TRAVAUX
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DE L'O.R.S.T.O.M.

EVALUATION OF ANNUAL RUNOFF IN TROPICAL AFRICAN SAHEL

Translated by Mrs Angela EELES

J. A. RODIER

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EVALUATION OF ANNUAL RUNOFF IN TROPICAL AFRICAN SAHEL

by

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ABSTRACT

The estimate of the annual total runoff from watercourses in the SAHEL which is the object of this study, forms, together with the estimate of the maximum flow rates and volumes of exceptional floods, one of the two problems which are most difficult to solve before any project for the management of water resources may be undertaken.

Results from the few hydrometric network stations, from regional studies and, above all, from the representative watersheds of ORSTOM, form the body of available data. This has been used to guide the engineer in the determination of statistical distribution curves of the annual total runoff for most types of drainage basin encountered in the SAHEL.

For reasons of convenience use has been made of the idea of the depth of runoff in millimetres which is assumed to have been distributed over the whole surface of the drainage basin, although it has little physical significance ; particular attention has been given to exceptionally dry years.

This study has been made on a zone demarcated in the north by the 22nd parallel, in the south by the 750 mm annual isohyet, in the west by the Atlantic Ocean, in the east by the western frontier of the SUDAN.

This zone has been divided into three parts ; the desert regions to the north of the 100 mm annual isohyet, for which only the most scant information can be given, the subdesert regions between the 100 mm and 300 mm isohyets which are distinctly better known, and finally the regions of the SAHEL between the 300 mm and 750 mm isohyets for which the engineer may be given more accurate and full information. However, for these regions there still remain gaps in information which are far from negligible.

For each of these three parts we first study the annual precipitation : a general map of the annual precipitation has been drawn up, taking into account the last rainfall surveys and the temporal statistics of the distribution of rainfall is represented by a family of curves from the centennial dry years to the centennial wet years. A general mathematical expression is given for these curves with a view to their being used on a computer.

In the SAHEL the regimen of the flow varies in very wide proportions, in accordance with the area of the drainage basin. That is why several instances have been taken into consideration in each of these three parts : drainage basins several hectares in size (the problem of the replenishment of the cisterns) : small drainage basins of between 2 and 40 km^2 ; drainage basins of between 40 and 300-500 km^2 ; drainage basins of more than 1,000 km^2 in size ; and for the flow in the SAHEL we have also taken into account the drainage basins of more than 10,000 km^2 in size. The 2-40 km^2 category has been subdivided into basins of 25 km^2 and basins of 5 km^2.

For everyone of these instances the total information available year by year is given, in the form of annual runoff and generally of the annual precipitation with, in this instance, their ratio : the runoff coefficient Ke.

The basins in each category have been classified in major geomorphological types. In the instance of the basins in the SAHEL which are between 2 and 40 km^2 in size, for which the classification is most complete, we have taken into consideration the following categories - sandy soils ; basins with subsoils formed of granite or granite gneiss ; sandstone conglomerates ; basins on sand and marl in the west of Senegal ; basins on schist ; basins on rock formations of the ADER DOUTCHI and of the MAGGIA (continental terminal). Every one of these categories corresponds to a representative grouping of differing types of soil. For each of these categories we are considering at least one basin type. In the more complex cases - drainage basins on granite, for example - we have studied three types of instance corresponding to the total runoff capacities, which cover nearly all the conditions encountered on drainage basins of this kind. For each basin, as a starting point, - either by the reconstruction of annual flow patterns on a long series by models established for the representative basins which have been studied, or by an estimate based on direct data from these drainage basins, we are establishing the statistical distribution curve for the runoffs corresponding to this basin type and its regimen of rainfall. Next a family of curves is traced for the same geomorphological conditions but for the depths of annual median precipitation which vary between 300 mm and 750 mm per year.

For the drainage basins of more than 40 km^2, the transpositions are more difficult. A certain number of examples of the statistical distribution curves are given for watercourses which are characteristic of each geomorphological category. For drainage basins of more than 1,000 km^2 the distribution curves make exclusive use of the data from hydrometric networks. This does not present too many difficulties since the period studied, from 1956 to 1973 or 1974, includes both exceptionally wet years (1961) and exceptionally dry ones (the period between 1971 and 1973).

For the areas of more than 10,000 km^2, the statistical distribution given concerns the majority of the watercourses in the SAHEL.

The tropical watercourses which emerge in the SAHEL zone (Senegal, Chari, Niger) are not studied here. All the necessary information may be found in ORSTOM monographs.

After the presentation of the statistical distribution curves of the annual runoff determined for the basin types, every necessary recommendation has been provided for the determination of the same curves for the varied basins which may be encountered by the civil engineer.

As a supplement, may be found an example of rainfall sequence, reconstructed over a period of 300 years, which permits one to pass on to sequences of annual runoff for the same period.

The accuracy of the results which may be obtained is limited by the very great irregularity in the regimen in the SAHEL in time and space, and by the difficulty of the extension of data from one basin to another.

EVALUATION OF ANNUAL RUNOFF IN THE TROPICAL AFRICAN SAHEL

CONTENTS

INTRODUCTION

Among the different hydrologic characteristics needed by the engineer for the completion of a reservoir project in the Sahelian regions, two groups of data are particularly important and difficult to calculate in these regions, those linked with annual runoff (average or median value, statistical distribution) and with exceptional floods (maximum flow rate and volume).

The floods which gave rise to numerous disappointments in the course of the realisation of exploitation of dams in this zone, led the authorities responsible for them, before and after Independence, to finance many study and fundamental research programmes, the results of which have been presented in memoirs concerning various regions: Brakna, Tagant, Affole, Aïr, Ader Doutchi, Tibesti, Ennedi, Mortcha, Ouaddaï, Guera and in a large part of the Sahelian Volta zone. ORSTOM has made two syntheses at the instigation of the Interafrican Committee for Hydraulic Studies. These deal with the exceptional daily storms and decennial flows from small basins. Let us add that the collection of basic data from ORSTOM's representative and experimental basins contributes useful complementary information in a different form.

On the other hand, the problem of annual runoff has not been favoured. It is only treated in certain local studies but has not hitherto been the object of any synthesis study. There are two reasons:- The construction engineers and the operators of the dam have been led, as the result of bitter experience, to give the study of flood flows a priority which resulted in the study of the volume of annual runoff being eclipsed. The second reason is the lack of long duration statistical series of flow, which may only be produced by the setting up of networks and these, in the Sahel zone are difficult to operate and very expensive.

For the flood flows in the Sahelian zone, by using the following group of factors, data on precipitation, data from representative basins and the reconstruction of flood flows from the floodmarks, it is possible to reach either a close approximation in the case of small drainage basins or, for larger basins, an estimate which is occasionally sufficient for the planner.

The same group of data is far more difficult to make use of when it comes to estimating annual volumes.

Nevertheless, the engineer building the dam needs to know whether his reservoir will be filled every year or at least nearly every year, and if it does not fill up, he needs to be able to estimate the importance of this failure and the likelihood of its reoccurrence. He also needs to know the greatest annual volumes that he may encounter; this problem being linked with that of flood flows of low frequency.

The aim of the present memoir is to furnish some elements with a view to reaching a first approximation of the statistical distribution of annual volumes. This ambitious object was preferred to that of the estimation of the interannual mean of annual volumes or of the modulus, because, this last element, if it is useful to know at the very first stage of the project, is quite inadequate as soon as it is a matter of calculating the characteristics of the works. However, one has to take into consideration the fact that it is a matter of a simple orientation of the studies, because we are really far from being able to give any rules for calculating the parameters of the distribution curves in the different instances, as will be shown later, and ones evaluation will as often as not present an empirical character. However, they still retain a certain value since they have behind them twenty-five years of studies of the terrain made by dozens of hydrologists; some of whom are now well known.

It is advisable to delimit precisely the zone forming the object of this study. In the north it may be marked by the twenty-second parallel, so that the part of the Sahara which is included in it, is largely under the influence of the monsoon, although the other processes which arise in the dynamics of the air masses above the desert may also be observed there. In the south we will take as the boundary the 750 mm isohyet which corresponds to the southernmost part of the Sahelian regime of the hydrologists. This regime is characterized by the appearance of the hydrographic degradation in opposition to the purely tropical regime for which this phenomenon does not exist.

For a watercourse in a normal hydrographic network, the bed is well defined, each tributary will enlarge the size of the main river with its flow as far as the estuary or the delta by which this river joins the sea. When a cubic metre of water has entered the upstream end of the basin, it pursues its way without too many losses by evaporation or infiltration, and more than 50% reaches the downstream end of the basin.

In the Sahelian zone, if there is degradation, the continuity of the bed in a hydrographic system is not evident, even if it is not a question of a water course which is to a greater or lesser extent fossil. The losses are huge as soon as the slope lessens, the water forms inundation pools where it evaporates very quickly; effluent arms may leave the main bed and generally do not return.

Broadly speaking, at the head of the basin, if the slope is appreciable and the soil not very porous, there forms, very close to the watershed, a network of fine channels with well defined beds. These increase rapidly in size as the discharges become concentrated, forming a main course with very clear banks, the depth of which is not very great (an even shallow in desert regions). The bottom is unstable. This bed is only really full in instances of violent floods. At the same time, the basin is subject to intense erosion (if anything still remains which may be carried away by erosion). Such is the position for a basin of a few square kilometres in size, when the banks get lower, one or more depressions filled with sand become detached from the main bed, alluvial form a deposit in the bush. At least a zone is reached which has less slope and the main arm then ends in a short delta; all the liquid and solid deposits settle in a shallow depression with a clayey bottom surrounded by and to a greater or lesser extent, covered with thorny growth.

However, it also happens that watercourses do not quickly reach this stage; the upper channels may emerge in a swampy depression with a shallow slope before having acquired the morphology of a wadi and this depression is sometimes inundated over several tens of kilometres in extent with occasionally even a runoff which is far from negligible. In which direction? This is something else again. It depends on both the morphology of the depression and on the tributaries which are in flood at that moment in time, for it is a classic occurrence that, at its arrival in the depression, the flood wave divides in two parts, one going towards the theoretical upstream area and the other towards the theoretical downstream area (true in certain parts of the Beli in Upper Volta).

The watercourses may join the depression just after having formed a well defined main bed. There are therefore a series of torrents joining the main depression where runoff is a good deal calmer than in the upper reaches.

The runoff in the main depression may present several aspects, the most common of which are the following: a serie of pools mark the depression, they are fed by lateral torrent watercourses. The pools separated by sills behave like isolated systems until the sills are submerged then a current is produced towards the pool whose level is the lowest, and when most of the sills downstream are drowned, runoff occurs towards the lower reaches. Reversals in the direction of the current are frequent. The sills are often ill defined, in some cases they are swamped once in fifty or a hundred years: for example, the sill between the Bourzanga lake and the Bam lake (Upper Volta) which was inundated at the time of the exceptional floods in 1974.

The depressions comprises multiple, narrow, meandering channels which appear and disappear without apparent reason in the midst of abundant bush cover; at times the main bed becomes clearly defined, further on there is only a grassy plain. The Maggia valley (Niger) was like this in its natural state, whereas the lateral tributaries and the upstream course had torrents very comparable to the wadis of North Africa.

Depressions of this type may thus be fed over a great length. Two examples are interesting; the Ba Tha (Chad) whose upper branches originate in Ouaddaï; they concentrate with difficulty and at the point where the watercourse is about to die away, receives the tributaries of the Guera, which allow it to form a well defined bed which joins lake Fitri without too much difficulty.

There are the two following extreme cases as well: that of the clayey plains where the water accumulates between storms without forming a well organised drainage system, and that of the bare dunes, with pools which dry up very quickly in the depressions.

As a contrast, in the important highland massifs, whose valleys still have a marked slope, there is almost no degradation and one encounters once more a morphology very similar to that of the watercourses in the non-desert area of North Africa.

It is understood that in the general conditions of hydrographic degradation, the data obtained by dividing the values of the hydrologic characteristics by the area of the drainage basins do not have much meaning.

This degradation occurs for the following reasons:-

Firstly, the length of the dry season: 8 or 9 months at least, leads to the disappearance of the herbaceous vegetation, the bare soil has good surface runoff and is subject to considerable erosion.

Secondly, runoff is made by sporadic flood flows whose total duration is extremely short, which are inadequate for permitting transport of all the eroded material and the maintenance of a continuous bed as soon as the slope becomes slight.

In the south of the Sahara this is aggravated by the morphology of the valleys which corresponds to far more abundant hydrological regimes than exist at the present time. These regimes were modified only relatively recently, some thousands of years ago. The present network is developing largely in very wide valleys with slight slopes or in the dry basins of very large lakes which, in some cases, were veritable inland seas, a fact that obviously lead to more important hydrographic degradation.

Note that this phenomenon is observed in all desert or subdesert regions, in Southern Africa, in North Africa, in the Middle East, in the great Asiatic deserts, etc...

The southern boundary : the 750 mm isohyet is rather arbitrary. If the general slope is very slight, it may be further south towards the 900 mm isohyet, as on the AOUK (Chad), but this is a rather exceptional case.

Between the two boundaries defined by us, three regimens are taken into consideration :

- the desert region regimen
- the subdesert regimen
- the Sahelian regimen.

They are rapidly characterised as follows :

. In the desert region regimen, runoff is an exceptional phenomenon in time and space. In a certain number of highland massifs, with soil which is not porous and which have a steep slope, on watercourses whose basin covers more than 100 km^2, there is on average a flood every year, usually in July or August, or one flood each two years, one each five years, one each ten years, in relation with the region's character - desert or more or less desert - where the highland massif is found and especially in relation to its exposure to winds which may bring rain. When it is said that there is a flood on average every year, this means that some years there are two or three floods and that, from time to time, a year is observed where there is absolutely no runoff at all.

. In the regimen for the subdesert, there are several floods a year, all brought about by the monsoon over a short period from July to the end of August in the highland massifs and foothills. Runoff phenomena, which are to a greater or lesser extent erratic, occur in most instances, except if the soil is highly porous. In some exceptional years, there is no runoff, even in the most privileged zones.

In the proper Sahelian regimen there are a series of floods everywhere, every year, which extend over between two and a half months and four months depending on the latitude, with quite often slight runoff between floods.

In all three cases hydrographic degradation occurs as soon as the slope becomes smaller, the more so as the regimen approximates to desert conditions.

The boundaries of these three regimens are defined by the following annual isohyets:-

Desert regimen to the north of the 100 mm isohyet;
Regimen for the subdesert between the 100 mm and 300 mm isohyets;
Sahelian regimen between the 300 mm and 750 mm isohyets.

Of course, these boundaries are rather fluid because the passage from one regimen to another is progressive and, more, the determination of the isohyet lines can only be made with difficulty, taking into account the very low density of the rain gauge network and the quality of observations for quite a few stations.

1 – RUNOFF IN DESERT REGIONS

1.1. Available information. The data at our disposal are relatively scanty. In the first place there is the raingauge information to which we will return a little later and which formed the subject of J. DUBIEF's dissertation "Essay on surface hydrology in the SAHARA", on one side, and of ORSTOM's critical study of daily rainfall, but solely for the stations which affect this study, on the other.

With regard to runoff, J. DUBIEF, in the aforementioned study, collected data on the duration and extreme point reached by the floods from a good many Saharan wadis, but there are not flow rate values, and the wadis studied are for the most part situated in ALGERIA and MOROCCO.

ORSTOM proceeded to three extensive study missions in the AÏR (R.LEFEVRE 1959 and 1960, M ROCHE 1964), to three study missions in the ENNEDI (R. BRAQUAVAL 1957, M ROCHE 1958 and 1959) and to one in the TIBESTI (Y BRUNET-MORET 1962). The zones studied in the first two series of missions affected the south of the desert belt and bordered on the subdesert belt, whereas the last mission took place in the open desert. It is also possible to make use of the studies carried out on the representative basins of SOFAYA (south of the MORTCHA).

The main objective of these missions, during which numerous stream gauging measurements were carried out, was the determination of the maximum discharge during floods. However, three representative basins were equipped (KOURIEN DOULIEN in the ENNEDI (one year), BACHIKELE in the same massif (two years) and the two basins of the INTIZIOUEN (two years) in the AÏR. The observations have been sufficient to determine the volume of flood flows for a good many water-courses and occasionally the annual volume of runoff.

The study made on flood marks also provided valuable results. And lastly the ORSTOM evaporation station of FAYA-LARGEAU allowed the data observed in CHAD further south to be extended to the desert.

This direct information about flow rates is somewhat scanty and that is why maximum use will be made, in what follows, of the raingauge data which have the advantage of offering several large duration series which are totally lacking with regard to corresponding annual volumes of runoff.

1.2. Some data on rainfall in the desert zone.

1.2.1. Average and median values of annual rainfall

The raingauging stations are few in number, and, besides, the quality of the readings is frequently inadequate for at least one part of the observation period. It is a good thing to specify the degree to which one is demanding about these questions of quality in the desert region. If for one region where 1,000 mm falls, for example, there are from time to time errors totalling 50 mm or 100 mm, this does not bias the results. Nor is it the case when 10 mm or 30 mm a year fall. Moreover, in a desert region, anything is possible; one may not observe any rainfall for three years, and in the Classic tropical period of July-August 100 mm may fall in 24 hours, or even outside this period.

We specially recommend that in order to characterise annual rainfall the median values are used, as they have a more interesting physical significance than average values.

Use of the average in a design project in the desert means that during years of copious rainfall the projected dam could use all the available water : It is generally impossible and in such a case the dam may even be destroyed.

As, however a considerable number of papers only provide the average, it has been judged useful to give a table with corresponding medians and averages in the most prevalent instances.

TABLE I

Related averages and medians in the desert zone
(to the South of the 22nd Parallel)

Median (mm)	Average (mm)	Median (mm)	Average (mm)	Median (mm)	Average (mm)
5	8	30	38	80	90
10	14	40	48	90	99
15	21	50	60	100	109
20	27	60	71	110	119
25	32	70	81	120	128
				130	138

The relation diminishes when the depth of precipitation increases, which is normal, as will be seen later.

1.2.2 Areal distribution of precipitations

As written above, the rainfall stations are sparse and the records shall be carefully checked. At first many stations with doubtful records have been eliminated. Afterwards median annual values have been computed for the rainfall stations which have been kept and which are listed in following Table. The quality of records is not sufficient, for all stations, for the establishment of a good distribution curve of annual values, but for all of them it is possible to estimate the median value without significant error.

For all stations : median and mean values have been given below and also the maximum annual value. Two of them seemed doubtful, but they have not been rejected because their occurrence is not impossible.

TABLE II

Median values of annual rainfall in the desert region
(South of the 22nd Parallel)

Stations	Median	Average	Max. 24 hours	Stations	Median	Average	Max. 24 hours
AGADES (51 years)	151	158	65,5	IFEROUANE (31 years	50	59,5	47
AKJOUJT (42 years)	90	98,5	90	KIDAL (48 years)	125	135	125
ARAOUANE (18 years)	57		215(1)(?)	KORO TORO (18 years)	33		49
ATAR (51 years)	98	99	68	NOUADHIBOU (60 years)	22	37	83
BARDAÏ (9 years)	7		18	NOUAKCHOTT (41 years)	119	127,5	183 (2)
BILMA (50 years)	15	19,5	48,5	OUNIANGA (14 years)	2	4	15,5
BOUREM (40 years)	143		62	TESSALIT (25 years)	74	87	65
CHINGUETTI (42 years)	51	60,5	57,5	TICHITT (29 years)	86		64,5
FADA (37 years)	79		67	TIDJIKJA (47 years)	157		117
FAYA LARGEAU (38 years)	12	17,5	48,5	ZOUAR (17 years)	28		44
GOURMA RHAROUS (44 years)	165		58,5				

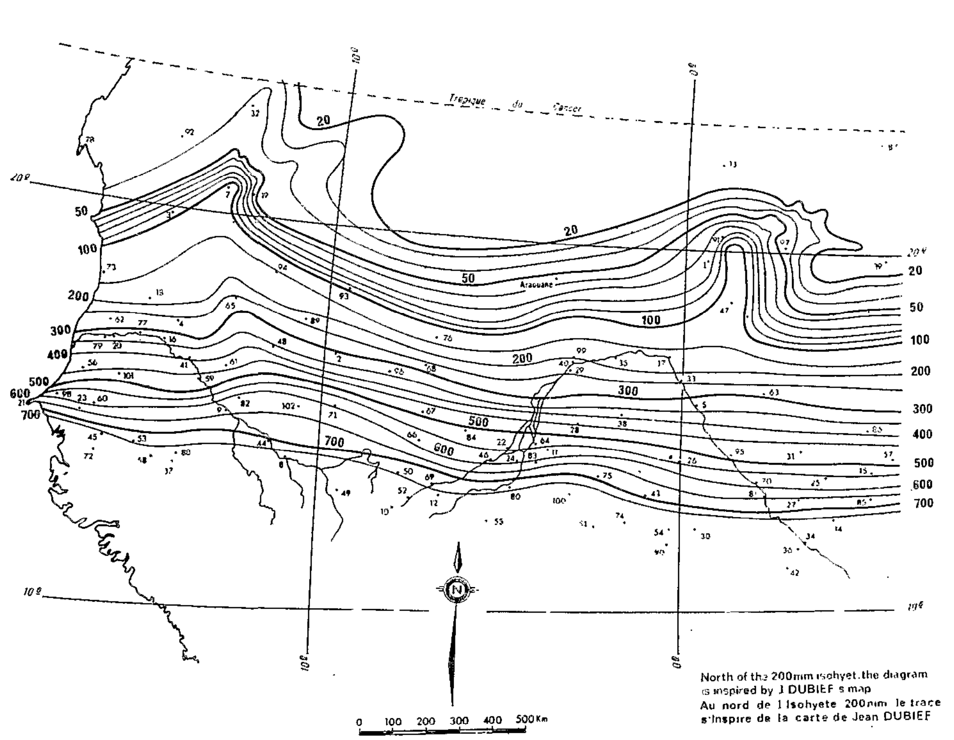
(1) 215 (?) in 1930 62 in 1931 (2) 183 in 36 h. in 1932 70,2 in 1956

Annual depths of precipitations in the SAHEL Fig. 1

Hauteurs de precipitations annuelles au SAHEL

(Median values in mm)

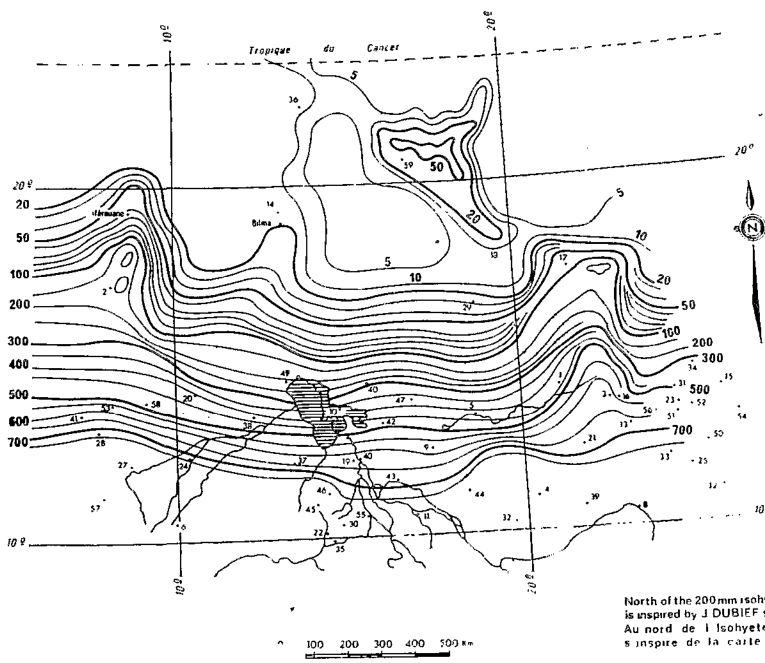
(Valeurs medianes en mm)



North of the 200mm isohyet, the diagram is inspired by J DUBIEF s map
Au nord de l Isohyete 200mm le trace s'inspire de la carte de Jean DUBIEF

LEGEND
LEGENDE

1	[illegible]	52	Koulikoro
2	Aioun-El-Atrous	53	Koungheul
3	Akjouj	54	Koupela
4	Aleg	55	Koutiala
5	Ansongo	56	Louga
6	Araouane	57	Madaoua
7	Atar	58	Maka
8	Bafoulabe	59	Matam
9	Bakel	60	M'Bake
10	Bamako	61	Mbout
11	Bandiagara	62	Mederdra
12	Baroueli	63	Menaka
13	[illegible]	64	Mopti
14	Birni N'Kebbi	65	Moudjeria
15	Birni N'Koni	66	Mourdiah
16	Boghe	67	Nara
17	Bourem	68	Nema
18	Boutilimit	69	Niamina
19	Chinguetti	70	Niamey
20	Dagana	71	Nioro
21	Dakar	72	Nioro-Du-Rip
22	Dia	73	Nouakchott
23	Diourbel	74	Ouagadougou
24	Djenne	75	Ouahigouya
25	Dogondoutchi	76	Oualata
26	Dori	77	Podor
27	Dosso	78	Port-Etienne
28	Douentza	79	Rosso
29	[illegible]	80	San
30	Fada-N'gourma	81	Say
31	Filingue	82	Selibaby
32	Fort-Gouraud	83	Sofara
33	Gao	84	Sokolo
34	Gaya	85	Sokoto
35	[illegible]	86	Tahoua
36	[illegible]	87	Tamanrasset
37	[illegible]	88	Tambacounda
38	Hombori	89	Tamchakett
39	In Guezzam	90	Tenkodogo
40	Kabara	91	Tessalit
41	Kaedi	92	Tichela
42	Kandi	93	Tichitt
43	Kaya	94	Tidjikja
44	Kayes	95	Tillabery
45	Kaffrine	96	Timbedra
46	Ke Macena	97	Tin Zaouaten
47	Kidal	98	Tivaouane
48	Kiffa	99	Tombouctou
49	Kita	100	Tougan
50	Kolokani	101	Yang-Yang
51	Koudougou	102	Yelimane



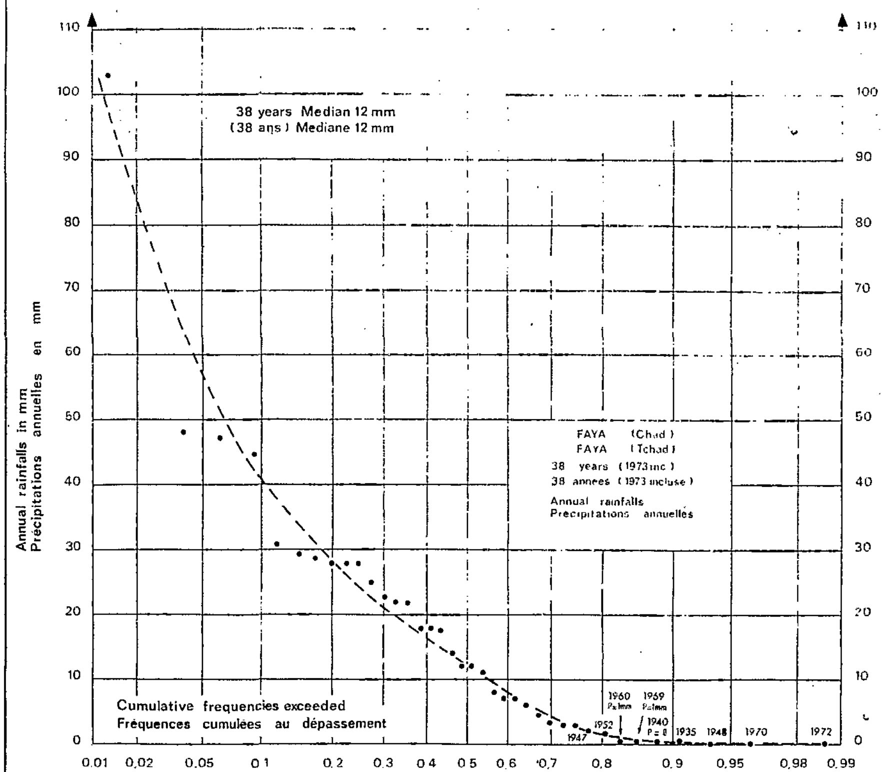
North of the 200mm isohyet, the diagram is inspired by J DUBIEF s map
Au nord de l Isohyete 200 mm le trace s inspire de la carte de Jean DUBIFF

LEGEND
LEGENDE

1	Abeche	31	[illegible]
2	[illegible]	32	[illegible]
3	Adre	33	[illegible]
4	[illegible]	34	[illegible]
5	Ati	35	Lere
6	[illegible]	36	Madama
7	Bilma	37	Maidouguri
8	Birao	38	Maine-Soroa
9	[illegible]	39	Mangueigne
10	[illegible]	40	Mao
11	Bousso	41	Maradi
12	[illegible]	42	Massakory
13	[illegible]	43	Massenya
14	Dirkou	44	Melfi
15	[illegible]	45	Mokolo
16	[illegible]	46	Mora
17	Fada	47	Moussoro
18	Faya Largeau	48	Nd'amena
19	[illegible]	49	N'Guigmi
20	[illegible]	50	Nyala
21	[illegible]	51	[illegible]
22	[illegible]	52	[illegible]
23	[illegible]	53	Tessaoua
24	[illegible]	54	[illegible]
25	[illegible]	55	Yagoua
26	[illegible]	56	[illegible]
27	[illegible]	57	Zaria
28	[illegible]	58	Zinder
29	[illegible]	59	Zouar
30	[illegible]		

Experimental distribution curve of annual rainfalls for 1 station in the desert zone
Courbe de distribution experimentale des precipitations annuelles pour 1 station en zone desertique: FAYA-LARGEAU

Fig: 2



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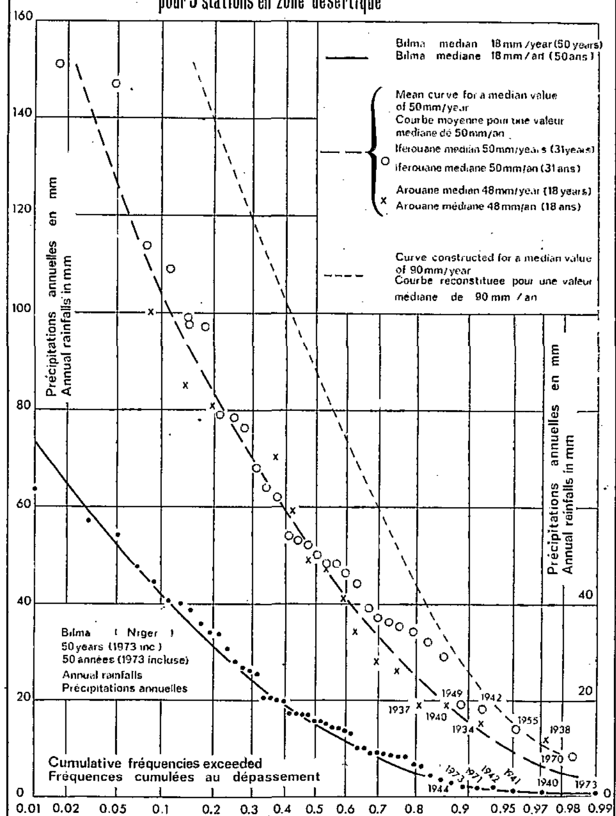
Experimental distribution curve of annual rainfalls for 3 stations in the desert zone
Courbe de distribution experimentale des precipitations annuelles pour 3 stations en zone desertique

Fig: 3



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It is naturally understood that it is a question here of depth of rainfall measured in the Association raingauges. It would be advisable for the hydrologic budgets to consider the depth of rainfall reaching the soil which, it has been seen from the latest studies, in a desert zone is on average more than 15% to 20% higher than rainfall in the Association raingauge at normal height, if the raingauge is on a site exposed to the wind. If it is sheltered to one side by hills or a curtain of trees even of low height, at less than 50 m distance, the rainfall at soil level is almost the same as the rainfall in the Association raingauge. In all that follows we will only consider the depth measured in the Association raingauge, without making any correction. It will be necessary to keep in mind, however, that here it is only a matter of a reference point which is not very accurate, since the correction varies from one site to another and, also, a priori, we are unable to make it accurately.

Moreover, the readings used for the calculation of averages and medians take in the dry years of 1970, 1971 and 1972, so that, a priori, these data are not over-estimated.

From the map of annual rainfall included in J. DUBIEF's notable study "Essay on surface hydrology in the SAHARA", we have tried to outline an up-to-date account, taking into consideration data of rainfall from the period between 1951-1972. It will be seen later how one should make use of this outline. One might think that it would be possible to get better results by choosing a probable value for the rainfall gradient with altitude. However, what has been observed so far at the TIBESTI and the ENNEDI is rather perplexing. In particular, there is a lack of systematic studies with a bearing on at least five years, and at first sight it does not seem that, in general, any happy surprises may be expected from the rainfall gradient.

In 1962, Y.BRUNET-MORET, during the months of July and August, observed on the north slope of the TIBESTI, some 5 mm at BARDAI (about 1,000 m altitude) and, respectively, 85 mm at GIDZONO, 50 mm to the north east of the TARSO VOON and 55 mm at SOBOROM; these three raingauges being on the border of the TARSO VOON. Other indications tend to show that it rains nearly every year at high altitude. The year 1962 being clearly in excess, a depth of median annual precipitation from 20 mm to 40 mm per year is not improbable on the TARSO whereas the BARDAI median is only 2 mm per year. It is possible that on the upper part of the MISKY (south slope) which is far better exposed, the depth of annual precipitation reaches 100 mm per year on really priviliged small areas. Always in the TIBESTI the few observations made by BRUNEAU of MIRE lead to the same result. The influence of exposure to the rainbringing winds is at least as important as that of altitude. A priori, there is no appreciable modification to make to J DUBIEF's isohyet map for the TIBESTI massif.

The observations carried out in the ENNEDI in 1957, 1958 and 1959 (an excessive year) have shown a clear increase in rainfall on the plateau; in 1959 251 mm were recorded at ARCHEI, 321 mm to the north of this, and 275 mm at TOURBA, while FADA received 148 mm. SEBE in the massif, observed for three years, probably has a median value neighbouring on 120 mm, as does BACHIKELE further south, while their altitude is clearly less than that of the BASSO. It is not improbable that some points of the ENNEDI receive between 150 mm and 200 mm per year (median value) as J DUBIEF has shown. What is almost sure is that the zone included within the 100 mm isohyet must be enlarged towards the west, as it appears from the extensive studies made in the ENNEDI and from research on the representative basins of BACHIKELE and SOFOYA.

The research carried out by ORSTOM in the AÏR suggests that the old outline should be left exactly as it is.

It would be completely illusory to give values for the rainfall gradient with altitude. Generally speaking, it is remarkable to be able to state that with a twenty year period of supplementary observations and studies on the terrain in three highland massifs, the improvements to be made on J DUBIEF's rainfall map are insignificant (see Figure 1).

In practice, this map will have to be thought of only as a simple guide; in a highland massif when the map gives a median value of 70 mm per year for a small basin, the actual value of this mean is perhaps 30 mm, perhaps 90 mm, it depends on altitude and exposure (and this is the very reason why we only present it on a small scale). An on the spot enquiry, to the extent that it can be made, on the number of annual rain seasons, the examination of what one considers to be vegetation cover in the desert, and of the condition of vegetation along the banks (taking into account rainfall the previous year), may help in making a choice between 30 mm and 90 mm.

1.2.3 Statistical distribution of annual rainfall

The statistical distribution of runoff is more useful in subdesert and desert zones than the annual mean volume of runoff or the specific discharge. It results more or less directly from the statistical distribution of annual precipitation. This is why it is necessary to know as fully as possible the latter distribution.

It is not at all easy because a minimum of 50 to 60 years of good observations are needed if we are to have an outline of it. In addition, the stations on the ATLANTIC littoral must be eliminated, as the factors for rainfall conditions are different from those of the interior.

Finally, only four stations have been retained:-

BILMA = average P = 19.5 mm, median P = 15 mm (50 years of complete observations).

FAYA-LARGEAU: average P = 17.5 mm, median P = 12 mm (38 years of complete observations)

AROUANE and IFEROUANE median P = 50 mm

Despite samples which are scarcely adequate it is easy enough to plot regular curves which approximate fairly well to the experimental points, at least for the two first stations.

The representative curves have been transferred on to the diagrams (Figs. 2 and 3), the cumulative frequencies being translated into gaussian co-ordinates. Of course, the high values are rather ill defined, the value to be attributed to the centennial wet frequences at BILMA lies somewhere between 65 mm and 90 mm and, for FAYA, between 70 mm and 120 mm. The collection of observations for the fifteen stations retained in the desert zone (median P lower than 100 mm) causes maximum annual rainfall to appear between two, four and five times the median value with some high isolated values. The observation periods being comprised of between 18 and 60 years for the most part and the total station-years being 481. It is normal that in the total there will be several hundred year values. There are certainly some spurious values in this sample, but also a good proportion of accurate values. The following has been deduced:-

Figures like 120 mm for the hundred year value for an average of 20 mm, and of 200 mm-250 mm for a median value of 50 mm, do not seem improbable.

For minimum values, the situation is clearer for the first two stations: the two curves from BILMA and from FAYA-LARGEAU appear to have at lower values a level between 0 and 1 mm for FAYA and 1 and 2 mm for BILMA. This word "level" may make one smile when for these two stations the curve is more or less asymptotic to the abscissa axis, but its full significance will be seen when we go on to consider stations which are better irrigated.

For FAYA, the annual rainfall is lower than or equal to 1 mm in 20% of the cases, and for BILMA, it is lower than or equal to 2 mm for 10% of the cases.

