equivalent runoff on plot 3. This result therefore does not change the observation that runoff is < 10%.

The vegetation halves the runoff and with vegetation the runoff is < 5%.

7.2.4. Agbeby Site II

7.2.4.1. The raindepths-runoffdepths humidity index relation

With the aid of graphical representations of tables 27-30 the runoffdepths at equivalent raindepths of 100, 75 and 50 mm and soil humidities of IK = 0, 30, 50, 100, 150 and 200 were tabulated.

7.2.4.2. The influence of the soil differences

The relations between runoffs on plots P5 and P7, and of P5 and P8, with denuded soils are found in fig. 17. The relation between runoffs of P5 and P7 shows that P7 has a runoff which starts before that of P5 but when there is renoff on P5, runoff of P7 only increases 25% of that of P5. Both soil types have a runoff of < 4%. Plot 8 has a runoff of about 200% of that of plot 5. Maximum runoff occurs at plot 8 (7 mm) when IK = 200 and raindepth = 100 mm and soil is bare. This condition is only satisfied if on 3 consecutive days rainstoms of 100 mm each day fall on denuded soil. A more reasonable limit is IK = 100. This followed by a rainstorm of 100 mm would require such stoms on 2 consecutive days. Maximum runoff is then 6 mm or about 6% of raindepth.

7.2.4.3. The influence of the vegetation (Fig. 18)

The vegetation intercepts about 1,5% of the rain. Taking a possible maximum runoff as on plot 8 (6%) and subtracting the interception of the vegetation (1,5%) one comes to a maximum runoff of a soil with vegetation of 4,5%.

7.2.4.4. Values representative of the site

As has been mentioned in the previous paragraphs a representative value for maximum runoff on denuded soils is 6% of the raindepth and for soils with vegetation is 4,5% of raindepth.

7.2.5. Conclusion

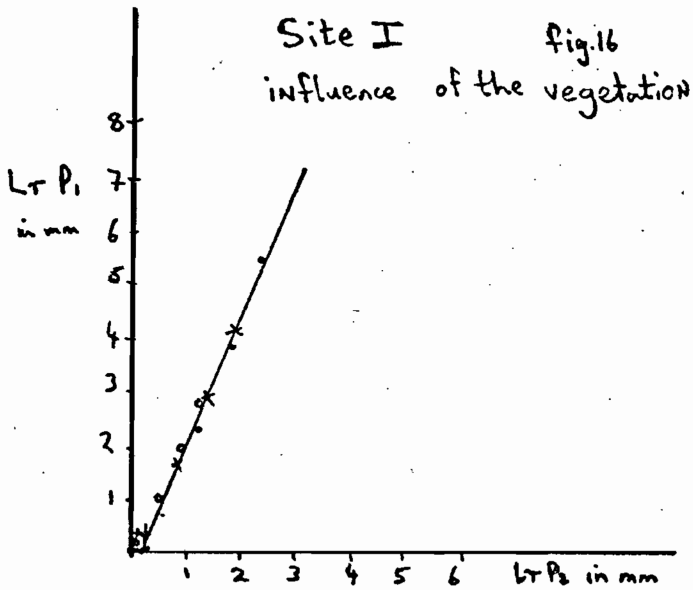
Summing up the previously obtained results.

Table 43 : Maximum runoff coefficients in %

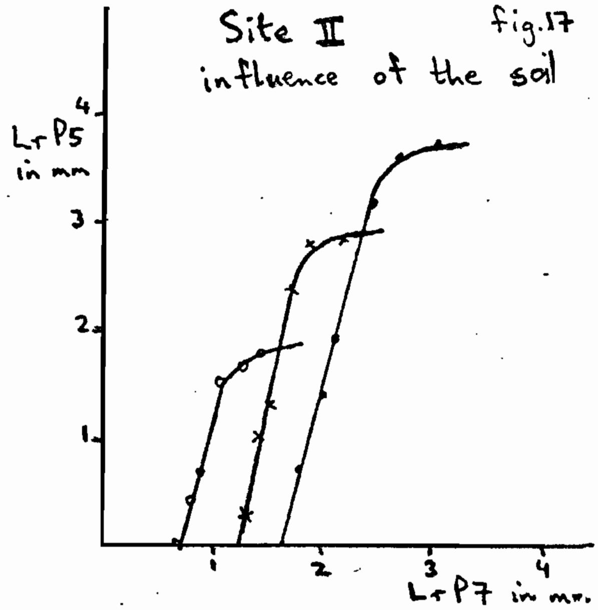
Sites	With vegetation	Denuded
Agbeby I	5	10
Agbeby II	4,5	6
Nyon I	(2)	10
Nyon II	2	4

(2) represents plot 2 only.