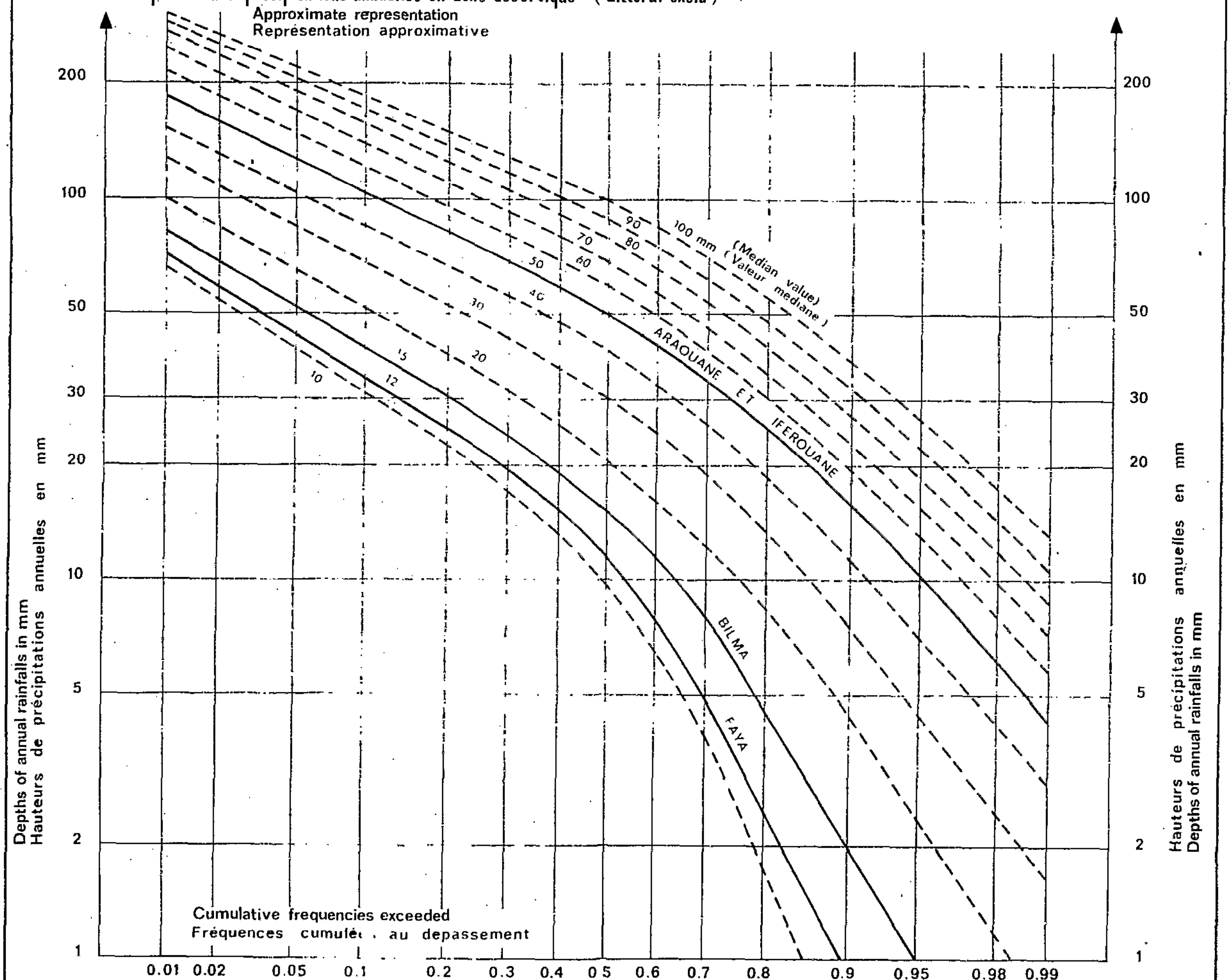
It would be useless to look for a classic statistical distribution which would fit these two empirical curves. They would add nothing to the information we have at our disposal.

Unfortunately, the two curves under consideration concern low annual rainfall and there is not a good, complete series for a median value of rainfall of 40 mm to 60 mm per year.

By plotting on the same diagram representative points for the stations of ARAOUANE (median P 48 mm, observation over 18 years), and of IFEROUANE (50 mm), one may draw an indefinite distribution curve for median P (50 mm). The upper part has been plotted, taking into account what has been said earlier:- annual hundred year rainfall neighbouring on 200 mm. It is observed that the

Temporal distribution of annual rainfalls in the desert zone (Exclusing the littoral)
Distribution temporelle des précipitations annuelles en zone desertique (Littoral exclu)

Fig: 4



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lower part of the curve remains between 10 mm and 15 mm between the decennial and vicennial frequency. But the values found for each station, taken individually, vary considerably as the samples are inadequate.

This lower part of the curve is of cardinal importance for any eventual installation scheme. Examining the observations as a whole and applying to the low frequencies a method akin to those of the station-years, one finds the following results:

median P from 2 to 5 mm	annual P is nil in 30% to 50% of the cases
median P from 8 to 13 mm	annual P is lower than 1 mm in 10%-30% of the cases
median P from 13 to 20 mm	annual P is lower than 3 mm in 8%-22% of the cases
median P from 20 to 40 mm	annual P is lower than 4 mm in 2%-10% of the cases
median P from 40 to 60 mm	annual P is lower than 10 mm in 3%-8% of the cases
median P from 60 to 80 mm	annual P is lower than 15 mm in 3%-7% of the cases
median P from 80 to 100 mm	annual P is lower than 20 mm in 3%-6% of the cases

These figures must only be considered as orders of magnitude.

We will see later the consequences to runoff of this characteristic of the form of the distribution curves.

On Fig.4 we have marked in gaussian logarithmic co-ordinates the curves from Figs. 2 and 3, and have traced by interpolation the distribution curves for the median values of the depth of rainfall varying in 10 mm steps between 10 mm and 110 mm. The curves do not represent the law of rainfall distribution; it is only a convenient method for the estimates which are to come.

These diagrams correspond with the most frequent cases, but in certain conditions one can find slightly different types of distribution. For example, on the littoral, in a year of exceptional rainfall, the annual depth is perhaps greater for the same frequency in the interior. This is clear for NOUADHIBOU which for median P = 22 mm, presents in 60 years, three values greater than or equal to 132 mm, one of which might have reached 301 mm. This is a phenomenon which one encounters in a slightly different form (exceptionally heavy rainfall in 24 hours) for the littoral of West Africa.

A second case should be pointed out: when the altitude is high, more than 2,000 m, it is very likely that the frequency of years with nil annual rainfall is less. On the other hand, it is quite probable that isolated storms give lower depths than for regions situated at less than 2,000 mm.

1.2.4 Seasonal distribution of rainfall

Rainfall almost always occurs in July and August, but some years one sees rainfall appearing in May, as is found in the central SAHARA, and even rain in January, February or March.

Thus the summits of the TIBESTI are occasionally snow covered. But as far as runoff is concerned it is a question of a second order phenomenon.

1.2.5 Evaluation of the depth of annual rainfall

One important point is the determination of the depth of rainfall (median or mean) on the site where a small reservoir or dam is to be installed. For this one will refer to Map 1 relating to the depth of rainfall. But, in the mountains, the depth of annual rainfall is irregular from one point to another, so that the map only gives a general idea and it will often be necessary to interpret.

If the site to be studied is next to a raingauge at the same altitude and in the same conditions of exposure, it is highly probable that the readings from the station will not permit the easy plotting of the distribution curve for annual rainfall. In the south of the SAHARA, at least 30 years of good quality observations will be necessary to achieve it. But with the few years at our disposal and taking into account the particularly dry or wet character of the period of observation in this region of the desert, an estimate of the median value may be attained. If the mean value is necessary we shall refer to Table 1.

If we cannot profit by these favourable conditions we will consider three elements:-

- information which may be obtained through enquiries about the frequency of floods
- the nature of the vegetation
- the condition of the hydrographic network.

The enquiry is difficult because all those questioned will have the objective of providing an answer which will please the enquirer, and not an objective answer. It is therefore advisable to be extremely careful in the formulation of questions, to question several people individually, and to try all possible cross-checking.

Flood frequency is characterized by a flood almost every ten years, every 5 years, every 2 years or "every year". The last case supposes that some years there are two or three floods and, from time to time, none at all. These questions must be posed for watercourses whose drainage basin does not exceed 100 km^2. The depth of rainfall to be considered corresponds to the centre or upper third of the basin and not to the basin mouth where there is generally less rain.

What follows should only be considered qualitatively:-

One flood nearly every 10 years corresponds to median rainfall lower than 5 mm-10 mm per year.

One flood every five years corresponds to depths of rainfall between 10 and 15 mm per year.

One flood every two years corresponds to depths of rainfall between 15 and 30 mm per year.

One flood "every year" corresponds to rainfall greater than 25 to 30 mm per year.

Relating to vegetation:

" Bare " desert with very few trees in bad condition in the bed of the water courses corresponds to less than 5-10 mm per year.

Desert where there are few trees outside the wadi beds, fairly frequent palm-groves or some doum palms in the wadi beds, corresponds to 25-30 mm per year. In this zone the interfluves are devoid of herbaceous vegetation, except for an extremely short period (8-10 days) after rainfall of at least 1 mm.

If trees are greater in number, though still sparse, outside the beds of the watercourses, if the vegetation forms a continuous belt along the watercourse, and if it is in good condition, then the depth of rainfall is greater than 40 mm per year where there is a steep slope, 60 mm to 80 mm if it is less.

Beyond 100 mm per year a graminaceous characteristic appears, the CENCHRUS BIFLORIS or CRAM CRAM which marks the end of the desert.

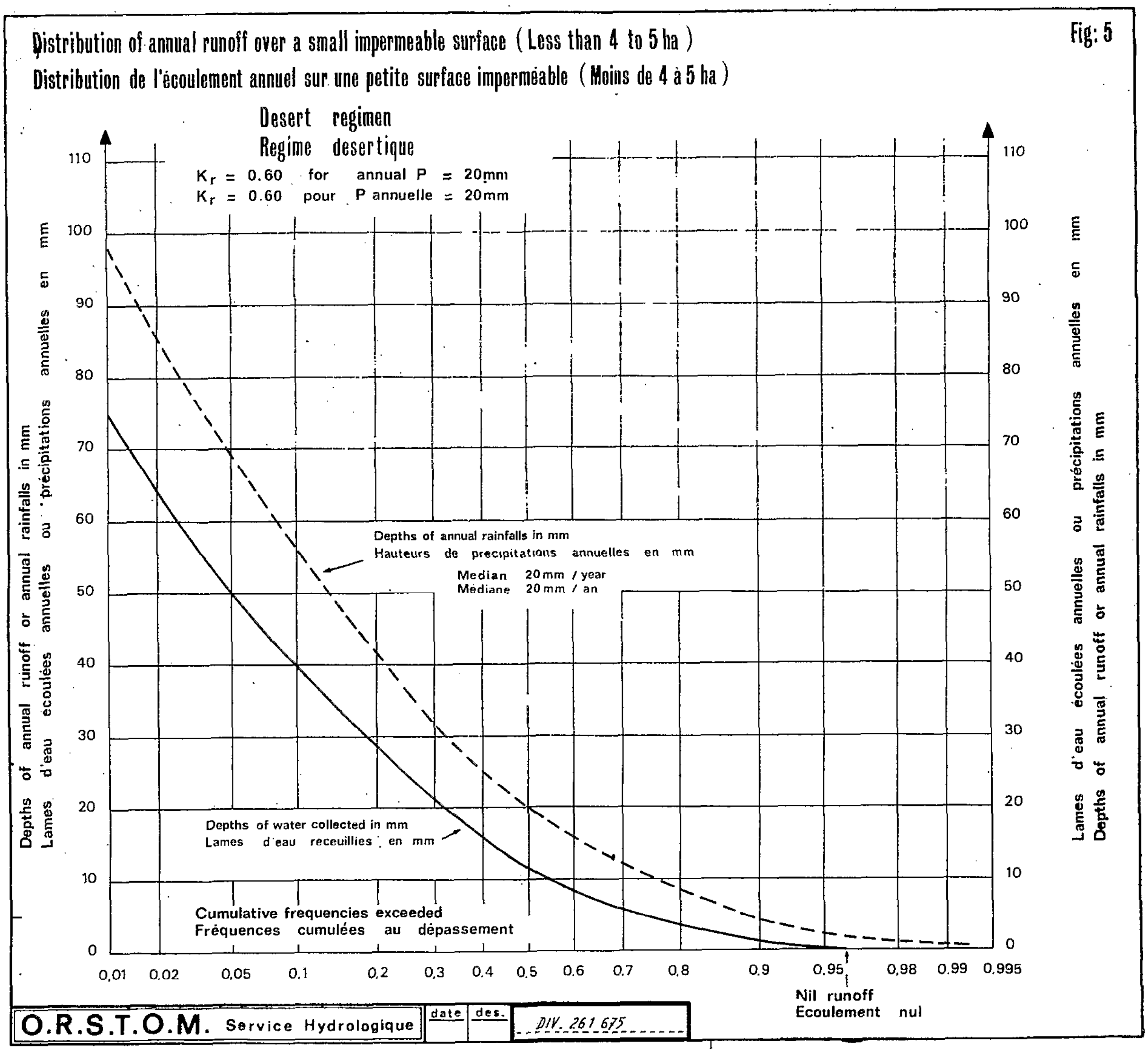
All this presupposes corrections in two cases: after a drought lasting several years a large number of trees die or are destroyed by Man, after a period of plentiful rainfall, it is the opposite, and all the trees are in excellent condition.

One must not mistake the action of rainfall and runoff for that of the resurgence of groundwater (the water levels in the apparent bed of the water courses being excluded).

Finally, as soon as a region is populated (relatively speaking), denudation does its work and all the natural vegetation is destroyed. Some ethnic groups are more destructive than others.

With regard to the drainage network, a network which has water once every year is much more defined than if it has no runoff for several years, but in this case, the interpretation is difficult, because if the study of the terrain is made just after a year of exceptional rainfall the drainage network is clear. After several dry years, the reverse is true.

We repeat that we are only giving a few guide lines.



Distribution of annual runoff over a small impermeable surface (Less than 4 to 5 ha)
Distribution de l'écoulement annuel sur une petite surface imperméable (Moins de 4 à 5 ha)
Fig: 5
Desert regimen
Regime desertique
K_r = 0.60 for annual P = 20mm
K_r = 0.60 pour P annuelle = 20mm
Depths of annual runoff or annual rainfalls in mm
Lames d'eau écoulées annuelles ou précipitations annuelles en mm
Depths of annual rainfalls in mm
Hauteurs de precipitations annuelles en mm
Median 20 mm / year
Médiane 20 mm / an
Depths of water collected in mm
Lames d'eau receuillies en mm
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
0,01 0,02 0,05 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 0,95 0,98 0,99 0,995
0 10 20 30 40 50 60 70 80 90 100 110
Nil runoff
Ecoulement nul
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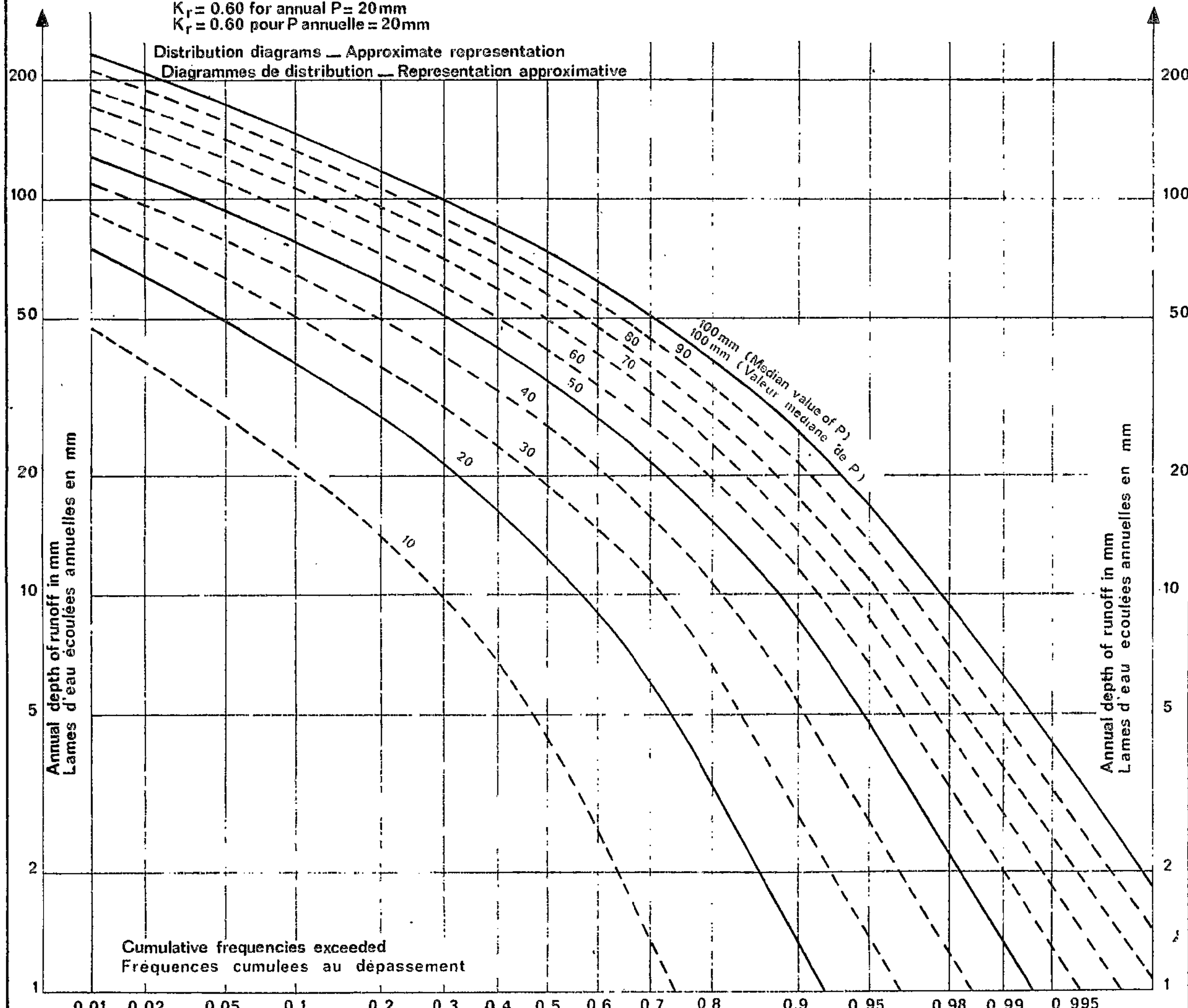
Annual runoff over a small impermeable surface (Less than 4 to 5 ha)
Ecoulement annuel sur une petite surface impermeable (Moins de 4 à 5 ha)

Fig: 6



Runoff
Ecoulement = 0
for
pour
Annual median P =
P médiane annuelle =

10 mm	f = 0.78
20 mm	f = 0.96
30 mm	f = 0.986
40 mm	f = 0.995
50 mm	f = 0.998
60 mm	f = 0.999

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1.3 Annual runoff in the desert zone

We will be examining four cases which differ from one another according to the area of the basin under consideration :

a. areas for the replenishment of cisterns : a few hectares in size at most

b. small drainage basins of 2 - 40 km^2, capable of replenishing a reservoir.

c. watercourses whose drainage basin is between 40 and 300 km^2 with little hydrographic degradation. The area may reach 400 to 800 km^2 or more if the relief is marked.

d. desert basins of more than 1,000 km^2, affected to greater or lesser extent by hydrographic degradation.

It is necessary to make this distinction because the regime of the variations of annual volumes, from one instance to another varies in an extremely important way with the area of the drainage basin. The principles of estimation are no longer by any means the same.

1.3.1 Drainage basins of at maximum a few hectares in size

For such basins rainfall is equal to that received in the raingauge, after multiplication by the correction factor between rainfall at soil level and rainfall in the raingauge. On the other hand, very often, the surface is treated so that it may be as impermeable as possible. In some cases, it is very impermeable (metallic surface, plastic film) in which case the runoff coefficient would in theory be equal to 1; in fact, there is always some retention of the raindrops by the receiving surface, followed by evaporation, and this is appreciable for rainfall less than 1 mm (for some stations which receive 5 to 10 mm per year, there are a certain number of these). That is why it would be a good thing to take into consideration, for the depth of annual rainfall, a runoff coefficient lower than 90% of the rain reaching soil level, and this for small areas; a few hundreds of m^2 at most. For the same reasons of being cautious, one will not assume the correction between rain at soil level and rain in the raingauge. This coefficient, the mean of which may be 15% to 20% in some cases, is variable from one storm to another and in particular from one site to another, and the researches now in progress do not permit the giving of a precise figure.

If the surface is not impermeable to a high degree, one will take a runoff coefficient varying between 40% and 80%, according to the nature of the surface, the surface area of the reception area and the depth of annual median rainfall, the lowest figure corresponding to depths of annual rainfall of 10 to 20 mm and to a soil on a clayey earth beaten flat, with a minimum slope of 1% and an area of less than a hectare. Of course, it is a mean figure if the annual depth of 10 mm was constituted by ten falls of 1mm, for example, the runoff coefficient would be lower than 40%. If there was one fall of 10 mm in strength it would be higher than 40%.

The cistern will have to be designed so that it will not be destroyed in case of exceptional storms. In Table II you will get an idea of exceptional rainfall over a 24 hour period.

Then you will find Figure 5 (giving the depth of water in millimetres) of use for a reception area which is relatively impermeable and which, for a median value of rainfall of 20 mm, has a runoff coefficient of 60%. Of course, this coefficient increases slightly in a wet year and decreases appreciably in a dry year. The results must be considered merely as an initial estimate. The median value of runoff would be in the nature of 12 mm. It may be seen that in one year in nine the cistern collects nothing, the runoff threshold being agreed equal to 2 mm.

If the median depth of rainfall is different by 20 mm, it is easy to plot the distribution curve of rainfall with the series of curves from Fig. 4, and by considering that to a similar depth of annual rainfall there corresponds a similar runoff coefficient, one may easily deduce the values of this coefficient from the diagram.

Fig. 6 gives in gaussian logarithmic co-ordinates, for the depth of annual runoff, a complete family of curves for a relatively impermeable reception area. The runoff coefficients corresponding to the adopted median values to establish each of these curves, have been selected in a rather simplistic way, taking into consideration a rapid increase between the median values 10 and 50 mm, then a more gradual increase from 50 to 100 mm. Given the actual precision which must be expected from this type of estimation, it would have been utterly useless to pinpoint a relatively regular increase.

Accordingly, the values of the runoff coefficient are as follows :

P = 10 mm	Ke = 42.5%	P = 60 mm	Ke = 70%
P = 20 mm	Ke = 60%	P = 70 mm	Ke = 71%
P = 30 mm	Ke = 63%	P = 80 mm	Ke = 72%
P = 40 mm	Ke = 66%	P = 90 mm	Ke = 73%
P = 50 mm	Ke = 69%	P = 100 mm	Ke = 74%

On this system we are making exactly the same reservations that we had in point 1.2.3. In a very wet year, runoff may lead to extensive damage if the constructions are under-dimensioned; for safety's sake, the curves probably give rather over-estimated values for exceptionally wet years. (K_R = 75% to 80%).

If L is in mm, depth of runoff, S the surface of the reception area in m^2, then the volume collected per year V will be given in m^3 by the formula :-

$$V = S \times L \times 10^{-3}$$

In estimating annual runoff the following course should be taken :-

- Determination of the depth of annual rainfall (mean or median), reference should be made to point 1.2.5.
- Determination of the distribution curve of annual rainfall by interpolation from Fig 4;
- Determination of the distribution curve of annual runoff, from Fig. 6;
- Eventual correction if the reception area is completely impermeable (increase allowing the attainment of K_R = 80% for annual P = 10 mm, K_R=90% for annual P = 100 mm for less than a hectare), or if one is not really satisfied with the impermeability of the said area (reduction to K_R = 40% for annual P = 20 mm) and if the surface area of the reception area is larg
- Study of the available annual volumes for the different frequencies.

The frequency of years where there is no runoff is of cardinal importance, as is the maximum value of the flood flow. According to the case, a return period will be considered, in content between ten and fifty years. Table II gives some idea of rainfall of various frequencies over a 24 hour period. Using discretion a runoff coefficient of 90% will be taken for these flood flows, if the reception area is not, rigorously speaking, impermeable.

1.3.2. Small drainage basins of between 2 km^2 and 40 km^2

Even in the favourable conditions which will be studied further on, runoff phenomena will occur far less easily than in the preceding case.

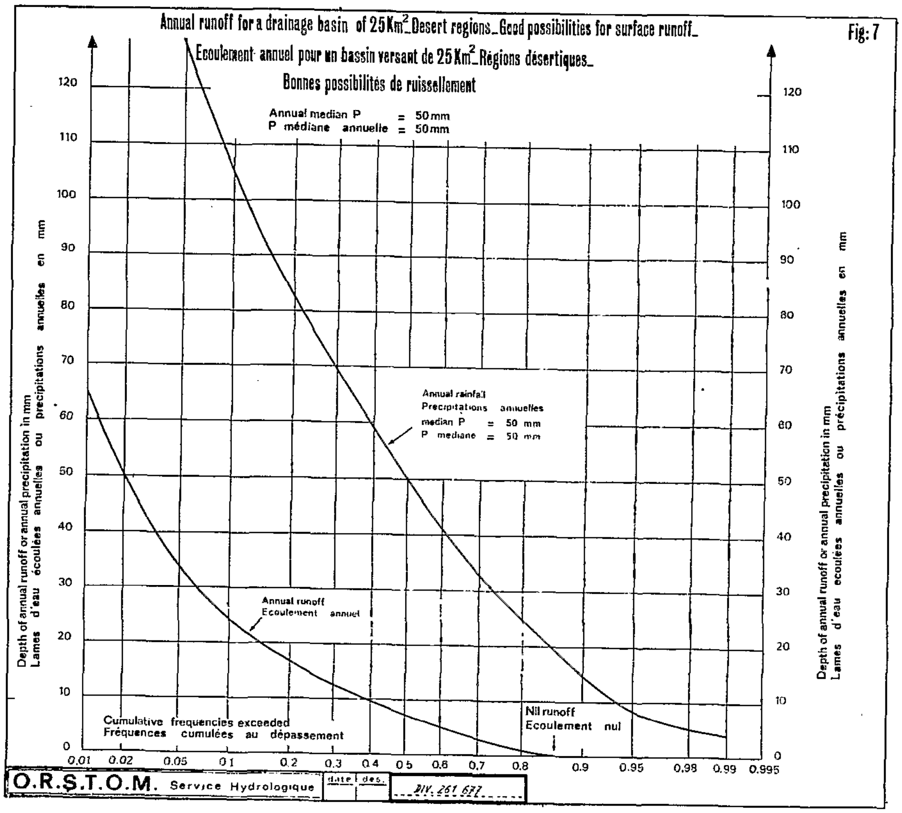
For this climatic zone the number of years without any runoff at all on a small basin with good surface runoff is far from negligible, except perhaps in the instance of basins at high altitude, (at more than 2,000 m, and well exposed) for which the rainfall distribution curve is perhaps a little different with elimination of the lower part of the curve (less than 5 mm - 10 mm per year). This is, however, an exceptional case.

For small basins where surface runoff conditions are mediocre, the result is certainly worse, with, for example, runoff on average one in two years and with several series of three or four consecutive years without runoff. As a matter of fact, in the great majority of cases, the engineer will not try to complete a reservoir in such conditions and it is a good thing, because available data for this type of basin are inexistent.

All the more so for basins where conditions of surface runoff are poor and which only know runoff once in 30 or 50 years, when they receive a storm flood of 60 mm to 70 mm.

Here we will only consider basins whose physiographical characteristics are favourable to surface runoff : this is to say, steep or quite steep slope (index of total slope in metres per kilometre at least 15), with fairly impermeable soil (drainage density greater than 2.5), without any hydrographic degradation. It is useless to speak of the influence of vegetation cover, in any case this influence is nil in the desert zone, except for the avenues of trees along the thalwegs in the more privileged zones.

With regard to permeability, one will have to be very careful about the following fact : a massif of rocks, impermeable in principle, may make a good impression. These rocks may be very fractured, a fact which has no very significant consequences, except for the recharging of groundwater bodies, but when the state of decay of these rocks is such that there is a significant overlapping of stony blocks, there results from it a very serious increase of permeability. If this occurs over the greater part of the drainage basin, it is no longer a basin "which has good surface runoff".


Annual runoff for a drainage basin of 25 Km² Desert regions_Good possibilities for surface runoff_
Ecoulement annuel pour un bassin versant de 25 Km² Régions désertiques_
Bonnes possibilités de ruissellement
Fig: 7
Annual median P = 50mm
P médiane annuelle = 50mm
Annual rainfall
Précipitations annuelles
median P = 50 mm
P mediane = 50 mm
Annual runoff
Ecoulement annuel
Nil runoff
Ecoulement nul
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
Depth of annual runoff or annual precipitation in mm
Lames d'eau écoulées annuelles ou précipitations annuelles en mm
0.01 0.02 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.95 0.98 0.99 0.995
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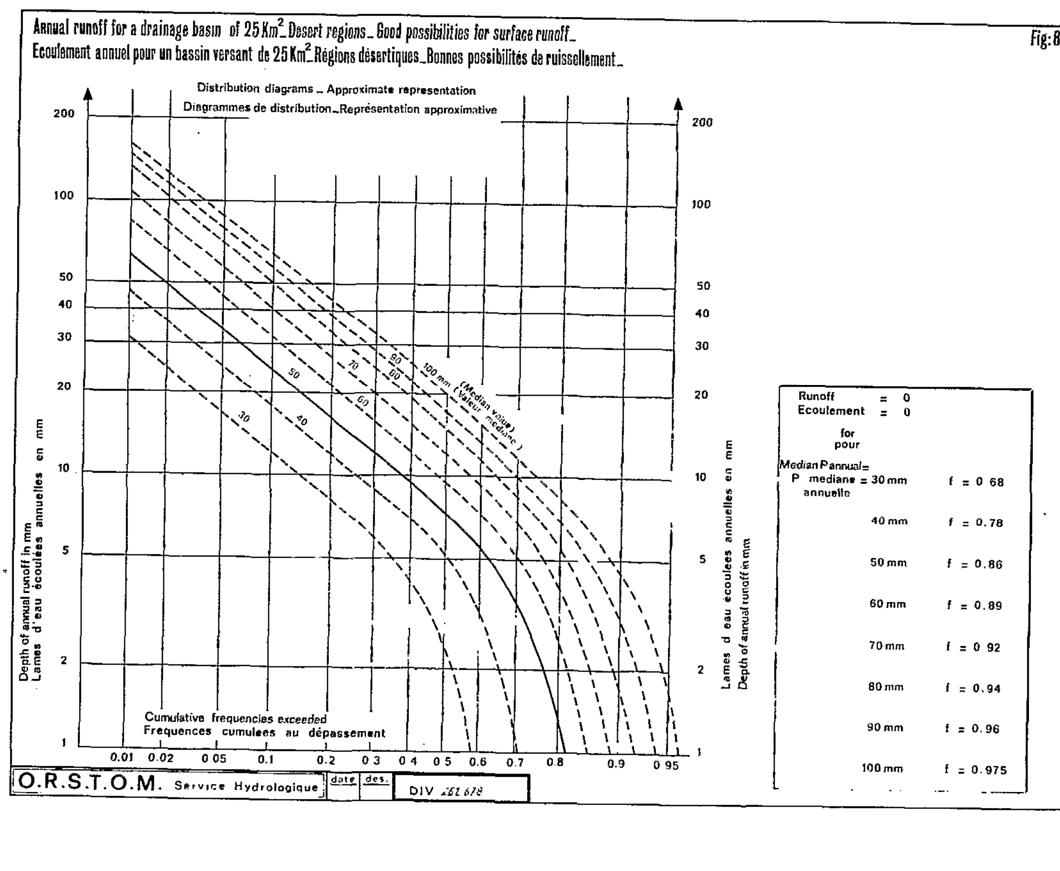
Annual runoff for a drainage basin of 25 Km² Desert regions_Good possibilities for surface runoff_
Ecoulement annuel pour un bassin versant de 25 Km² Régions désertiques_Bonnes possibilités de ruissellement_
Fig: 8
Distribution diagrams _ Approximate representation
Diagrammes de distribution_Représentation approximative
100 mm (Median value) (Valeur médiane)
90
80
70
60
50
40
30
Cumulative frequencies exceeded
Frequences cumulees au dépassement
Depth of annual runoff in mm
Lames d'eau écoulées annuelles en mm
0.01 0.02 0.05 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.95
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date
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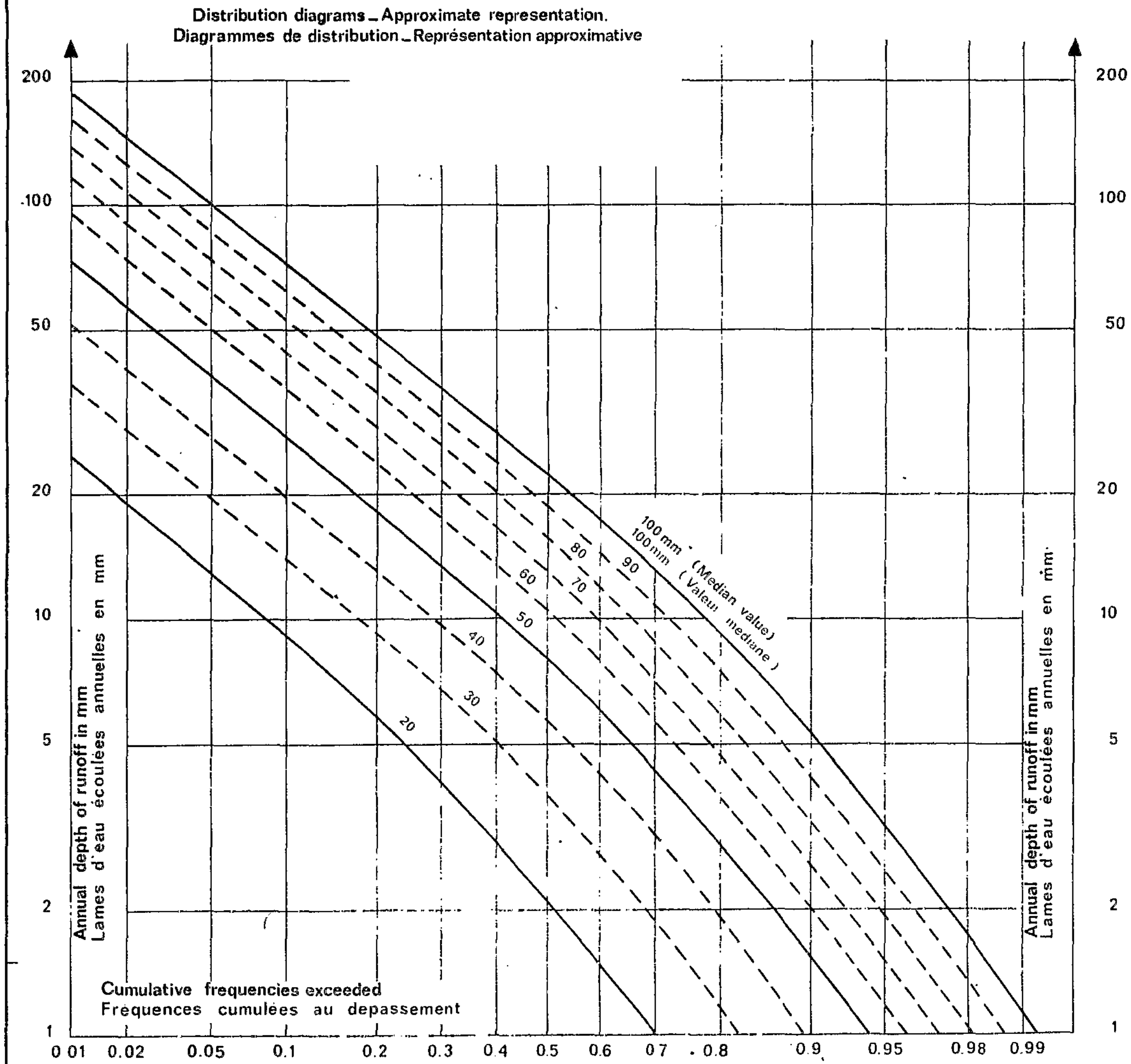
DIV 261 678
Runoff = 0
Ecoulement = 0
for
pour
Median P annual =
P mediane annuelle = 30 mm f = 0.68
40 mm f = 0.78
50 mm f = 0.86
60 mm f = 0.89
70 mm f = 0.92
80 mm f = 0.94
90 mm f = 0.96
100 mm f = 0.975

Annual runoff for a drainage basin of 5 Km² – Desert regions – Good possibilities for surface runoff.
Ecoulement annuel pour un bassin versant de 5 Km² – Régions désertiques – Bonnes possibilités de ruissellement.

Fig: 9



Runoff = 0 Ecoulement = 0 for pour		
Annual median P = P médiane annuelle =	20 mm	f = 0.84
	30 mm	f = 0.90
	40 mm	f = 0.96
	50 mm	f = 0.977
	60 mm	f = 0 986
	70 mm	f = 0 991
	80 mm	f = 0.994
	90 mm	f = 0.999

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It is the same for drifting sand which must not cover more than 15% to 20% of the basin.

In all cases, with considerable slopes, the soil has disappeared.

The data at ones disposal are those from the representative basin of KOURIEN DOULIEN (median P = 80 mm) and one may draw some information from the representative basins situated at the northern limit of the sub-desert zone : IN TIZIOUEN (AÏR) (median P = 140 - 150 mm), BACHIKELE (ENNEDI) (median P = 110 - 120 mm) and SOFOYA (ENNEDI) (median P = 120 - 130 mm), as well as from extensive studies from the TIBESTI, ENNEDI and AÏR.

The foregoing studies show that storm floods of 8 to 15 mm may give a runoff corresponding to 20% - 30% and, occasionally, 50% of the volume of runoff. For very violent storms 30 - 50 mm, this coefficient of runoff may reach 50% - 60%. But, inspite of the absence of soil, storms of the order of 7 to 8 mm and sometimes more, may not give rise to any runoff. The absorption capacity in sandstone, for example, is probably of the order of 20 mm per hour. The influence of preceding rains is not nil on the storms observed with the most surface runoff. The distribution of the storm peaks in time is not negligible. A storm of 10 mm, with several peaks of intensity of equal importance extending over several hours, does not often give surface runoff.

For example, at KOURIEN DOULIEN, over an annual total neighbouring on 70 mm in 1957, 23 mm rainfall contributed something in the order of 90% of the runoff, with the result that the annual runoff coefficient is 19%. One finds 22% at BACHIKELE in 1958, for a depth of rainfall of 154 mm. For the small basin of AOUE in ENNEDI, one finds 12% to 15% for a depth of annual rainfall of 150 mm. The basins of IN TIZIOUEN which are very small (0.67 to 2.61 km^2) and with a steep slope, gave for the depth of rainfall about 140 mm in 1959 and 1960, annual runoff coefficient of about 22% in 1959 and 14% in 1960.

From this it is deduced that between the 50 mm and 100 mm isohyets one may forecast a runoff coefficient of between 14% and 20% for a drainage basin of 10 km^2 to 30 km^2.

For a similar depth of rainfall, for a given year, the runoff coefficient varies according to the temporal distribution and the intensity of rainfall. The value of 15% already represents a mean.

This gives us a first point of the statistical distribution curve of annual runoff, in millimetres. One may know the approximate position of 2 other points by considering the following :-

Below a certain threshold there is no runoff and, in a year of plentiful rainfall, for which there is often a violent storm and several less significant falls, one may have an idea of the runoff coefficient.

What is the surface runoff threshold? Here, too, one must think that it is a question of an annual total depth. It has to be admitted that one isolated downpour of 10 mm constitutes a threshold for a basin of 25 km^2. It might be necessary to admit perhaps 8 mm for a basin of 10 km^2 and 6 mm for a basin of 4 km^2. Of course, a storm of 10 mm, of exceptional intensity, will clearly give surface runoff and, on a basin of 25 km^2, an intense downpour of 6 mm, falling over 1 km^2 over the downstream part of the basin, may give rise to a slight surface runoff at the station. But in more frequent conditions of distribution in time and space, 10 mm constitute a threshold for 25 km^2, always for what we call a basin with good surface runoff. This corresponds to an isolated fall. It may always be admitted, in the more frequent case, that a depth of annual rainfall of 20 mm, comprising, for example, one isolated fall of 10 mm and some less significant downpours, constitutes a threshold for a basin of 25 km^2. This threshold may be taken to 16 mm for 10 km^2 and 12 mm for a basin of 4 km^2. For smaller surfaces one will interpolate between these figures and the threshold of 2 mm forecast in point 1.3.1.

With regard to the upper part of the curve, if one considers a region where median value of the depth of annual rainfall is 50 mm, for a depth of annual rainfall of 150 mm ($f = 0.025$), comprising a 24 hour storm of 60 mm, one may admit a runoff coefficient of 30%.

For a region where the depth of annual rainfall presents a median value of 90 mm, the threshold remains the same; one considers for the high point of the curve, an annual depth of rainfall of 200 mm, with a runoff coefficient of about 35%, still for an area of between 10 to 30 km^2.

From these data Figure 7 has been plotted representing the distribution curve of annual runoff for median $P = 50$ mm.

It is established that if a reservoir is set up on a basin of this area, it will remain empty for the following frequencies :-

One year in twenty-fine	below the 90 mm isohyet (median value)
One year in seven	below the 50 mm isohyet (median value)
One year in three	below the 30 mm isohyet (median value)
One year in two	below the 20 mm isohyet (median value)

It will be understood why we have not tried to plot the curve corresponding to this last instance.

It is easy enough to plot other curves for all depths of median rainfall between 20 mm and 100 mm per year. Figure 8 represents, in logarithmic coordinates, the approximate distribution curves for a basin of 25 km^2.

At an altitude of more than 2,000 m, the frequency of years with nil runoff is a little lower.

For areas of less than 10 km^2 the distribution curves of annual rainfall in millimetres are defined from the following runoff thresholds 8 mm for 10 km^2, 6 mm for 4 km^2, 4 mm for 2 km^2. The runoff coefficient would be a little higher, between 16% and 22%, for a drainage basin of 5 km^2, for a depth of annual rainfall from year to year between 50 mm and 100 mm, and for the median value. For 150 mm it would reach 40%. From this one derives Figure 9, representing the distribution curves for annual runoff corresponding to 5 km^2, for the annual median depths of rainfall between 20 mm and 100 mm.

For areas of 2 km^2 one will consider the intermediary values between those which have been specified above and the values given in point 1.3.1. It must not be forgotten that in the case dealt with in point 1.3.1. one is making an effort to make the soil surface impermeable, something which one cannot do in case 1.3.2.

For the estimation of annual runoff the step to pursue is the following :-

determination of the area of the drainage basin,
determination of the depth of annual rainfalls (mean or median, one refers to point 1.2.5)
determination of the distribution curve of annual rainfall from Figs 8 or 9

If the area of the basin is too far from the given examples, it will be necessary to interpolate between the results given by Figs 8 and 9, or perhaps even Figs. 9 and 6.

- Study of available annual volumes for the different frequencies

The problem of exceptional floods is still more important than in case 1.3.1. One will refer to the studies of exceptional rainfall in West Africa while remembering that for basins with an area of more than 4 km^2, the upper limit for the runoff coefficient is in the order of 80% in the desert zone (calculated from rainfall at the raingauges and not in relation to rainfall at soil level).

1.3.3 Drainage basins of 40 km^2 to 300 - 500 km^2 in the desert regimen

1.3.3.1. The most typical case is that of the basin of 100 km^2, i.e. 80 km^2 to 120 km^2 in reality. In mountain massifs, it is not a rare occurrence for hydrographic degradation to be not very advanced, but it is again advisable to verify this. The slightest levelling in the longitudinal section, especially when it is combined with a widening of the valley, gives rise to sediment deposits and to important water losses, even if the degradation is not very advanced. Often these same zones are occupied by small interior deltas. There is, besides, the problem of recharge of the apparent bed which absorbs 20 m^3 per metre length in a longitudinal direction for the ZOUMRI between NEMA NEMASSO and YOUNTIOU (a width of 20 m).

On the other hand, the depth of annual rainfall, for one given year, varies considerably from one point to another of the basin, even if over a long period, the depth of rainfall is homogeneous over the basin, which is moreover somewhat rare. Small tributaries in the neighbourhood of the station play a principal part. It is equally difficult to fix a threshold for annual rainfall from which there is surface runoff, one may consider a case where the mean of rainfall over the basin is 18 mm for one given year, but there is runoff because a tributary next to the station has received 50 mm in the same year. The slope, the type of soil, the nature of the hydrographic network play an even more important part than in the case of small basins, with the result that even if one was able after a fashion to plot a family of curves like the one in Figure 8, it would be necessary to repeat this operation a dozen times, with the certainty of covering at the end of the operation only a third or a quarter of the cases encountered in practice, because there are myriad specific cases. So, in order to plot these curves, the information at ones disposal is very scant, as will be seen later.

1.3.3.2. Available information

J. DUBIEF'S synthesis "Essay on surface hydrology in the SAHARA" is most cautious about the south of the SAHARA, and in particular AÏR and TIBESTI; furthermore this work only gives depths of flood flows or qualitative indications on runoff, but if it only gives very little direct information about the zone which we are studying, it does give a good idea of the extreme variability of annual runoff and of the occurrence of years without runoff.

ORSTOM'S missions to the TIBESTI, in ENNEDI, MORTCHA and AÏR collected the following data which often are only simple evaluations :-

S = surface of the drainage basin Pm = annual rainfall observed
E = depth of runoff in mm Ke = $\frac{E}{pm}$

- ZOUMRI to YOUNTIOU (TIBESTI) median P = 20 mm?
  S = 739 km^2 1962 Pm = 25 to 40 mm E = 1.18 mm Ke = 3% to 4.7%
  Volcanic rocks, steep slopes, high altitude (more than 2,000 m for one part of the basin). Very little degradation.

- ZOUMRI to NEMA NEMASSO (TIBESTI) median P = 20 to 30 mm?
  S = 206 km^2 1962 Pm = 35 to 40 mm E = 1.54 mm Ke = 3.5% to 5%
  Same characteristics, no degradation
  KORI TAMGAK (IFEROUANE (AÏR)) median P = 60 mm?
  S = 560 km^2 1958 PM = 60 mm? E = 5 mm Ke = 8%?
  1959 (IFEROUANE = 32 mm) PM = 80 mm? (IFEROUANE = 79 mm) E = 1.15 mm Ke = 1.5%
  1960 PM = 50 mm? (IFEROUANE = 46 mm) E = 0.13 mm Ke = 0.25%
  Steep slopes, very little degradation.

- OHOUKA (ENNEDI) median P = 80 to 100 mm?
  S - 550 km^2 1957 PM = 60-70 mm E = 2 mm Ke = 2.8 to 3.3%
  Sandstone, quite steep slope, a little degradation
  At the boundary between desert and subdesert one finds the following data:

- MAYA (ENNEDI) median P = 110 to 120 mm?
  S = 85 km^2 1957 Ke = 11 to 12%

- ARCHEÏ (ENNEDI) median P = 110 mm?
  S = 800 km^2 1957 PM = 80 - 110 mm E = 0.6 mm Ke = 0.5 to 0.75%
  Sandstone, quite steep slope, fairly advanced degradation

- ENNERI OROUE (ENNEDI) median P = 110 - 120 mm?
  S = 180 km^2 1958 P = 175 mm E = 27.6 mm Ke = 15.8%
  Sandstone, quite steep slope, no degradation

- OUADI SOFOYA (representative basin) median P = 110 to 120 mm
  MORTCHA
  BV I -

S = 345 km^2	1965	P = 132 mm	E = 4.8 mm	Ke = 3.6%
	1966	P = 110 mm	E = 2.3 mm	Ke = 2.1%
	1967	P $\geqslant$ 128.6 mm	E = 8.5 mm	Ke 6.6%

  Moderate slope, a little degradation

- OUADI SOFOYA (representative basin)
  BV II -

S = 175 km^2	1965	P = 124 mm	E = 6.7 mm	Ke = 5.4%
	1966	P = 110 mm	E = 2.8 mm	Ke = 2.45%
	1967	P = 138 mm	E = 15.7 mm	Ke = 11.4%

  Moderate slope, little degradation

- OUADI SOFOYA
  BV IV -
  S = 81 km^2 1967 P = 138.6 mm E = 6 mm Ke = 4.3%
  Moderate slope, quite advanced degradation. Nil runoff every 15 or 20 years.

- KORI EL MEKI (AIR) median P = 140 to 160 mm
  S = 165 km^2
  1956 runoff
  1957 runoff
  1958 very good runoff P = 200 to 250 mm? E = 30 to 40 mm?
  1959 P = 180 mm E = 12.7 mm Ke = 7.5%
  1960 P = 190 - 200 mm? E = 62 mm Ke = 31-32%

  Steep slope, no hydrographic degradation

1.3.3.3. Some practical conclusions

For a similar depth of annual rainfall, the volume of runoff varies quite considerably according to the temporal distribution of storms, as the study of OUADI SOFOYA shows.

Slope plays an important part, as one may see from the ZOUMRI, KORI TAMGAK, ENNERI OROUE and KORI EL MEKI. The area of the basin has an equally great influence.

For basins with steep slope and without hydrographic degradation, and which have an area varying between 150 to 250 km^2, in a median year the surface runoff coefficient varies from 2% to 4% for depths of mean rainfall comprising between 30 mm and 110 mm (for basins of 25 km^2, it varies from 7% to 20%).

For basins of 500 km^2, it probably varies from 1% to 3% in a median year, if hydrographic degradation is limited.

For basins of 30 km^2 to 100 km^2 with steep slope and without hydrographic degradation, one would have to be able to count on a runoff coefficient of 6% to 15% in a median year.

The principal difficulty is the determination of the surface runoff threshold. Some water courses, above mentioned, have the reputation of flowing "every year", but this does not exclude years with no runoff once in ten, twenty or fifty years. Unfortunately, we have no data on runoff for the periods 1912-1915, 1940-1945 and 1970-1973 when, very probably, this phenomenon occurred. Between the years 1957 to 1960 and 1965-1967 there is no deficit year.

OUADI OUM CHALOUBA is without runoff once every ten or twenty years.

The ZOUMRI at NEMA NEMASSO presents no runoff, perhaps once every fifty years or every two hundred years, thanks to the high altitude situation of its basin.

The KORI TAMGAK seems to be without runoff much more frequently, runoff in 1960 was really very slight.

It has been estimated that OUADI SOFOYA would be without runoff once every fifteen or twenty years.

In any case, before admitting that a water course in this category has runoff strictly every year, it will be advisable to proceed to a really thorough study of the runoff factors, rainfall, geological constitution of the basin, slopes, hydrographic network and of the effects of this runoff :-

- existing palm groves, or stands of doum palms (without forgetting that some years the underground water level in the apparent bed may be augmented by flood flows upstream without there being any runoff downstream, and that is sufficient for the palms, as is the case with ENNERI OHOU DAHOM in 1957),

- a very difficult enquiry in countries where there are very few residents.

One will have an idea of the variability of runoff from some data relative to point 1.3.4.

If at the other extremity of the distribution curve, one may have an idea of the maximum values of runoff, the problem is almost as difficult.

For areas of 150 km^2 to 800 km^2 one cannot for mountain desert regimes pass from the point rainfall to rainfall over the drainage basin. For the OUADI SOFOYA (BV1 - 345 km^2) studied for three years as a representative basin (median P = 120 m - 130 mm), one found by extrapolation a depth of runoff of 30 mm for a depth of mean annual rainfall of 200 mm, and so a coefficient of runoff of 15%.

In the extreme north of the zone studied in the TIBESTI, the depth of ten year runoff at NEMA NEMASSO on the ZOUMRI is perhaps comprised of between 1.5 mm to 3 mm for 206 km^2. On the KORI TAMGAK (median value of P in the order of 50 mm), it is perhaps in the order of 5 mm for 550 km^2. But, for basins of 25 km^2 to 100 km^2 one must find much higher runoffs for the decennial year : perhaps 8 mm and 40 mm, according to the median value between years of the depth of annual rainfall comprising between 30 mm and 100 mm.

1.3.3.4. Some advice on the evaluation of annual volumes of runoff

- To proceed to a very thorough study of the terrain and to determine the following points if possible :-

  * area of the drainage basin
  * slopes
  * hydrographic network (especially in the downstream part of the basin),
  * marks of hydrographic degradation (especially in the downstream part of the basin),

* vegetation on the slopes (if any)
* vegetation along the water course
* marks of flood flows

As far as possible, one will proceed to an enquiry on the runoff phenomena, and one must deduce from this :

* an idea of the mean depth of rainfall on the basin for the 0.5 frequency (median value) by making use of map 1.
* indications of the existence of years without runoff
* a general view of hydrographic degradation and the possibilities of absorption of the apparent bed.

- Having taken the preceding into account, in particular the area of the basin, of the average slope and the hydrographic degradation, one will select, in the order of magnitude given in point 1.3.3.3., those which seem to suit the basin studied

- From these elements one will outline : median value of runoff, start of runoff, ten year values of flow rates, a runoff distribution curve like that in Figure 8, which one will have to consider only as a guide.

1.3.4. Desert basins of more than 1,000 km^2

1.3.4.1. Generalities

The hydrographic degradation is almost always important, only those water courses are interesting whose basin presents a vigorous relief over the greater part of the surface. The station studied must be at the way out of the massif or at the interior, if not there will be runoff once every 10 or 20 years, which is of no interest for the management of the surface hydrology (it is not even of interest for the recharge of groundwater). Each water course is a specific case.

1.3.4.2. Available information

Later one will find, a certain number of evaluations, often very summary ones, taken from measurements made in the course of the missions called to mind earlier.

- ZOUMRI at BARDAÏ (TIBESTI) median P = 15 to 20 mm?

S = 4050 km^2	1954	E = 5 mm?
	1955	E = 0
	1956	E = 0
	1957	E = 0
	1958	E = 0.005 mm
	1959	E = 0
	1960	E = 0.005 mm
	1961	E = 0.013 mm
	1962	E = 0.19 mm

Steep slopes, high altitude, hydrographic network with very little degradatio
A large part of the basin receives less than 10 mm per year in a median year.

- ENNERI HOHOU DAHON, on the road to FADA (ENNEDI) median P = 70 - 80 mm

S = 1000 km^2	1956	Violent flood	
	1957	E = 0	P = 60 mm

Sandstone, quite steep slopes, pretty advanced hydrographic degradation

- ENNERI ARCHEÏ (ENNEDI) median P = 110 mm?

S = 800 km^2	1957	E = 0.6 mm	Ke = 0.5 to 0.75%

Sandstone, quite steep slopes, pretty advanced hydrographic degradation.

- OUADI HAOUACH (MORTCHA) median P = 120 mm

S = 7,700 km^2	1959	E = 0.37 mm	P = 240 mm	Ke = 0.18%
	1966	very wet year E perhaps 0.2 mm		
	1967	E = 0.22 mm		

Sandstone in the upstream part, then rocky, quite a gentle slope, advanced hydrographic degradation

- OUADI OUM CHALOUBA (MORTCHA) median P =

S = 2,000 km^2	1965	P = 47 mm (1) at OUM CHALOUBA	E = 0(1)	
	1966	P = 130 mm	E = 0.5 at 1 mm	Ke = 0.8 to 1.2%
	1967	P = 130 - 150 mm	E = 3 mm	Ke = 2 to 2.5%

(1) in the rainy season, but a flood in March.

- KORI TELOUA (AÏR) median P = 170 mm

S = 1,170 km^2	1959	P = 170 mm	E = 39.3 mm	Ke = 23%
	1960	P = 116 mm	E = 12 mm	Ke = 10.4%
	1964	P = 125 mm	E = 14.7 mm	Ke = 11.2%

Rocky, steep slope, no hydrographic degradation

1.3.4.3 Some conclusions

Some water-courses with very steep slopes, without any degradation at all and receiving 60 to 100 mm rainfall in the median year, appear, as the case of KORI TELOUA shows, to present runoff coefficients which reach perhaps 5% to 6% at the maximum, and flow perhaps every year or nine out of ten years. This is probably the case for two water courses on the south slope of the TIBESTI : the MISKY and the MAROU.

However, if the median value of annual rainfall is very low, as on the ZOUMRI, there is runoff every two years and the runoff coefficient is almost always very low.

If, on the contrary, the median value of the depth of annual rainfall is relatively high, as in the subdesert regimen, one may find in exactly the same conditions a runoff coefficient of 10 to 20% in the median year, for median P comprising between 150 and 200 mm (see further on in the next chapter).

If these extremely favourable conditions are not met and if degradation is not too accentuated, the runoff coefficient falls to 0.1 - 0.5% in the median year for median P comprising between 50 and 100 mm and there is no runoff one year in five, in ten or twenty, according to the case involved.

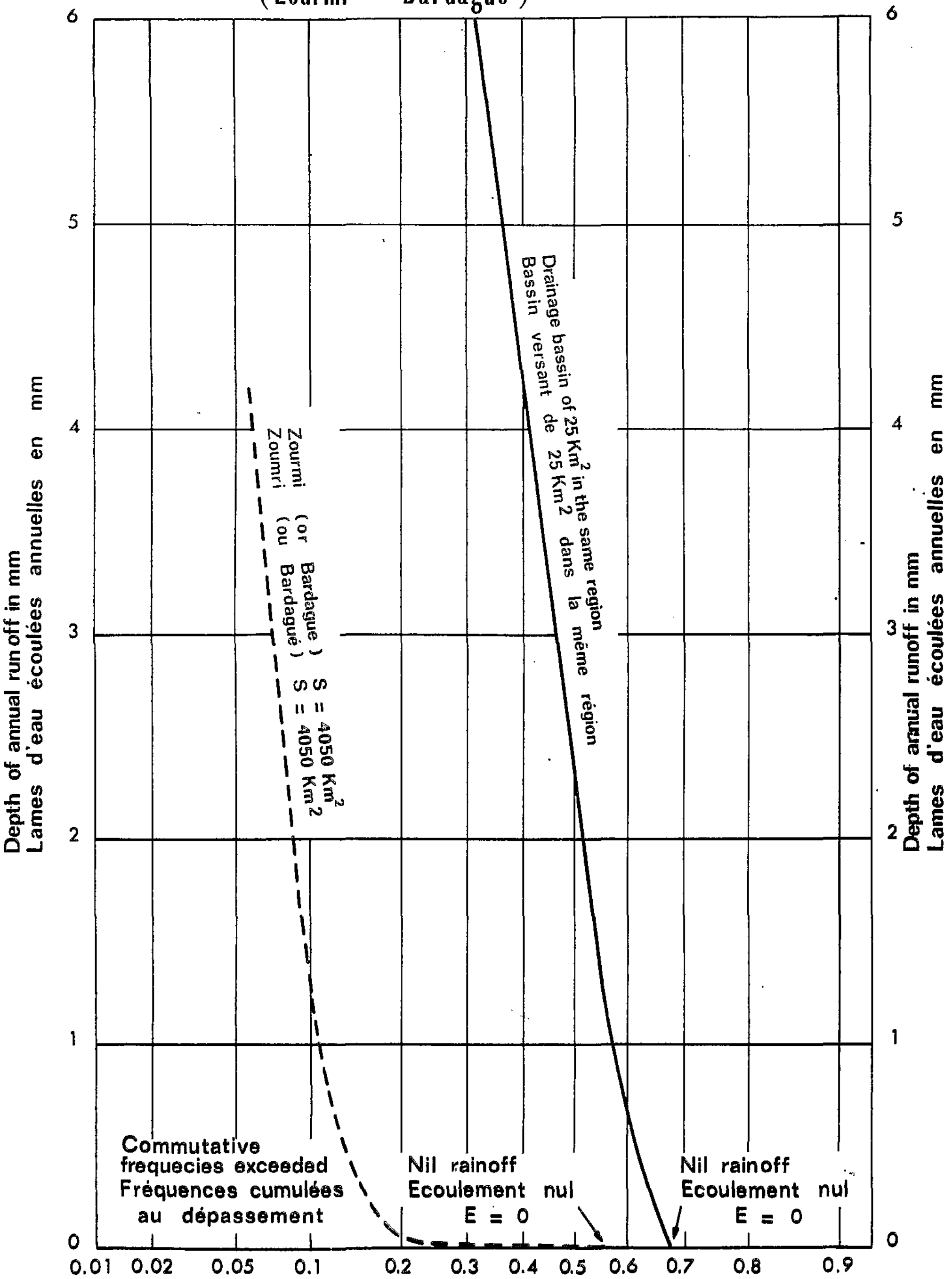
The annual volume of runoff is perhaps very high in an exceptionally abundant year, if there is no degradation, there is a runoff coefficient reaching or even perhaps exceeding 10% in some cases.

If there is degradation, although the exceptional annual volume is very much greater than the median value, the depth of runoff remains very low. 1 or 2 mm or a fraction of a millimetre.

There has been outlined on Fig 10 what would be the distribution curve of annual runoff in the ZOUMRI (ENNERI BARDAGUE) at BARDAÏ, which gives an idea of the extreme irregularity of annual runoff in this particular case where surface runoff becomes a really exceptional phenomenon.

In a general way, the recommendations for the study of these water-courses are the same as in paragraph 1.3.3 with this difference, that, in general, runoff being very inferior to those of basins of 25 km^2, it is practically impossible to use as a guide the shape of the distribution curves of these small basins. This case 1.3.4 is the limit of the possibilities for quantitative evaluations.

Distribution curves of depth of surface runoff from the Zourmi at Bardaï **Fig:10**
Courbes de distribution des lames d'eau ruisselées du Zourmi à Bardaï
(Zourmi - Bardagué)



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2 – RUNOFF IN SUBDESERT REGIONS

2.1 Available information

Data are clearly more plentiful than in the desert regimen.

With regard to rainfall, one may count on the readings from about thirty stations which are almost totally of use and excellent where some of them are concerned.

As for runoff, no more information than for the desert regimen. No readings originating from networks are at ones disposal, so there is no report of long series flow rates. On the other hand, the extensive studies' missions in the AÏR, ENNEDI, BRAKNA, TAGANT and the north of the OUADDAÏ, then again the study of the representative basins, provide the elements which allow rainfall to be transformed into flow rates.

One may use the results from the ORSTOM missions already mentioned in point 1.1; also missions in the AÏR (1959 and 1960), mission in the ENNEDI (1957, 1958 and 1959), as well as ORSTOM'S missions in the BRAKNA and the TAGANT (BRUNET - MORET 1958 and 1959), that of the north of the OUADDAÏ(OUADI ENNE in CHAD in 1961) and that of the AFFOLE in MAURITANIA (ROCHE, 1960).

To this type of studies one may link those carried out by the "Service du Genie Rural" of MAURITANIA on the KETCHI wadi and lake ALEG and those of the IRHAZER (1966 and 1967) carried out in succession by the "Service du Genie Rural" of NIGER and ORSTOM.

The ORSTOM representative basins of BACHIKELE (1958 and 1959) and of SOFOYA (1965 and 1967) mentioned earlier provide elements for the northern limit of the subdesert regimen. The ORSTOM representative basins of KADJEMEUR (1965-1966) in CHAD, of RAZELMAMOULNI (1959 and 1960) in NIGER, of the SELOUMBO wadi (1957, 1958 and 1959) and of DIONABA (1958 and 1959) in MAURITANIA, of TIN ADJAR (1956, 1957 and 1958) in MALI are located at the centre of the subdesert zone. The representati basin of AM NABAK (CHAD) and those of the TARAIMAN near BILTINE (CHAD) correspond to the southern limit of the subdesert zone.

The data on evaporation from the BOL climatological station, those from the

TIN ADJAR evaporation pan allow, in conjunction with the hydrologic budget of lake CHAD, the provision of sufficient elements for the determination of losses by evaporation at the surface of a reservoir.

As in the case of the desert regimen, the lack of data from the network will lead us to continue on to a thorough study of the rainfall regime which will enable us to have a brief evaluation of the permanent statistical characteristics of the runoff in the easiest instances, the data on runoff giving us an idea of the relations between rainfall/flow rate. These relations are, moreover, not simple. On the annual scale the liaison between these two elements is rather loose, the distribution of rainfall in time playing a very important role.

2.2 Some data on rainfall in the subdesert zone

2.2.1 Mean and median values of annual rainfall

The situation is much better in the desert regimen than in the subdesert regimen. Nevertheless, the number of raingauge stations still remains small and the considerable variations year to year force one to be very insistent on the importance of statistical samples. That is why it has been thought useful to reproduce here essential data from all the stations whose readings are capable of being turned to account, and to use median values in preference to mean values as was done for the desert regimen. Moreover, a certain number of the stations already mentioned in the previous chapter have been taken up again.

Table III, to follow, presents the correspondence between the mean value and the median value. It is worth saying that there is an appreciable dispersion on this side and that from the line of regression, as one will realize from the data on Table IV.

Table III

Relations between mean and median in the subdesert zone

Median (mm)	Mean (mm)	Median (mm)	Mean (mm)	Median (mm)	Mean (mm)
100	109	150	161	200	210
110	119	160	170	220	231
120	128	170	180	240	251
130	138	180	190	260	271
140	150	190	200	280	291
				300	311

The relative importance of the variation between mean and median decreases progressively from north to south. Below the annual 300 mm isohyet, the variation is no more than 3.7%. The statistical distribution gets closer to a normal distribution. Given the share of inaccuracy in the evaluation which will be presented further on, there is no grave objection to admitting that the median value determined, from a sample taken over at least 20 years of observation, is equal to the mean value.

2.2.2. Spatial distribution of rainfall

On Table IV we have entered the mean and median values of annual rainfall observed at thirty raingauge stations which have been retained.

One can make the same remarks about these data as in paragraph 1.2.2. with this difference, that the mountain massifs in the subdesert zone, being not so high as the TIBESTI, the problem of the variation in annual depth of rainfall at altitude is a little less pronounced there. However, it is quite incontestable that, the south of the AÏR, of the ENNEDI and the ADRAR of the IFORAS, and probably also the TAGANT, receive annual rainfall which is clearly greater than that in the surrounding lowlying zones.

Use will be made of J. DUBIEF'S isohyet map with a few slight alterations. The fact that we are taking median values instead of mean values changes the map not one whit. Even a systematic variation of the order of 5% is not to be taken into account, on the scale on which this map is presented.

In mountain regions in particular this rainfall outline must only be considered as a simple guide.

2.2.3. Statistical distribution of annual rainfall

The situation, as has been mentioned earlier, is a little improved in relation to the desert regimen, however, the exploiting of rough data with a view to the analysis of statistical distribution of rainfall, cannot follow classic methods.

On Figure 11 we have presented the representative points of annual rainfall classes from two stations where the readings are good in quality : KIDAL (median P 125 mm) and BOL (median P 285 mm). On the abscissa is marked the frequency exceeded in gaussian coordinates. The two lowest values of P for BOL : 1913 46 mm and

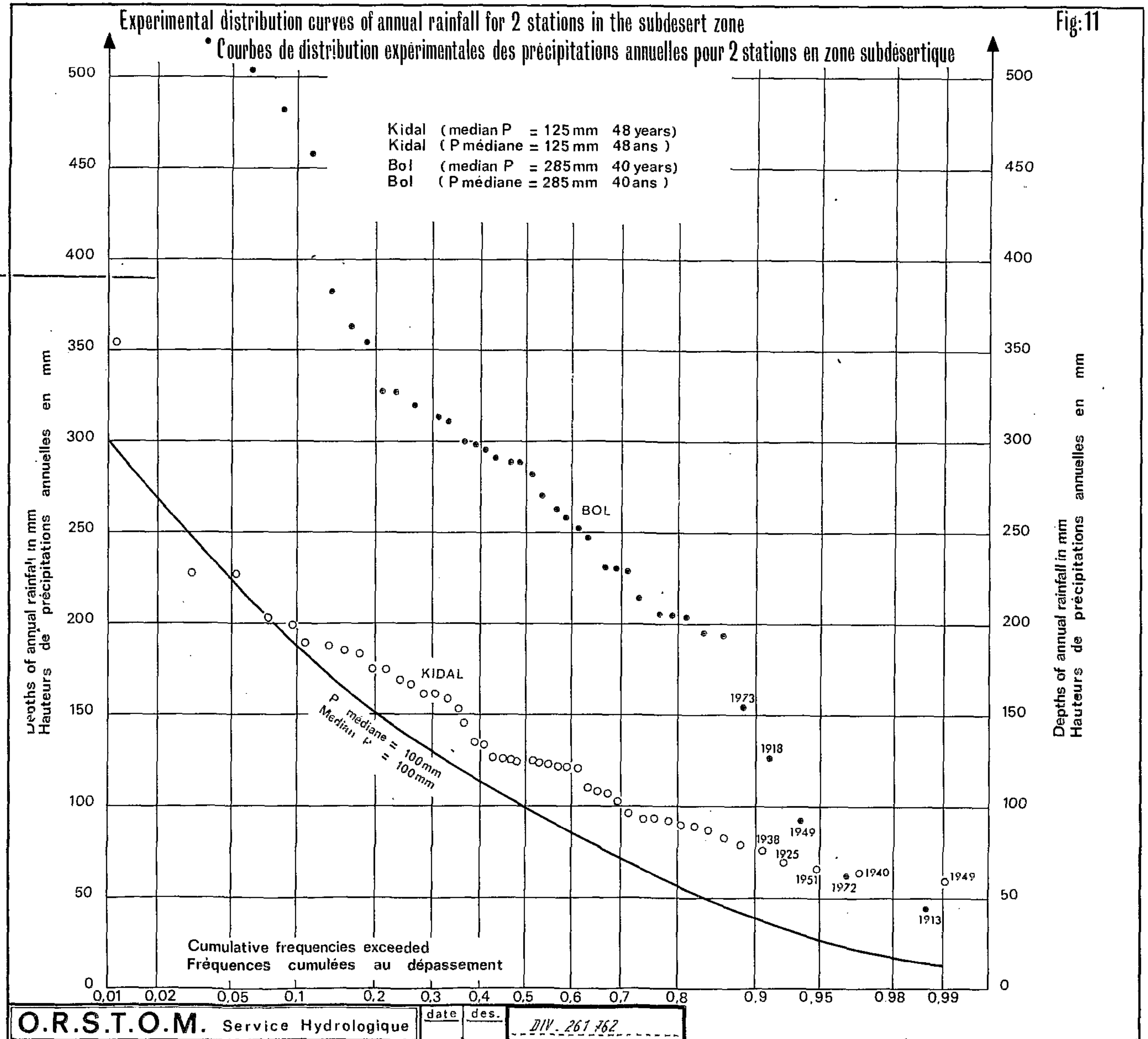
Experimental distribution curves of annual rainfall for 2 stations in the subdesert zone
Courbes de distribution expérimentales des précipitations annuelles pour 2 stations en zone subdésertique
Fig: 11
Kidal (median P = 125 mm 48 years)
Kidal (P médiane = 125 mm 48 ans)
Bol (median P = 285 mm 40 years)
Bol (P médiane = 285 mm 40 ans)
BOL
KIDAL
P médiane = 100 mm
Median P = 100 mm
Depths of annual rainfall in mm
Hauteurs de précipitations annuelles en mm
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
0,01 0,02 0,05 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 0,95 0,98 0,99
0 50 100 150 200 250 300 350 400 450 500
1973 1918 1949 1938 1925 1951 1972 1940 1949 1913
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TABLE IV

Median values of annual rainfall in the subdesert region

Stations	Median	Mean	Stations	Median	Mean
AGADES (51 years)	151	158	SRIBA (12 years)	250	283
AIOUN EL ATROUSS (24 years)	310	301	KIDAL (48 years)	125	135
ALEG (47 years)	266	281	M A O (27 years)	306	332,5
ANSONGO (39 years)	328	303,5	MEDERDRA (42 years)	249	245,5
ARADA (10 years)	192	194,5	MENAKA (48 years)	264,5	281
BAMBA (23 years)	199	206	MOUDJERIA (43 years)	215	225
BILTINE (16 years)	270	301	N E M A (48 years)	288,5	288,5
B O L (40 years)	285	285	NGUIGMI (50 years)	192,5	214
BOUREM (40 years)	143	150	NOUAKCHOTT (41 years)	119	127,5
BOUTILIMIT (50 years)	176,5	183	OUALATA (19 years)	120	126
D I R E (37 years)	263	271,5	SARAFERE (31 years)	281	301
G A O (51 years)	258	260	TIDJIKJA (47 years)	157	160
GOUNDAM (49 years)	237	246	TAMCHAKETT (38 years)	221	243
GOURMA RHAROUS (44 years)	165	176	TANOUT (31 years)	251	278
IN GALL (15 years)	206	199	TOUMBOUCTOU-KABARA (66 years)	206	204,5

1972 62 mm are absolutely accurate as well as the maximum value : 1954 699.5 mm. The minimum value of BOL is distinctly lower than the minimum value of KIDAL;this is not surprising because the samples are not absolutely comparable. The station at KIDAL, contrary to that at BOL, gives no reading for the great drought of 1913-1914. Moreover, the drought of 1971-1973 was more marked in CHAD and in MAURITANIA than in the North of MALI. Finally, everyone knows that in any experimental frequency analystis, the extreme values are not significant since, in fact, their exact frequency is either not well known or completely unknown. So, for some sites in dry years and for a given value of median P, the rainfall sinks very low or, the opposite, is retained, relatively speaking, as is the case, for example for the stations of the interior delta of the NIGER, or even of the valley of this river as far as GAO, stations for which the rainfall sinks very rarely below 100 mm per year, and never below 73 mm per year.

So, in the study of annual runoff, the importance of the lower part of the distribution curve is of cardinal importance. It is from this that one will be able to conclude whether or not it is certain that a reservoir will be filled every year or whether there are risks of failure.

Figure 11 clearly shows that it is not possible to start directly from the distribution of the experimental points from each station, in order to plot the base of these curves, this is why use has been made of the following method which is related to that of the station years:

These stations have been divided up into three groups :

- median P 100 and 160 mm,
- median P between 160 and 220 mm,
- median P between 220 and 300 - 310 mm

The first group comprises the following stations : AGADES, KIDAL, NOUAKCHOTT, TIDJIKJA, OUALATA with 206 station-years (BOUREM, NIGER valley has been excluded).

The second group comprises the following stations : BOUTILIMIT, IN GALL, MOUDJERIA, NGUIGMI, TAMCHAKETT with 196 station-years. (BAMBA, GOURMA-RHAROUS and TOMBOUCTOU-KABARA, the NIGER valley have been excluded).

The third group comprises the following stations : ALEG, BILTINE, BOL, IRIBA, MAC MEDERDRA, MENAKA, NEMA, TANOUT with 311 station-years (DIRE, GAO, GOUNDAM, SARAFERE, the NIGER valley have been excluded).

In each group, annual rainfall has been classified by increasing size, independently from the station where it was observed : one gets the following experimental rainfall-frequency pairs :

First group :

mean of the median P = 140 mm	f = 0.997	P = 18 mm/per year
	f = 0.99	P = 34 mm
	f = 0.98	P = 40 mm
	f = 0.95	P = 58 mm
	f = 0.90	P = 69 mm

Second group :

mean of the median P = 200 mm	f = 0.99	P = 38 mm
	f = 0.98	P = 45 mm
	f = 0.95	P = 65 mm
	f = 0.90	P = 94 mm

Third group :

mean of the median P = 270 mm	f = 0.99	P = 58 mm
	f = 0.98	P = 88 mm
	f = 0.95	P = 112 mm
	f = 0.90	P = 147 mm

Only the values for f = 0.90 are truly significant, taking into account the statistical sample available and they seem probable.

For f = 0.99, the values for groups 1 and 2 seem too close; with samples from 200 years, one can only attain an order of size for hundred year values. But it is a fact that the distribution curves tend to narrow towards these very low values.

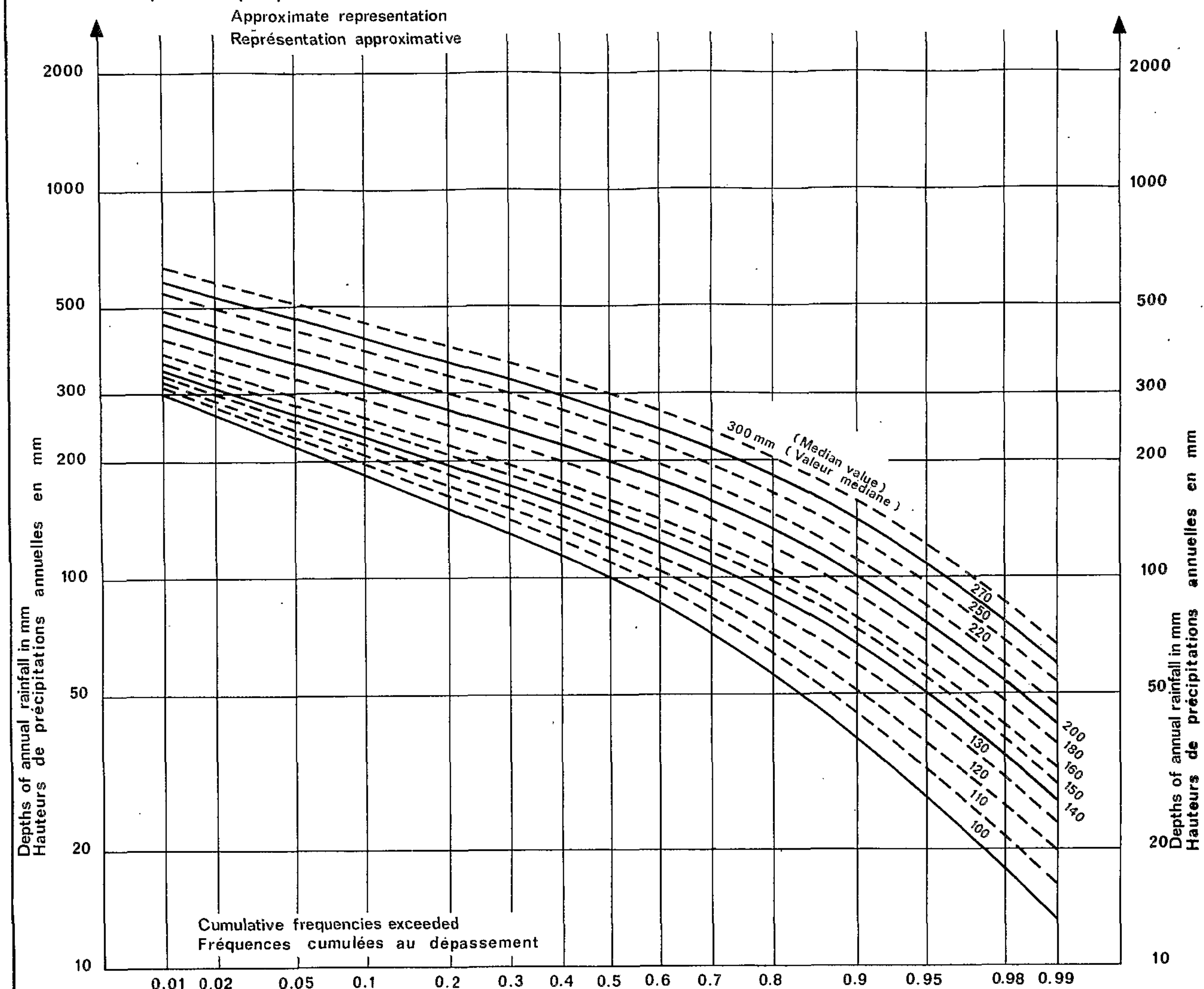
One operated in the same way for very wet years, but this time results from the NIGER valley stations were taken into consideration, which significantly increased the number of station-years. The following results were achieved :-

Ist group (246 station-years)	f = 0.002	P = 421 mm
	f = 0.01	P = 335 mm
	f = 0.02	P = 315 mm
	f = 0.05	P = 263 mm
	f = 0.10	P = 221 mm
2nd group (329 station-years)	f = 0.0015	P = 535 mm
	f = 0.01	P = 470 mm
	f = 0.02	P = 405 mm
	f = 0.05	P = 373 mm
	f = 0.10	P = 320 mm
3rd group (479 station years)	f = 0.01	P = 630 mm
	f = 0.02	P = 530 mm
	f = 0.05	P = 462 mm
	f = 0.10	P = 411 mm

It is from these data that the distribution curves presented in Figure 12 were plotted, in gaussian logarithmic coordinates. There was no difficulty in passing by "experimental" points for high values and ten year low values. For the lowest values, in particular the hundred year and fifty year values for the first groups, the 140 mm curve was placed a little below the experimental points (some mm) to result in a regular family of curves. Of course, what we call 140 mm curve, is the curve corresponding to a rainfall regime for which the median value is 140 mm and the mean 150 mm.