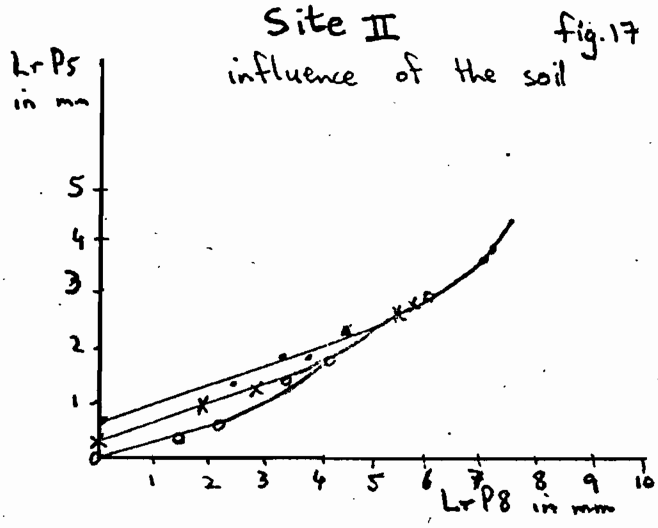
Agbeby



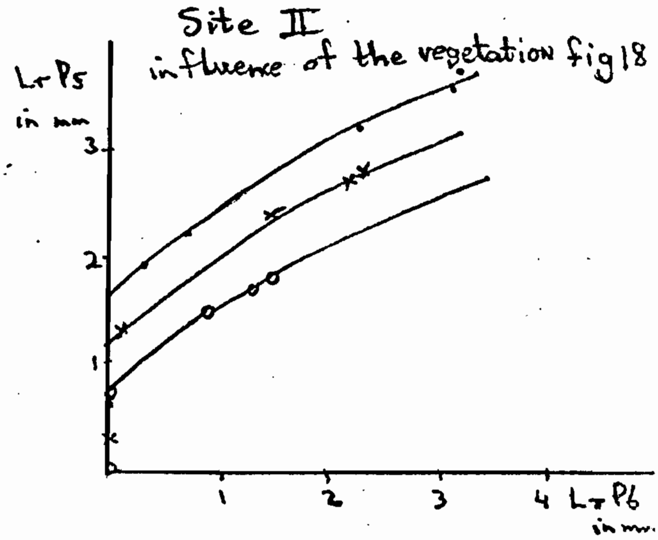
Site I fig.16 influence of the vegetation



Site II fig.17 influence of the soil



Site II fig.17 influence of the soil



Site II influence of the vegetation fig 18

The most remarkable about these results is that for sites at Nyon the runoff coëfficients for soils with vegetation (those used for calculating the maximum discharge with 10 years frequency) were lower than those at Agbeby. This is contrary to what has been concluded form previous studies. In his article(IV),

"Estimation des débits de crues décennal pour les petits bassins versants forestiers en Afrique tropical", Rodier uses an ORSTOM classification with 6 cathegories (see Appendix III) in which he places studied small forest river basins. According to his information the Nion River basin has a runoff coefficient of 10-16% and falls in cathegorie IV. Results obtained with the present study would classify the Nion basin 2 cathegories lower, with the Agbeby basin wich runoff coefficient < 5%, in cathegorie VI.

Which is now the representative value for Nion ?

As Rodier mentions, just after classifying the various basins, it was with insufficient knowledge about the nature of the soil that the Nion bassin was classified.

More important is the deceiving magnitude of the infiltration found at Nion, with the rain simulation experiments. Here the infiltration is great (upto depth of ± 40 cm), but thereafter the water is blocked by a ferralitic conglomerate and is forced to runoff as interflow. Because there was a hole made to install the reservoire* of the water-level recorder, the water in the soil under the plot was able to drain into the hole. In this way the infiltration is not limited by a saturation of the subsoil. In this case the infiltration capacity and the transmissibility of the soil determine the runoff.

Reflecting on last years results one can conclude that with little permeable soil and large runoff, the runoff figures are a result of limited infiltration capacity of superficial horizons and drainage of interflow plays only a small role.

Because of the drainage effect of the hole, in soils like that occurring at Nion, it is advisable to place the reservoire further downhill at a distance one or two meters away from the plot sothat the unfavourable effect of drainage can be moderated.

For the results at Agbeby, with a sandy soil upto 120 cm and no water appearing in the trough as a sign of drainage, the runoff coefficients are acceptable and compared to previous results give a true representation of the runoff.

For the two basins it can be collectively stated that for tested conditions small runoffdepths, Kr < 10%, occurred and that vegetation will intercept from 25-50% of the runoff. For the response at Nion however, another campaign in similar circumstances with an improved experimental set-up, is called for.

It has been shown that the effect of the soil types can cause a runoff difference varying a factor 4.

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* see Appendix I. fig. 4, N° 7.

7.3. Study of the maximum runoff intensity

Similarly as for runoffdepths, now the maximum runoff intensities (Rx), as appear in tables 25-37, have been graphed as a function of the humidity index (IK), with separate curves for rain intensites (I) of 100, 75 and 50 mm/h. For different IK values the maximum runoff intensities of different plots have been compared with one-another in influence curves (influence of the vegetation). Many runoff intensities were so small that they approached zero (plots 4, 7 and 8 of Agbeby and plots 3,4 and 7 of Nion). For these it has not been possible to give a curve showing influences of soil types. For others this has not been possible because of the great spread in results. In all these cases only spontaneously occuring maximum values can be given.

The maximum runoff intensities at Agbeby for plots with vegetation was 3,2 mm/h and for bare plots was 27,2 mm/h (occuring on plot 1). Unfortunately no soil samples were taken (at Agbeby Site I) besides those at the surface. Subsurface influences cannot be observed by humidity profiles but possibly description done by pedologists, when they become available, can clear the picture. One thing is certain : vegetation smoothes out the runoff peaks.

For Nion the curve showing the influence of the vegetation for Site II (maximum of the 2 sites) is shown in fig. 20. The maximum runoff intensities are effected the most by vegetation at IK-values below 100. The maximum runoff intensity measured in the Nion basin was 19,2 mm/h for bare soil on plot 1 during the first rain and a rainintensity of 140 mm/h, while the initial humidity index was only 6. For plots 1 and 5, where the highest runoff intensities were found, the humidity gradient between 15 and 20 cm depths was also found to be the greatest. This could indicate that near 20 cm an increasing clay content takes place. After wetting and saturation of the top 15 or 20 cm a decrease in infiltration rate (caused by the clayey horizon) causes an increased runoff and runoff intensity. Over a depth of 200 mm a volumic humidity increase of only 5% requires 10 mm of rain. The raindepth (Pu) reaches this point during the rain intensity of 140 mm/h. A high rain intensity and a slight decrease in transmissibility result in an increased soil humidity in the top horizon and an increased runoff intensity.

Concluding one finds that the depths of an infiltration decellerating layer, as well as the water bearing capacity of the horizons above it, produce a serious influence to be reckoned with in connection with the rain intensity and the resulting runoff intensity. These factors determine the moment at which the rain falling on an initially good infiltrating soil comes to an increase in runoff. The length of time with which the increased runoff is maintained (from then on determined mainly by the rain intensity) determines to a large extent the runoff depth.

For the sites at Nion with vegetation the maximum runoff intensity was only 2 mm/h. This occurred on a different site and comparison, with the above mentioned conditions playing a role, is difficult. In any case the vegetation buffers the runoff and reduces the peaks.

Agbeby

Site I

Influence of the vegetation

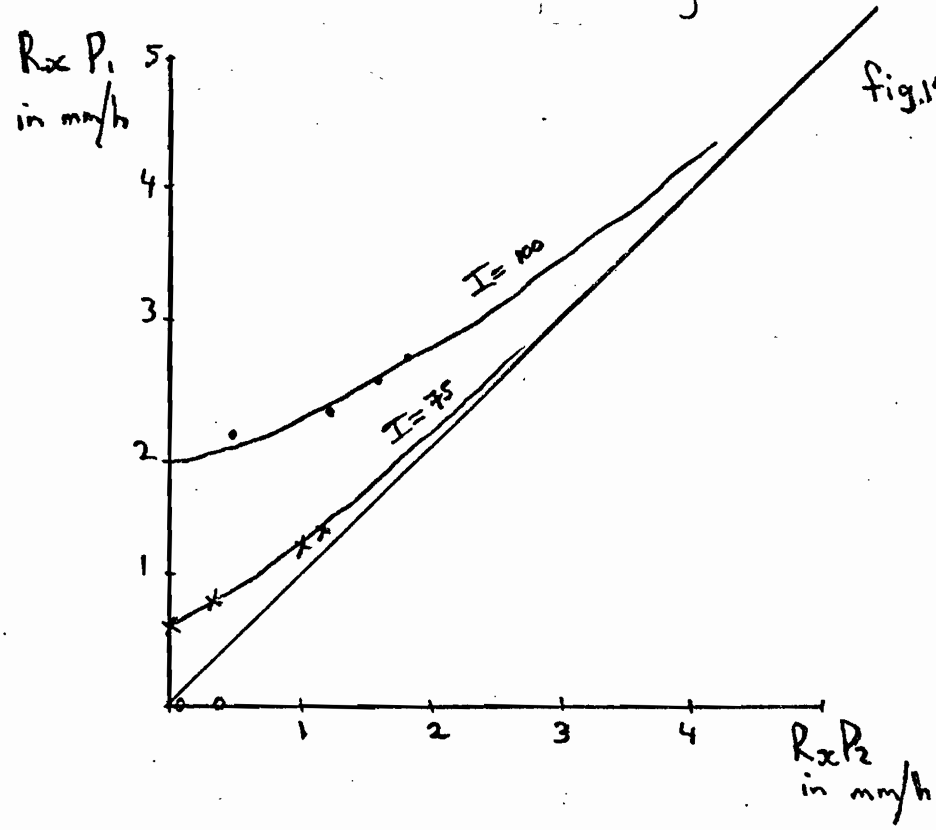

fig.19

Nion

Site II

Influence of the vegetation

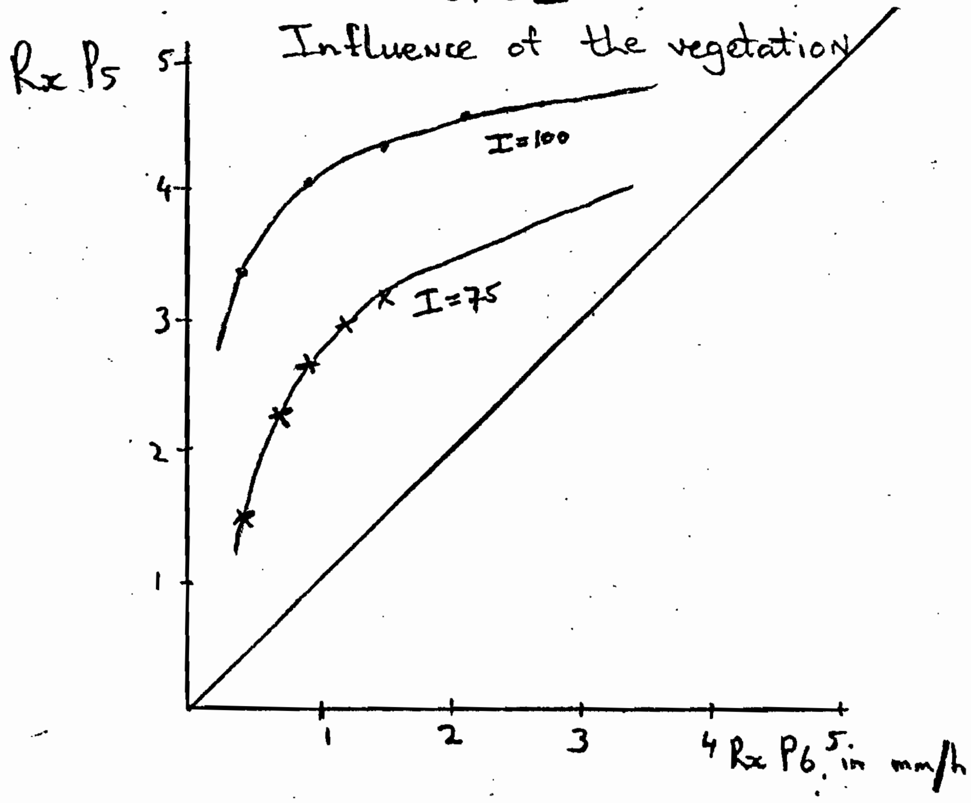

fig.20

7.4. Interpreting soil-humidity profiles

7.4.1. Introduction

Unfortunately the thermic shock method produced too few values to warrant interpretation. The neutron-probe and the soil sampling methods differ in that the first in-volves a quick measurement offering a possibility of several measurements in the course of the rain, whereas the second takes more time and is less accurate thus demanding triplicated determinations and more work.

7.4.2. Neutron-probe observations

For Agbeby site II the neutron-probe was used at plot 5 and 6. Per rain 7 profiles were made allowing for a study of the passage of water during 70 minutes. Here follow observations for :

Plot 5

The first rain infiltrated immediately to 30 cm. Only after 40 minutes of rain and infiltration does the infiltration reach a depths of 50 cm. A further passage of water is only noted one hour after commencing the rain. In a dry profile the infiltration is discontinuous at 30 and at 50 cm.