Temporal distribution of annual rainfall in the subdesert zone (Littoral excluded)
Distribution temporelle des précipitations annuelles en zone subdésertique (Littoral exclu)

Fig: 12



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As in paragraph 1.2.3., these curves correspond to the most frequent cases. One may find sites where, for a similar value of median rainfall, the exceptionally low values are distinctly lower or higher than those of the curves in Figure 12. Moreover, it is a question of approximate representation; one must not suffer under a delusion about the actual precision which these curves give when the expansion of the ordinates with the depth of rainfall is lower than 50 mm per year.

2.2.4. Seasonal distribution of rainfall

Winter rainfall, rare in the previous zone, has practically disappeared in subdesert regions. Sometimes there is rainfall in spring, from March to May, which may give rise to runoff phenomena, but almost always the rainfall occurs in July-August and September, and more exactly, from 15th July to 10th September. This period is on average a little longer than in desert regions. It should be noted that the increase of the annual total rainfall is due as much to a greater number of storms as to more violent storms. The depth of exceptional daily rainfall, for a similar frequency, grows less rapidly from south to north than the depth of annual rainfall. For these two reasons, and all the other conditions remaining the same elsewhere, a small subdesert drainage basin will not, a priori, present higher runoff coefficients than a small desert drainage basin.

2.2.5. Evaluation of the depth of annual rainfall

In this zone, there is some scrub vegetation outside the bed of the water courses, but it is difficult to give simple indicators to define the difference between the zones receiving 100 mm per year and 300 mm per year. One will have to leave out of account the action of Man, who changes into desert the immediate surroundings of any built up area. One will also have to eliminate the influence of temporary water tables and, with greater reason, permanent ones. All that one can point out is that vegetation below the 300 mm isohyet is clearly less-sparse than below the 100 mm isohyet.

One will therefore compare the density of this vegetation from the drainage basin whose rainfall regimen is to be determined, with that of another zone with an annual depth of rainfall which is already known.

A systematic study of rainfall limits for some types of scrub vegetation might allow a good appreciation, it has been made in other dry regions, but not to our knowledge in the zone which interests us.

A large part of the recommendations in paragraph 1.2.5. remains valid for subdesert regions.

2.3. Annual runoff in the subdesert zone

For the same reasons as those stated above, one will be led to consider the four anticipated instances :-

(a) the replenishment areas of cisterns : a few hectares in size at the maximum.

(b) small drainage basins of 2 km^2 to 40 km^2 : general instance for reservoir sites,

(c) water courses whose drainage basin is between 40 km^2 and 300 km^2, with little hydrographic degradation. The area may reach 400 km^2 to 800 km^2 if the relief is prominent. Dams on these watercourses often present difficult problems for the drainage of flood flows,

(d) subdesert basins of more than 1,000 km^2, affected to a greater or lesser degree by hydrographic degradation.

As in the desert zone, the hydrologic regimen varies a great deal with the area of the drainage basin, hence the necessity for singling out these four instances.

One must not forget that rain extends over a clearly longer period than in the desert zone. In a year of plentiful rainfall it may be that there is no exceptional storm; in any case, the actual contribution of an exceptional storm in a very rainy year is relatively far less important than in the desert zone. This explains the fact that, for the same depth of annual rainfall, in a year of heavy rain, it is possible for the runoff coefficient to be higher in the desert zone. Finally, more abundant rain permits the use of basins whose characteristics are less favourable to surface runoff. For all these reasons, there are, a priori, slight differences between the diagrams in Chapter 1, concerning runoff, and the diagrams of Chapter 2, towards the 100 mm isohyet.

2.3.1 Drainage basins of a few hectares in size at the most

It must be admitted that, for these basins, average rainfall on the surface is equal to the point reading at the raingauge, after corrections between rainfall at the raingauge and rainfall at soil level. In fact, this correction will not be made. What we call rainfall is what is shown in all the records. For the subdesert zone it is an index which is perhaps 10% to 20% lower than true rainfall. The surface runoff coefficients KR which will be used here are those given in all the existing publications on the SAHEL, they are often over-estimated by 10% to 20%.

Even with this approximation, maximum values of KR do not exceed a limit clearly less than 100%.

In the southern Tunisian area, at the end of 1973, after torrential storms totalling more than 200 mm in 24 hours, the surface runoff coefficient was in the order of 80% to 90% for an impermeable soil, but naturally for rainfall distributed over the whole rainy season, the runoff coefficient which is in this case a coefficient of surface runoff, is a little less.

Only for artificial surfaces will one admit the figure of 75% for the centennial wet year and a fairly impermeable soil, whatever the median value of the depth of annual rainfall between 100 mm and 300 mm.

With regard to the surface runoff coefficient for median values, one will admit to 60% which corresponds to slightly less favourable conditions than in the case of Figure 5 (paragraph 1.3.1). In some cases, natural soil without either treatment or even cleansing of the few existing shrubs will give this result. It is an example of some " reg " surfaces which are well drained and have a good slope.

For the same type of surface, an examination of Fig. 12 shows that there is surface runoff even for the centennial dry year.

A study has been carried out on daily rainfall from the driest year observed at BOL and from the three driest years observed at TIDJIKJA. This is made from the surface runoff model for the plots of land from KOUNTKOUZOUT in NIGER (natural surface). Without previous rain, a downpour of 6 mm is running off ; after a storm there is surface runoff beyond a threshold of 2 mm. In these conditions, the four above mentioned years, for which depths of rainfall comprise between 34 mm and 46.1 mm, would give surface runoff coefficients of between 20% and 32%. Consequently, one will admit the following surface runoff coefficients for the centennial dry year :-

15% for a depth of annual rainfall of 15 mm, corresponding to a median value of 100 mm to 120 mm per year,

20% for a depth of annual rainfall of 20 mm to 50 mm, corresponding to a median value of 120 mm to 220 mm per year,

30% for a depth of annual rainfall of 50 mm to 70 mm, corresponding to a median value of 220 mm to 300 mm per year.

With these three points corresponding to the cumulative frequencies 0.01, 0.50 and 0.99, it is easy to plot frequency curves, noting that between the frequencies 0.5 and 0.01 (median value and centennial wet year) the curve in gaussian logarithmic co-ordinates is nearly a line, for these regions, something one had already known for sometime. So, we have not though it useful to present diagrams for this case.

For surfaces which are very slightly permeable, one may admit a surface runoff coefficient of 40% for the median year, 60% to 70% for the centennial wet year and between 5% and 10% for the centennial dry year.

For artificial surfaces, on the contrary, it will not be forgotten that the surface runoff coefficient always stays decidedly lower than 100%. If the depth of annual rainfall gets down as far as 35 mm, it will be wise not to adopt a value of KR higher than 60%, for a very impermeable surface which is well prepared. A depth of rainfall of this type corresponds to 10-15 storms ; in each storm there is immediate evaporation of the first drops, permeation and accumulation in some micropools. It is not possible to obtain perfectly flat surfaces in the SAHEL conditions, except for very small surfaces.

For the estimation of annual runoff the following step should be taken :-

- determination of the depth of annual rainfall (median or mean value), one will use map No. 1, the indications set out in paragraphs 1.2.5 and 2.2.5,

- determination of the distribution curve for annual rainfall by interpolation from Fig 12,

- determination of the distribution curve for annual runoff from the preceding curves and from three values of the surface runoff coefficient given earlier, according to the characteristics of the surface of the reception area,

- study of the annual volumes for the different frequencies.

Installation schemes will have to take into account exceptional floods whose fequency must be taken in relation with the degree of risk which is admitted (cumulative frequency 0.10, 0.02, 0.05 or 0.01).

2.3.2. Small drainage basins of 2 to 40 km^2

2.3.2.1. Generalities

In subdesert regions, there are not only a few privileged regions which may be the object of runoff phenomena almost every year. There are sufficient conditions favourable for their occurrence : a fairly impermeable soil, marked slope : 5 metres per kilometre (overall index). But vast zones have no surface runoff; a region of bare dunes, soil with a heavy sandy covering, and hydrographic degradation occurs very rapidly, whence the necessity of taking into consideration several categories of basin surfaces in order to study runoff.

Moreover, basins where runoff occurs generally have a soil on the rock substratum, contrary to the case of most of the small basins studied in the desert zone. For a similar area one will therefore be led to consider several categories of basins :

- Category I : basins with steep slope and which are impermeable, Dd, drainage density 4 (type of the BACHIKELE representative basin). This category corresponds to those which, in the desert zone, formed the subject of Figure 8.

- Category II : basins with quite steep slope, relatively impermeable, there may be a covering of sand or an accumulation of rocky debris over a considerable part of the basin, drainage density comprising between 0.50 and 4. This is the most general type of basins which will be studied for the establishing of accumulation reservoirs,

- Category III : basins with moderate slope which are still less permeable, with hydrographic degradation over a part of the surface (case of the reduced basin of TIN ADJAR). For want of something better, it is the type of basins which one will frequently be obliged to use.

2.3.2.2. Available information.

We have extracted all it seemed possible to extract from the data from the representative basins, and since the mass of information remained reduced, we have estimated that it would be useful to reproduce the data further on. For the surface runoff coefficients, they sometimes show slight differences from the data from the collection of basic data from ORSTOM'S representative and experimental basins, principally as a result of correction on annual rainfall (estimation of rainfall from March to June missing for some basins).

BACHIKELE (CHAD) median P = 110 to 120 mm
16° 30'
S = 19.8 km^2 Dd = 4.09 1958 P = 154 mm Ke = 22%
1959 P = 190 mm Ke = 34%
Ig = 17.7
(Ig = overall slope index)

SOFOYA (CHAD) median P = 120 to 130 mm
16° 04'

I - S = 345 km^2	Dd = 0.52	1965 P = 132 mm	Ke = 3.6%
		1966 P = 110 mm	Ke = 2.1%
		1967 P = 129 mm	Ke = 6.6%
II - S = 173 km^2	Dd = 0.75	1965 P = 125 mm	Ke = 5%
		1966 P = 110 mm	Ke = 2.45%
		1967 P = 138 mm	Ke = 11.4%
IV - S = 81 km^2	Dd = 0.50	1967 P = 139 mm	Ke = 4.3%
V - S = 1.63 km^2	Dd = 0.92	1966 P = 80 mm	Ke = 15.5%
		1967 P = 113 mm	Ke = 14.5%

Runoff nil every fifteen to twenty years

KADJEMEUR (CHAD). median P : 170 mm
15° 18'

I - S = 245 km^2	Dd = 0.75	1965 P = 146 mm(1)	Ke = 7%
		1966 P = 216 mm	Ke = 7.8%
II - S = 195 km^2	Dd = 0.75	1966 P = 209 mm	Ke = 6.8%
IV - S = 16 km^2	Dd = 0.41	1966 P = 205 mm	Ke 12.7%

TIN ADJAR (GOURMA-MALI) median P : 180 mm
16° 19' - Complete basin

S = 35.5 km^2	Dd = 1.61	1956 P = 380 mm	Ke = 10.8%
	Ig = 4.26	1957 P = 246 mm	Ke = 3.9%
		1958 P = 260 mm	Ke = 3.8%

(1) Rainfall and runoff in March, not well known, have been eliminated.

Reduced basin

$S = 16.5\ km^2$		1956 P = 380 mm	Ke = 19%
		1957 P = 260 mm	Ke = 5.1%
		1958 P = 260 mm	Ke = 6.5%

Hydrographic degradation

RAZELMAMOULMI (AÏR-NIGER) median P = 160 mm

17° 09'

I - $S = 1.87\ km^2$	Dd = 6.81	1959 P = 150 mm	Ke = 20.6%
	Ig = 13.1	1960 P = 140 mm	Ke = 15.6%
II - $S = 0.67\ km^2$	Dd = 6.72	1959 P = 150 mm	Ke = 25.2%
		1960 P = 140 mm	Ke = 12.1%

IN AZENA

$S = 2.61\ km^2$	Dd = 6.48	1959 P = 145 mm	Ke = 19.2%

OUED SELOUMBO (TAGANT - MAURITANIA) median P = 220 mm

17° 47'

OUED MOKTAR

$S = 12.2\ km^2$	Dd = 2.11	1957 P = 210 mm	Ke = 10.5%
	Ig = 12	1958 P = 255 mm	Ke = 13%
		1959 P = 172 mm	Ke = 25.6%

OUED ALI

$S = 10.4\ km^2$	Dd = 1.88	1957 P = 190 mm	Ke = 10.3%
	Ig = 11.1	1958 P = 265 mm	Ke = 12%
		1959 P = 160 mm	Ke = 15%

DIONABA (BRAKNA-MAURITANIA) median P = 280 mm

17° 05'.

I - $S = 111\ km^2$	Dd = 2.01	1958 P = 350 - 375 mm	Ke = 14.7%
	Ig = 2.65	1959 P = 226 mm	Ke = 9.1%
II - $S = 34.1\ km^2$	Dd = 3.50	1959 P = 243 mm	Ke = 14.8%
	Ig = 3.94		

TARAIMAN (CHAD) median P : 270 mm

14° 33'

$S = 11.25\ km^2$	Dd = 0.80	1961 P = 700 mm	
	Ig = 3.0	August 405 mm	Ke August 36 %
			Ke annual = 30% ?

AM NABAK (CHAD)	median P : 330 mm	
14° 15'		
	1965 P = 330 mm	Ke = 2%
S = 60 km^2	1966 P = 380 mm	Ke = 6.6%
Residual basin		

2.3.2.3. Distribution curves of annual runnof

From the preceding data one may deduce the following calculated or interpolated indications. Values of Ke correspond to about the mean for values of P designated opposite. In some cases we have reduced the results to areas of 25 km^2 :-

		P	Ke
Basins of 2 to 5 km^2 :-			
SOFOYA V 1.63 km^2	Dd = 0.92	120 mm	15%
RAZELMAMOULNI 1.87 km^2	Dd = 6.7	150 mm	15% - 20%
IN AZENA 2.6 km^2	Dd = 6.5	145 mm	20%
Basins of 15 to 40 km^2 :-			
BACHIKELE 20 km^2	Dd = 4.09	150 mm	22%
		200 mm	34%
(SOFOYA 25 km^2)	Dd = 0.80	120 mm	(10%)
KADJEMEUR 16 km^2	Dd = 0.41	200 mm	13%
(AM NABAK 25 km^2)	Dd = 0.40	350 mm	(8%)
DIONABA 30 km^2	Dd = 3.94	243 mm	15%
OUED MOKTAR 12.4 km^2	Dd = 2.11	213 mm	13%
OUED ALI 10.4 km^2	Dd = 1.88	210 mm	12%
TIN ADJAR 16.5 km^2 reduced		260 mm	5.5%

If one excludes TIN ADJAR, AM NABAK (residual drainage basin) (category III), BACHIKELE (category I) and TARAIMAN (exceptional year), one finds values of Ke which are quite homogeneous between 12% to 13% for depths of annual rainfall comprising between 150 mm and 250 mm.

Consequently, for category II, which, on average, corresponds to these basins one will admit a Ke coefficient of varying between 11% for a basin receiving 100 mm per year, and 16% for a basin receiving 300 mm per year, as the median values. It has been admitted, for category II, that there was no runoff for a depth of rainfall lower than 30 mm per year.

It has been accepted that for P = 35 mm Ke was equal to 2.8% leading to a depth of runoff of 1 mm.

For very heavy years (hundred year frequency), the coefficient of runoff has been accepted as being equal to 40%, a value which probably admits of a comfortable safety margin.

It is from these elements that the curves on Fig 13 have been plotted. It is found that the rate of runoff is nil for far from negligible frequencies, but one is a great deal lower than in the desert regimen :-

- one year in sixteen for the 100 mm isohyet
- one year in thirty for the 120 mm isohyet
- one year in one hundred for the 150 mm isohyet
- one year in one thousand for the 300 mm isohyet

But if the mesometeorological conditions are more unfavourable than the average, the annual rainfall distribution curves plunge still lower on Fig. 13. It is the same if conditions of runoff are a little worse than those of category II, the return periods which precede may be reduced to a third or a tenth of their value.

It seemed useless to try to fit any mathematical relation on these curves, let us note that over a good portion of their length, they correspond to the GALTON distributions (gaussian logarithmic), but unfortunately not for the most interesting part, that is to say for the exceeded frequencies above 0.8.

Figure 13 corresponds to the most general cases (category II). For categories I and III, one has plotted curves with the extremes 100 mm and 300 mm, drawing inspiration from the following considerations :-

Category I corresponds to Fig 8 for the desert zones, at least where exceeded frequencies lower than 0.5 are concerned. For median values, the surface runoff coefficient varies between 20% for 100 mm per year and 35% for 300 mm per year. The runoff threshold varies between 20 mm and 25 mm per year.

For the centennial wet year, the runoff coefficient varies between 53% and 60%. From this are derived the two outer curves of Fig 14 which may serve as a guide for the plotting of intermediary curves.

Category III, on the contrary, has worse surface runoff from category II. For the median frequency, the runoff coefficient is neighbouring on 5%. The two outer curves of figure 14 estimate, for median values, a coefficient of 3% for 100 mm per year and 7% for 300 mm per year. The runoff threshold is in the order of 50 mm per year.

The runoff coefficient is in the order of 25% for the centennial wet year for the 300 mm isohyet, 20% for the 100 mm isohyet.

Once again we repeat that all the evaluations made with these diagrams can only be very improvised.

It is seen that for Category III, towards the 200 mm - 250 mm isohyet, there is no runoff once in fifty or once in one hundred years, and this is certainly what has been established during the years of 1972 and 1973.

For smaller basins, of the order of 2 km^2 to 5 km^2, one would be able to accept the following figures which are a little higher than for areas in the neighbourhood of 25 km^2.

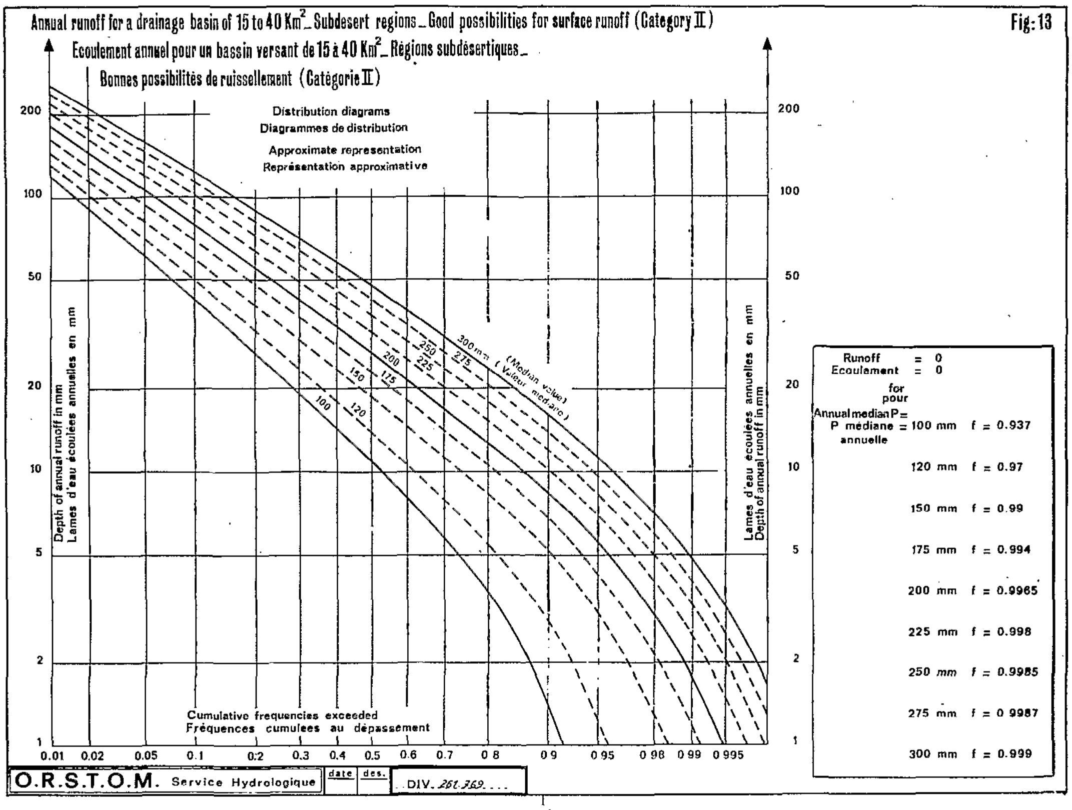
For median years, a surface runoff coefficient of 18% for category II, 10% for category III and 30% for category I (between 30% and 40% of 100 mm to 300 mm).

The distribution curves would have the general shape of those of Fig. 15 corresponding to category II. For categories I and III, one may draw inspiration from the curves of Fig. 16 which are given only as an indication.

2.3.2.4. Step to follow for the evaluation of annual runoff :

- Determination of the area of the drainage basin
- Determination of the depth of annual rainfall (mean or median). One will refer to paragraphs 1.2.5 and 2.2.5.
- Determination of the distribution curve for annual rainfall from Fig. 12.
- Classification of the drainage basin in one of the three categories I, II or III. This is the most difficult point.

Qualitatively, a category I basin has very good surface runoff, a category II basin has good surface runoff, a category III basin has reasonable surface runoff, with just a little hydrographic degradation noticeable. One may determine the drainage density Dd, but unfortunately, this is not sufficient. A basin with Dd = 4 or 6 (without drainage into interior basins) certainly does not belong to


Annual runoff for a drainage basin of 15 to 40 Km² _ Subdesert regions _ Good possibilities for surface runoff (Category II)
Fig: 13
Ecoulement annuel pour un bassin versant de 15 à 40 Km² _ Régions subdésertiques _
Bonnes possibilités de ruissellement (Catégorie II)
Distribution diagrams
Diagrammes de distribution
Approximate representation
Représentation approximative
Depth of annual runoff in mm
Lames d'eau écoulées annuelles en mm
300 mm (Median value) (Valeur médiane)
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
Runoff = 0
Ecoulement = 0
for
pour
Annual median P =
P médiane annuelle = 100 mm f = 0.937
120 mm f = 0.97
150 mm f = 0.99
175 mm f = 0.994
200 mm f = 0.9965
225 mm f = 0.998
250 mm f = 0.9985
275 mm f = 0.9987
300 mm f = 0.999
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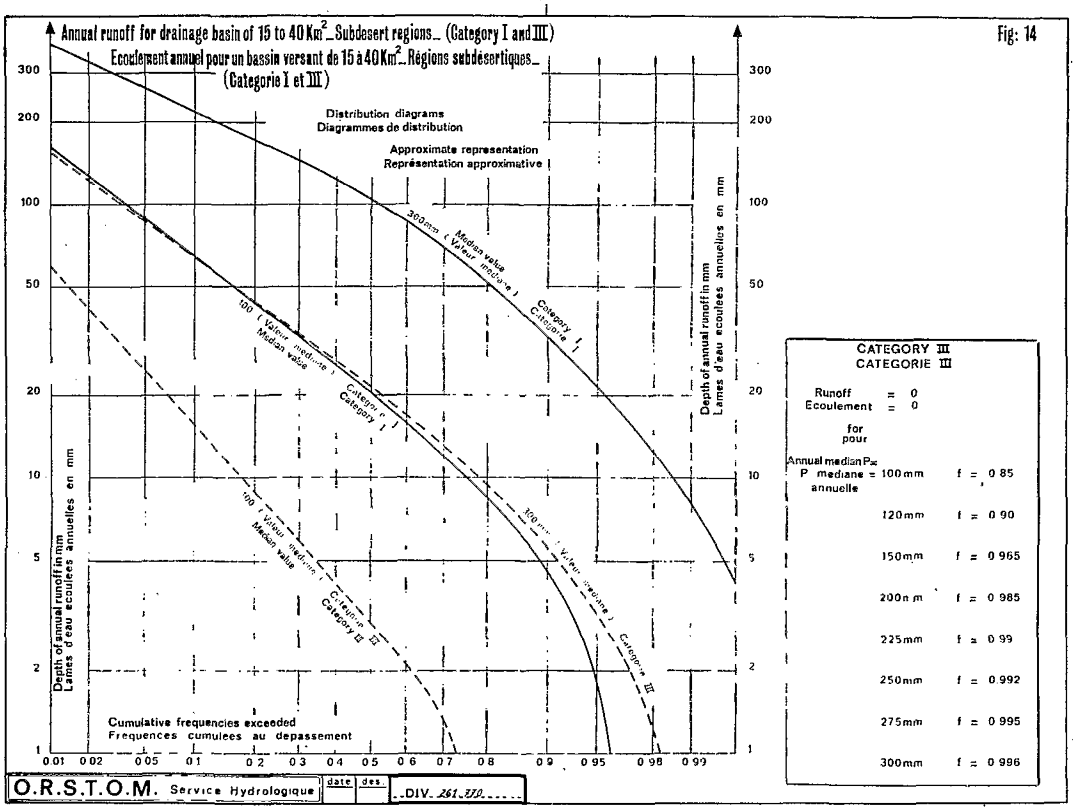
Annual runoff for drainage basin of 15 to 40 Km² _ Subdesert regions _ (Category I and III)
Fig: 14
Ecoulement annuel pour un bassin versant de 15 à 40 Km² _ Régions subdésertiques _
(Catégorie I et III)
Distribution diagrams
Diagrammes de distribution
Approximate representation
Représentation approximative
300 mm (Median value) (Valeur médiane) Category I Catégorie I
100 (Valeur médiane) Median value Catégorie I Category I
100 (Valeur médiane) Median value Catégorie III Category III
300 mm (Valeur médiane) Catégorie III
Depth of annual runoff in mm
Lames d'eau écoulées annuelles en mm
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
CATEGORY III
CATEGORIE III
Runoff = 0
Ecoulement = 0
for
pour
Annual median P =
P médiane annuelle = 100 mm f = 0.85
120 mm f = 0.90
150 mm f = 0.965
200 mm f = 0.985
225 mm f = 0.99
250 mm f = 0.992
275 mm f = 0.995
300 mm f = 0.996
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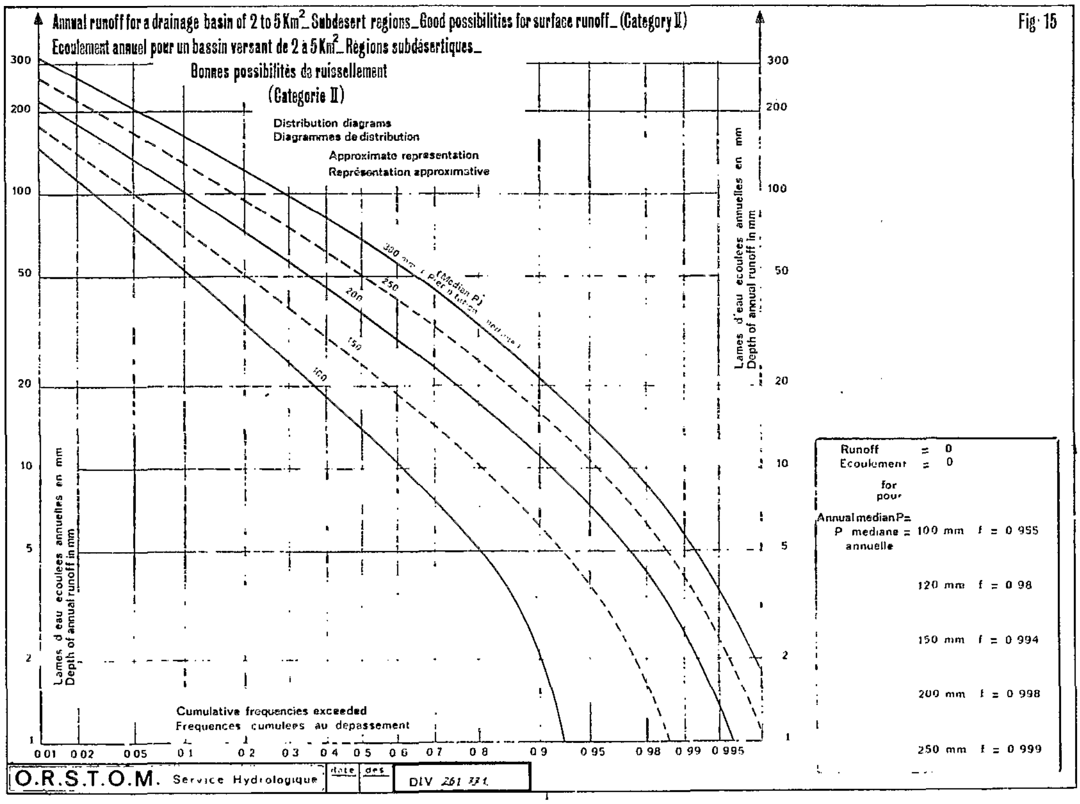
Fig·15
Annual runoff for a drainage basin of 2 to 5 Km² Subdesert regions_Good possibilities for surface runoff_(Category II)
Ecoulement annuel pour un bassin versant de 2 à 5 Km²_Régions subdésertiques_
Bonnes possibilités de ruissellement
(Categorie II)
Distribution diagrams
Diagrammes de distribution
Approximate representation
Représentation approximative
Lames d'eau ecoulees annuelles en mm
Depth of annual runoff in mm
Cumulative frequencies exceeded
Frequences cumulees au depassement
Runoff = 0
Ecoulement = 0
for
pour
Annual median P=
P mediane = 100 mm f = 0 955
annuelle
120 mm f = 0 98
150 mm f = 0 994
200 mm f = 0 998
250 mm f = 0 999
O.R.S.T.O.M. Service Hydrologique
DIV 261 331

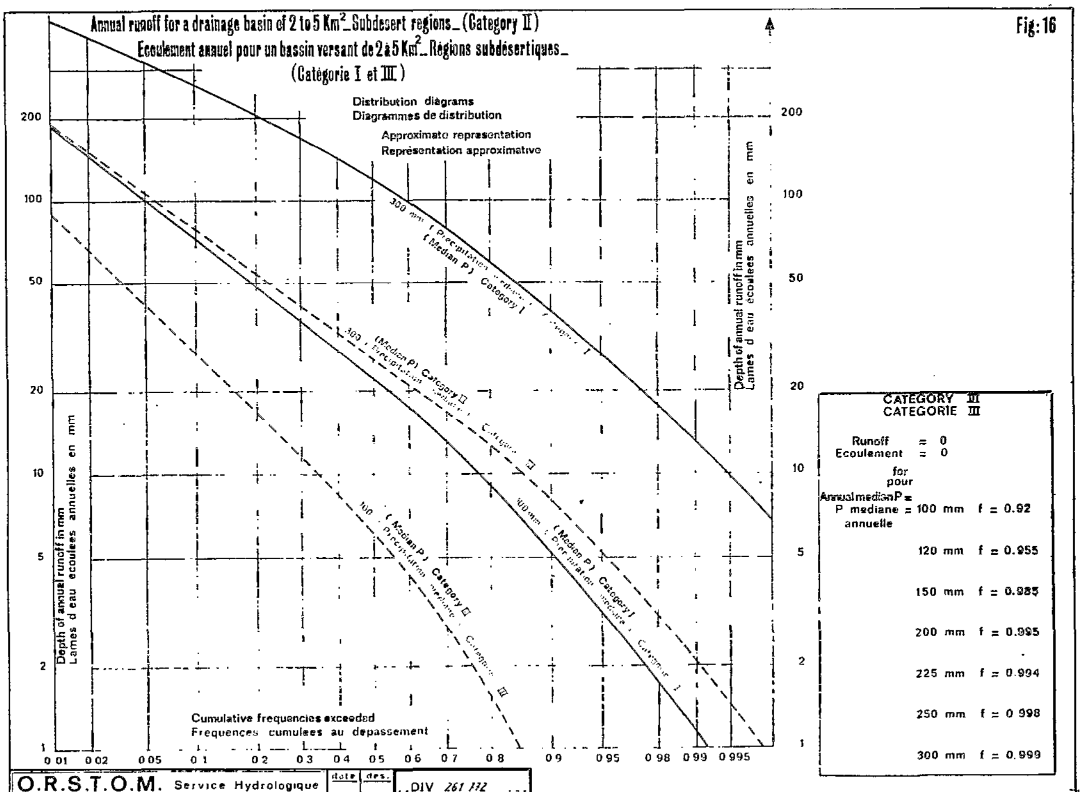
Fig:16
Annual runoff for a drainage basin of 2 to 5 Km²_Subdesert regions_(Category II)
Ecoulement annuel pour un bassin versant de 2 à 5 Km²_Régions subdésertiques_
(Catégorie I et III)
Distribution diagrams
Diagrammes de distribution
Approximate representation
Représentation approximative
Depth of annual runoff in mm
Lames d'eau ecoulees annuelles en mm
Cumulative frequencies exceeded
Frequences cumulees au depassement
CATEGORY III
CATEGORIE III
Runoff = 0
Ecoulement = 0
for
pour
Annual median P =
P mediane = 100 mm f = 0.92
annuelle
120 mm f = 0.955
150 mm f = 0.985
200 mm f = 0.995
225 mm f = 0.994
250 mm f = 0 998
300 mm f = 0.999
O.R.S.T.O.M. Service Hydrologique
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category III, but it could just as well be in Category I as in Category II, only the slope and soil permeability allow one to judge which.

A basin with Dd = 0.5 may be in Category II or III, there, too, reference has to be made to slope, soil permeability and indices of hydrographic degradation. The appearance of the bed and flood marks may serve as a guide. In arid regions in the UNITED STATES, L. LEOPOLD has shown that in general, the bed was filled right up to the tops of the banks for the floods of the return period of 1-5 years. The flow rate is calculated by MANNING'S formula with :-

- a coefficient of roughness K equal to 30-35 if the bed is sandy, 15 to 20 if it is very irregular :-

$$V = K\, R^{2/3}\ I^{1/2}$$

V = mean speed in m/s
R = the hydraulic radius in metres
I = slope in metre per metre

The width of the bed, the mean section, the mean slope may be determined with great care, by comparing, as far as possible, the regime of the flood runoff.

So one must pass to the volume of this flood flow giving oneself a probable hydrograph shape (see study of ten year flood flows for basins less than 200 km^2 in Western Africa, where one will find the base width of the hydrograph), then to the annual volume of the same frequency, by multiplying the volume of the flood flow by a coefficient of between 1.5 and 3.

All this is rather qualitative in nature and is only able to furnish a cross check.

- Determination of the distribution curve for annual runoff from Figs. 13, 14, 15 and 16, according to the area of the drainage basins and the category into which they fall.

One will interpolate between the curves of the graphs which correspond for the areas of between 5 km^2 and 15 km^2 (Figs. 13 or 14 and Figs. 15 or 16). For areas of less than 2 km^2, one will interpolate between the data from Figs. 14 and 16 and those from paragraph 2.3.1.

- Study of the available annual volumes for the different frequencies.

The frequency of years where there is no runoff is still to be considered, especially between the 100 mm isohyet and the 200 mm isohyet, and for Category III.

Only Category I always presents runoff. One will refer to the studies on exceptional rainfall in Western Africa, and on ten year flood flows for basins of less than 200 km^2, for the determination of the flood flow to be taken into consideration. One will remember that all our diagrams only correspond to improvised evaluations.

2.3.3. Drainage basins of 40 to 300-500 km^2 in the sub desert regimen

2.3.3.1 Generalities

Hydrographic degradation occurs less rapidly than in desert regions. But it happens that basins which are over their entirety in the mountains, that is to say practically without degradation, are less numerous. There are some in the TAGANT (Mauretania), the AÏR, the south of the ENNEDI and in the north west of the OUADDAÏ. But surface runoff being a very general phenomenon, one is led to consider drainage basins whose capability of surface runoff is not so good as in the desert zone, as in the preceding case. Moreover, everything being equal in other respects, runoff is prolonged much further on towards the downstream area.

The problem of the recharging of the alluvium of the apparent bed still remains the same.

The heterogeneity of spatial distribution of rainfall plays a big part. Finally, for one given year, the depth of annual rainfall is only a factor of runoff, the temporal distribution like the spatial distribution plays a big part.

In fact, each basin of this size is a specific case with, in the front rank of physiographical factors, the presence and absence of hydrographic degradation zones and their position on the water course in relation to active recharging areas and to the station being studied, and especially the possible existence near this station of a drainage basin of 10 to 50 km^2, belonging to category I or II quoted in point 2.3.2. In such a case, four years in five or nine years in ten, runoff at the station studied is in fact runoff over this basin of 10 to 50 km^2 with, in addition, occasionally small flood flow, quite gentle and of low total volume, originating from the upstream area. But one year in five or ten upstream runoff becomes significant :-

- either it leads to a flat hydrograph the total volume of which is in the same order as that of the small basin of 10 to 50 km^2, in the case where the basin is vast with a very much degraded main bed, without a significant area with very strong surface runoff upstream,

- or the whole basin is water filled at one go and in this case all happens as if one was dealing with a water course with a far more plentiful regimen. The volume of runoff is therefore without any common measurement with that from the preceding years. This occurs if the degradation is not very advanced.

For the runoff threshold, one must only consider tributary basins near the station (see paragraph 2.3.2). If there are none of Category I or II, one must expect to find nil runoff every 20 or 30 years, or even occasionally every 10 years (of course one excludes the downstream end of the subdesert water-courses, where water comes every 50 or 100 years, as the Wadi of the OUADDAÏ when they reach the MORTCHA or those issuing from the AÏR when they reach the fossil network of the AZAOUAK).

All this is particularly valid for water-courses whose drainage basin exceeds 200 to 300 km^2.

Consequently, it is impossible and of no use to plot families of curves such as those which have been presented earlier.

Nevertheless, it has been considered a good idea to collect all that is known about annual runoff for water courses of this importance in the next paragraph

2.3.3.2. Available information

The ORSTOM missions in the south of the ENNEDI, the MORTCHA, the north of the OUADDAÏ, the south west of AÏR, IRHAZER, BRAKNA and the TAGANT have collected the following data a great of which are only simple evaluations.

One will indicate, later, the most important data concerning water courses at the limit of the desert and subdesert zone, which have been mentioned in paragraph 1.3.3.2 and some which have already been the subject of paragraph 2.3.2.2

ENNERI OROUE (ENNEDI, CHAD)	Median P :	120 - 140 mm	
S = 180 km^2	1958 P =	175 mm	Ke = (16%)
steep slope			
ENNEDI MAYA (ENNEDI, CHAD)	Median P :	120 - 140 mm	
S = 85 km^2	1957 P =	100 mm ?	Ke = (10%)
WADI SOFOYA (MORTCHA, CHAD)	Median P :	120 - 130 mm	
S = 345 km^2	1965 P =	132 mm	Ke = 3,6%
	1966 P =	110 mm	Ke = 2,1%
	1967 P =	129 mm	Ke = 6,6%

S = 173 km^2	1965 P = 125 mm	Ke = 5.4%
	1966 P = 110 mm	Ke = 2.45%
	1967 P = 138 mm	Ke = 11.4%
S = 81 km^2	1967 P = 139 mm	Ke = 4.3%

KORI EL MEKI (AÏR-NIGER) median P : 140 to 160 mm

S = 165 km^2	1958 P = 240 mm	Ke = 15% ?
	1959 P = 180 mm	Ke = 7.5%
	1960 P = 190 - 200 mm	Ke = 31% - 32%

Steep slope, no hydrographic degradation

KORI OUADJOU (AIR - Niger) median P = 150 - 170 mm

S = 200 km^2	1959 P = 180 mm	Ke = 10% ?

KADJEMEUR (North OUADDAI - Chad) median P = 170 mm

S = 245 km^2	1965 P = 146 mm	Ke = 7%
	1966 P = 216 mm	Ke = 7,8%
S = 195 km^2	1966 P = 209 mm	Ke = 6,8%

Wadi DEBOULGUI (TAGANT - Mauritania) median P = 180 mm

S = 225 km^2	average year	Ke = 13%?
	decennial dry year 90 mm	Ke = 2.2%?

Wadi NIEMELANE (TAGANT - Mauritania) median P = 180 mm

S = 105 km^2	average year	Ke = 15% ?
	decennial dry year = 90 mm	Ke = 3% - 4% ?

KORI TIGERWITT (IRHAZER - Niger) median P = 210 mm

S = 800 km^2 (1)	1966 P = 150 mm	Ke = 5.3%
	1967 P = 210 mm	Ke = 6.8%

TAMOURT in NAAJ Group (TAGANT - Mauritania) median P = 220 - 240 mm

S = 6 190 km^2	1956 P = 210 mm	Ke = 3.9%
	1957 P = 280 mm	Ke = 2.5%
	1958 P = 320 mm	Ke = 3.4%
	1959 P = 170 mm	Ke = 1.9%
	1960 P = 250 mm	Ke = 4.9%

Wadi SANGARAFA (BRAKNA - Mauritania) median P = 260 mm

S = 156 km^2	average year	Ke = 10%
	dry year P = 130 mm	Ke = 6.5%

(1) Zones of total drainage into interior basins are excluded

TACHOTT-TAGANT (BRAKNA - Mauritania) median P = 260 mm

S = 115 km^2	average year	Ke = 9%?

DIONABA (BRAKNA - Mauritania) median P = 280 mm

S = 111 km^2	1958 P = 350 - 375 mm	Ke = 14.7%
	1959 P = 226 mm	Ke = 9.1%

Wadi ACHRAM (BRAKNA - Mauritania) median P = 280 mm

S = 280 km^2	average year	Ke = 9% ?

Wadi AMOUR II (BRAKNA - Mauritania) (Wadi AGMIMINE)

S = 95 km^2	average year	Ke = 11%?

Wadi OUINDIE (BRAKNA - Mauritania) median P = 290 mm

S = 265 km^2	average year	Ke = 10%?

MARE DE GADEL (BRAKNA - Mauritania) median P = 300 mm

S = 410 km^2	average year	Ke = 10%?
	1958 P = 400 mm	Ke = 11%
	1959 P = 215 mm	Ke = 13% (1)

(1) The greater part of annual P fell in two storms.

MARE DE CHOGGAR (BRAKNA - Mauritania) median P = 310 mm

S = 190 km^2	average year	Ke = 10.5%
	1958 P = 380 mm	Ke = 11.5%

LAKE MAL (BRAKNA - Mauritania) median P = 320 mm

S = 900 km^2	average year	Ke = 8%
	1958 P = 280 mm	Ke = 7.5%
	1959 P = 200 mm	Ke = 1%
	1960 P = 370 mm	= 7.1%

AM NABAK (OUADDAI - Chad) median P = 330 mm

Reduced basin

S = 60 km^2	1965 P = 330 mm	Ke = 2%
	1966 P = 380 mm	Ke = 6.6%

For Mauritania, a goodly number of the above pieces of information concern natural or artificial reservoirs = TAMOURT in NAAJ, MARE de GADEL, MARE de CHOGGAR, LAKE MAL etc. In this case, volume of runoff is fairly well known, on the other hand depth of average rainfall over the drainage basin is much more imprecise. Moreover, only the depths of rainfall of the WADI SOFOYA, of WADI KADJEMEUR, of DIONABA, of the AM NABAK representative basin, and if need be of KORI EL MEKI and KORI TIGERWITT are really certain.

2.3.3.3. Some practical conclusions

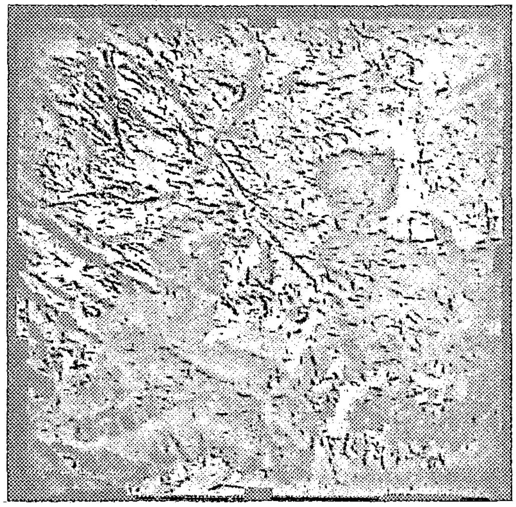
To a greater extent than in the preceding case, the volume of runoff for a similar depth of annual rainfall varies considerably according to temporal distribution of rainfall. In a deficit year from the point of view of raingauging, a single heavy localised storm may give rise to clearly surplus runoff. One would need to have several years of rainfall bordering on the average in order to have a good idea of the runoff coefficient. Naturally, hydrographic degradation, when it exists, plays a most important role. For these basins of medium size, a priori the value of the median of depths of annual rainfall does not play a leading part over the surface runoff coefficient. Its influence is masked by that of the other factors and available records do not permit it to be estimated.

The area of the drainage basin plays an essential role, especially when the physical characteristics of the basin lend themselves to hydrographic degradation. For the area scale to which paragraph 2.3.3. is relevant, it is really no longer possible to present diagrams in the same way as for basins of 2 to 40 km^2. The relation between rainfall and runoff is too loose and in particular the hydrologic regimen varies much too much according to the basins characteristics.

Let us note that, in what follows, one will not take into consideration the coefficient of reduction between point rainfall and average rainfall over the basin. This is playing safe for deficit years (paragraph 1.3.3.3.).

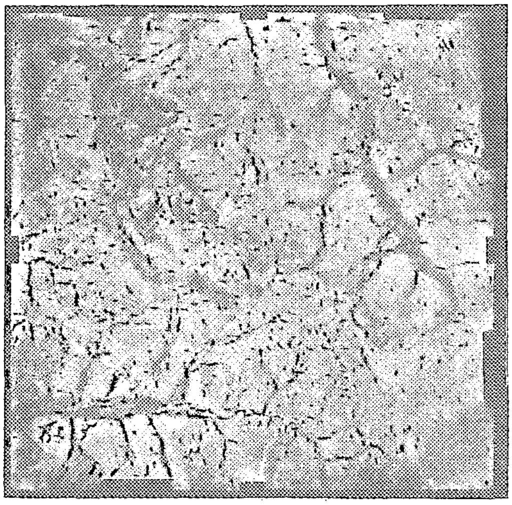
As previously a first case is conspicuous : that where there is, in practice, no hydrographic degradation and where slope is fairly marked. In the examples from the previous paragraph, this is the case for ENNERI OROUE, ENNERI MAYA, KORI EL MEKI, for the tributaries of the KORI TELOUA - and namely the KORI OUADJOU, the tributaries of the Wadi EL ABIOD (TAGANT-Mauritania) and namely the Wadis of DEBOULGUI and NIEMELANE. One must add that for the group comprising the KORI TELOUA at RAZELMAMOULNI, before degradation, the runoff coefficient, in an average year, seems to be in the order of 15% to 20%.

From this one draws the conclusion that, in this category, in a year approximating to the median, the coefficient of runoff is between 10% and 20%



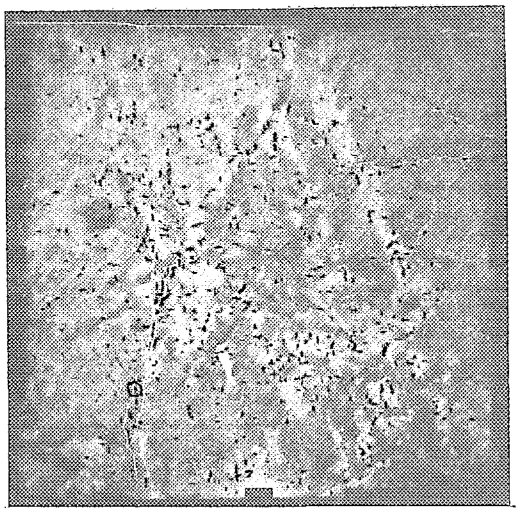
BACHIKELE drainage basin (Chad)

Pratically no soil, steep slopes, no hydrographic degradation
(Plate by IGN Mission AEF 54 - 55 NE 34 IV. Photo n° 272)
○ *Gauging station site.*



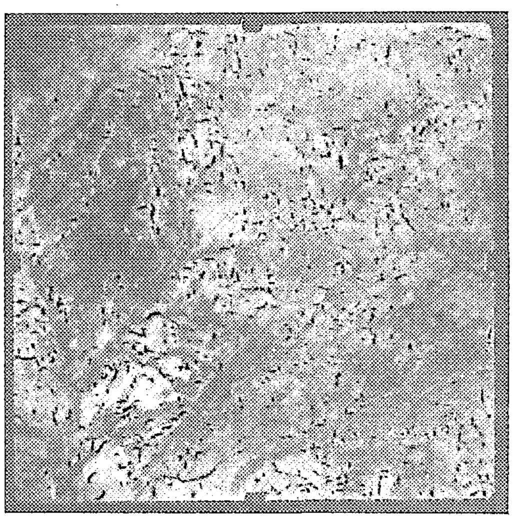
Small drainage bassin DIONABA (Mauretania)

Bare rock in places, appreciable but moderate slope, clear hydrographic network but already weathered over the main water course.
(Plate by IGN Mission AOF 54 M^{n} 095. Photo n° 042)



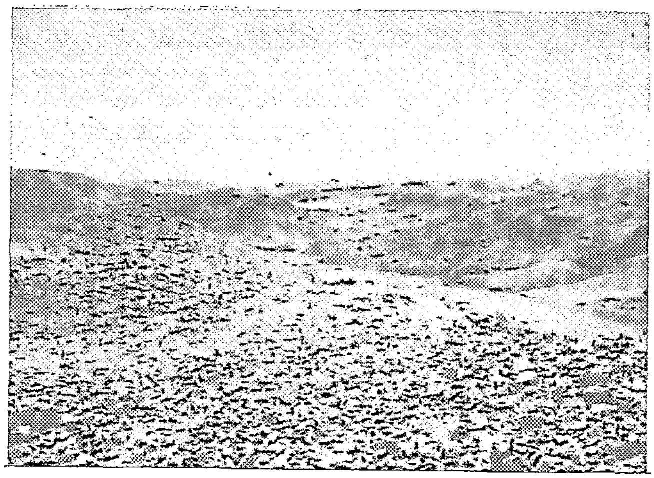
ABOU GOULEM (Chad) small drainage basin
lefthand side of the photo

Note the presence of soil and vegetation cover. The bed of the main water course is cleary defined.
(Plate by IGN Mission AEF 54 - 54 Mn 143 - Photo n° 500)
○ *Gauging station site.*

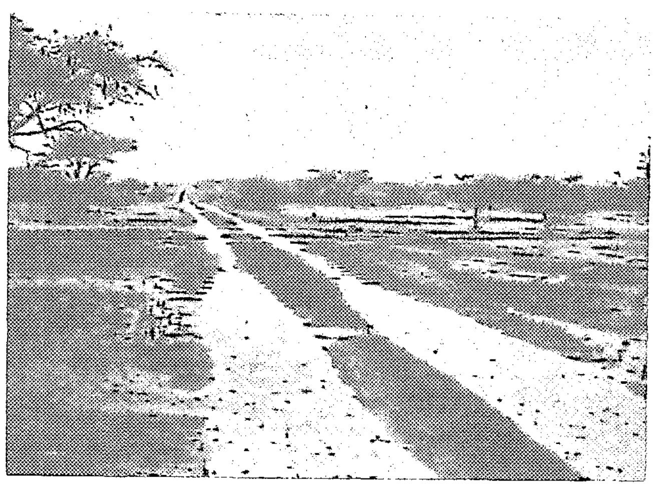


KADIEL (Mauretania) drainage basin
Lefthand post of the photo and confluence with wadi DJAJIBINE

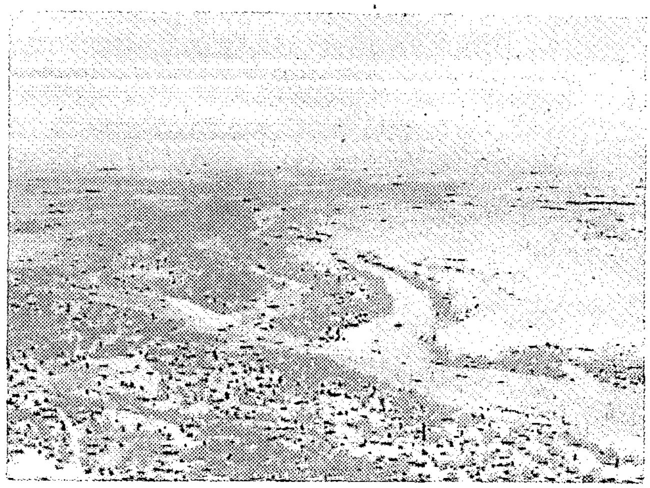
Presence of soil over almost the whole of the basin, traces of erosion over a considerable part of the area. Note the definition of the bed of the wadi, DJAJIBINE, indication of good runoff.
Plate by IGN Mission AOF 52-53 Mn 058 - Photo n° 237.
○ *Gauging station site.*



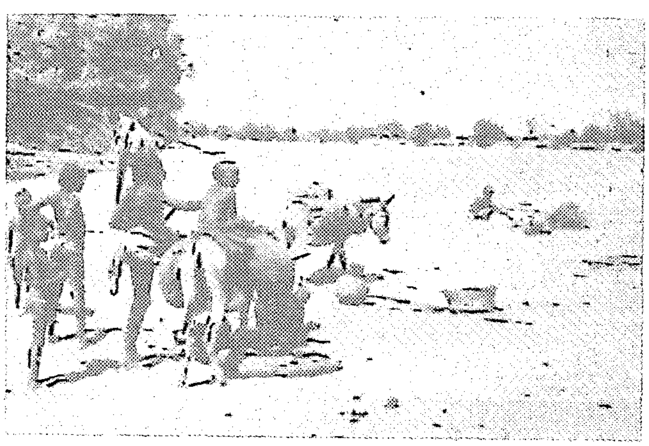
Example of the «mineral» desert between BARDAI and AOZOU (Chad)
(Plate by J.A. RODIER)



Example of surface runoff on the reg in the north of AGADES (NIGER)
(Plate by R. LEFEVRE)



Example of hydrographic degradation
The Kori TELOUA to the west of AGADES (NIGER)
(Plate by R. LEFEVRE)



The BATHA (Chad) in the dry season near OUM HADJER
(Plate by J.A. RODIER)

for areas varying between 40 and 300 km^2. But if there is no hydrographic degradation these figures are valid for up to 1,000 km^2.

These values decrease considerably for such a basin when rainfall shows a deficit, values of 3% to 10% would be highly probable in the decennial dry year, for median $P > 150$ mm, the last figure corresponding to median $P = 300$ mm. Do these water courses show nil runoff? For annual rainfall of less than 40 or 50 mm (ten year or hundred year value according to the median value of the depth of annual rainfall), this is most probable, especially if the basin exceeds 150 km^2 to 200 km^2 and if there is no small basin of 2 to 40 km^2 with good surface runoff in the neighbourhood of the station. However, one must make a note of the fact that in 1971, 1972 and 1973 annual runoff was very low but not nil in the KORI TELOUA at RAZELMAMOULNI and the KORI EL MEKI at EL MEKI.

The foregoing is applicable to tributaries of the Wadi EL ABIOD (TAGANT), to the tributaries of the KORI TELOUA, to the most favoured KORIS of the AÏR and perhaps to some water courses of the ADRAR of the IFOGHAS. It is not impossible that some wadis feeding the TAMOURT in NAAJ might be put in this category. The figures given for their group represent what remains in the downstream area after passage into permeable zones or into depressions where losses by evaporation are enormous. The final mean value of Ke, which is in the order of 3%, must be conspicuously greater when one passes from 6,000 km^2 to 200 km^2, although the data from Wadi MOKTAR and Wadi ALI cause the prediction of values which are clearly lower than those from the KORI TELOUA. However, on average, a runoff coefficient of 10% to 12% in the median year would not surprise us.

In the decennial wet year, runoff coefficients of 18% to 25% would be probable.

A second case is that of basins whose soil has less good surface runoff (covering partially sandy, slightly permeable soils, zones with debris, moderate slopes) and whose hydrographic system presents traces of degradation. The most typical cases of this are those of the Wadis SOFOYA and KADJEMEUR, of the IRHAZER, of DIONABA and of the reduced basin of AM NABAK. For basins of 200 km^2, one no longer encounters relatively wide apparent beds with well defined banks, as on the affluents of the TELOUA. These beds are relatively narrow with zones of overflowing covered with vegetation in the natural state and, on the important tributaries of these water courses, it is a frequent occurrence for the bed to disappear to a greater or lesser extent (case of the tributary on the main left bank of SOFOYA). These are no longer mountain water courses. For these water courses, in the median year, the coefficient of runoff is between 3% and 10%, the lower figure corresponding to either a rainfall measuring regime close to the desert regimen (100 mm < median P < 200 mm), or to relatively unfavourable conditions of runoff. For this type of basin, the influence of the median value of the depth of annual rainfall is quite perceptible. The ten year dry values of the runoff coefficient are perhaps between 0 and 5%. The first figure would correspond to 100 < median P < 150 mm and to runoff conditions at the lower limit of this second category. Against this the value of 5% would correspond to a depth of annual median rainfall in the order of 300 mm (ten year P = 160 mm) with quite good runoff conditions.

In the decennial wet year, one may expect coefficients of runoff of 15% to 20%.

One may be led to set up a water management project on drainage basins with bad conditions of runoff, one part of the drainage basin being more or less endorheic. This is the case of drainage basins of the type of TIN ADJAR, but with an area of more than 100 km^2 instead of 35.5 and of the reduced basin of AM NABAK with likewise a greater area. It seems that in the median year, the total runoff coefficient would be between 1% and 2%. In the decenrial dry year everything depends on the recharge areas of 2 km^2 to 10 km^2 situated closest to the station. If there are none in the immediate vicinity, runoff will be nil.

Finally there are basins with fair degradation which only give rise to runoff in a wet year.

Generally speaking, and especially for water courses belonging to the second category, the regime is unusually irregular since, for a basin below the 250 mm isohyet, runoff would vary between 3 to 55 mm, or from 1 to 18 mm from the decennial dry year to the decennial wet year. In the setting up of reservoirs, one would therefore encounter difficult problems both for recharging and for the drainage of exceptional flood flows.

2.3.3.4. Some advice on the evaluation of annual volumes of runoff

These are the same as in paragraph 1.3.3.4.

- One will proceed to a very thorough study of the terrain on the following points :-
  - area of the drainage basin,

- slopes,
- hydrographic network,
- marks of hydrographic degradation,
- vegetation on the banks,
- vegetation along the water courses
- flood marks

The study of the hydrographic network, especially in the vicinity of the station, and of the marks of hydrographic degradation is of cardinal importance.

As far as possible, one will proceed to an enquiry directed on :- establishing whether there are years without runoff, evaluating the duration of runoff when there is runoff, and finally determining the maximum level of the water.

From this one must deduce -

- some indications of the depth of annual rainfall with a frequency of 0.5 over the basin, which will state precisely the data obtained with map No 1,

- a vague indication of the frequency of years without runoff,

- data concerning the drainage basin, which will allow it to be classified in one of the categories described in the previous paragraph.

- In the category which has thus been determined, one will select, in the range of runoff coefficients indicated in the preceding paragraph, values corresponding to the frequencies of 0.5, to the ten year dry frequency and the ten year wet frequency. This choice is passably subjective and will take into account safety margins.

With these three Ke values and the depths of annual rainfall derived from Fig 12, one will plot a statistical distribution curve for annual runoff which will give only summary evaluations.

2.3.4. Subdesert basins of more than 1,000 km^2

2.3.4.1. Generalities.

In this case hydrographic degradation becomes very important, but the water courses still have an active life at a certain distance from the mountain massifs from which they came, especially when the depth of rainfall exceeds 200 mm per year. Water courses which present runoff nine years in ten or nineteen years in twenty are far more numerous than in the desert regimen, but one is also led to consider basins whose capability of surface runoff is definitely less good than in the desert regimen. The runoff coefficients will therefore not increase in spectacular conditions. Moreover stress is laid on the fact that for the majority of drainage basins of this type, the ideas of runoff coefficient and depth of runoff are used here only because they are convenient for comparisons, because they have almost no physical significance for these large basins. Only a part, and sometimes a very small part, of the basin coincides with the runoff being observed, as will be shown further on. As in the desert regimen, each wadi is a specific case.

2.3.4.2. Available information

Next we have collected all that is known about runoff originating from basins of more than 1,000 km^2.

ENNERI ARCHEÏ (ENNEDI-Chad) median P = 110 mm

S = 800 km^2	1957 P = 80 to 110 mm		Ke = 0.5% to 0.75%?

OUADI HAOUACH (MORTCHA - Chad) median P = 120 mm.

S = 7,700 km^2	1959 P = 240 mm	E = 0.37 mm	Ke = 0.18%
	1966 P?	E = 0.4 mm ? (1)	

OUADI OUM CHALOUBA (MORTCHA-Chad) median P = 120 - 130 mm

S = 2,000 km^2	1959 P = 165 mm (2) (3)		Ke = 0.2% to 0.4%
	1965 P = 47 mm		Ke = 0
	1966 P = 130 mm	E =(1.5) mm (4)	Ke = 0.8% to 1.2%
	1967 P = 130 to 150 mm?	E = 3 mm (5)	Ke = 2% to 2.5%

KORI TELOUA at RAZELMAMOULNI (AÏR Niger) median P = 170 mm

S = 1,170 km^2	1959 P = 170 mm	E = 39.3 mm	Ke = 23%
	1960 P = 116 mm	E = 12 mm	Ke = 10.4%

KORI TELOUA at AGADES TOUDOU median P = 160 mm

S = 1,370 km^2	1960 P = 120 mm	E = 2,9 mm	Ke = 2.4%

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(1) Runoff 15 to 20 days
(2) Rainy season only
(3) Runoff 15 days
(4) Runoff 15 days
(5) Runoff 20 days

KORI TOROUK (IRHAZER - Niger) median P = 210 mm

S = 4,000 km^2	1966 P = 100 mm	E = 0.075 mm	Ke = 0.075%
(5 to 800 km^2 active)	1967 P = 170 mm	E = 2 mm	Ke = 1%

GORGOL BLANC (BRAKNA - Mauritania) At GLEITA TOR median P = 290 mm

S = 3,770 km^2	1958 P = 400 mm	E = 26.5 mm(1)	Ke = 6.5%
(1,510 km^2 active)	1959 P = 220 mm	E = 9.6 mm	Ke = 4.3%
average year	P = 290 mm	E = 15.9 mm	Ke = 5.5%

AT AGNEIBAT median P = 320 mm

S = 8,370 km^2	1958 P = 450 mm	E = 24 mm	Ke = 5.3%

TAMOURT IN NAAJ (TAGANT - Mauritania) median P = 220 - 240 mm

S = 6,190 km^2	1956 P = 210 mm	E = 8.3 mm	Ke = 3.96%
	1957 P = 280 mm	E = 6.9 mm	Ke = 2.5%
	1958 P = 320 mm	E = 10.75 mm	Ke = 3.4%
	1959 P = 170 mm	E = 3.2 mm	Ke = 1.9%
	1960 P = 250 mm	E = 12.2 mm	Ke = 4.9%
average year	P = 230 mm	E = 4.5 mm	Ke = 1.95%

OUED KETCHI (BRAKNA - Mauritania) TACHOUNDA median P = 300 mm

S = 3,420 km^2	1958 P = 240 mm	E = 9.7 mm	Ke = 4%
	1959 P = 180 mm	E = 4.6 mm	Ke = 2.5%
	1960 P = 340 mm	E = 34 mm	Ke = 10%

E 1961 = 7 to 8 mm

E 1962 comparable to E 1958

E 1963 comparable to E 1958

average year P = 300 mm E = 22 mm Ke = 7.3%

MAL LAKE (BRAKNA - Mauritania) median P = 320 mm

S = 900 km^2	1958 P = 280 mm	E = 25.5 mm	Ke = 7.5%
	1959 P = 200 mm	E = 1.7 mm	Ke = 1%
	1960 P = 370 mm	E = 26 mm	Ke = 7.1%
	average year P = 320 mm		Ke 8%

OUADI FERA AT KOURNELIA (OUADDAÏ - Chad) median P = 400 - 450 mm

S = 5,540 km^2	1965 P = 350 mm	E = 0	Ke = 0
	1966 P = 400 mm ?	E = 0.005 mm	Ke Ke ≠ 0

OUADI FERA AT AM NABAK median P = 400 - 450 mm

S = 5,600 km^2	1965 P = 350 mm	E = 0.07 mm	Ke = 0.02%
	1966 P = 400 mm	E = 0.27 mm	Ke = 0.067%

(1) Runoff 15 to 20 days

Among these data, four examples are particularly striking - first that of the WADI FERA at AM NABAK. Runoff comes solely from a reg zone of 30 km^2 in the upstream area of the station. For the year 1966, which was a surplus year not over the basin but in the AM NABAK region, the most important flood flow at AM NABAK presented nearly an exceptional character. Well, it comes almost solely from this reg zone. At KOURNELIA, several kilometres upstream, the volume which was conveyed towards the downstream area by the WADI FERA is at the very maximum the fiftieth of what passed at AM NABAK, one must still add that this volume is supplied by the few km^2 immediately upstream from KOURNELIA.

Over the GORGOL BLANC basin, in 1959, the ACHRAM dam in the upstream area burst on the 29th August, freeing 3,000,000 m^3, corresponding to 0.8 mm if they had been redistributed over the basin. This volume of water was entirely lost between the ACHRAM dam and GLEITA TOR.

The wadi KETCHI, after TACHOUNDA, crosses a region of dunes and by way of a delta zone where losses through evaporation are considerable, flows into lake ALEG. Between TACHOUNDA and lake ALEG the wadi KETCHI lost 40% of its water in 1958 and 51% in 1959.

The KORI TELOUA between RAZELMAMOULNI, where there is no hydrographic degradation, and the outskirts of AGADES lost 75% of its water in 1960.

So one perceives the full importance of a small basin with good or quite good surface runoff beside the station; one also perceives the possibility of total degradation over the upstream areas of the basin, and the speed of hydrographic degradation at the downstream end of this kind of watercourse, especially when the soil is permeable.

2.3.4.3. Some conclusions

One must set on one side the KORI TELOUA at RAZELMAMOULNI and perhaps two or three wadis of the same sort, for which there is steep slope and negligible hydrographic degradation. In this particular case it is a frequent occurrence for the whole of the basin to have surface runoff at the same time and for the runoff coefficient to be raised, this is the first category from the preceding case.

In the other cases, runoff only occurs over part of the area of the basin and in the median year the runoff coefficient is much lower. It may reach 2% to

5% in the most favourable cases, when a good portion of the basin is active and depth of rainfall is greater than 200 mm (GORGOL BLANC, TAMOURT in NAAJ, wadi KETCHI at TACHOUNDA), if not the coefficient quickly drops : 0.5% to 1% and even below when the bed is extremely degraded, for example for OUADI HAOUACH. But runoff may be regenerated by a downstream portion which is active, the most typical case is that of KORI TOROUK where the runoff coefficient, in the median year, is perhaps in the order of 1% while more than two thirds of the basin contribute nothing. The case of the OUADI FERA is an extreme case.

We have very few data on the dry years. Temporal distribution of rainfall playing an almost more important role than the annual total.

It seems that for water courses such as the KORI TELOUA, the decennial dry year corresponds to a depth of water of 8 mm, or 8% of the ten year value of the annual depth of point rainfall, which is quite theoretical, because the ten year dry rainfall, ever a basin of more than 1,000 km^2, must be greater than the ten year dry rainfall at one point, but do not let us forget that it is a question of annual and not daily rainfall.

For the TAMOURT, more degraded, the decennial dry year corresponds perhaps to a depth of water of 1.2 mm, or 1% of the ten year value of the annual depth of point rainfall.

For wadi KETCHI, the decennial dry year has a coefficient of runoff of perhaps between 1% and 2%, which leads to a depth of runoff of 1.6 to 3.2 mm. Likewise one finds 1% for lake MAL whose drainage basin is far smaller.

All these water courses have relatively good surface runoff, but there are far worse.

Very often, as in the case of wadi FERA, the regime is that of a partial drainage basin, occasionally of very reduced area, close to the station, except in an exceptionally wet year.

For ten year wet frequencies, we likewise have few indications for the same reasons. With regard to the KORI TELOUA, there was at RAZELMAMOULNI a discharge corresponding to a depth of runoff of 50 mm in 1958, corresponding to a runoff coefficient of 18.5% of the depth of ten year point rainfall.

On the TAMOURT, the depth of water at the downstream end would be perhaps 15 mm for the same frequency, which would correspond to a theoretical coefficient of runoff of 4% to 5%. However, the tributaries of the TAMOURT certainly present, for this coefficient, much higher values.

For the GORGOL BLANC at GLEITA TOR, in the decennial wet year, the depth of runoff is perhaps 30 mm, corresponding to a theoretical coefficient of runoff in the order of 6.7%

For the wadi KETCHI at TACHOUNDA, for the same frequency, one would find a depth of water of 35 to 40 mm, or a theoretical runoff coefficient a little lower than 10%.

For the evaluation of annual volumes, one will follow the recommendations of paragraph 2.3.3.4. attaching the greatest importance to the following points :-

- Will it be immediately on the downstream side of the dam site a basin of 2 to 40 km^2 or of 40 to 500 km^2 with good surface runoff? In which case the regime is the one for this basin,

- are there important parts of the drainage basin which do not obviously contribute to runoff? (Do not forget that these parts may contribute once every 50 or 100 years),

- is the site to the upstream or downstream of a loss zone?

All this for a case where the basin is not analogous with that of the KORI TELOUA at RAZELMAMOULNI which, itself, does not present hydrographic degradation.

One must never lose sight of the summary character of these evaluations.

3 – RUNOFF IN THE SAHELIAN REGIONS

This applies to the zone demarcated by the 300 mm and 750 mm isohyets.

3.1 Available information

Available data are still inadequate owing to the great variety of conditions of runoff. In addition, despite some network observations, the lack of flow rate observation over long periods is a serious obstacle to most statistical studies. The hydrometric networks of the sahelian water courses are only being exploited normally in UPPER VOLTA and NIGER. The development of the one in CHAD has been halted by recent political events. The sahelian networks of the MALI and MAURITANIA would be very costly to organise. The Senegalese sahelian watercourses are very few in number.

The raingauging regime is quite well know from SENEGAL up to NIGER; more than 70 raingauge stations are giving usable data and, among these, are some old stations whose data are of good quality.

The study of runoff may be based on three categories of data:-

(a) On the results of the network of the GOROUOL and its tributaries in NIGER and UPPER VOLTA, the one from the tributaries on the right bank of the NIGER downstream from the GOROUOL, the network of the dry valleys which run along the northern frontier of NIGERIA as far as lake CHAD, and some network elements, the exploitation of which has been pursued with greater or lesser continuity in the last few years, on the BA THA and the BAHR AZOUM in CHAD.

(b) On the regional studies carried out over period of between two and four years: the GORGOL NOIR (MAS 1958-1961), the AFFOLE (ORSTOM 1960), wadi GHORFA (ORSTOM 1964, 1965, 1966 and 1967) in MAURITANIA. The rivers flowing into the BAM LAKE (ORSTOM 1966-1974), in the northern-DORI (ORSTOM 1963, 1964 and 1965), TIKARE region (Fonds Europeen de Developpement ORSTOM-SOGETHA, 1963-1964 and 1965) in UPPER VOLTA, the valleys of the ADER DOUTCHI (ORSTOM 1965, 1966 and 1967) and more especially that of BADEGUICHERI (ORSTOM 1969, 1970 and 1971) in the NIGER, the regional studies in the OUADDAÏ (ORSTOM 1959 and 1961) in the basin of the BA THA (1956, 1957 and 1958) and of the GUERA (ORSTOM 1959 and 1960) in CHAD.

(c) On representative basins of all sizes studied by ORSTOM from 1955 to 1971: TARAIMAN, AM NABAK (Chad), KOURO (Chad), GOSI (Chad), KOUNTKOUZOUT (Niger), CAGARA (Upper Volta), wadi KAOUN (Chad), KAORA ABDOU (Niger), wadi GHORFA (Mauritania)

BOUJI (Niger), KAOUARA (Niger), GALMI (Niger), HAMZA and ALOKOTO (Niger), ABOU GOULEM (Chad), KOUMBAKA (Mali), NIAMEY (Niger), BODEO (Upper Volta), SEBIKOTANE (Senegal), ANSOURI (Upper Volta), TIKARE (Upper Volta), BOULSA (Upper Volta), BARLO (Chad), GODOLA (Cameroun). In most cases, they provide accurate values for runoff and annual rainfall but unfortunately for periods which do not exceed three or four years. As will be seen later they have been provided for the study of flood flows, but some of them permit models to be made with which one may reconstruct annual runoff from a rainfall record.

The big tropical rivers like the SENEGAL,NIGER, LOGONE and CHARI are not considered here. All useful information for these will be found in the Hydrological Monographs published for these different rivers.

As in the two preceding cases, it has been necessary to go on to make a systematic study of the extreme values of rainfall, especially with a view to determining what the values of runoff might be in a deficit year. For this purpose 73 raingauge stations have been selected for which the quality of data seemed adequate and the period, over which observations have been made, seemed long enough.

3.2 Rainfall in the sahelian zone

3.2.1 Mean and median values for annual rainfall

For these 73 raingauge stations selected in this way median and mean values have been determined, taking into account data from the years 1971 to 1973 and critical studies made recently on the original data.

For the sahelian stations, the distinction between median and mean is far less useful than in the two preceding instances. Experimental values were compared for the 73 stations selected and the following results were obtained:

1. For 37 stations the mean is higher than the median by at least 2%.
2. For 23 stations mean and median are equal to within 1%.
3. For 13 stations the mean is lower than the median.

In the first instance, the difference is higher than or equal to 4% for 14 stations, higher than or equal to 6% for 7 stations, higher than or equal to 8% for 3 stations.

For 10 stations, the median is greater than the average by at least 2%, the difference is higher than or equal to 4% for 4 stations. The maximum difference is of the order of 5%.

It should be noted that the median is higher than the mean, especially in the case of stations from which the quality of observations is mediocre and, for a relatively low number of samples. The median is often, on the contrary, clearly lower than the mean for stations with good quality data which have been observed over a long period.

It is obvious that, according to slight differences in the sahelian regime, the asymmetry of statistical distribution varies in a certain measure, and the influence of latitude on the asymmetry coefficient is not the only one. However, in many cases one will not be making any appreciable error by saying that the mean is higher than the median by 2%.

This is the increase which will be systematically given to median values in order to pass to the mean values, since, in what follows, one will be led to make use of the median values again, as has been done in the two foregoing cases.

3.2.2 Spatial distribution of rainfall

It has not been adjudged useful to copy out here the mean and median values of annual rainfall at the 73 raingauge stations which were used. Generally speaking, map no.1 of the isohyets permits simpler determination of the depth of mean and median rainfall than in the case of desert or subdesert regions, thanks to a greater density of raingauge stations.

However, some massifs which are distinctly lower than those of the desert do disturb the rainfall regime just a little: for example, the OUADDAÏ and the GUERA in CHAD, the Northern extremity of the MANDARA mountains in CAMEROUN, the massifs of the AFFOLE and the ASSABA in MAURITANIA. In these zones with strong relief it will be advisable to take care when using map no.1, taking special account of the greater rainfall on slopes exposed to the west and the south, and of its reduction on the northern and eastern slopes.

3.2.3 Statistical distribution of annual rainfall

3.2.3.1 Method used

It is essential to represent in as good a light as possible the statistical distribution of annual rainfall for periods of deficit, and the same difficulties are encountered as in paragraph 2.2.3. It is not possible to make use of the individual curves from each station. Some correspond to a sample which is too short, others have been relatively spared by the drought in 1971-1973. Others on the contrary have not only suffered severely from it but also contain, within their data, the three droughts of 1913-1914, 1940-1945, and 1971-1973. Some comprise none of these three but, on the other hand, present the run of years of abundant rainfall between 1950-1960. Finally, it should not be forgotten that individual curves may be seriously distorted by one or two erroneous years.

In what follows we have repeated the same method related to that of the station-years which were used in paragraph 2.2.3.

Stations were divided up into nine groups:-

median P between 300 and 350 mm per year (median value)
350 and 400 mm per year
400 and 450 mm per year
450 and 500 mm per year
500 and 550 mm per year
550 and 600 mm per year
600 and 650 mm per year
650 and 700 mm per year
700 and 750 mm per year.

These groups include the following stations:

Group 1: AIOUN EL ATROUSS, BOGHE, KIFFA, ROSSO, TIMBEDRA, DAGANA, PODOR, ST. LOUIS, DIFFA.

Group 2: TAHOUA, KAEDI.(did not form the object of analyses).

Group 3: KAEDI, MBOUT, LOUGA, ABECHER, ATI, DJEDDAH, OUM HADJER, MAINE-SOROA, GOURE.

Group 4: DAHRA, MATAM, ZINDER, TILABERY, FILINGUE, MADAOUA, TERA.

Group 5: DAHRA, LINGUERE, MBAO, MASSAKORY, KOLO, MYRRIAH, OUALLAM, TSERNAOUA, DORI, KE MACINA, MOURDIAH.

Group 6: BAMBEY, DIOURBEL, TIVAOUANE, DOGONDOUTCHI, BIRNI N'KONI, MAGARIA, NIAMEY, DJIBO, BANDIAGARA, KARA, SOFARA, YELIMANE.

Group 7: SELIBABY, BAMBEY, DIOURBEL, THIES, ADRE, N'DJAMENA, MAGARIA, MARADI, DJIBO, BAM, BANKASS, DIEMA, DJENNE, MARKALA, NIORO.

Group 8: AM DAM, GOZ BEIDA, MASSENYA, DOSSO, SAY, BOGANDE, KAYA, KAYES,SEGUE.

Group 9: KAFFRINE, MBOUR , KAYA, OUAHIGOUYA, KAYES, NYAMINA, SAN, SEGOU.

Given the fact that, generally speaking, median values even for these stations are determined to within a few percent (sometimes worse), one will occasionally find the same station in two successive groups (example, KAEDI, DAHRA, etc.) when the median value is approaching the limit for the group.

It was intentional that the stations of Dakar were not taken into consideration, as their very exceptional conditions of exposure resulted in the data not being comparable with that from stations in the interior.

The second group, in which there are only two stations, could not form the object of analyses.