During a second or later rain the top 10 cm are immediately wetted to 24% volumic. Once the soil is humid, infiltration quickly takes place to 100 cm depth. For a long time hereafter (at least 10 days), independant of rains fallen more than 24 hours in advance, a fairly constant soil-humidity profile appears upto 60 cm.

at 10 cm	H_V = 15 %
at 40 cm	H_V = 20 %
at 60 cm	H_V = 23 %

Plot 6

In a dry profile humidification upto 80 cm is fairly regular. With an initial soil-humidity of less than 17% for the lower horizons (1st rain only), the humidification is much slower and these horizons will not be affected during the rain.

For second or further rains the increase in soil humidity proceeds slower below the 50 cm than above, but infiltration will reach at least 120 cm.

In general the infiltration process in a dry profile is bothered by certain layers. The humidifying-front moves slowly en the above lying layers are saturated and runoff occurs.
These dry layers occur at plot 5 at 30 and 50 cm depths and at plot 6 at 80 cm depth.

7.4.3. Soil sample observations

These samples are taken over longer time intervals and give a view of what happens during a sequence of rains.

Agbeby Site II : for Agbeby plot 5 and 6 an overlap of this method and the previous method occurs. It has there for been possible to obtain a humidity percentage by weight (H_p) as well as by volume (H_v).

The relation $$H_p = \frac{H_v \times \rho w}{(1-\varepsilon) \times \rho s}$$

where ρw = specific mass of water
ρs = specific mass of soil
ε = porosity

can be re-written for ε as follows.

$$\varepsilon = 1 - \frac{H_v \times \rho w}{H_p \times \rho s}$$

The horizons (at 30 and 50 cm) which seemed to form barriers for infiltrating water during the rain, were the water-bearing horizons after the rain.

For plot 5 average porosity values were calculated.

50%	at	10 cm
49%	at	20 cm
48%	at	30 cm
47%	at	40 cm
40%	at	50 cm

At 50 cm the density of the soil increases. This explains the irregular seepage of water through the profile.

Nyon : The profiles after different rains were found to lie very close to each other. This could indicate conditions of field capacity (water carrying capacity of the soil) after the rain. This is a result of drainage into the hole where the reservoire is situated. At these sites water was found streaming down the sides of the hole. This usually started 20 cm. The ferralitic conglomerate below formed a semi-permeable substratum over which interflow stramed.

The most plots at Nion (plots 2, 3, 5, 6, 7) had highly water-retaining surface horizons (i.e. 0-5 cm). This can be explained by the organic material in this horizon.

7.5. Study of initial raindepths

The initial rain (P_i) can be graphed as a function of the initial soil humidity index (IK). The results obtained, showed a decreasing P_i for an increasing IK. That is to say that more rain must fall on a dry soil than on a humid soil before runoff begins : (Pi values are given in tables 3-17, IK values in tables 23-37).

VIII. CONCLUSIONS

The facts in brief are the following :

- For many situations the rain simulator can be used effectively. Taï and Agbeby are proof of this. The fact that the Agbeby basin falls into cathegorie VI, of the small forest river basin classification, has been affirmed.

- One must constantly be on the guard against situations where the rainsimulator-results could fail to be representative. The Nion set-up with artificial drainage is an example of this. A second campaign to test a correct set-up is advisable.

- A hole, in which to place the waterlevel-recorder's reservoire, must be out of the sphere of influence of the experimental plot, as much as possible.

- The thermic shock apparatus is capable of giving accurate results. Consistency, guaging and measuring form the main problems to realise this.

- Electrical appliances are, where possible, to be avoided or else to be well protected for field conditions, eg. the clock work of the pluviograph and the electrical circuits of the thermic shock functioned unsatisfactorily.

- The depth to an infiltration-decellerating layer, the water bearing capacity of the horizons above it, the duration of the rain intensity determine to a large extent the runoff of an initially good infiltrating soil.

- Vegetation not only intercepts rain, but also smoothes peaks of runoff intensity.

- A study on the correlation between runoffdepths and coëfficients of granulometry (of Taï), yielded no results.

Appendix I

2. PRÉSENTATION ET CONSTRUCTION DE L'INFILTROMÈTRE
(cf. planche de photographies et figure 1)

2.1. Principe de l'appareil

Cet appareil se distingue essentiellement des modèles existants par le fait que l'intensité de l'averse mesurée sur 1 m² est réglable à tout moment, sans interruption, d'une manière progressive et continue, dans une gamme allant de 30 à 140 mm/h (le modèle de Bertrand et Parr ne fonctionne qu'à 64-83 et 117 mm/h).

Pour cela, en faisant varier l'angle de balancement du gicleur, on augmente ou diminue la surface arrosée alors que la quantité d'eau utilisée reste constante. La parcelle de 1 m² reçoit plus ou moins d'eau alors que la surface de garde varie entre 2,5 et 13 m² (limitée à 6,5 m² lors de l'emploi d'une bâche).

Lorsque l'on immobilise le gicleur situé à 3,50 m du sol, l'eau se répartit sur une ligne d'environ 25 cm d'épaisseur et sur une largeur qui est fonction de la pression (fig. 5). Cette largeur et l'amplitude de balancement du gicleur déterminent la surface arrosée.

2.2. Construction

Les détails de construction de l'appareil sont indiqués sur les figures 2 et 3. De plus amples renseignements peuvent être fournis directement par les auteurs.

L'arrosage de la parcelle est assuré par un gicleur monté sur certains appareils de traitements phytosanitaires (Teejet 6560, vendu par Emani, 75, Boulevard Raspail, 75260 Paris). Ce gicleur est animé d'un mouvement de balancier par une biellette entraînée par un moteur électrique (12 V SEV Marchal). L'ensemble est supporté par une tour démontable, en forme de pyramide tronquée, susceptible de recevoir une bâche pour la protection contre le vent. Un dispositif permet de maintenir l'axe d'oscillation du gicleur au-dessus du centre de la parcelle d'expérimentation.