Annual rainfall within each group was classed in increasing order for dry years and in decreasing order for wet years, independently of the station where it was observed. In this way one arrives at the experimental pairs of rainfall and frequencies enumerated in the following paragraph:-

3.2.3.2 Dry Years

1st Group	f = 0.9988	P = 53 mm
Weighted mean of the median P = 320 mm	f = 0.99	P = 110 mm
	f = 0.98	P = 127 mm
	f = 0.95	P = 153 mm
	f = 0.90	P = 188 mm
2nd group		
(Sample inadequate)		
3rd group	f = 0.9984	P = 120 mm
Weighted mean of the median P = 420 mm	f = 0.99	P = 150 mm
	f = 0.98	P = 190 mm
	f = 0.95	P = 236 mm
	f = 0.90	P = 259 mm
4th group		
Weighted mean of the median P = 480 mm	f = 0.9984	P = 156 mm
	f = 0.99	P = 206 mm
	f = 0.98	P = 229 mm
	f = 0.95	P = 264 mm
	f = 0.90	P = 320 mm
5th group		
Weighted mean of the median P = 530 mm	f = 0.9987	P = 171 mm
	f = 0.99	P = 213 mm
	f = 0.98	P = 244 mm
	f = 0.95	P = 295 mm
	f = 0.90	P = 361 mm
6th group		
Weighted mean of the median P = 580 mm	f = 0.999	P = 156 mm
	f = 0.99	P = 248 mm
	f = 0.98	P = 316 mm
	f = 0.95	P = 362 mm
	f = 0.90	P = 417 mm

7th group

Weighted mean of median P = 620 mm

f = 0.999	P = 228 mm
f = 0.99	P = 267 mm
f = 0.98	P = 329 mm
f = 0.95	P = 368 mm
f = 0.90	P = 440 mm

8th group

Weighted mean of median P = 670 mm

f = 0.9984	P = 230 mm
f = 0.99	P = 394 mm
f = 0.98	P = 430 mm
f = 0.95	P = 467 mm
f = 0.90	P = 522 mm

9th group

Weighted mean of median P = 720 mm

f = 0.9986	P = 208 mm
f = 0.99	P = 412 mm
f = 0.98	P = 445 mm
f = 0.95	P = 497 mm
f = 0.90	P = 542 mm

The values of P up to f = 0.98 or 99 are significant, those for f = 0.999, are not. However, generally, results are sufficiently coherent for the groups as a whole, which is cheering and leads one to think that the number of very low values corresponding to errors in observations is very small. For dry years the influence of test tube errors is not very great, in contrast to what one will be able to see for wet years, however the lack of homogeneity in the various statistical series is such as to falsify the results. Whatever may be the case, in spite of the regularity of the increase in values for annual rainfall for a given frequency as a function of the median value of rainfall, we have been led to make slight corrections to these values (as a general rule by a few mm., 20 mm at most), so as to arrive at a regular family of curves.

This correction is minimal in relation to the accuracy in measuring rainfall and especially to the far lower one in relation to the evaluation of annual runoff.

3.2.3.3 Wet years

We worked in the same way for wet years and achieved the following raw results:-

1st group

Weighted mean for median P = 320 mm

f = 0.0012	P = 816 mm
f = 0.01	P = 675 mm
f = 0.02	P = 633 mm
f = 0.05	P = 558 mm
f = 0.10	P = 468 mm

2nd group

(sample inadequate)

3rd group

Weighted mean for median P = 420 mm

f = 0.0016	P = 944 mm
f = 0.01	P = 880 mm
f = 0.02	P = 798 mm
f = 0.05	P = 681 mm
f = 0.10	P = 602 mm

4th group

Weighted mean for median P = 480 mm

f = 0.0016	P = 1120 mm
f = 0.01	P = 870 mm
f = 0.02	P = 810 mm
f = 0.05	P = 738 mm
f = 0.10	P = 677 mm

5th group

Weighted mean for median P = 530 mm

f = 0.0013	P = 1095 mm
f = 0.01	P = 915 mm
f = 0.02	P = 895 mm
f = 0.05	P = 855 mm
f = 0.10	P = 719 mm

6th group

Weighted mean for median P = 580 mm

f = 0.001	P = 1501 mm
f = 0.01	P = 1130 mm
f = 0.02	P = 990 mm
f = 0.05	P = 914 mm
f = 0.10	P = 823 mm

7th group

Weighted mean for median P = 620 mm

f = 0.00:	P = 1579 mm
f = 0.01	P = 1248 mm
f = 0.02	P = 1108 mm
f = 0.05	P = 956 mm
f = 0.10	P = 858 mm

8th group

Weighted mean for median P = 670 mm

f = 0.0016	P = 1136 mm
f = 0.01	P = 1090 mm
f = 0.02	P = 1006 mm
f = 0.05	P = 930 mm
f = 0.10	P = 872 mm

9th group

Weighted mean for median P = 720 mm	f = 0.0014	P = 1681 mm
	f = 0.01	P = 1150 mm
	f = 0.02	P = 1130 mm
	f = 0.05	P = 992 mm
	f = 0.10	P = 899 mm

Note will be taken of the abnormally high values from the seventh group which are due to a four figure series from NIORO station: 1579 mm, 1481 mm, 1385 mm and 1243 mm which figure in the seven most exceptional values in the group. They correspond to four successive years from 1927 to 1930, this series seems fairly suspect unless it was a test tube error. The classic error of 27% would be enough to explain this succession of four figures. In any case we have had to readjust the distribution curves with more significant corrections than for the dry years.

3.2.3.4 Distribution curves of annual precipitation

From the preceding data distribution curves for annual rainfall have been plotted which correspond to the median values: 320 mm per year, 420 mm per year, 480 mm per year, 530 mm per year, 580 mm per year, 620 mm per year, 670 mm per year and 720 mm per year. As has been stated earlier, it was necessary to slightly alter some of them from the lines of representative points defined in the two preceding paragraphs, and in particular for the upper parts of the curve for the seventh group. This was necessary in order to give regular spacing to the lower or upper parts of these curves.

By interpolation between the curves from this first set, it was easy to complete the series of curves which represent (in gaussian logarithm coordinates) the distribution of annual rainfall for median values varying between 300 mm to 750 mm, in 50 mm steps (mean values only differ by 2%). A system of gaussian normal coordinates could have been used, but the diagram would have been less convenient for use where dry years were involved.

At a second stage a generalized exponential law was adjusted on these curves (F_1 being the cumulative frequency not exceeded). This law is expressed as follows:

$$F = 1 - F_1 = 1 - \exp - \frac{(x-x_o)}{s}^{1/0.4}$$

The parameters x_o and s being defined as follows, from the median value for the depths of annual precipitation P_m:-

$$x_o = 7.6 \times 10^{-4} P_m^2 - 52.4$$

$$s = (P_m - x_o) \; 1.1579$$

These parameters are given later for some values of median P P_m:-

P_m	300 mm	400	500	600	700
x_o	16.0	69.2	137.6	221.2	320.0
s	328.84	383.03	419.62	438.61	440.00

This adjustment which is indispensable for calculation by computer involved insignificant corrections for the experimental curves; these are the curves corresponding to the above mentioned exponential law which have been represented on diagram 17.

These curves correspond to the most frequent cases. There are particular sites where the distribution of rainfall presents an asymmetry which is greater or less than is the general case and for which the exceptionally low values are clearly lower or higher than those indicated by diagram 17.

Apart from certain regions of the OUADDAI, altitude does not play an important part in creating such anomalies, but exposure and above all proximity to the coast must exert quite a considerable influence.

3.2.4 Seasonal distribution of rainfall

Compared with the foregoing regions the rainy season extends over a distinctly longer period. The month with most rain is still almost always August, but rainfall in July and September is quite considerable and, in some years, it is heavier than in August. There is frequently appreciable rain in June and at the beginning of October, the June rains may be a factor in the saturation of the soil, and those of October may come on wet soils and give rise to far from negligible runoff phenomena. Finally, there is quite often rain in May and occasionally in April; these last rains are due to the monsoon and not to typically Saharan disturbances, as in desert regions. However, the periods in which runoff phenomena occur is for the most part limited to the period between July 1st and the beginning of October.

This protraction of the rainy season and irregularity from one year to the next in the distribution of rainfall during this rainy season, may lead to very different runoff for a similar annual total for rainfall, which does not facilitate analysis of data relative to runoff. Exceptional daily rainfall plays a lesser part than in subdesert regions for a large number of the basins, but this is not an absolute rule, since it has importance of the first order for basins with poor surface runoff. In this case, a year with slight deficit may present considerable runoff, if there has been an exceptionally heavy rainstorm. Let us remember that the depth of exceptional storms, for a given frequency, increases far less rapidly than the mean value of the depth of annual precipitation.

3.2.5 Evaluation of the depth of annual precipitation

It is still more difficult than in a subdesert zone (because of the natural vegetation cover) all the more so as the action of Man is more significant. Trust may be placed in the general data given on isohyet map no. 1 and in the data from some raingauge stations observed over a short period, after a very serious critical study using original daily rainfall readings.

3.3 Annual runoff in Sahelian zones

Hydrographic degradation, less rapid than in the sub-desert regimen, is nevertheless very distinct in most cases, and this is why the hydrologic regimen will vary a great deal with the area of the drainage basin. This will lead us to consider several area scales, as has been done hitherto. On the other hand surface runoff is a phenomenon (for the regime we are taking into consideration) which occurs very distinctly every year in the greater part of the zone being studied. Practically speaking it is not restricted, in the average year, to mountain massifs and their approaches, or to the slope of the fossil valleys, as in the sub-desert regimen.

In fact, in the sub-desert regimen, there are surface runoff phenomena which occur everywhere to some extent, but in the main part of the sub-desert zone they only arise in a favourable year, and often in such conditions that the use of this surface runoff water cannot be envisaged.

Further south, in the sahelian regimen proper, when planning water management schemes one will be led to take into account drainage basins whose capacity for surface runoff will be distinctly less than the least interesting among the basins studied in the sub-desert zone. As a result there will be a far greater variety in conditions for runoff; the simplistic method, which would consist of considering three categories of basin with very good surface runoff (category I), with good surface runoff (category II) and with average surface runoff (category III), would no longer suffice in the Sahelian regimen proper.

The study will be divided up into five parts similar to those in the preceding chapter, except for the last category which did not exist :-

(a) catchment areas of only a few hectares at most (as in the case of cisterns)

(b) small drainage basins between 2 km^2 and 40 km^2 corresponding to the sites of small reservoirs, and on the study plan, to most representative basins

(c) water courses whose drainage basin comprises between 40 km^2 and 500 km^2. The area may reach 600 km^2 to 800 km^2 if hydrographic degradation is not too marked. For this regimen, the type of water-course corresponds to the case of the most common reservoirs.

(d) basins of more than 1,000 km^2 are almost always affected by hydrographic degradation, but in the sahelian regimen the area of the drainage basins in this category may greatly exceed 1,000 km^2

(e) basins of more than 10,000 km^2. There are less of these and their regimen differs significantly from that of the preceding category.

3.3.1 Drainage basins of a few hectares at most.

It is a question of the catchment areas of cisterns, perhaps not so necessary as in sub-desert regions, but these small areas may also be used to create hill lakes, and this is why it seemed helpful to give a few indications about the estimation of available volumes. Moreover, there are at our disposal some experimental elements, thanks to research carried out on sediment traps whose replenishment area presents roughly the same surfaces.

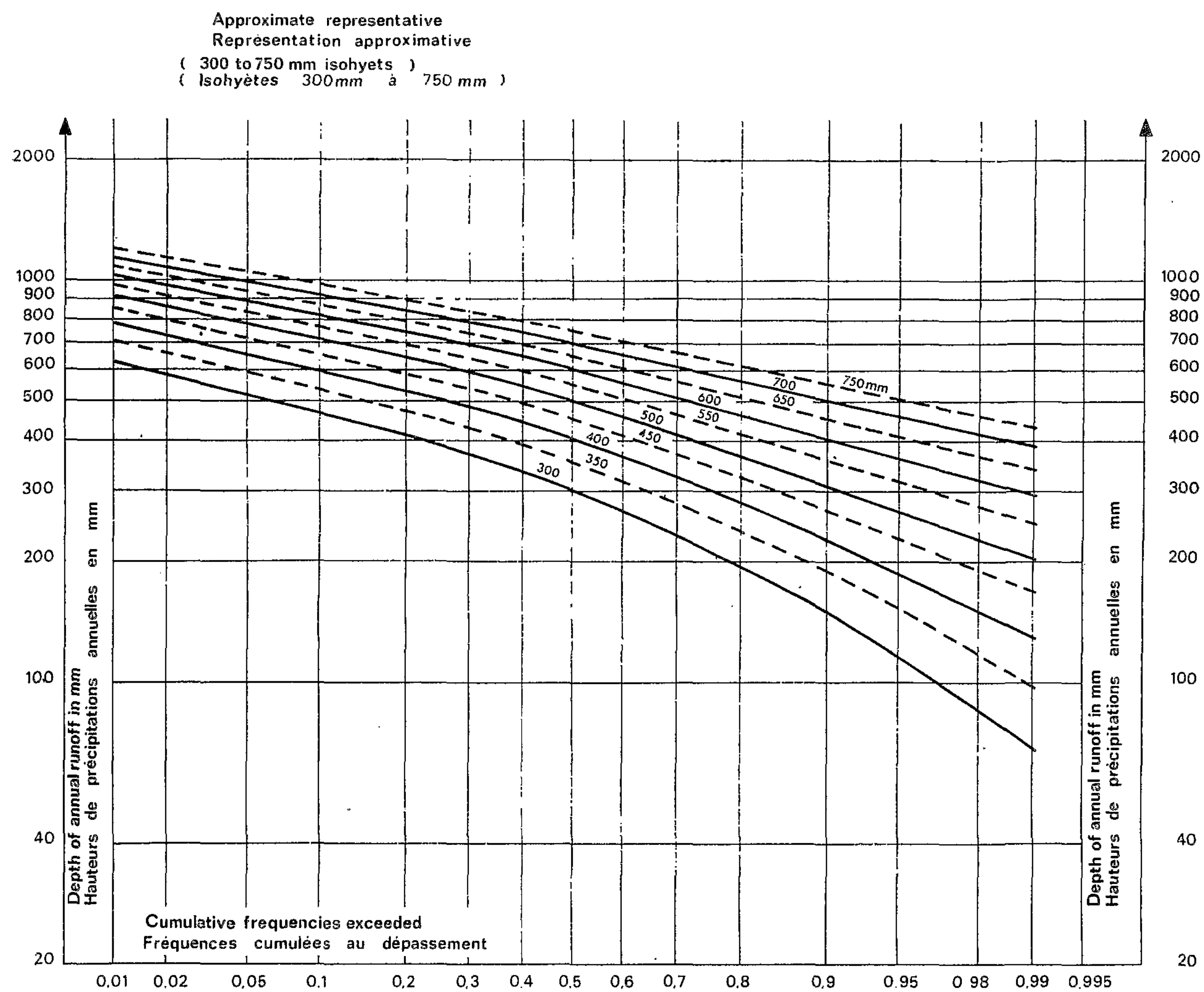
At KOUNTKOUZOUT, near TAHOUA, with average year to year precipitation 400-410 mm, median 390-400 mm, the results were as follows :-

TRAP N° 1				
S = 3.52 hectares	Ig = 36	1965 P = 487 mm	E = 208 mm	Ke = 42.5%
Marl-limestone		1966 P = 496 mm	E = 252 mm	Ke = 50.8%
(clayey reg)		1967 P = (410) mm	E = (240) mm	Ke = 58.5%
TRAP N° 2		1965 P = (487) mm	E = (136) mm	Ke = 27.9%
S = 4.7 hectares	Ig = 127	1966 P = 496 mm	E = 220 mm	Ke = 44.2%
Clayey reg + sub-arid brown				
soil		1967 P = (410) mm	E = (170) mm	Ke = 41.3%

Temporal distribution of annual precipitation in the property so called sahelian zone

Distribution temporelle des précipitations annuelles en zone sahélienne proprement dite

Fig: 17



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TRAP N° 3

S = 3.55 hectares	Ig = 26	1966 P = 496 mm	E = 222 mm	Ke = 42.6%
Marl-limestone		1967 P = (410) mm	E = (176) mm	Ke = 42.7%
(clayey reg)				

TRAP N° 5

S = 10.6 hectares	Ig = 127	1965 P = (454) mm	E = (64) mm	Ke = 14%
Sandstone deposit		1966 P = 550 mm	E = 135 mm	Ke = 24.6%
from the ADER DOUTCHI		1967 P = (410) mm	E = (85) mm	Ke = 20.7%

TRAP N° 6

S = 9.10 hectares	Ig = 10.5	1965 P = (441) mm	E = (35) mm	Ke = 7.9%
Sand with the cultivation		1966 P = 482 mm	E = 60 mm	Ke = 12.5%
of millet		1967 P = (380) mm	E = (46) mm	Ke = 12.1%

At ALOKOTO, in the NIGER, on the sediment trap installed in 1958, the following results were obtained from 20th August to the end of September for an area of 5.5 hectares in clayey soil :-

Rainfall	= 161 mm
Runoff	= 94 mm
Coefficient of runoff	= 58 %

For a complete year, the coefficient of surface runoff is a little lower even for a basin with very good surface runoff, as in this case; small rainstorms at the beginning of the rainy season are often lost from the surface runoff. Consequently a coefficient of annual surface runoff of 50% seems probable.

At TIKARE (towards KONGOUSSI (Upper Volta)) the following results were found :-

TIKARE I		1963 P = 800 mm	E = 14 mm	Ke = 1.7%
S = 11.3 hectares	Dd = 7.08	1964 P = 815 mm	E = 35 mm	Ke = 4.4%
covering of laterite gravel	Ig = 48	1965 P = 853 mm	E = 123 mm	Ke = 14.4%

On those natural soils considered above, that is to say those without treatment, one sees that in a median year on clayey soils on the moderate slope of the ADER DOUTCHI (which also takes in the basins of KOUNTKOUZOUT and ALOKOTO) the annual surface runoff coefficient in a median year is between 40% and 50%.

For zones of very broken sandstone with steep slopes it is no more than 15% - 20%. For cultivated sandy or sandy clay terrain it is between 8% and 12%. There are lighter sandy soils than those of KOUNTKOUZOUT, for which lower values are certainly found.

For a soil with a thick bed of laterite gravel and non-negligible vegetation cover, as at TIKARE I, the coefficient of surface runoff is perhaps of the order of between 4% and 8%.

This coefficient varies little with the depth of annual precipitation. It would tend rather to decrease from north to south, since the density of the vegetation cover in the rainy season increases with the depth of annual precipitation and checks surface runoff still more.

In most cases one will not go on to the treatment of the catchment areas (elimination of the stones or blocks and bushes, improvement of the drainage network), but in these conditions use will need to be made of the figures just quoted. However, for soils with good surface runoff, these are lower than those in paragraph 2.3.1, which generally correspond to treated basins.

These four sets of figures do not cover the whole range which may be encountered.

On clays derived from schist, coefficients of surface runoff of 40% to 50% may be anticipated.

On a basal complex, three cases may be encountered :- zones of blocks with a low coefficient of surface runoff, perhaps in the order of 10% or still less, even if the slope is steep. Directly at the foot of these blocks there is a zone of infiltration which cannot have much greater surface runoff, and then a slight glacis with a coefficient of surface runoff which, from what we have been able to see on the BODEO, would be perhaps in the region of 30%.

For impermeable soils, or soils of low permeability, the coefficient of surface runoff varies relatively little from one year to the next, for the same depth of rainfall.

If the soil is quite permeable or very permeable, annual surface runoff varies considerably according to whether rainfall is concentrated in August or in September, or whether it is split between July and October with a reduction in August or in September, in which case surface runoff is slight. This will be much worse for more extensive basins.

However, the <u>mean</u> value for any given depth of rainfall on a given site must vary little with the depth of annual precipitation, except in a year of exceptional rainfall or in an exceptionally dry year.

3.3.1.2. Exceptionally wet years.

(a) In an exceptionally wet year, for the 300 mm to 500 mm isohyet, one must be able to adopt KR values slightly lower than that for the sub-desert zone, perhaps 70% for the hundred year wet year (P of between 620 mm and 920 mm) and for soils with good surface runoff, marl-limestone soils of the ADER DOUTCHI, clay reg, perhaps glacis in the vicinity of rocky massifs.

This figure must perhaps be reduced to 60% between the 500 mm and 750 mm isohyets.

(b) In soils for which surface runoff is mediocre, such as that for trap No. 5, it is not improbable that in the centennial year the coefficient of annual surface runoff attains 40% to 50%.

(c) In relatively permeable soils, 20% to 30% would perhaps be an upper limit for the same frequency.

3.3.1.3. Exceptionally dry years

What figures might be envisaged in dry years? One recalls that the annual precipitation would be as follows for the centennial year :-

300 mm isohyet	: 68 mm
400 mm isohyet	: 130 mm
500 mm isohyet	: 203 mm
600 mm isohyet	: 290 mm
700 mm isohyet	: 360 mm
750 mm isohyet	: 430 mm

(a) In the case of soils with good surface runoff, there is runoff every year whatever the rainfall regime may be, and in particular, the median of mean interannual value of the depth of annual precipitation. For the 750 mm isohyet, in the hundred year dry year, the coefficient of surface runoff is certainly lower than that in the median year, but it remains of the same order of size. It falls from 40% in the median year to perhaps 25% - 30%.

(b) For homogeneous basins, with mediocre surface runoff, the runoff coefficient, in the hundred year dry year, would be :-

2% to 4% for the 300 mm isohyet
4% to 6% for the 400 mm isohyet
6% to 9% for the 500 mm isohyet
9% to 11% for the 600 mm isohyet
11% to 13% for the 700 mm isohyet.

We recall that for these basins, in a mean year, the coefficient of surface runoff is between 15% and 20%; one may see that, from the 600 mm isohyet, the coefficient of surface runoff decreases little in a dry year.

(c) Permeable basins give poor runoff with a coefficient varying between 4% and 12% (type TIKARE I, trap n° 6 of KOUNTKOUZOUT) in a mean year and they can only form the object of a management scheme when no others are to be found.

The runoff coefficient, for the hundred year dry frequency, corresponding the hundred year dry precipitation, would be :-

effectively 0 for the 300 mm isohyet
from 0 to 5% for the 400 mm isohyet, depending on the permeability of the basins
from 0.5% to 5% for the 500 mm isohyet, depending on the permeability of the basins
from 1% to 5% for the 600 mm and 700 mm isohyet, depending on the permeability of the basins.

For this evaluation, which is rather qualitative in character, we had to take into account both the depth of the hundred year precipitation and the depths of daily rainfall, since, below the 300 mm isohyet, a year with a depth of annual rainfall of 68 mm may contain a daily rainstorm of 40 mm which gives rise to runoff, whereas a year with a depth of annual rainfall of 100 mm to 110 mm may not have a single storm exceeding 15 mm, in which case there is no runoff.

It is just the same for the variation of the coefficient of surface runoff in wetter regions.

Of course, more permeable and flatter basins than those of TIKARE I do exist which have still poorer runoff.

It may be seen that for these small basins, the method used is very similar to that for the three categories used in the subdesert zone.

3.3.1.4. Procedure to follow for the evaluation of annual runoff

The steps are rather similar to those described in paragraph 2.3.1.

The following operations should be carried out :-

Determination of the depth of annual precipitation (median or mean value), using diagram No. 1. Some corrections would need to be made to it, in relation with the particular nature of the site, exposure etc., but it is difficult to give advice on how these corrections should be made.

- Determination of the distribution curve for annual rainfall by interpolation making use of diagram 17.

- An examination of the terrain, and if need be, of large scale aerial photographs which allow the catchment area to be connected with one of the studies made earlier. Interest will be shown in the "roughness" of the soil in the broad sense, not favourable to surface runoff, and in surface runoff runnels or traces of erosion which are an indication of a high surface runoff coefficient.

Determination of the distribution curve for annual runoff, working from three points the median values, hundred year dry and wet values of the coefficient of runoff Ke given in paragraphs 3.3.1.1., 3.3.1.2., and 3.3.1.3. for the particular case with which the catchment area considered may be connected. In the case of soil with poor surface runoff, one will take upper or lower limits of the intervals of Ke as given earlier, upper limit if one is dealing with conditions of surface runoff which are still not too poor, like those of the basin of trap No 6 of KOUNTKOUZOUT, slightly favoured by a relatively fine grain size in the composition of the top part of the soil, and a marked slope or lower limit with clearly unfavourable functioning conditions, as in the case of the TIKARE I basin.

- A study of annual volumes for the different frequencies.

Schemes will have to take into account exceptional flood flows whose cumulative frequency must correspond to the degree of risk allowed; a cumulative frequency of 0.10 or less.

3.3.2. Small drainage basins from 2 km^2 to 40 km^2.

3.3.2.1 Generalities

As has been said earlier, one will need to take into account many more types of basins than in subdesert zones.

Our documentation stems from the study of representative basins set up generally for the study of exceptional floods, so, for each type of terrain, hydrologists have turned to small basins which are often more favourable to runoff than their neighbours. Even if the study of the exceptional flood is not the main purpose of these studies, hydrologists automatically carry out research over a section of the water course which is easy to gauge, namely a well defined bed, which generally corresponds with conditions of runoff which are more favourable than the average.

This is compensated by the fact that when the engineer is trying to set up a small reservoir or a water catchment, his manner of procedure is the same.

In what follows, it will be necessary to make use of marginal studies, often studies of poor quality, in order to get some idea of runoff on basins with poor surface runoff.

The drainage basins dimensions are such that, in many cases, it is impossible to consider the soils homogeneous. This is clearly the case for the ADER-DOUTCHI basins (Niger), that is to say KOUNTKOUZOUT, ALOKOTO, BOUNJI, GALMI, KAOUARA, KAORA ABDOU. In interpretation this will have to be taken into consideration. It is likewise true for many basins on the basal complex.

For many basins of small area, there will be no hydrographic degradation, but on some basins whose soil is derived from crystalline rocks, runoff is perhaps rather poor, and, in this case, the slightest glacis at the foot of the rocks creates appreciable surface runoff and an element of heterogeneity, the basin in this case often behaves as though some hydrographic degradation had already teken place.

Generally speaking, interpretation will be both less brief and more difficult than in the sub-desert zone.

3.3.2.2. Available information

This comes from the data from representative basins. It has been necessary to revise all the data from this type of basin studied in the sahelian zone, usually by ORSTOM. Occasionally it was necessary to extend rainfall and runoff data; some basins were only studied during the rainy season, or even during part of this season when runoff is at its most active.

Error stemming from these complements is minimal on the total for annual precipitation, on runoff, and consequently on the coefficient of runoff Ke.

We saw to it that runoff corresponded to the total : surface runoff + intermediate runoff (whether delayed, or subsurface). One single basin presented runoff stemming from groundwater bodies, but it had to be eliminated, because the base flow was determined with too great a lack of precision. Available volumes, which will be estimated from rainfall and from the coefficient of runoff Ke, will therefore correspond to runoff as a whole.

Below, all the values of Ke which it was possible to calculate or estimate have been reproduced. Occasionally they show some slight differences from those published in the Collection of basic data from the ORSTOM representative or experimental basins, almost always as a result of the corrections implemented to complete annual precipitation and (more rarely) runoff (over the period May-June).

TARAIMAN (Chad)		median P : 270 mm		
14° 33'				
S = 11.25 km^2	Dd = 0.80	1961 P = (700 mm)		Ke = 30% ?
clay reg	Ig = 3.0	Aug 1961 P = 405 mm	E = 153 mm	Ke = 37%
AM NABAK (Chad)		median P : 330 mm		
14° 15'				
Reduced basin		1965 P = 330 mm	E = 6,3 mm	Ke = 2%
S = 60 km^2		1966 P = 380 mm	E = 25 mm	Ke = 6.6%
30% clay reg				
Residual basin				
KOURO (Chad)		median P : 330 mm		
14° 18'	Dd = 2.77			
S = 16 km^2		1961 P = (850 mm)	E = 9 mm ?	Ke = 1%-1.5%
Granite with arenaceous				
soil and a little	Aug	1961 (1) P = 475 mm	E = 6 - 7 mm	
sand				

(1) Aug 1st - Sept 3 rd

GORI at TOROU (Chad)	median P : 330 - 350 mm			
14° 17'				
S = 60 km^2	Dd = 2.18	1961 P = (910 mm)	E = 28 mm?	Ke = 3% - 4%
Granite with arenaceous		Aug-Sept 1961(2) P = 199 mm	E = 14 mm	Ke = 7%
soil and sand		(2) Aug 22nd - Sept 13th		

KOUNTKOUZOUT (Niger)	median P : 390 mm - 400 mm			
14° 50'		1964 P = 540 mm	E = (130 mm)	Ke = 24%
S = 16.6 km^2		1965 P = 460 mm	E = 60.7 mm	Ke = 13%
(marl-limestone, sandy		1966 P = 531 mm	E = 93.8 mm	Ke = 17.7%
clay soil, fragmented		1967 P = 400 mm	E = (56 mm)	Ke = 14%
sandstone				

CAGARA (Upper Volta) median P : 400 mm - 420 mm
14° 28'

CAGARA West	Dd = 1.15	1956 P = 530 mm	E = 80 mm	Ke = 15%
S 28.1 km^2	Ig = 3.72	1957 P = 385 mm	E = 45 mm	Ke = 11.7%
granite and gneiss covered				
with sandy clay products				
CAGARA East (Upper Volta)		median P : 400 mm - 420 mm		
S = 32.35 km^2	Dd = 0.68	1956 P = 530 mm	E = 85 mm	Ke = 16%
granito-gneiss	Ig = 2.88	1957 P = 395 mm	E = 44 mm	Ke = 11.2%
with vertisol				
on the plateau				

WADI KAOUN (Chad)	median P = 420 mm			
13° 47'				
S = 56 km^2	Dd = 0.93	1956 P = 497 mm	E = 6.32 mm	Ke = 1.3%
granite arenaceous	Ig = 7.25	1957 P = (476 mm)	E = 3.59 mm	Ke = 0.75%
Reduced basin				
S = 25 km^2		1956 P = 497 mm	E = (13 mm)	Ke = 2.6%
granite and arenaceous		1957 P = (476 mm)	E = 6 mm	Ke = 1.25%

KAORA ABDOU (Niger)	median P = 470 mm			
14° 27'		1970 P = 420 mm	E = 100.4 mm	Ke = 23.5%
S = 5.65 km^2		1971 P = 271.4 mm	E = 43.8 mm	Ke = 16.1%

WADI GHORFA (Mauritania)		median P : 450 - 475 mm		
15° 50'				
PO S = 2.71 km^2				
	Dd = 2.34	1966 P = 468 mm	E = 135 mm	Ke = 28,8%
	Ig = 8.5	1967 P = (558 mm)	E = (170 mm)	Ke = 30.5%

KADIEL

S = 39.5 km^2				
	Dd = 2.23	1964 P = 520 mm	E = 147.5 mm	Ke = 27.4%
Schist and clays				
	Ig = 4.18	1965 P = 414 mm	E = 100 mm	Ke = 24.2%
		1966 P = 380 mm	E = 45.2 mm	Ke = 11.9%

BOUJI (Niger) median P = 450 mm - 470 mm

14° 30'			
S = 8.5 km^2	1969 P = 343 mm	E = 62 mm	Ke = 18.1%
Sandstone on the plateaux			
marl-limestone on the slopes	1971 P = 291 mm	E = 40.3 mm	Ke = 13.9%

KAOUARA (Niger) median P = 490 mm

14° 06'				
S = 3.3 km^2	Dd = 2.28	1964 P = 630 mm	E = 160 mm	Ke = 25.4%
ferruginous Sandstone				
and marl limestone soils	Ig = 20.5	1965 P = 590 mm	E = 103 mm	Ke = 17.5%
continental margin		1966 P = 332 mm	E = 39 mm	Ke = 11.7%

GALMI (Niger) median P = 490 mm - 500 mm

13° 58'

GALMI I	1969 P = 480 mm	E = (107 mm)	Ke = 22.3%
S = 20 km^2	1970 P = 455 mm	E = (188 mm)	Ke = 41.4%
R 4 marl-limestone	1971 P = 358 mm	E = (140 mm)	Ke = (39%)
	1974 P = 503 mm	E = 197 mm	Ke = 39%

GALMI II			
S = 39 km^2	1969 P = 473 mm	E = 158 mm	Ke = 33.4%
R4	1970 P = 444 mm	E = 139 mm	Ke = 31.3%
marl limestone	1971 P = 344 mm	E = 88 mm	Ke = 25%
	1974 P = 420 mm	E = 165 mm	Ke = 39.5%

The studies carried out in 1974 tend to augment the area occupied by the plateaux; the area of GALMI I passes to 29.2 km^2, that of GALMI II to 46.5 km^2. The Ke values would need to be reduced by 30% for GALMI I and 15% for GALMI II.

HAMZA (Niger) median P : 490 mm

14° 10'	Dd = 4.03	1957 P = 520 mm	E = 28 mm	Ke = 5.4%
S = 16.6 km^2	Ig = 9.1	1958 P = 589 mm	E = 61 mm	Ke = 10.3%
R3-R4				
Sandstone and clay soils				

The values of E and Ke must be multiplied by at least 2 if only the active parts are taken into consideration.

ALOKOTO (Niger)

$S = 48.3\ km^2$	Dd = 3.71	1956 P = 630 mm	E = 60 mm	Ke = 9.5%
R3 - R4	Ig = 8.7	1957 P = 494 mm	E = 22.7 mm	Ke = 4.6%
Sandstone and clay soil		1958 P = 604 mm	E = 73 mm	Ke = 12.1%

The values of E and Ke must be multiplied by 2 at least if only the active parts are taken into consideration.

ABOU GOULEM (Chad) median P = 500 mm - 520 mm

13° 35'

Reduced basin

$S = 12.3\ km^2$	Dd = 2.34	1958 P = 500 mm	E = 12.5 mm	Ke = 2.5%
granite, arenaceous soil and sands	Ig = 12.6			

KOUMBAKA (Mali) median P = 570 mm

13° 52'

Station III

$S = 8.9\ km^2$	Dd = 0.65	1956 P = 616 mm	E = 75.5 mm	Ke = 12%
Sandstone	Ig = 22.3	1957 P = 715 mm	E = 90 mm	Ke = 12.5%

Station II

$S = 30.4\ km^2$	Dd = 1.03	1956 P = 587 mm	E = 101.5 mm	Ke = 17.3%
Sandstone	Ig = 10.8	1957 P = 770 mm	E = 136 mm	Ke = 17.7%

Station I

$S = 87\ km^2$	Dd = 0.84	1955 P = (595 mm)	E = (46 mm)	Ke = 7.8%
The same +	Ig = 9.35	1956 P = 587 mm	E = (57.8 mm)	Ke = 10%
ferruginous tropical soils		1957 P = 714 mm	E = (69.8 mm)	Ke = (10%)

NIAMEY (Niger) median = 575 mm - 590 mm

NIAMEY VI

13° 30'

$S = 1\ km^2$	1963 P = 560 mm	E = ((30 mm))	Ke = 5.4%
Sand and ferruginous shields	1965 P = 660 mm	E = ((35 mm))	Ke = 5.3%

NIAMEY VII

$S = 20\ km^2$	1963 P = 560 mm	$E \leqslant 2$ mm	Ke $\not\approx$ 0
Sand with millet cultivation	1965 P = 660 mm	$E \leqslant 5$ mm	Ke $\not\approx$ 0

BODEO (Upper volta) median P = 600 mm
14° 07'

Upstream basin	Dd = 3.85	1964 P = 680 mm	E = 148 mm	Ke = 21.7%
S = 3.45 km^2	Ig = 6.6			
R2 R3 : schist with glacis				
Downstream basin	Dd = 3.12	1963 P = 659 mm	E = (8 mm)	Ke = 1.2%
S = 11.2 km^2	Ig = 5.8	1964 P = 630 mm	E = (29 mm)	Ke = 4.6%
R3				
Significant proportion of permeable soils				

SEBIKOTANE (Senegal) median P = 620 mm
14° 44'

DIAM NIADIE	Dd = 3.81	1962 P = 650 mm	E = 91.4 mm	Ke = 14%
S = 2.62 km^2	Ig = 10.8?			
R2 Black clay on marl				

KIPE KIPE

S = 43 km^2	Dd = 2.35	1962 P = 613 mm	E = 46.5 mm	Ke = 7.6%
R2 black clay	Ig = 4.4 ?			
on marls and				
ferruginous tropical soils				

ANSOURI (Upper Volta) median P = 640 mm - 670 mm

13° 18'	Dd = 2.26	1963 P = 780 mm	E = 24 mm	Ke = 3.1%
S = 0.69 km^2	Ig = 16.8	1964 P = 672 mm	E = 35 mm	Ke = 5.2%
Schists and clay glacis		1965 P = 767 mm	E = 56 mm	Ke = 7.3%

TIKARE (Upper Volta) median P = 640 mm - 670 mm
13° 17'

TIKARE I	Dd = 7.08	1963 P = 800 mm	E = 14 mm	Ke = 1.7%
S = 0.113 km^2	Ig = 48	1964 P = 815 mm	E = 35.6 mm	Ke = 4.4%
covering of laterite		1965 P = 853 mm	E = 123 mm	Ke = 14.4%
gravel				
TIKARE II	Dd = 5.85			
S = 2.36 km^2	Ig = 50	1964 P = 778 mm	E = 16 mm	Ke = 2%
Schist and laterite gravel		1965 P = 813 mm	E = 45 mm	Ke = 5.5%

BOULSA (Upper Volta) median P = 750 mm

12° 22'		1960 P = 725 mm	E = 28.4 mm	Ke = 3.9%
KOGHNERE	Dd = 0.682	1961 P = 685 mm	E = 16.6 mm	Ke = 2.4%
S = 22 km^2	Ig = 4.26	1962 P = 1140 mm	E = 123 mm	Ke = 10.8%
Arenaceous soils				

KOGHO		1960 P = 775 mm	E = 26.2 mm	Ke = 3.4%
S = 84.7 km^2	Dd = 0.98	1961 P = 675 mm	E = 5.9 mm	Ke = 0.9%
arenaceous soils	Ig = 2.29	1962 P = 1120 mm	E = 94 mm	Ke = 8.4%
BARLO (Chad)		median P = 790 - 800 mm		
12° 7'				
Reduced	Dd = 2.48	1959 P = 721 mm	E = ((80 mm))	Ke = 11%
basin	Ig = 29			
S = 17.8 km^2				
R5 granite				
Big basin	Dd = 2.08	1958 P = 710 mm	E = (40 mm)	Ke = 5.6%
S = 36.6 km^2	Ig = 22	1959 P = 643 mm	E = 58.7 mm	Ke = 9.2%
R5 granite				
MOTORSOLO (Cameroun)		median P = 800 - 820 mm		
10° 40'				
S1 : LELENG	Dd = 8.52	1966 P = 740 mm	E = 175 mm	Ke = 24%
S = 4 km^2	Ig = 45.5	1967 P = 792 mm	E = 263 mm	Ke = 33%
granite		1968 P = 978 mm	E = 512.5 mm	Ke = 52%
		1969 P = 960 mm	E = 249 mm	Ke = 26%
S4 : GODOLA	Dd = 5.83			
S = 42 km^2	Ig = 15.3	1968 P = 918 mm	E = 299 mm	Ke = 33%
granite, R5 R4		1969 P = 909 mm	E = 147 mm	Ke = 16%
BOULORE (Cameroun)		median P = 800 - 820 mm		
10° 38'	Dd = 5.54	1954 P = (850 mm)	E > 92 mm (1)	Ke = 12.5%
S = 3.75 km^2	Ig = 58	1955 P = 831 mm	E = 46.1 mm	Ke = 5.6%
Green rock (andesite) ferruginous tropical soil				

For the year 1954 from April to November Ke would be of the order of 11%.