La figure 4 présente la parcelle proprement dite et le limnigraphe :

1) Bac pluviométrique. Il permet, à l'aide de trois tuyaux qui le relient au limnigraphe, de contrôler les intensités avant ou après les mesures en le plaçant au-dessus du cadre nº 2 (1 m² avec bordure de 5 cm de hauteur).

2) Cadre permettant l'enfoncement par battage de la bordure en tôle nº 4.

3) Tôle de protection venant couvrir le canal de ruissellement et une partie de la goulotte.

4) Cadre délimitant le périmètre de mesure de l'infiltration. Il est muni sur un côté d'une ligne de trous et au-dessous d'une gouttière collectant les eaux de ruissellement. Construit en tôle galvanisée 20/10ᵉ, il forme un carré de 100 × 100 cm intérieur et 18 cm de hauteur. Sur les côtés, une cornière de 40 × 40 mm rend l'ensemble rigide et limite l'enfoncement dans le sol à 80 mm. la base de la ligne de trous (⌀ 10 mm, tous les 20 mm) est également à 80 mm du bord inférieur. Une double pente de 3% guide l'écoulement au centre de la gouttière.

5) Les eaux sont évacuées par une goulotte (5 × 5 × 25 cm) et se déversent dans la cuve du limnigraphe. Une tôle de 20 × 25 cm incurvée ou une feuille de plastique suffisent à l'isoler de la pluie.

6) Limnigraphe de laboratoire A. OTT, modèle VIII, fixé sur un socle muni de 4 pieds.

   Equipé de roues E avec 48 dents au tambour et 64 à la commande, on obtient une rotation du tambour en 96 mn avec une avance de papier (A. OTT, nº 460, RK 35) de 6 mm à la minute (code LAGAG). Le flotteur agit directement sur une tringle, le rapport est de 1/1 et permet d'enregistrer une hauteur de 35 cm.

   L'ensemble est protégé par un couvercle en tôle galvanisée 10/10ᵉ, 22 × 30 × 55 cm, muni d'une vitre en plexiglas de 22 × 41 cm.

7) Cuve cylindrique du limnigraphe.

   Cette cuve a été construite afin d'obtenir une élévation de 10 mm du flotteur pour un litre d'eau écoulée, soit 1 mm de pluie sur le bac pluviométrique de 1 m². Tôle galvanisée de 10/10ᵉ, diamètre intérieur 356,8 mm, hauteur 45 cm dont 35 utiles. La différence est occupée par le flotteur. A la base de la cuve est soudé un tube muni d'une vanne 20×27 permettant des vidanges rapides.

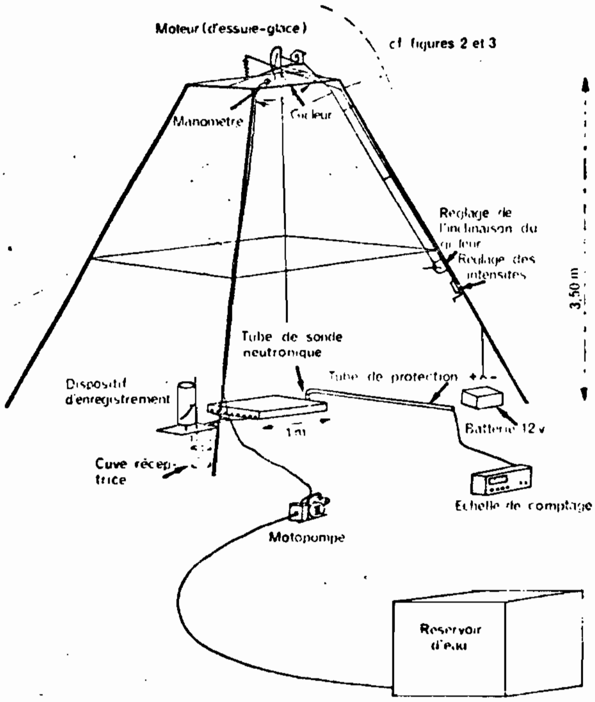

Fig. 1. — Schéma de l'infiltromètre à aspersion

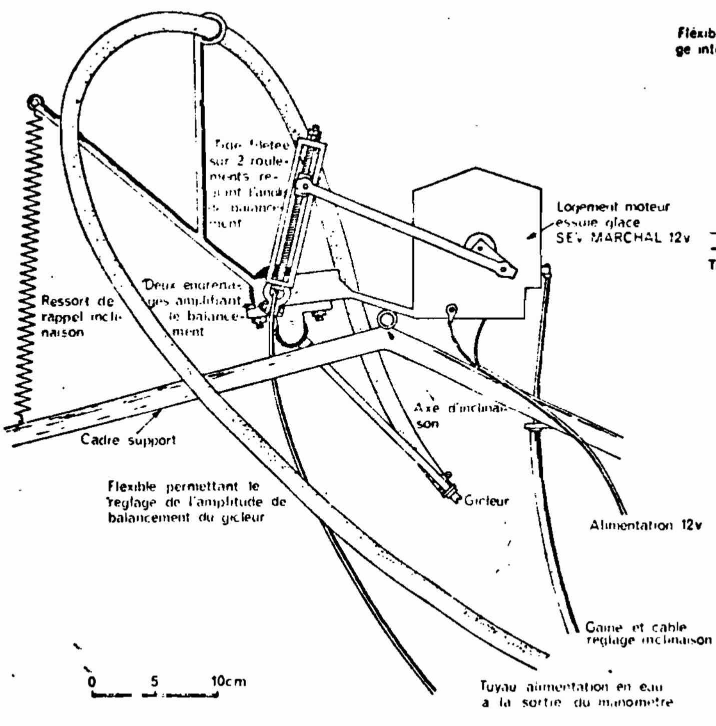

Fig. 2

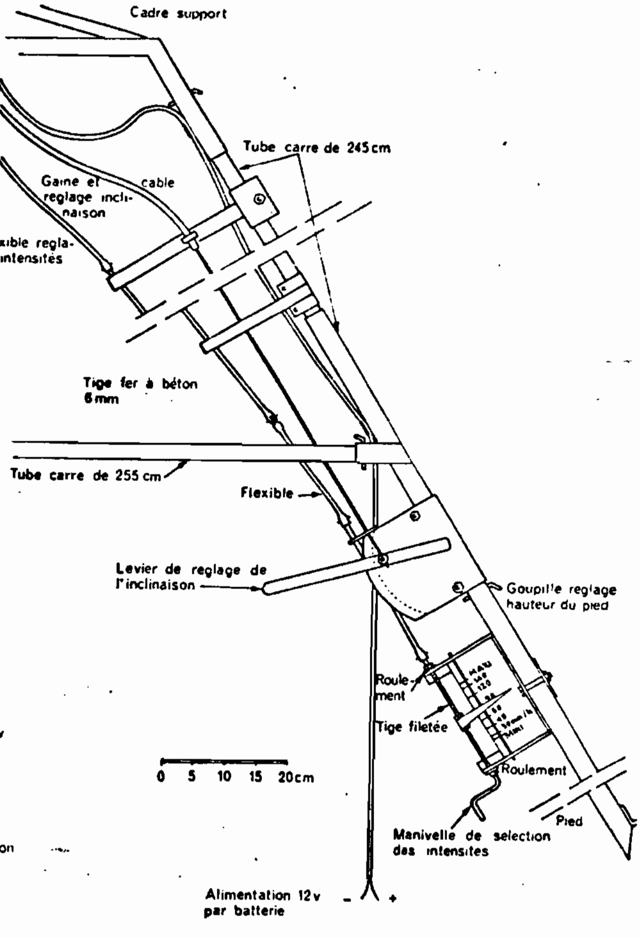

Fig. 3

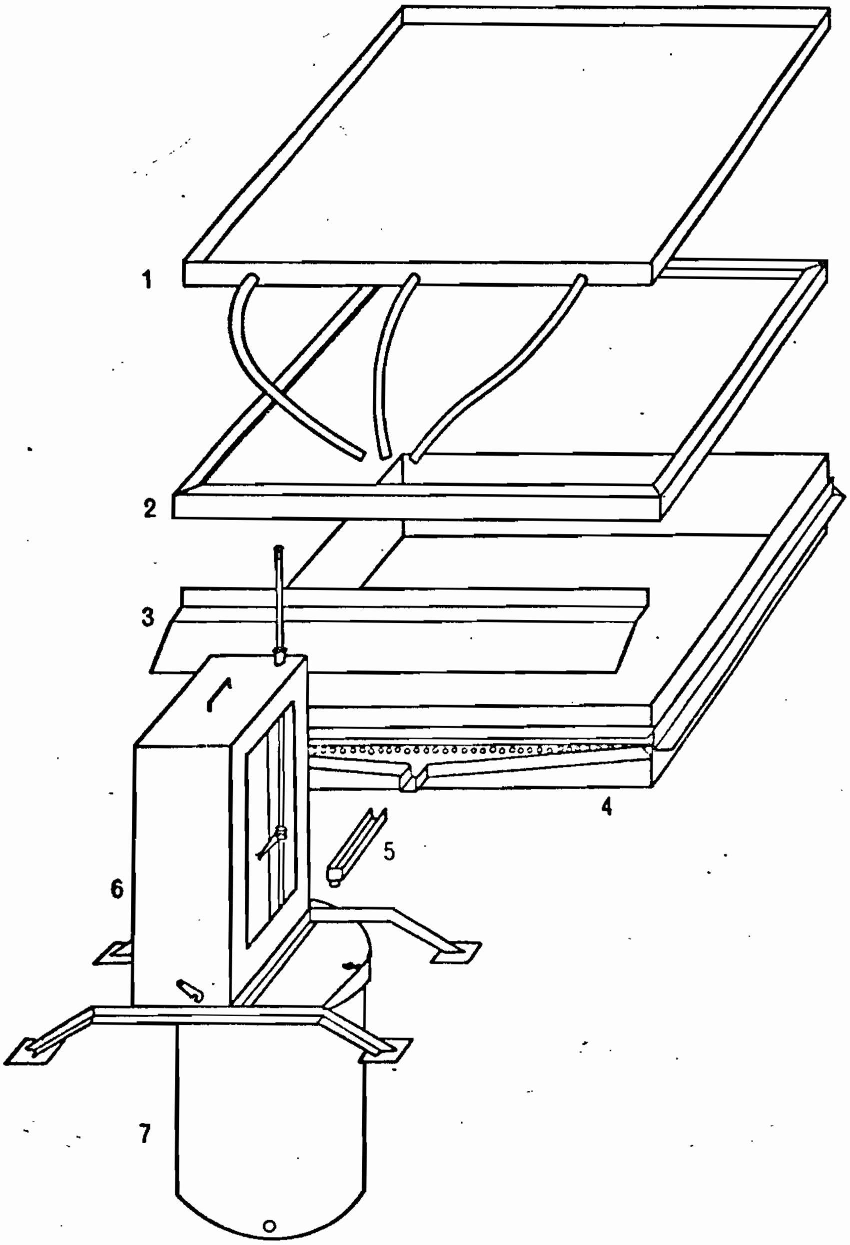

Fig. 4. — Infiltromètre : dispositif de recueillement et d'enregistrement des eaux de ruissellement

3. CARACTÉRISTIQUES D'UTILISATION

3.1. CHOIX DE LA PRESSION

3.1.1. *Consommation en eau*

Afin de conserver à cet appareil un caractère de légèreté, de facilité de transport et d'emploi, il est nécessaire de consommer le moins d'eau possible, mais un certain volume s'impose : une parcelle et sa garde, réduites au minimum à 3 m², recevant 140 mm pendant une heure, nécessite 420 l d'eau.

TABLEAU 3

INFLUENCE DE LA PRESSION SUR LA CONSOMMATION EN EAU

Pression (g/cm²)	250	300	350	400	450
Consommation d'eau (l/h)	380	410	470	510	545

Au vu de ce tableau, nous nous placerons entre 300 et 350 g (surface de garde suffisante).

3.1.2. *Surface de garde*

Pour un ensemble surface de garde + parcelle d'au moins 3 m², la pression ne doit pas être inférieure à 300 g/cm² (fig. 5).