The foregoing list does not contain all the information available as for almost all the basins mentioned here, one has at ones disposal for each individual rainstorm both the values of the depth of mean rainfall over the basin and of the depth of runoff which corresponds to this rainstorm.

It is therefore possible, for the best observed basins, to establish models permitting calculation of the runoff from different flood flows in the year in terms of the succession of storms in this year. This permits the

(1) Is calculated from the 1st June corresponding to P = 730 mm

reconstruction of annual runoff from raingauge data.

Unfortunately, it must not be forgotten that most representative basins situated in the sahelian zone have been studied so as to provide the value of the ten year flood flow (often even without the need for establishing a model) and that the study of annual runoff has only been provided for some of them.

For example, there is very often a lack of data for the making of a model which will also permit the reconstruction of slight flood flows in particular those for which there was no surface runoff; so, inspite of the set of simultaneous observations for the occurrences of rainfall and flow rates, it would still not be possible to reconstruct annual runoff for a series of depths of annual precipitation for all the representative basins.

3.3.2.3. Classification of the drainage basins studied.

3.3.2.3.1. Generalities.

First it is important to classify the different categories of basins according to their capacity for runoff, taking into consideration what would be the value of the relation between the median value of annual runoff and the median value for the depth of annual precipitation, which corresponds appreciably with the mean value of the coefficient of runoff for a series of depths of annual precipitation near the median value.

This has its problems, for it may easily be seen from the data in the preceding paragraph that, for a similar basin and for years of similar depth of precipitation, the annual depth of runoff and, consequently, the coefficient of runoff varies a great deal from one year to the next, according to the distribution of rainfall within the two and a half to three and a half months of the rainy season.

So as to facilitate the estimation of the value of the runoff coefficient Ke, corresponding to the median, depths of annual runoff have been reconstructed for two representative basins with very different physiographical conditions - that of KADIEL ($S = 39.5\ km^2$) which is relatively impermeable, and the small drainage basin of ABOU GOULEM ($12.3\ km^2$) which is permeable - thanks to a simplified rainfall/flow model perfected by G. GIRARD after the general study of model for runoff made of the wadi GHORFA (mathematical models for evaluating depths of runoff in the sahelian zone and their limitations, G. GIRARD, PARIS. 1975). For the KADIEL basin the model made use of several samples of daily rainfall data which showed noticeable correspondence with the 450 mm annual isohyet, these were provided by the stations of MBOUT, KANKOSSA and MADAOUA, corresponding to a total of 94 station-years. Depths of annual runoff were reconstructed by transformation into flow rates of the depths of daily rainfall, and from this came three samples of annual depths of runoff from which a distribution curve was derived, to which we will be returning later on. The median value of E is 86 mm corresponding to a Ke value equal to 19%.

The same was done for the small drainage basin of ABOU GOULEM for which :- E = 17 mm, Ke = 4.15%.

For the other basins, working from the data observed and comparing their behaviour with that of the KADIEL and ABOU GOULEM basins, it was possible, after a fashion, to estimate the median value of Ke.

We came to a certain number of groups each corresponding with different physiographical conditions.

In practice, each group corresponds with heterogeneous basins having a grouping of a certain number of soils with different properties. According to the proportions of each type of soil over a basin from any given group, the total reactions of the basin to rainfall will be different. The studied basin type corresponds either with a relatively frequent distribution of the different soils, or with a border-line case. Often a group is represented both by a studied basin type which represents the most frequently occurring case, and by another basin type representing extreme conditions. It must be added that every basin type corresponds with general conditions of well determined slope.

At the distribution curves presented correspond to studied basin types. It will be advisable to choose a curve or a family of curves which are a little different, if the basin one wishes to set up has a distribution of different soils which clearly diverge from the one presented by the basin type.

For every group indications will be given for this kind of extrapolation.

3.3.2.3.2. <u>Basins with sandy soils</u> : dunes, generally dead, eolian casing of significant thickness with, often, several outcrops. These basins give rise to practically no runoff at all in the median year, and it has not been possible to get an idea of their susceptibility to surface runoff, except in a very occasional way. At the time of the study of urban surface runoff on the GOUNTI

YENA at NIAMEY, we were induced to set up gauging stations on the upstream part of the basin with a well cultivated sandy soil, simply in order to verify that the runoff coming from it was negligible, which was actually the case.

On basin No VII of 20 km^2, depth of runoff E in the median year, for a depth of rainfall of 600 mm, could not be in excess of 3 mm, Ke = 0.5%

These runoff conditions probably correspond to a maximum for this type of basin.

On basin No VI of NIAMEY, 1 km^2, a good part of which is taken up by outcrops :-

Median E = 30 mm　　　　Ke = 5%

3.3.2.3.3. <u>Basins with subsoil constituted by granites or granito-gneiss</u>

These are probably the most heterogeneous and the products of weathering of the parent material present physical properties which vary to a certain extent with its chemical constitution. In addition, some parts of the basin may be covered by deposits only having a distant relation or even no relation at all with what constitutes the sub-soil. Within the framework of such a study it is impossible to go into details, and in what follows we will take it for granted that all the formations actually stem from this sub-soil, which is often the case.

Surface formations which are encountered on these basins are from upstream to downstream :-

(1) Rocky outcrops. If the granite is disintegrated or very fractured, permeability is considerable, the water infiltrating into the interstices which are to a greater or lesser extent filled up with pebbles and arenaceous soils. Moreover, tree growth there is in excellent condition.

If the granite appears in domed form, or in very large slabs, it may be considered impermeable, but the slightest fissures absorb considerable quantities of water, and surface runoff generally occurring flow in the type of formation, as shown below, and at least is partly lost.

(2) Granitic arenaceous soils which fringe outcrops or massifs; very permeable zones where wells are generally dug.

(3) Sandy soils, of greater or lesser depth, cover the granite, when they are shallow, the soil quickly becomes saturated and they may have a relatively good capacity for runoff. If they contain more than 10% clay, they are compacted after the first storm and the result is the same.

(4) Glacis or pediments, with regular slope, surrounding the whole; outcrop or massif plus the two categories of soil just mentioned. These are sandy clay compact soils (solodised solonetz) which are impermeable ("naga" in CHAD) If they receive less than 450 mm - 500 mm, they present themselves in the form of reg, impermeable as soon as their surface is soaked with water.

(5) The bed of the small water courses, to the upstream of the basin is constituted by sands of more or less coarse texture, with folds of sandy clay banks. The whole is very permeable and according to the morphology of basin bottoms, it may form zones of surface spreading which vary in size.

(6) Further downstream, or if the general slope is slight, Valley bottoms are taken up by hydromorphic soils where one also encounters "perched" swamps as on the CAGARA-East basin which will be at issue later. Usually, it is a question of vertisols which present wide contraction cracks in the dry season. As soon as these soils have received sufficient rain, the cracks close up and they become impermeable.

(7) In certain cases, laterite gravels on the basin's surface, originating from the disintegration of former shields, show themselves over a thickness of more than 15 cm or 20 cm, as for TIKARE I but-with granite sub-soil, and in these conditions, the basin is permeable.

It is intentional that all the above mentioned present a qualitative character since we have yet to define the overall permeability of an area of several hectares in size and in addition, if an overall permeability were clearly defined, it would vary widely within certain types of soil which we have just shown.

Of course, it is rare for a small basin to present all six categories of soil together and as their capacity for surface runoff is very different, the runoff produced at the basin mouth will vary greatly, according to the types of soil which will be represented on the basin, and the relative importance of the area they cover.

If, taken as a whole, the soils are permeable, runoff decreases appreciably as soon as the slope becomes slight : Ig lower than 6 for 25 km^2 or Ip (The Roche Index) lower than 0.09. In this case, there is already hydrographic degradation. The existence of impermeable zones upstream or downstream of the basin, as well as the organisation of the hydrographic network play a very important part in runoff. For steeper slopes, the influence of the Ig (index) is far from negligible, but it is much less perceptible than that of the permeability of the various soil categories represented.

All things being equal elsewhere, the runoff coefficient decreases considerably as soon as the depth of annual precipitation passes from 400 mm to 300 mm per year.

Later, one will find the median values of the coefficients of runoff Ke corresponding with the median value of annual precipitation for all representative basins on granite or granite gneiss mentioned in paragraph 3.3.2.3. Basins with an area greater or less than 11 km^2 - 12 km^2 have been divided up into two columns and we have brought into the two columns at the same time the representative basins whose area is close to the limit. We have likewise pointed out (every time it was possible to determine) the overall index of slope Ig and the drainage density Dd. It should be noted that, on this type of basin, it is better to calculate Ip instead of Ig whenever it is possible to do so.

AM NABAK 60 km^2
reg 30%
P = 330 mm Ke = 2 to 4%

KOURO 16 km^2
P = 330 mm Dd = 2.77 Ke 1%
Granite, arenaceous soil
and sand, no reg

TARAÏMAN 11,2 km^2
clay reg Dd = 0.8 Ke = 15 to 20%
Ig = 3

GOSI (TOROU) 60 km^2
P = 330-350 mm Dd = 2.18 Ke = 1 to 2%
Balled granite,
no reg.

WADI KAOUN 25 km^2
P = 420 mm Ke = 1 %

All types of soil
except categories 6 and 7

WADI KAOUN 56 km^2
P = 420 Dd = 0.93 Ke = 0,7 %
Ig = 7.25

All types of soil,
except categories 6 and 7

CAGARA-West 28 km2
P = 400-420 mm Dd = 1.15 Ke = 13%
Ig = 3.72

Clay sandy soil

CAGARA-East 32 km^2
P = 400-420 mm Dd = 0.68 Ke = 13 %
Ig = 2.88

Clay sandy soil
+ perched vertisol

ABOU GOULEM 12.3 km^2
P = 500-520 mm Dd = 2.34 Ke = 4.2%
Ig =12.6

Granite, arenaceous soil
sandy clay soil,
coarse sand

ABOU GOULEM 12.3 km^2
P = 500-520 mm Ke = 4,2 %

Granite and
permeable soils

BOULSA KOGHNERE 22 km^2
P = 750 mm Dd = 0.682 Ke =3 to 5%
Ig = 4.26

Granite 80 % covered by
arenaceous soil and clay,
sand soil + schist

KOGHO 84.7 km^2
P = 750 mm Dd = 0.98 Ke = 2 to 4 %
Ig = 2.29

Granite 80 % covered by
arenaceous soil and clay,
sandy soil + schist

BARLO I 17.8 km^2
P = 790-800 mm Dd = 2.48 Ke =10 to 12%
Ig =29

Granite predominant
shallow sandy soil
and sandy clay

BARLO II 36.6 km^2
P = 790-800 mm Dd = 2.08 Ke = 8 to 10 %
Ig =22

Granite predominant
shallow sandy soil
and sandy clay

MOTORSOLO S 4 42 km^2
Dd = 5.83 Ke = 20 %
Ig = 15.3

Granite +
arenaceous soils

MOTORSOLO S 1 4 km^2
Dd = 8.52 Ke = 30 %
Ig = 45.5

In this group which is not sufficiently complete to be able to represent all types of basins on granite subsoils, three basin types have been selected.

One, ABOU GOULEM, 12.3 km^2, represents soils which, on the whole are permeable with a marked slope : Ig = 12.6
Ip = 0.13

The soils which cover the basin are distributed as follows :-

Fairly permeable soils Massifs and skeletal soils	= 81%	K (Muntz index) : 43 mm/h
Permeable soils, deep sandy soils	: 10%	K (Muntz index) : 65 mm/h
Very permeable soils	: 9%	K (Muntz index) : 166 mm/h

No sandy-clay compact soils (solodised solonetz)

Basins of this kind correspond to the limits of what may be interesting for creating reservoirs : but naturally in the case of basins with slighter slope, the coefficient of runoff is distinctly less for a similar depth of annual precipitation. Basin type does not represent the minimum of the runoff possibilities for this grouping of soils.

The second basin type BARLO I and BARLO II has steeper slope and a distinctly higher proportion of less permeable soils : Ig = 29 and 22, Ip = 0.19 and 0.17.

The soils which cover the basin are distributed as follows :-

		MUNTZ index on dry soil
- Granite massifs	: 40%	
- Very eroded zones occasionally covered by sands, generally shallow sands	: 15%	15-25 mm/h
- Sandy soils with coarse elements, arenaceous soils, soils in valley bottoms	: 11%	230-270 mm/h
- Deep sandy soils	: 24%	100-130 mm/h
- Sandy clay compact soils	: 10%	8-10 mm/h

These basins present one drawback for our study, they are too well watered : median P 790 mm - 800 mm. They have quite good surface runoff. It will be difficult to extrapolate the results to 300 mm.

The third basin type, CAGARA-West, 28 km^2, has a less marked slope :-

Ig = 3.7, Ip = 0.07, the area covered by the outcrops is small; most of it is covered by clay sandy soils and in valley bottoms by hydromorphic soils where the mass of sandy alluvium in the bed is not very important.

The whole is far more impermeable than in the case of the preceding basin type.

This type of basin has good surface runoff, but it does not represent maximum conditions. It seems that, related to the same depth of median rainfall for basins like those of the MOTORSOLO or the MAYO LIGAN in CHAD they would have a coefficient of runoff Ke perhaps of 15% to 20% higher, for the same value of slope index.

Anticipating what will be said later, let us show for the 500 mm isohyet and for 25 km^2 :-

- an ABOU GOULEM basin type would have a coefficient of runoff of 3.5%

- a BARLO basin type would have a runoff coefficient of 7%

- a CAGARA - West basin type would have a runoff coefficient of 14%.

For slight slope and permeable soils, in the same conditions Ke = 1.5% to 2% (median P = 500 mm) would be found. Let us be explicit and say that a flat, permeable basin with outcrops, whatever height, is a basin with slight slope.

For impermeable basins with steep slope, one may find Ke values equal to 16% or 18% (median P = 500 mm).

3.3.2.3.4. Bains on sandstone "dogons"

Like the foregoing, they comprise formations of very different types.

1. Sandstone in sub-horizontal layers which, in contrast to granite, often play an active part in surface runoff. However, it must be noted that screes of sandstone or very fractured sandstone absorb significant quantities of water, as may be seen on the MOUDJERIA basins and on some basins of Wadi GHORFA.

2. Sandy soils on sandstone which give rise to runoff when they are shallow and saturated with water.

3. Sandy-clay valley bottom alluvium.

4. Lateritic shields which sometimes cover the sandstone to a greater or lesser extent. These may have surface runoff.

5. Tropical ferruginous leached soils below these shields.

We have not much choice of basin type. Only two representative basins on sandstone have been studied, that of DOUNFING, too far south and whose lateritic cover plays too great a part and those of KOUMBAKA.

The "median" runoff coefficients of these last mentioned basins are as follows :-

KOUMBAKA II 30,4 km^2

P = 570 mm   Dd = 1.03   Ke = 17%
Sandstone 92%   Ig = 10.8
shields : 7%
Sandy soil over
sandstone : 1%

KOUMBAKA III 8.9 km^2

P = 570 mm   Dd = 0.65   Ke = 11%
Sandstone = 87% Ig = 22.3
shields : 6%
Sandy soil over
sandstone : 1%
Sandy clay soil : 5%

The basin type will be that of KOUMBAKA II. It comprises a very considerable proportion of sandstone with few cracks.

If the proportion of lateritic shields or of sandy soil is greater, the value of Ke naturally decreases.

3.3.2.3.5 Basins on sands and marls (SEBIKOTANE)

These basins comprise black clay on marls or calcareous marl or clayey sand and ferruginous soils on sands, as well as calcimorphic soils.

The clays are relatively impermeable.

A single group of basins has been studied, that of SEBIKOTANE :-

SEBIKOTANE II 43 km^2
P = 620 mm Dd = 2.35 Ke = 6% to 7%
Ig = 4.4

SEBIKOTANE III 2.6 km^2
P = 620 mm Dd = 3.8 Ke = 10% to 12%
Ig = 10.8

Black clays,
tropical ferruginous soils
on sands and calcimorphic soils

The basin type will be SEBIKOTANE II

3.3.2.3.6 Basins on schist

Clays, and clayey sand soils which are derived from them, are generally more impermeable than clayey sand soils or sandy clay soils derived from granites or granito-gneiss.

Again one encounters, as in the case of basins on granite from upstream to downstream, schist in place, relatively permeable sediment deposits, then clay or sandy clay talus and valleys with hydromorphic soils.

The basins studied present the following characteristics :-

OUED GHORFA KADIEL 39.5 km^2
P = 450 - 475 mm Dd = 2.2
Ig = 4.2
Clay on schist : 90% (reg)
quartzite : 10%

PO 2.7 km^2
Ke = 19%

Ke = 30%

BODEO 11.2 km^2
P = 600 mm Dd = 3.1 Ke = 3%
Ig = 5.8
Schist with glacis
+ significant proportion
of permeable soils

BODEO 3.5 km^2
P = 600 mm Dd = 3.8 Ke = 3%
Ig = 6.6
Schist and sandy
clay glacis

ANSOURI 0.7 km^2
P = 640 mm Dd = 2.26 Ke = 4 to 5%
Ig = 16.8
Schists, sediment deposits,
glacis, clayey sand

The basin type is that of KADIEL : because of its regular slope and homogeneous clay covering it represents the maximum surface runoff conditions for this type of basin. The influence of some quartzite outcrops is almost negligible. If they occupied 40% of the area of the basin instead of 10%, and especially if they were very cracked, the coefficient of runoff would be distinctly less.

In the same way, if the sub-soil is entirely formed from schist, and if outcrops and scree of schist occupy a significant part of the basin, as at ANSOURI, the basin will have far less surface runoff, although clearly more than if it were a question of granite outcrops and scree of granite.

3.3.2.3.7 Basins of the ADER DOUTCHI (Niger)

They correspond to the basins situated on the continental margin. The superficial formations on these basins are as follows :-

1. Horizontal plateaux or ridges of ferruginous sandstone disintegrated to a greater or lesser degree with relatively little surface runoff.

2. On the slopes calcareous marl soils and colluvions which are to a greater or lesser degree impermeable clay soils.

3. Brown-red soils on materials derived from sandstone, cultivated soils, relatively permeable (example of Trap n° VI of KOUNTKOUZOUT, paragraph 3.3.1),

4. In the bed of water courses of the upstream sector there are permeable sands.

5. Further downstream, hydromorphic soils.

To the north, at KOUNTKOUZOUT, the most clayey soils show themselves as regs.

The runoff coefficient of the basin will be in relation to the proportion of marl-limestone soils or impermeable colluvions.

The basins studied in this category present the following median values for the coefficient of runoff :-

KOUNTKOUZOUT 16.6 km^2	HAMZA 16.6 km^2
P = 390-400 mm Dd = 2.6 Ke = 15%	P = 490 mm Dd = 4.03 Ke = 5.5%
sandstone : 15% Ig = 8.1	sandstone : 90% Ig = 9.1
brown-red soils	marl-limestone and various others : 10%
sandy clay : 38%	
marl-limestone and various soils	no hydromorphic soil
KAORA - ABDOU 5.65 km^2	ALOKOTO 48.3 km^2
P = 470 mm Ke = 25%	P = 490 mm Dd = 3.7 Ke = 4.5%
	Ig = 8.7
	sandstone : 95%
	marl-limestone and others 5%
BOUJI 8.5 km^2	GALMI I 20 km^2
P = 450 - 470 mm Ke = 25% - 30%	P = 490 mm Ke = 39%
	90% clay colluvions
	and marl-limestone (62% with the area of 29 km^2)
KAOUARA 3.3 km^2	GALMI II 39 km^2
P = 490 mm Ke = 18%	P = 490 mm Ke = 35%
	90% clay colluvions
	and marl-limestone soils (76% with the area of 46.2 km^2)

The basin-types are KOUNTKOUZOUT and GALMI I - GALMI II. The GALMI basins represent nearly maximum runoff for this category. With the old areas, the coefficients of runoff at 39% and 35% are certainly over estimated; with the new ones, they would be 27% and 30%. It will be seen later that an intermediary value will be adopted between those corresponding to the old areas and to the new areas, so as to be certain of properly representing the maximum conditions of runoff over the basins in this region. For the KOUNTKOUZOUT basins where the brown-red soils are relatively permeable, the same coefficient for 25 km^2 would probably be equal to 14%.

The example of the data from HAMZA and ALOKOTO show that with a high proportion of sandstone, the coefficient of runoff drops to 5%, which does not prevent violent flood flows.

3.3.2.3.8. Limitations of this classification

It does not cover every type of drainage basin, in particular those which, in general, do not lend themselves to reservoir management schemes or which do not give rise to very violent flood flows and following from this, have not led to studies on representative basins. There are also regions which are difficult of access or sparsely populated which have not been studied, for example, below the 500 mm isohyet, from Wadi GHORFA and the AFFOLE massif down to the central delta of the NIGER.

Two types of soils, hardly studied at all on representative basins, are frequent in the Sahelian zone; coverings of eolian sands and vertisols. The first mentioned only give rise to very much reduced runoff in the depression bands; in paragraph 3.3.2.3.2. we have been to give an outline on runoff in the most favourable conditions. The second type, as soon as the contraction cracks are closed, behave like impermeable soils, but as slope is practically nil, they change into swamps in the rainy season except when drained, this is particularly true of the perched vertisols of CAGARA - East which give rise (for 32.3 km^2) to a runoff coefficient of 13% (median value) for a depth of annual rainfall of 400-420 mm. This basin may provide useful pointers for runoff over vertisols when they are drained, but, in relation to the distribution curve of the runoff values for CAGARA - West in a very dry year, it will be necessary to take values which are very much lower for the coefficient of runoff, because the vertisols absorb a significant quantity of water at the beginning of the rainy season. On the other hand, in a very wet year, runoff will be greater than over basins of the CAGARA-west type.

It may be hoped that it will be possible, in the case of a certain number of the types of basins which do not figure in this classification, to attach them to one of the categories described in paragraphs 3.3.2.3.3. to 3.3.2.3.7 by means of a study of the soil types found there, their permeability, vegetation cover, the hydrographic network and slope.

3.3.2.4. The plotting of statistical distribution curves for runoff for basins of 25 km^2 (10 to 40 km^2) in the Sahelian zone

3.3.2.4.1 Generalities

It is now advisable to offer some reflections in relation to the representativeness of the studied basin-types.

Each basin-type or group of basin-types corresponds to defined conditioning factors of runoff; area of the basin, the permeability of the various types of soil, vegetation cover, hydrographic network, slope, and is subject to a regimen of rainfall defined here by means of the median value of rainfall-Pmed. The basin which is to be managed will present conditioning factors which will not be entirely the same as those of the basin-type, in particular the Pmed. Further on the different factors are examined :

- In the first place all the results will be reduced to an area of 25 km^2:
- the depths of runoff will need to be slightly reduced or increased so as to pass from 17 to 25 km^2 or from 40 to 25 km^2, for example.

For the rainfall regimen, runoff over a particular basin-type is represented by a group of distribution curves, each being established for one given value of Pmed, varying by 50 mm steps, from 300 mm per annum to 750 mm per annum, as has already been done for subdesert and desert zones. We have to take into consideration the curve related to P med of the basin to be managed.

"Total permeability" is together with the depth of annual rainfall the most important value affecting the runoff. It must be considered within the framework of the categories examined in paragraphs 3.3.2.3.2 to 3.3.2.3.7. Every category corresponds to a permeability over a broader or narrower range. When the permeability range is very broad, as in the case of basins on granite or granite gneiss, three basin-types have been defined corresponding to different total permeability values and represented by groups of distribution curves, which allows all the basins to be reduced to a similar depth of annual rainfall. In this way, one will be able to interpolate between these three cases or to extrapolate slightly beyond them.

As for slope, its action is much less important for the annual volume of runoff than for the instantaneous flow rate of the flood peak. It plays a particularly important part when the soil is permeable, especially for the basins on granite and granite gneiss. For ABOU GOULEM, BARLO and CAGARA-West, total indices of slopes, reduced to 25 km^2, are respectively equal to 11, 24 and 4 m/km. The very high coefficient for the BARLO basin is due to the granite massifs which for the most part correspond with a very permeable zone. The low value for CAGARA-West would be more awkward if the soil was not rather impermeable. At a first approximation one may take into account the fact that slope does not lead to serious distortions in results from the three basins. On the ADER DOUTCHI basins, sandstones are nearly horizontal and the slope of marl-limestone soils and the impermeable colluvions are comparable to make up for it,. But that will play an important part in the instance of basins with an area of more than 25 km^2, the slope of the main collecting valley will play an important part.

It will be remembered from the foregoing that for basins on granite and granite gneiss, one needs to take into account slope when applying these results ; how will be explained later. However, where the comparison of data from the basin-types is involved, one may proceed as though they all had similar slopes.

As for vegetation cover, it is not very effective in curbing surface runoff in the sahelian zones, except in valley bottoms, and so they do not play a very significant part if the area of the basin does not exceed 25 km

The great majority of the previous figures have been established in nearly neutral conditions. That is to say that the few types of cultivation are carried out in accordance with traditional methods and that trees have only been destroyed to a moderate extent.

If for some reason or other, all vegetation were to be destroyed, the coefficients of runoff would be increased in a significant way. If, on the contrary, a drainage basin were to be completely closed off, if effective measures were taken to prohibit any fires, the grazing of cattle and various forms of cultivation, then runoff would also be significantly reduced. In any case, it must also be considered that the effect of vegetation cover is the same over all basin-types, it being understood that vegetation on the 300 mm isohyet is naturally more sparse than vegetation on the 750 mm isohyet, but this influence is continued with that of median P.

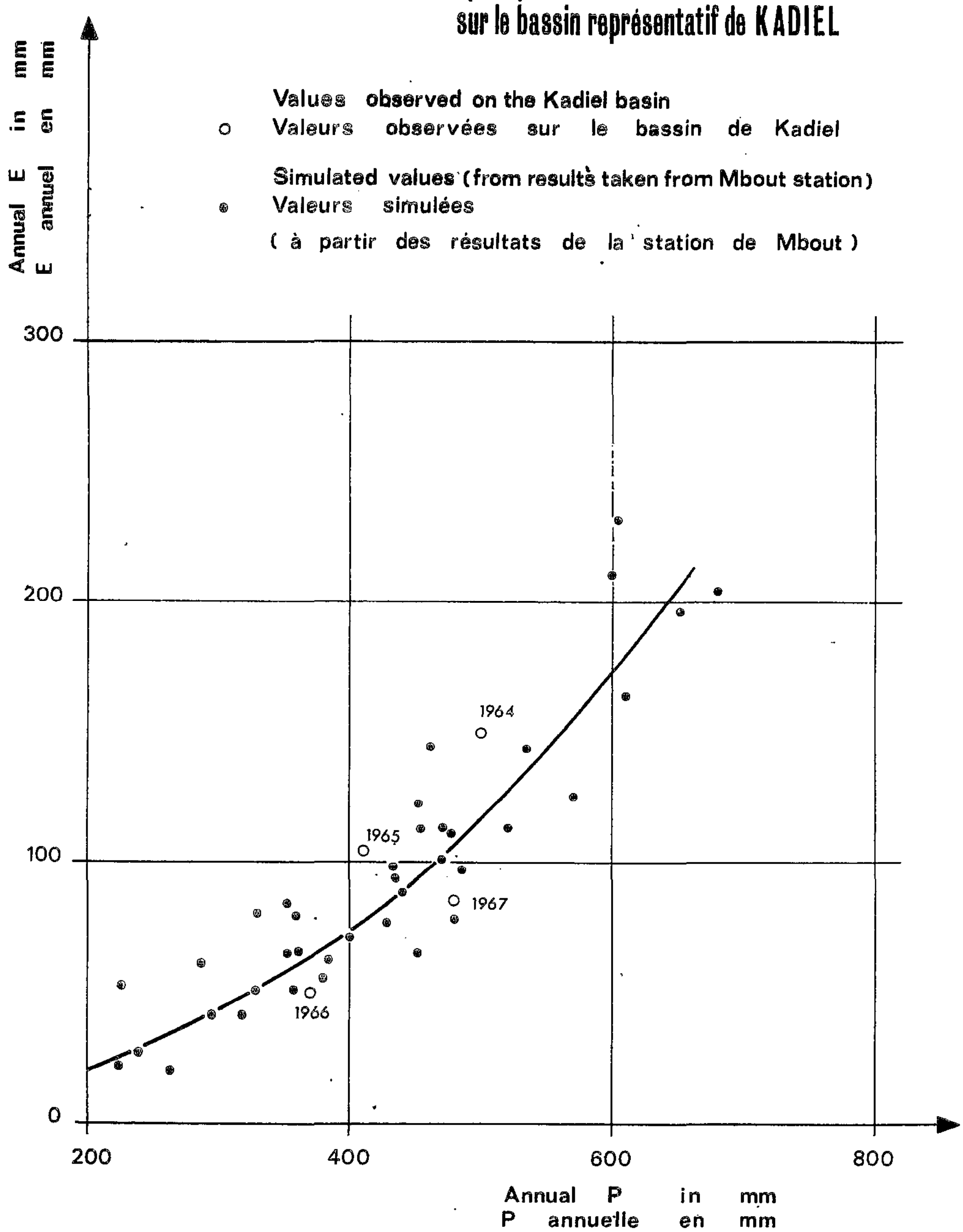
There remains only the hydrographic network : except on permeable soils below the 300 to 500 mm isohyets, there is few hydrographic degradation for basins with an area of 25 km^2 and care has been taken to avoid including in the basin-types instances of networks which deviate from what is generally encountered. So there likewise, results are comparable.

In conclusion, variations in the factors of area, median rainfall and "total permeability" have been taken into account. The factors of slope,

Simulated annual runoff in terms of annual rainfall over the representative basin of KADIEL

Fig: 18

Ecoulement annuel simulé en fonction des précipitations annuelles sur le bassin représentatif de KADIEL



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vegetation cover and that of the nature of the hydrographic network have not been of a type to provoke distortions in the set of distribution curves which are to be plotted, at least for those basin-types which have been classified.

3.3.2.4.2 Procedure method

For every basin-type one first plots the runoff distribution curve which corresponds appreciably with a clearly defined rainfall regime by its depth of median rainfall, for example 450 mm for KADIEL (instead of 450-475 mm) and the corresponding curve from diagram 17. This supposes in the first place the determination of the median value of runoff E, which by simplification one admits as being equal to the product of median P through the median value of the coefficient of runoff Ke. In fact, the relation between E and P being somewhat loose, one is able to see that what we have first pointed out is not self evident. As has been pointed out in paragraph 3.3.2.3.1 dispersion between the different values of E, for a corresponding value of P, is such that it would have been very unwise to determine median E and, even more so to determine median Ke on a simple examination of two or three observations years of the basin-type, even when taking into account the particular character of each year studied. This is why an attempt has been made to reconstruct the depth of annual runoff from the individual flood flows caused by every storm on the KADIEL drainage basin on schist, corresponding to surface runoff conditions scarcely lower than optimum, and on the small drainage basin of ABOU GOULEM, with rather unfavourable conditions.

The simplified model worked out by G. GIRARD on the occasion of the general study of models of runoff of Wadi GHORFA, although effecting the transformations of depth flow rate to the scale of 24 hours rainfall, has only been constructed for knowledge of the monthly or annual depth of runoff. On the daily scale, accuracy would be entirely inadequate.

As has been mentioned earlier, runoff was simulated for the rainfall from three raingauge stations. A separate study was made of the statistical distributions of runoff corresponding to each of the three stations, and to the total sample from the three stations corresponding to ninety-four station-years. The simulated and observed values represented on diagram 18 clearly show the great scatter of E as a function of a like value of P, and the difficulties of directly reconstructing regression.

It should be noted that the three stations fill out a picture : only one contains in full the dry period between 1940-1945, another the year 197: Only one contains an exceptionally wet year. In short, it is a good thing to have at ones disposal several very dry years with different distributions of daily rainfall, as may be done with the sample from the ninety-four years'own of data.

The curve corresponding to this total sample do not diverges significantly from the other curves for mean or dry years ; for very wet years, it diverges clearly from the curves derived from data from two stations - MBOUT and KANKOSSA which present no wet years with really exceptional runoff, in contrast to the MADAOUA station. Finally, the distribution curve corresponding to the sample from ninety-four years was adopted.

For a basin of low permeability, like that of KADIEL, and an area of that order, it was thought useless to correct runoff values in order to pass from 39.5 km^2 to 25 km^2.

The same was done for the small drainage basin of ABOU GOULEM with three raingauge stations : ABECHER, GOURE and ATI, a total sample of ninety-eight station-years was attained. However, in this instance, one might hesitate between two models for which the ten year dry year depths are, respectivel; of the order of 4.3 and 7.6 mm and the ten year wet year depths 48 mm and 95 mm, the two models corresponding to extreme conditions. Finally, we adopted a distribution curve with good correspondence with the lower limit and which corresponded best to the values observed. In addition, for the top part of the curve, the ABECHER station with its two exceptional years of 812 mm and 898 mm would lead to results which would certainly be over-estimated. This is why the adopted curve is definitely below the one corresponding to the ABECHER data for the 0.05, 0.01 frequencies. The definitive curve thus obtained would correspond to the median value of depth of rainfall of the entire sample from 98 years, suppose 410 mm or 400 mm in round figures.

The curve was changed so as to pass from 13.2 to 25 km^2, the correctio: is appreciable for a permeable soil.

From these two curves, KADIEL 450 mm and ABOU GOULEM 400 mm, one passe to two networks of curves 300 mm-750 mm.

For the 300 mm isohyet, inspiration was drawn from the results obtaine in the subdesert regimen on the basins of DIONABA and of MOUDJERIA for KADI data from other basins on granite were taken as a point of departure for ABOU GOULEM. In order to pass to the 500 mm-600 mm-700 mm curves, use was made of data from similar basins and of a reasonable variation in runoff coefficients for the different frequencies, taking into account the differing types of basins. On the KADIEL type basins Ke varies little with median P, on the ABOU GOULEM basin-types, it varies considerably more.

For the other basin-types, working from available data, the median value of Ke was first estimated, then the hundred-year dry and wet values for E or Ke taking as a guide line, if this was physically justified, the two groups of curves from KADIEL or ABOU GOULEM. Next one proceeded to a correction so as to obtain Ke corresponding to 25 km^2 whenever this correction proved necessary. If available data are inadequate, one goes on to consider the ten-year dry and wet values or occasionally even the five-year or some intermediate quantiles. Then a distribution curve is plotted for the median value of rainfall on the basin-type, drawing inspiration from the two groups of basic curves : KADIEL and ABOU GOULEM. Next one goes on to the group of curves by following procedures analogous to those used for KADIEL and ABOU GOULEM. The group of curves is only represented by the two extreme curves 300 mm and 750 mm and the curve for the basin-type outlined in full on diagram N° 21.

Perhaps the reader will find that all these manipulations present rather a disquieting character, but the many sets of cross-checking avoid major errors, and it needs to be realised that the relative errors stemming from these interpretations, interpolations and extrapolations are not very significant, perhaps 15 % to 25 % in serious cas, (more on granitic permeable basins where errors of the order of 50 % are normal) if they are compared with those inevitable mistakes which will be made while transposing these results from one basin-type to a basin which it is hoped to set up.

Later we will examine further the different basin-types studied earlier.

3.3.2.4.3 <u>A basin on sandy soil</u>

In such cases only orders of size are sought :

median P	:	600 mm for the NIAMEY basin
median E	:	3 mm
median Ke	:	0.5 %

For the ten-year frequency, it has been admitted that the essential part of runoff was provided by a ten-year flood flow whose specific maximum flow rate was of the order of 150 l/s. km^2 with a very slight hydrograph, from this results runoff of 13.5 mm :

$$Ke_{0.10} = 1.6\ \%$$

Then it was supposed :

$$E = 1 \text{ mm}, \quad Ke = 0.17\ \% \text{ for } f = 0.80$$

Even for the NIAMEY basin, all this corresponds to the higher limits of what might be runoff.

There is no correction in order to pass from 20 km^2 à 25 km^2; that would be ridiculous as it is only a matter of an order of size.

- For the 300 mm curve, it was allowed that runoff was of the order of 1 mm in the median year (Ke = 0.33 %).

- For the ten-year wet frequency P = 475 mm, Ke $\#$ 1 %. A value which will appear considerable in relation to that adopted for median P = 600 mm, however, in this case, the rains are far more concentrated in time and the individual storms are more violent.

- The 750 mm curve supposes the same median value for Ke, that is = 0.5 % for median P = 600 mm.

For the ten-year wet frequency P = 1,030 mm, Ke $\#$ 1.8 %, E = 18 mm.