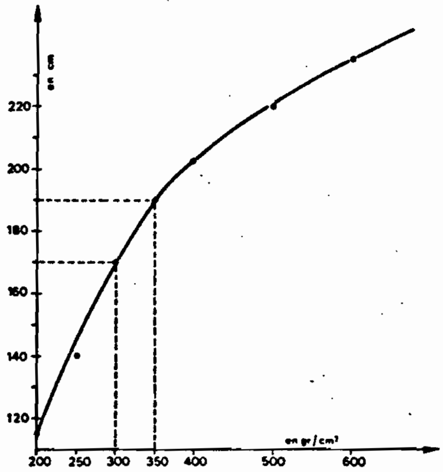

Fig. 5. — Largeur arrosée par le gicleur placé à 3,60 m du sol en fonction de la pression

3.1.3. *Régularité de l'intensité*

Le gicleur a été testé à l'arrêt à 3,50 m du sol à différentes pressions ; il ressort de ces essais que de 250 à 600 g/cm² l'intensité recueillie sur une largeur d'un mètre, centrée sous le jet, est strictement la même alors qu'elle a tendance à varier en dessous de 250 g/cm².

3.2. RÉGLAGE DES INTENSITÉS

L'appareil a été étalonné ; une aiguille permet de repérer le nombre de tours imprimés à la tige filetée par l'intermédiaire d'une petite manivelle.

Lors du montage, on place l'axe relié à la biellette (fig. 2) en butée inférieure ainsi que l'aiguille (fig. 3).

Dans cette position, on obtient le balancement maximum du bras portant le gicleur. L'intensité au sol est donc alors minimum, soit environ 30 mm/h.

Il faut noter que l'appareil, dans sa conception actuelle, ne fonctionne pas d'une façon satisfaisante à cette intensité. En effet, le cadre supérieur est atteint par le jet d'eau (fig. 2 et 3), ce qui provoque des retombées d'eau dans la parcelle et augmente ainsi l'intensité.

La bâche recouvrant l'ensemble de l'appareil a dû être reculée à plus d'un mètre de part et d'autre du gicleur pour les mêmes raisons. Aux autres intensités, ce problème n'apparaît pas.

3.3. Mise en place de la parcelle d'essais

La mise en place du cadre de 1 m² ne pose pas de problème particulier ; il est cependant nécessaire de déterminer au préalable, et de façon précise, la pente du sol afin de placer le côté troué du cadre rigoureusement en aval (l'emploi du niveau à bulle est suffisant). Le cadre renforcé (nº 2, fig. 4) permet l'enfoncement de la tôle en masse, de manière à mettre la cornière d'arrêt et la ligne de trous au niveau de la surface du sol. Une petite rigole de 3 à 5 cm de profondeur doit être aménagée sous la gouttière réceptrice du ruissellement. Il est bien évident que l'on évite de piétiner la surface de la parcelle ainsi que la surface de garde, lors de la mise en place du dispositif. Le cadre étant installé, la pente de la parcelle peut être déterminée avec précision, à l'aide d'un mètre, d'un niveau et d'un double décimètre.

Lors de l'étude de la toposéquence du Manso (Casenave et Guiguen, 1978) des infiltrations importantes ont été enregistrées sur les parcelles récemment implantées, l'enfoncement de la bordure en tôle perturbant en effet le sol et créant des zones d'infiltration privilégiée. Cet effet disparaît après une première pluie. Etant donné le faible prix de revient d'un cadre, la meilleure solution consiste à en construire un grand nombre et à les laisser en place si plusieurs mesures doivent être faites au même emplacement.

La cuve recueillant le ruissellement est installée dans une petite fosse (50 cm de profondeur sur 40 cm de diamètre) ; les pieds de l'appareil reposent sur un replat aménagé à 12 cm de profondeur. Afin de ne pas perturber l'enregistrement, il est important de s'assurer de l'horizontalité du limnigraphe. La cuve ne permet pas d'enregistrer une lame ruisselée supérieure à 35 mm ; aussi est-il nécessaire de vidanger la cuve au cours des pluies simulées dans le cas des forts ruissellements. L'emploi d'une seconde motopompe assure des vidanges rapides (30 s).

3.4. L'alimentation en eau

Une petite motopompe TAS Motor QCP 12 animée par un moteur 2 temps consommant environ 0,5 l à l'heure de mélange est utilisée pour fournir l'eau sous pression. Le moteur est employé à faible rendement, sa capacité pouvant aller jusqu'à 7 000 l à l'heure.

La même motopompe est utilisée pour remplir au point d'eau le plus proche un réservoir de 600 l aménagé afin d'être facilement transportable dans un véhicule léger (Land Rover, 404 bâchée). Quelques fûts de 200 l peuvent être employés si l'on désire une plus grande réserve d'eau.

3.5. Discussion, critiques, améliorations a porter

Après plusieurs missions effectuées sur le terrain avec l'infiltromètre précédemment décrit, il apparaît que le principe de fonctionnement de l'appareil est excellent ; il mérite cependant qu'on lui apporte un certain nombre d'améliorations.

3.5.1. *Solidité et fiabilité de l'appareil*

Ces deux caractères sont liés car toute torsion ou usure entraîne du jeu dans les organes mobiles et influe sur le réglage des intensités.

C'est pourquoi il est souhaitable de monter les axes des engrenages (fig. 2) sur roulements à billes. Le moteur pourrait être un peu plus puissant, il a tendance à chauffer à faible intensité (balancement maximum) (moteur d'essuie-glace de camion).

Appendix II

ANNEXE

Matériel employé et coût en 1977 a Abidjan

A. Matériaux de construction pour l'appareil, le réservoir et l'aménagement du limnigraphe :

1 tube galvanisé, 15 × 21 mm	2 790
1 tube galvanisé, 20 × 27 mm	3 608
4 tubes noirs carrés, 25 × 25 mm	7 410
2 tubes noirs carrés, 30 × 30 mm	4 590
2 fers à béton, ⌀ 6 et 10 mm	1 900
4 roulements S.K.F., ⌀ 6 × 19 mm	2 200
30 boulons, 8 × 50, 8 × 35, 6 × 25 mm	750
3 m tuyau plastique souple	510
8 colliers de serrage	400
1 tôle plane galvanisée, 100 × 200 mm, 20/10e	7 261
3 tôles planes galvanisées, 100 × 200, 15/10e	14 840
1 tôle plane galvanisée, 100 × 200 mm, 10/10e	3 338
1 tôle plane galvanisée, 100 × 200 mm, 6/10e	2 410
1 barre de fer cornière égale, 50 × 50 mm	4 099
1 barre de fer cornière égale, 40 × 40 mm	2 674
1 barre de fer cornière égale	2 023
1 tige filetée en laiton avec 10 écrous, ⌀ 6 mm	770
Total partiel (250 U.S. Dollars) :	**61 573 CFA**

B. Alimentation de l'infiltromètre et matériel annexe :

20 m de câble électrique, deux fois 2,5 mm + 2 pinces	4 500
1 batterie d'accumulateurs 12 V., 178 ampères	63 900
1 pompe de cale GEM BP 1 400, 4 500 l/h GEM marine. Products. Box 911 Lake City, USA.	19 840
1 moto-pompe TAS Motor QSZZ 7 200 l/h Tanaka Kogyo (Japan)	59 000
1 manomètre, 0 à 1 kg, ⌀ 18 cm	30 000
2 vannes bronze, 20 × 27	5 500
1 bâche Edsanyl, environ 45 m²	75 000
2 kg de peinture	2 280
Total partiel (1 050 U.S. Dollars) :	**260 000 CFA**

C. Matériel de récupération :

2 engrenages avec axe.
2 paliers bronze.
1 moteur essuie-glace.
2 flexibles câble de compteur.
1 gaine et câble de frein à main.

Soit un total de 321 600 F CFA (1 300 U.S. Dollars).

A cette liste, l'on doit ajouter :

— Le gicleur Tee jet SS 6560 dont nous ne connaissons pas encore le prix ;

— Le limnigraphe A OTT VIII de laboratoire, utilisé depuis plusieurs années sur d'autres programmes d'études.

Appendix III

La perméabilité globale des bassins étant impossible à chiffrer, il est impossible de procéder à une étude systématique de régressions pour définir des règles de calcul du coefficient de ruissellement K_R. Nous nous contenterons de définir six catégories de bassins d'après des indications qualitatives de perméabilité et l'indice global de pente.

Catégorie I (Sitou, Bafo, Manso, Nziémé III, crique Virgile)

La presque totalité du bassin est occupée par des sols argileux massifs *imperméables* en surface ou à faible profondeur : 20 à 50 cm, présentant dans ce dernier cas des phénomènes d'engorgement au voisinage de la surface dès que la saison des pluies est assez avancée. Ces bassins sont généralement sur schistes ou amphibolites dans un modèle sénile, parfois sur argilites et sur marnes à gisement sub-horizontal (Nziémé III).

K_R = 58 à 62% pour des pentes définies par $3 < I_g < 30$

K_R doit monter jusqu'à 70% si I_g atteint 70 à 80, mais ceci est très rare puisqu'avec des pentes de ce genre la pédogenèse conduit à des sols plus perméables.

Catégorie II (crique Grégoire, Nziémé I, Nzang, Mielekouka II, Nion I et Nziémé I)

Le bassin est recouvert pour 30 à 60% de sa surface par des sols correspondant à ceux de la catégorie I (très net pour Nion I et Nziémé I). Ces sols *imperméables* sont situés parfois dans la partie basse du bassin, en particulier lorsqu'il s'agit de sols hydromorphes. Dans le cas des monts de Cristal, Nzang, la partie imperméable du bassin occupe peut-être moins de 30%, mais ceci est compensé alors par une très forte pente ($I_g > 80$).

K_R = 30 à 40%

K_R croît bien entendu lorsque les surfaces imperméables occupent une partie plus importante du bassin jusqu'à tendre vers les valeurs données pour la catégorie I.

Catégorie III (Gboa, Loué, Mielekouka III, Foubou, Ottotomo III, Dzounza, Mitzibé, Amitioro I)

Bassins peu perméables en pente faible : $I_g < 10$ (Amitioro I) ou bassins avec moins de 30% de la surface, *imperméables* avec pentes modérées à très fortes $10 < I_g < 30$, ou bassins perméables en surface et en profondeur (sols sur charnockite par exemple, sols argileux à structure grumeleuse), avec *très fortes pentes :* $I_g \geq 70$ (pentes latérales très fortes : cas du Loué et du Gboa et de la Dzounza et du Fourou).

K_R = 20 à 30%

Catégorie IV (Nion II, Mielekouka I, crique Cacao, Amitioro II)

Bassins perméables homogènes à *assez fortes pentes :* $20 < I_g < 40$, ou bassins très perméables à très fortes pentes : $I_g > 80$ (crique Cacao), ou bassins de perméabilité moyenne à pentes modérées (Amitioro II).

La valeur (40) donnée pour le Nion tient compte des pentes transversales qui sont moins fortes que ne le laisserait supposer la seule pente longitudinale qui, elle, correspond à $I_g = 60$.

K_R = 10 à 16%

Catégorie V (Bibanga, Leyou, Avéa II, Ifou)

Bassins perméables, par exemple argile à structure grumeleuse puis microgrenue en profondeur, arènes argileuses, etc., sans horizon imperméable en profondeur. Pentes faibles à modérées : $5 < I_g < 25$.

K_R = 7 à 10%

Catégorie VI (Agbeby)

Bassins très perméables en surface et en profondeur à pente assez faible : $I_g < 10$ (Agbeby sur sables tertiaires de Côte-d'Ivoire).

K_R = 3 à 5%

Cette classification est loin d'être parfaite. Il est bien difficile de faire entrer la Mitzibé ou le bassin de l'Amitioro II dans cette classification par suite de nos connaissances insuffisantes sur la nature des sols.

Il en est de même pour le Nion II.

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