3.3.2.4.4 Basins on subsoils constituted by granite or granito-gneiss

The first basin-type ABOU GOULEM has been studied by means of a simplified model, a curve was achieved defined by the following points :

median P	= 410 mm	E = 17 mm	Ke = 4.15 %
F	= 0.985	E = 0 mm	Ke = 0 %
F	= 0.965	E = 1 mm	
P 0.01	= 800 mm	E = 120 mm	Ke = 15 %

For a basin of 25 km^2 it is allowed that Ke is reduced from 4.15 % - 3 %

median P	= 410 mm	E = 12.3 mm	Ke = 3 %
F	= 0.970	E = 0 mm	Ke = 0 %
F	= 0.952	E = 1 mm	
P 0.01	= 800 mm	E 104 mm	Ke = 13 %

The correction needed in order to pass from median P = 410 mm to median P = 400 mm is easy :

median P	= 400 mm	E = 12 mm	Ke = 3 %
F	= 0.965	E = 0 mm	Ke = 0 %
F	= 0.946	E = 1 mm	
P 0.01	= 780 mm	E = 101.5 mm	Ke = 13 %

The successive values of median Ke would be as follows :

median P =	300 mm	E = 7.5 mm	Ke = 2.5 %
	400 mm	E = 12 mm	Ke = 3 %
	500 mm	E = 17.5 mm	Ke = 3.5 %
	600 mm	E = 24 mm	Ke = 4 %
	700 mm	E = 31.15 mm	Ke = 4.5 %
	750 mm	E = 35.7 mm	Ke = 4.75%

For the hundred-year wet values :

median P = 300 mm	P = 0.01 = 620 mm	E = 62 mm	Ke = 10 %
400 mm	780 mm	E = 101.5 mm	Ke = 13 %
500 mm	920 mm	E = 138 mm	Ke = 15 %
600 mm	1 030 mm	E = 165 mm	Ke = 16 %
700 mm	1 140 mm	E = 188 mm	Ke = 16.5 %
750 mm	1 180 mm	E = 201 mm	Ke = 17 %

For exceptionally dry values, let us note that for the 300 mm isohyet :

P 0.99 = 68 mm P 0.98 = 90 mm P 0.95 = 124 mm
P 0.90 = 160 mm P 0.80 = 204 mm

The comparison of these depths of rainfall with runoff obtained on the simplified model of ABOU GOULEM, complete with corrections, leads to the following results for the 300 mm isohyet :

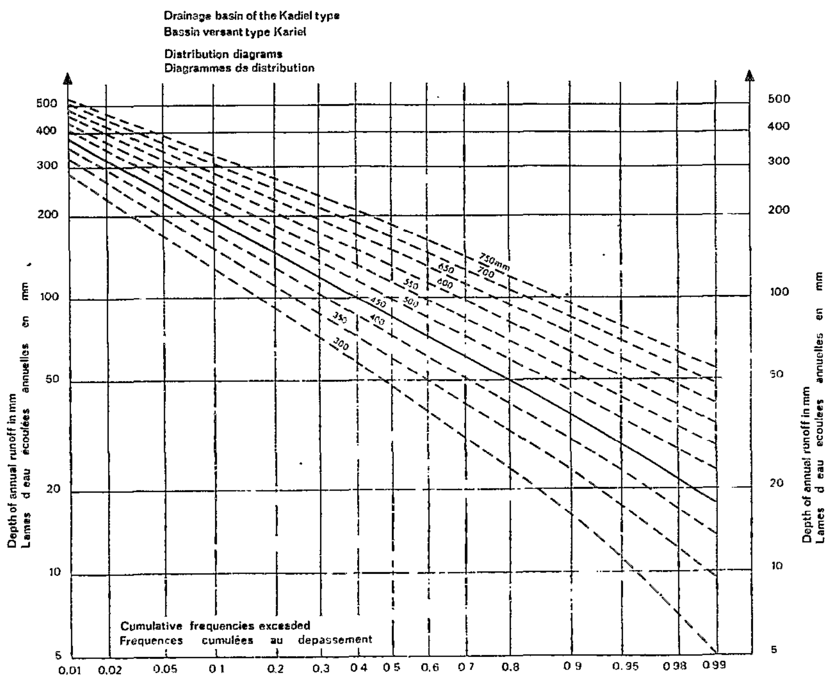
F = 0.875 E = 1 mm F $\neq$ 0.90 E = 0 mm

The plotting of the bottom part of the other distribution curves is deduced from rainfall for the varying frequencies such as are given on diagram 17, and one takes the coefficient Ke, which they would present if they were taken to the 400 mm distribution curve, with a correction variable with P med; taking into

Annual runoff for a drainage basin of 25 Km^2 _ Sahelian regions _

Ecoulement annuel pour un bassin versant de 25 Km^2 _ Régions saheliennes _

Fig: 19



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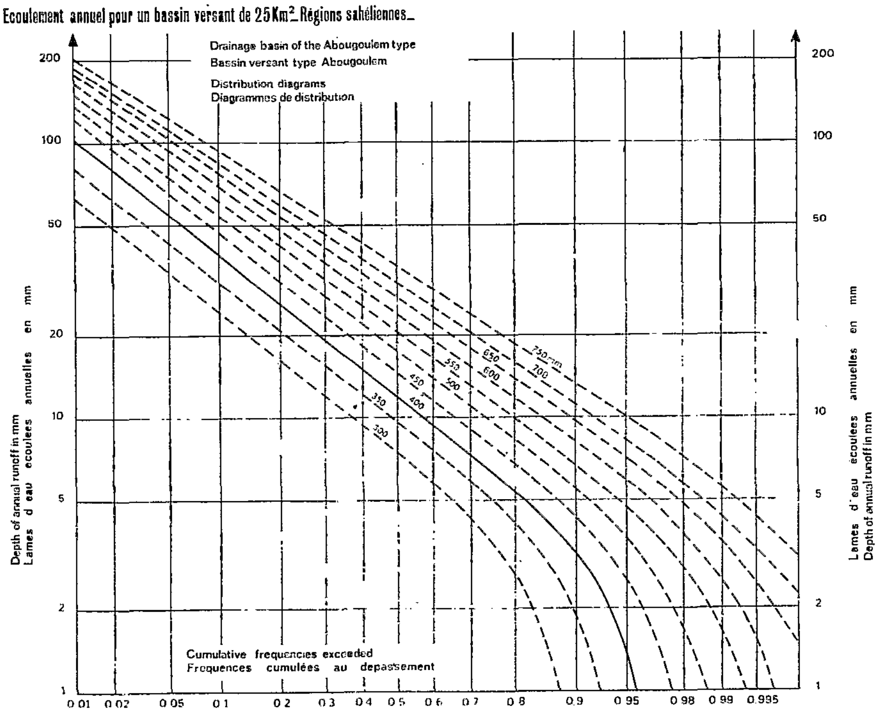
Annual runoff for a drainage basin of 25 Km^2 _ Sahelian regions _

Ecoulement annuel pour un bassin versant de 25 Km^2 _ Régions saheliennes _

Fig: 20



O.R.S.T.O.M. Service Hydrologique | date | des | DIV 261 776 account the fact that the higher P med. is the lower the latitude, the more the rains are spread over a long period and, consequently, the more Ke decreases for a like depth of annual rainfall.

The family of curves has been plotted in full right up to 750 mm even if there was no basin of the ABOU GOULEM granite type for the 750 mm isohyet, for this family of curves may serve for other categories of permeable basins possessing the same hydrological characteristics.

The curves for 350 mm, 450 mm, 550 mm and 650 mm have been interpolated between those for 300 mm, 400 mm, 500 mm and 600 mm. They are shown together on diagram 20.

For the basin-type of the BARLO, direct use has been made of the data from the basin, or rather from the two basins.

For BARLO	17.8 km^2	median Ke =	10 % - 12 %
For BARLO	36.6 km^2	median Ke =	8 % - 10 %

For 25 km^2, median Ke = 9 % - 11 % may be admitted.

Having taken into account the fact that the depth of median rainfall on the basin of the BARLO is of the order of 790 mm - 800 mm per annum, it may be admitted that for 750 mm, instead of 790 mm - 800 mm, Ke will be equal to 9.5 %, thus nearly double that for ABOU GOULEM. The same proportion is maintained, and from it the following values for median Ke are deduced :

median $\bar{P}$ =	300 mm	E = 15 mm	Ke = 5 %
	400 mm	E = 24 mm	Ke = 6 %
	500 mm	E = 35 mm	Ke = 7 %
	600 mm	E = 48 mm	Ke = 8 %
	700 mm	E = 63 mm	Ke 9 %
	750 mm	E = 71.3 mm	Ke 9.5 %

For the hundred-year wet years the following values have been kept :

median P = 300 mm	P = 0.01 = 620 mm	E = 112 mm	Ke = 18 %
median P = 750 mm	P = 0.01 = 1 180 mm	E = 378 mm	Ke = 32 %

For the hundred-year dry years :

median P = 300 mm	P = 68 mm	E = 0	Ke = 0
median P = 750 mm	P = 430 mm	E = 11 mm	Ke = 2.6 %

From these are deduced the two curves limits as shown on diagram 21.

For the basin-type of CAGARA-West whose area is 28.1 km^2, there was no area correction to be provided in order to pass to 25 km^2.

The median value for depth of rainfall is 400 mm - 420 mm. No great error will be made in admitting 400 mm. The examination made on the two observations years leads one to admit median Ke = 13 %.

The following values were admitted for median Ke :

median P =	300 mm	E = 36 mm	Ke = 12 %
	400 mm	E = 52 mm	Ke = 13 %
	500 mm	E = 72.5 mm	Ke = 14.5 %
	600 mm	E = 96 mm	Ke = 16 %
	750 mm	E = 135 mm	Ke = 18 %

For the hundred-year wet years the following values were kept :

median P =	300 mm	P 0.01 = 620 mm	E = 162 mm	Ke = 26 %
	400 mm	P 0.01 = 780 mm	E = 218 mm	Ke = 28 %
	750 mm	P 0.01 = 1 180 mm	E = 425 mm	Ke = 36 %

For the hundred-year dry years :

median P =	300 mm	P 0.99 = 68 mm	E = 1.6 mm	Ke = 2.3 %
	400 mm	P 0.99 = 130 mm	E = 5 mm	Ke ≐ 3.8 %
	750 mm	P 0.99 = 430 mm	E = 26 mm	Ke = 6 %

We should mention that after the correction for passing from 800 mm to 750 mm and from 42 km^2 to 25 km^2, the basin of the MOTORSOLO would have a coefficient of runoff of the order of 20 % instead of 18 %, which gives some idea of the increase necessary in order to pass from an index of slope of 4 to 15.

It should not be forgotten that in the north, the clay regs are represented by this basin-type and that they play a principal rôle in runoff.

3.3.2.4.5 Basins on sandstone

The basin-type of KOUMBAKA II, for an area of 30.4 km^2, presents a runoff coefficient of 17 %. There is no need for correction in order to pass from 30 km^2 to 25 km^2 for surface runoff conditions of this kind. The depth of median rainfall is 570 mm. For the same median value of 570 mm, the CAGARA basin would present a runoff coefficient of 16 %. It will be admitted that the complete set of curves for CAGARA-West is the same as for KOUMBAKA. There are no serious reasons for admitting differing values for exceptionally dry or wet years.

3.3.2.4.6 Basins on sand and marls (SEBIKOTANE)

By comparing the results from SEBIKOTANE II and III one comes to the conclusion that for 25 km^2 this type of basin would admit a median value for Ke equal to 10 % for median P = 620 mm.

On basins of the BARLO and CAGARA type, Ke = 8 % and Ke = 16 % are found. Therefore the group of curves will be plotted above that of BARLO at 1/4 of the interval which separates the corresponding curves from BARLO and CAGARA.

We did not represent this group of curves on diagram 21 so as to avoid overloading it.

3.3.2.4.7 Basins on schists

We showed earlier how the distribution curve for annual runoff for the KADIEL basin had been established. It is characterised by the following values (corresponding to the sample of 94 years in paragraph 3.3.2.5.2).

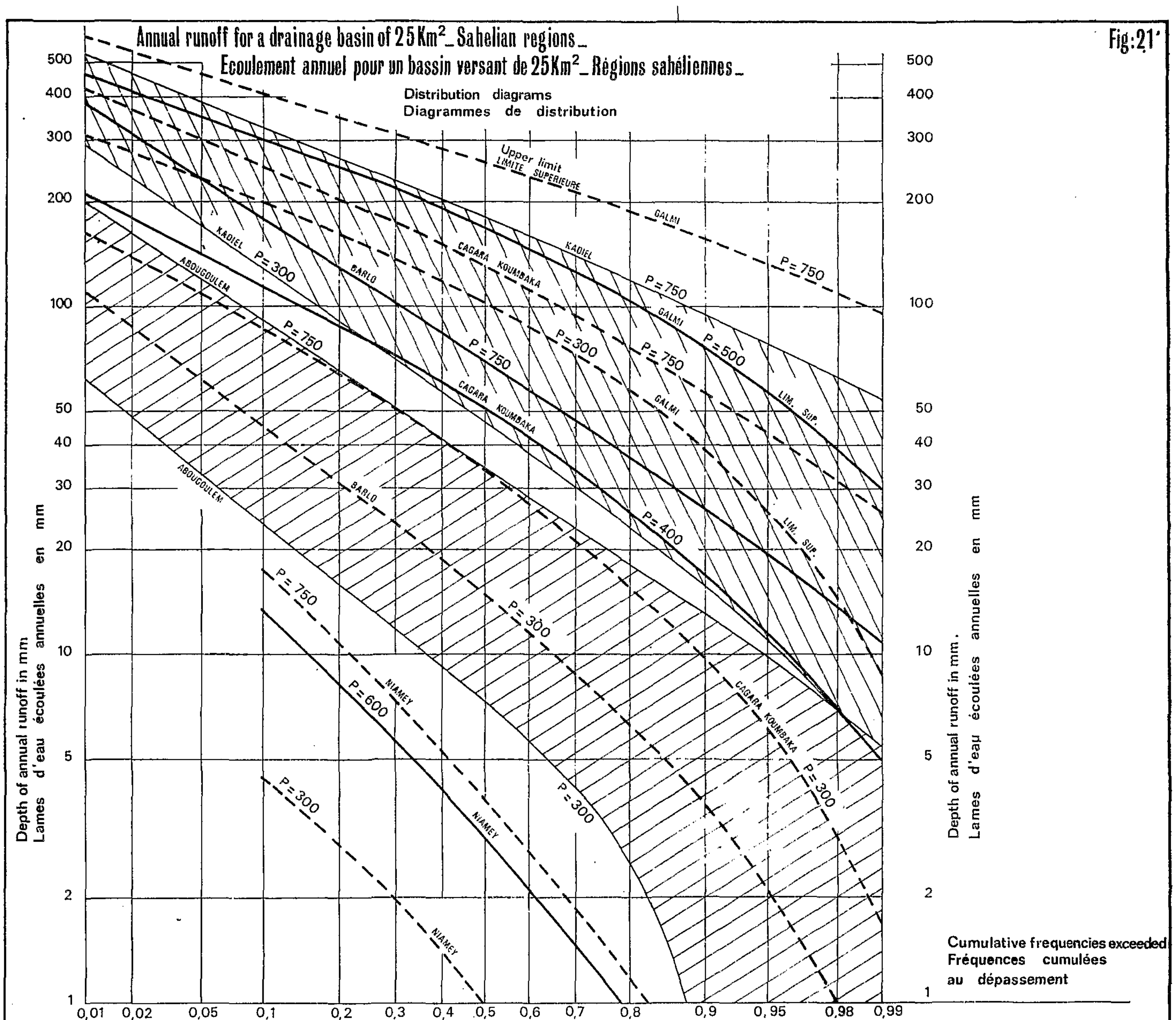
median P = 450 mm	E = 86 mm	Ke = 19 %
P 0.01 = 850 mm	E = 383 mm	Ke = 45 %
P 0.98 = 200 mm	E = 22 mm	Ke = 11 %

For a basin of this kind it is admitted that Ke does not increase when the area passes from 39.2 km^2 to 25 km^2.

The comparison of this curve with the one established for subdesert regimes and for category II whose capacity for surface runoff are comparable, shows that for the 300 mm isohyet the coefficient of median runoff would be of the order of 16 %. The decrease from 19 % to 16 % is, moreover, quite normal.

Consequently the following values for Ke are admitted for the different values of median P :

median P = 300 mm	E = 48 mm	Ke = 16 %
400 mm	E = 73 mm	Ke = 18 %
450 mm	E = 86 mm	Ke = 19 %
500 mm	E = 98 mm	Ke = 19.5 %
600 mm	E = 132 mm	Ke = 22 %
700 mm	E = 168 mm	Ke = 24 %
750 mm	E = 188 mm	Ke = 25 %



Annual runoff for a drainage basin of 25 Km² _ Sahelian regions _
Ecoulement annuel pour un bassin versant de 25 Km² _ Régions sahéliennes _
Fig: 21'
Distribution diagrams
Diagrammes de distribution
Upper limit
LIMITE SUPERIEURE
GALMI
KADIEL
BARLO
CAGARA KOUMBAKA
ABOUGOULEM
NIAMEY
LIM. SUP.
P = 300
P = 400
P = 500
P = 600
P = 750
Depth of annual runoff in mm
Lames d'eau écoulées annuelles en mm
Cumulative frequencies exceeded
Fréquences cumulées au dépassement

For the hundred-year wet values a coefficient of uniform runoff of 45 % has been admitted which leads to the following values for the two extreme curves :

median P = 300 mm	P 0.01 = 620 mm	E = 280 mm	Ke = 45 %
median P = 750 mm	P 0.01 = 1 180 mm	E = 531 mm	Ke = 45 %

For the centennial dry values :

median P = 450 mm	P 0.99 = 170 mm	E = 18 mm	Ke = 10.6 %
median P = 300 mm	P 0.99 = 68 mm	E = 5 mm	Ke = 7.3 %
median P = 750 mm	P 0.99 = 430 mm	E = 56 mm	Ke = 13 %

It is quite easy to interpolate the bottom sections of the distribution curves by taking inspiration from the form of the 450 mm curve which is relatively well determined.

From this diagram N° 19 is derived.

3.3.2.4.8 <u>Basins of the ADER DOUTCHI</u>

The first basin-type is KOUNTKOUZOUT : P 390 - 400 mm, the median value of Ke is of the order of 15 % for an area of 16.6 km^2. Reduced to 25 km^2 the runoff coefficient would be in the neighbourhood of 13 %, the value found for CAGARA-West (400 mm isohyet) for the 0.5 frequency. Very similar amounts are also found for the hundred-year wet year and there are good physical reasons for it to be same in a dry year.

The group of curves from KOUNTKOUZOUT will therefore be the same as that from CAGARA-West.

The second group of basin-types which corresponds to the conditions for maximum runoff is a group very close to the GALMI group with a plateau area of between 10 % and 20 %.

It will therefore be considered that GALMI presents a median runoff coefficient of 35 % :

median P = 500 mm E = 175 mm Ke = 35 %

It is improbable that median Ke varies with the depth of rainfall, beyond 500 mm to 600 mm the growth of vegatation and the protraction of the rainy season would tend to preserve Ke at the same value. Thus it will be found that :

median P = 300 mm	E = 105 mm	Ke = 35 %
median P = 750 mm	E = 262.5 mm	Ke = 35 %

The coefficient of runoff in an exceptionally wet year is certainly higher than for the KADIEL basin-types. Nevertheless, it could not exceed the figures accepted for basins in category I in subdesert regions; the rainy season is much longer, and the vegetation cover thicker, that is why a limit of Ke = 50 % has been accepted whatever the depth of median annual rainfall.

Consequently :

median P = 300 mm	P 0.01 = 620 mm	E = 310 mm	Ke = 50 %
median P = 500 mm	P 0.01 = 930 mm	E = 465 mm	Ke = 50 %
median P = 750 mm	P 0.01 = 1 180 mm	E = 590 mm	Ke = 50 %

In an exceptionally dry year, we have a direct pointer provided by the year 1971 at BOUJI (P = 291 mm), KAORA ABDOU (P = 271 mm) and at GALMI (P = 344 mm and 358 mm) Remembering, however, that BOUJI and KAORA ABDOU's capacity for surface runoff is definitely less than that of GALMI, these results are obtained :

median P = 300 mm	P 0.99 = 68 mm	E = 8.9 mm	Ke = 13 %
median P = 500 mm	P 0.99 = 200 mm	E = 30 mm	Ke = 15 %
median P = 750 mm	P 0.99 = 430 mm	E = 95 mm	Ke = 22 %

From these are derived the group of curves shown on diagram 21.

The ADER DOUTCHI formations do not exist for the 750 mm isohyet, however, the network of curves has been extended that far, because it may serve for drainage basins which are very impermeable and have simular slope.

3.3.2.4.9 CONCLUSION

So as not to overload the present memorandum, we will not comment on the group of curves on diagram 21. Nevertheless, we will underline the following two points :

1°) - The basin-types do cover a very wide gamut of conditions of runoff, since for the 500 mm isohyet, for example, median runoff varies from 2mm per annum to 175 mm per annum. Therefore it would be a simple matter to trace by interpolation the distribution curve for a given basin in the middle of the network of curves, but the difficulty will lie in classifying this basin within a given category.

2°) - Curves corresponding to the 400 mm isohyet and in particular to the 300 mm isohyet drop very noticeably toward the frequencies $F = 0.1$, $F = 0.01$. This phenomenon is general and this general characteristic does not take into account the fact that, for the plotting of certain curves, inspiration is drawn from those already completed. This part of the curves rests especially on three groups of independent data : the simplified models of KADIEL and ABOU GOULEM, and the data obtained in the ADER DOUTCHI in 1971. The underlying reason for this aspect of curves which are very unfavourable for management projects, is the very significant rainfall deficit in the fifty-year year and the hundred-year year for the 300 mm and 400 mm isohyets.

It will be recalled that for :

$$\text{median } P = 300 \text{ mm} \qquad P\ 0.99 = 68 \text{ mm}$$
$$\text{median } P = 400 \text{ mm} \qquad P\ 0.99 = 130 \text{ mm}$$

and there is insistence on the fact that the figure of 68 mm is pretty reliable. Since 1913, some stations for the 300 mm isohyet have presented utterly incontestable values of less than 68 mm.

3.3.2.5 Statistical distribution curves for drainage basins of 2 km² to 10 km²

In many cases, conditions of runoff differ too greatly from those of basins of 10 km² - 40 km² (25 km²) for it to be possible to make use of the same families of curves.

As has been done for the subdesert regimen, the curves will be plotted for an area of 5 km².

3.3.2.5.1 Generalities

Except in the case of very permeable basins for the 300 mm and 400 mm isohyets, there is no hydrographic degradation.

Moreover, all things being equal, slope is generally greater than for the preceding cases since it is a question of heads of basins.

As may be seen in paragraph 3.3.2.2. available documentation is of far less importance than in the instance of basins with an area of between 10 km² to 40 km². However, on the basin of PO ($S = 2.7$ km²) belonging to the same system as the KADIEL basin (wadi GHORFA in MAURITANIA), G. GIRARD succeeded in producing a simplified model of rainfall-flow which made it possible to plot a mean curve of the relations between annual rainfall and the depth of annual runoff. From this a family of curves analogous with that of KADIEL has been derived.

- It was necessary to plot a further clusters of curves for basins of the ABOU GOULEM type, but there were no small representative basins like that of PO at our disposal. Fortunately, the area of the small ABOU GOULEM basin is midway between the "25 km^2" category and the "5 km^2" category so that the extrapolation of results is not too chancy.

Procedures comparable to those in paragraphs 3.3.2.4.3 to 3.3.2.4.7 were followed for basins with an area of 5 km^2 which corresponded with other basin-types for 25 km^2, account was taken of the fact that the more impermeable the basins the more closely the coefficient of median runoff Ke for 5 km^2 resembles that of the corresponding 25 km^2 basin.

It was judged of no advantage to take up a further study of basins on sandy soil which were only mentioned earlier so as to give an idea of the conditions of runoff on this sort of formation. To make up for this it did appear useful, to consider what the depth of runoff would be over a permeable basin and on a granitic subsoil with slope corresponding at maximum to 1/3 of the slope, from the small ABOU GOULEM basin. Detailed information on the basic elements which served in the establishing of distribution curves for 5 km^2 basin-types is given later.

3.3.2.5.2 Basins on granite or granito-gneiss

ABOU GOULEM basin-type

Relatively permeable soils and permeable soils with index of slope : Ig = 8 to 15 m/km.

For 12,3 km^2, median Ke on ABOU GOULEM is equal to 4,2 %. For 5 km^2, 6 % for median P = 400 mm may be admitted. Generally speaking one adopts for Ke values equal to half those in paragraph 3.3.2.4.4. for median rainfall. For dry years Ke is clearly higher than for basins of 25 km^2, however it would be unwise to forecast that there is runoff for the hundred-year dry year for the 300 mm isohyet with P = 68 mm.

The essential points on which the set of curves for ABOU GOUMEM is based are as follows :

300 mm isohyet :

median P	= 300 mm	E = 15 mm	Ke = 5 %
P 0.99	= 620 mm	E = 81 mm	Ke = 13 %
P 0.01	= 68 mm	E = 0	Ke = 0

400 mm isohyet :

median P	= 400 mm	E = 24 mm	Ke = 6 %
P 0.99	= 780 mm	E = 125 mm	Ke = 16 %
P 0.01	= 130 mm	E = 1 mm	Ke = 0,7 %

500 mm isohyet :

median P	= 500 mm	E = 35 mm	Ke = 7 %
P 0.99	= 920 mm	E = 166 mm	Ke = 18 %
P 0.01	= 200 mm	E = 3,5 mm	Ke = 1,75%

600 mm isohyet :

median P	= 600 mm	E = 46 mm	Ke = 7,5 %
P 0.99	= 1 030 mm	E = 196 mm	Ke = 19 %
P 0.01	= 290 mm	E = 6,8 mm	Ke = 2 %

700 mm isohyet :

median P	= 700 mm	E = 56 mm	Ke = 8,2 %
P 0.99	= 1 140 mm	E = 228 mm	Ke = 20 %
P 0.01	= 300 mm	E = 11,5 mm	Ke = 3 %

750 mm isohyet :

median P	= 750 mm	E = 62 mm	Ke = 8,2 %
P 0.99	= 1 180 mm	E = 236 mm	Ke = 20 %
P 0.01	= 430 mm	E = 15 mm	Ke ≠ 3 %

The family of curves is shown on Fig. 22

<u>Permeable basin with slight slope</u>

The same data as those given above,are taken into account by dividing by 2 the corresponding values of median Ke, but for the 400 mm isohyet, runoff is nil for the hundred-year dry year.

300 mm isohyet :

median P	= 300 mm	E = 7,5 mm	Ke = 2,5 %
P 0.99	= 620 mm	E = 49,5 mm	Ke = 8 %
P 0.01	= 68 mm	E = 0	Ke = 0

750 mm isohyet :

median P	= 750 mm	E = 34 mm	Ke = 4,5 %
P 0.99	= 1 180 mm	E = 153 mm	Ke = 13 %
P 0.01	= 430 mm	E = 5 mm	Ke = 1,15%

The two corresponding curves are shown on Fig. 23 .

BARLO basin-type

The small basin of BARLO, S = 17,8 km^2, gives an idea of the increase in median Ke in order to go from 25 km^2 to 5 km^2.

Median Ke = 17 % may be admitted. Median depth of rainfall is of the order of 790 - 800 mm. The value of median Ke for the 750 mm isohyet is appreciably the same. Taking into account results found on PO basin, and those accepted for the ABOU GOULEM basin-type 5 km^2, the following data are arrived at :

750 mm isohyet :

median P	= 750 mm	E = 127,5 mm	Ke = 17 %
P 0.99	= 1 180 mm	E = 401 mm	Ke = 34 %
P 0.01	= 430 mm	E = 34,5 mm	Ke = 8 %

300 mm isohyet :

median P	= 300 mm	E = 33 mm	Ke = 11 %
P 0.99	= 620 mm	E = 162 mm	Ke = 26 %
P 0.01	= 68 mm	E = 1,35mm	Ke = 2 %

CAGARA - West basin-type

We have taken into account data from the small MOTORSOLO basin, S = 4 km^2, with a reduction relation corresponding to the relation of the surface runoff coefficients between MOTORSOLO and CAGARA-West, reduced to the same rainfall regimen and most of all to the same slope, namely $\frac{29}{22}$, a value of median Ke equal to 17% is achieved for annual median depth of rainfall of the order of 400 mm.

We have seen to it that the curves from CAGARA are kept at an appreciable distance from the curves from PO which will be considered later.

We have deduced that :

400 mm isohyet :

median P	= 400 mm	E = 68 mm	Ke = 17 %
P 0,99	= 780 mm	E = 313 mm	Ke = 35 %
P 0,01	= 130 mm	E = 10,4 mm	Ke = 8 %

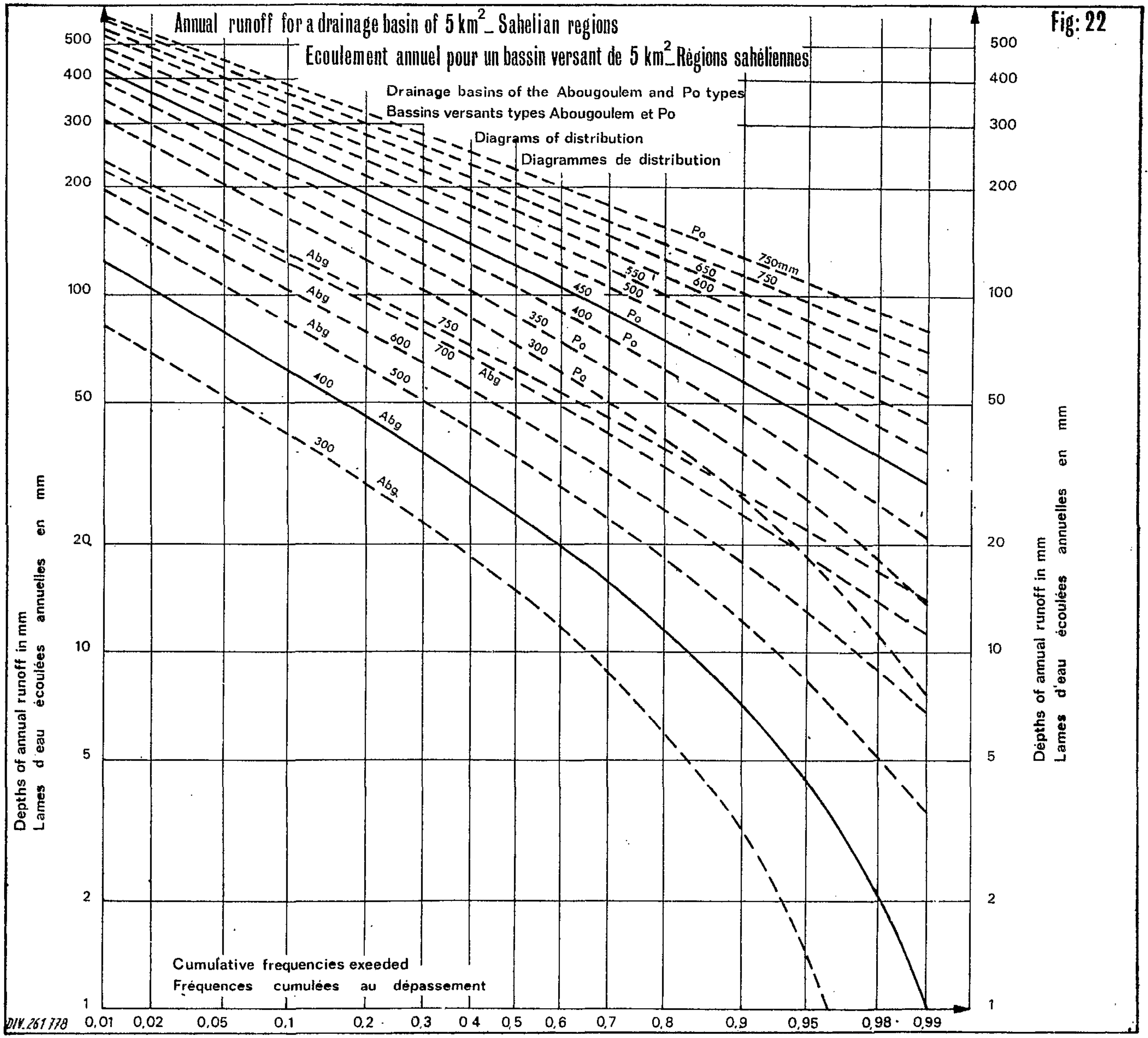


Fig: 22
Annual runoff for a drainage basin of 5 km² _ Sahelian regions
Ecoulement annuel pour un bassin versant de 5 km² _ Régions sahéliennes
Drainage basins of the Abougoulem and Po types
Bassins versants types Abougoulem et Po
Diagrams of distribution
Diagrammes de distribution
Depths of annual runoff in mm
Lames d'eau écoulées annuelles en mm
Cumulative frequencies exeeded
Fréquences cumulées au dépassement
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300 mm isohyet :

median P	=	300 mm	E	=	48	mm	Ke	=	16	%
P 0,99	=	620 mm	E	=	204	mm	Ke	=	33	%
P 0,01	=	68 mm	E	=	3,4	mm	Ke	=	5	%

750 mm isohyet :

median P	=	750 mm	E	=	172	mm	Ke	=	23	%
P 0,99	=	1 180 mm	E	=	472	mm	Ke	=	40	%
P 0,01	=	430 mm	E	=	52	mm	Ke	=	12	%

The three corresponding distribution curves will be found on fig. 23.

3.3.2.5.3 Basins on black marls and sands (SEBIKOTANE)

As in the case of the basins of 25 km^2, curves for this category will be plotted above those from the BARLO 5 km^2 basin types at ¼ of the interval between the curves corresponding to the BARLO 5 km^2 basin-types and those corresponding to basins of the CAGARA-West 5 km^2 type. In application it will be necessary to make a very close check of the proportion of black marls and sands + lateritic shields which are far more permeable.

3.3.2.5.4 Basins on sandstone

Dependence cannot be put on the results from KOUMBAKA III basin for which calibration was inadequate and slope slight. One may accept without too great conviction that, as in the case of the basins of 25 km^2, distribution curves are the same as those of CAGARA-West.

However one will have to fall back on the curves for the BARLO or even ABOU GOULEM type, if the sandstone has very slight slope or is very weathered, or if the lateritic covers a considerable part of the basin.

3.3.2.5.5 Basins on schists

PO basin-type

The family of distribution curves plotted, as has been mentioned earlier, supposes a correction in the values obtained on the PO basin, S = 2,7 km^2 in order to apply it to those of the 5 km^2 basin-type.

For PO the mean runoff coefficient is in the order of 30 %. For 5 km^2, 27 % is accepted corresponding to the 450 mm isohyet.

median P	= 450 mm	E	= 121 mm	Ke	= 27 %
P 0,99	= 850 mm	E	= 425 mm	Ke	= 50 %
P 0,01	= 165 mm	E	= 30 mm	Ke	= 18 %

For permeable basins, like those, the same coefficient of 50 % may be kept for the hundred year wet year, no matter what the rainfall regimen may be .

300 mm isohyet :

median P	= 300 mm	E	= 72 mm	Ke	= 24 %
P 0,99	= 620 mm	E	= 310 mm	Ke	= 50 %
P 0,01	= 68 mm	E	= 7,5 mm	Ke	= 11 %

400 mm isohyet :

median P	= 400 mm	E	= 104 mm	Ke	= 26 %
P 0,99	= 780 mm	E	= 390 mm	Ke	= 50 %
P 0,01	= 130 mm	E	= 21 mm	Ke	= 16 %

500 mm isohyet :

median P	= 500 mm	E	= 138 mm	Ke	= 27,75 %
P 0,99	= 920 mm	E	= 460 mm	Ke	= 50 %
P 0,01	= 200 mm	E	= 36 mm	Ke	= 18 %

600 mm isohyet :

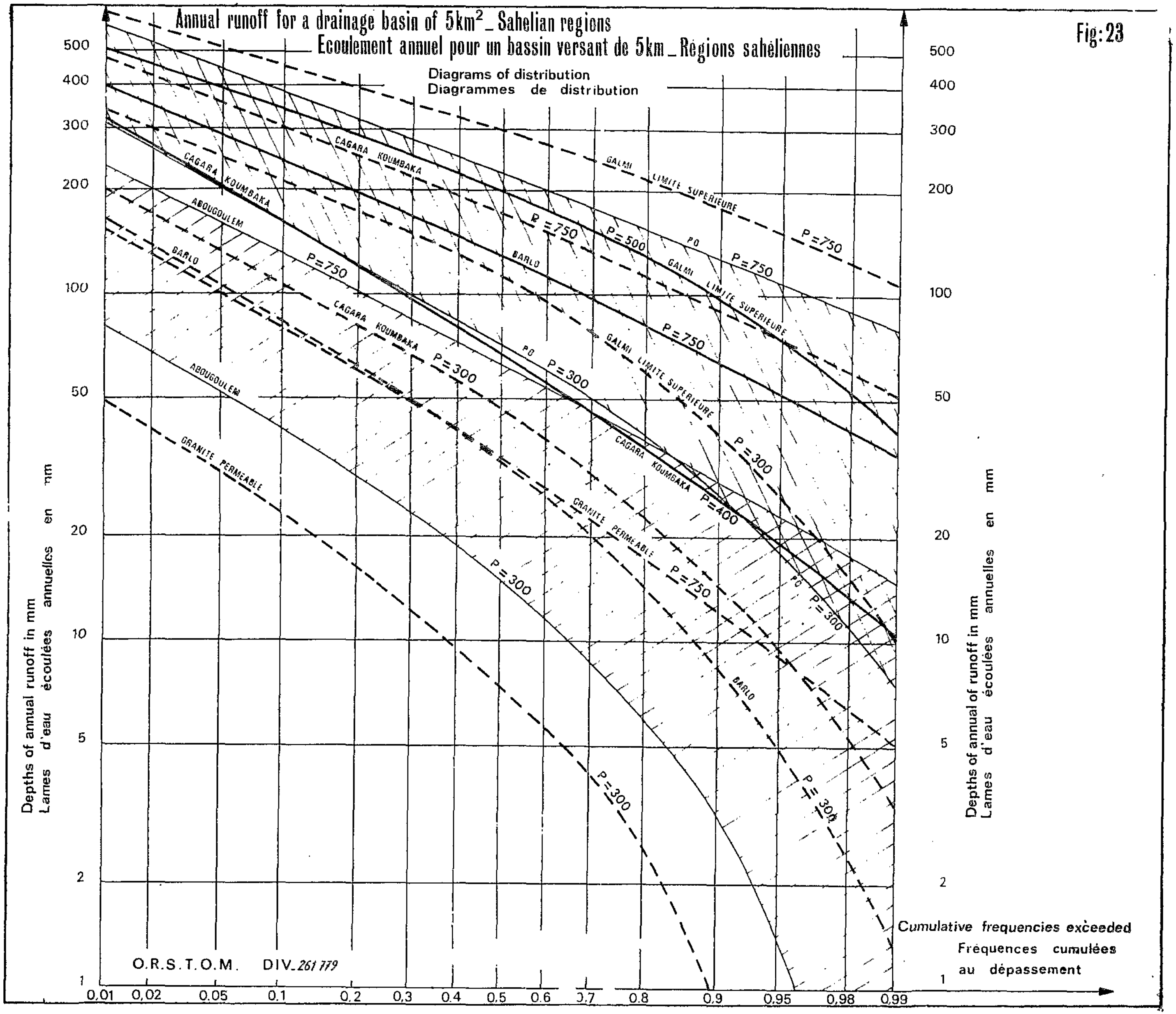
median P	= 600 mm	E	= 172 mm	Ke	= 28,50 %
P 0,99	= 1 030 mm	E	= 515 mm	Ke	= 50 %
P 0,01	= 290 mm	E	= 53 mm	Ke	= 18,25 %

700 mm isohyet :

median P	= 700 mm	E	= 206 mm	Ke	= 29,5 %
P 0,99	= 1 140 mm	E	= 570 mm	Ke	= 50 %
P 0,01	= 380 mm	E	= 70,5 mm	Ke	= 18,50 %

750 mm isohyet :

median P	= 750 mm	E	= 225 mm	Ke	= 30 %
P 0,99	= 1 180 mm	E	= 590 mm	Ke	= 50 %
P 0,01	= 430 mm	E	= 80 mm	Ke	= 18,50 %


Annual runoff for a drainage basin of 5km² _ Sahelian regions
Ecoulement annuel pour un bassin versant de 5km _ Régions sahéliennes
Fig:23
Diagrams of distribution
Diagrammes de distribution
Depths of annual runoff in mm
Lames d'eau écoulées annuelles en mm
Depths of annual of runoff in mm
Lames d'eau écoulées annuelles en mm
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
O.R.S.T.O.M. DIV_261 779
500
400
300
200
100
50
20
10
5
2
1
0,01 0,02 0,05 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 0,95 0,98 0,99
CAGARA KOUMBAKA
ABOUGOULEM
BARLO
GRANITE PERMEABLE
GALMI LIMITE SUPERIEURE
PO
P=750
P=500
P=400
P=300

As for the 25 km^2 drainage basins the family of curves has been extended as far as the 750 mm isohyet although formations such as those of the Wadi GHORFA in all probability does not exist in such a southerly situation. The network of these curves has, like that for the 5 km^2 ABOU GOULEM basin-type, been shown on fig. 22.

3.3.2.5.6 ADER DOUTCHI basin-type

Two basin-types have been taken : that of KOUNTKOUZOUT and the GALMI group.

For the first, as in the case of 25 km^2, the CAGARA-West curves may be adopted; median precipitation : 500 mm.

For the second it has been necessary to slightly increase the coefficients of runoff adopted for basins of 25 km^2.

A constant coefficient of runoff has been accepted for P 0,99 and for median Ke from 400 to 750 mm. For 300 mm, a slightly lower value for Ke has been accepted.

Here likewise conditions of runoff are approaching optimum conditions.

Thus the following figures are obtained :

300 mm isohyet :

median P	=	300 mm	E	=	112,5 mm	Ke	=	37,5 %
P 0,99	=	620 mm	E	=	341 mm	Ke	=	55 %
P 0,01	=	68 mm	E	=	10,2 mm	Ke	=	15 %

500 mm isohyet :

median P	=	500 mm	E	=	200 mm	Ke	=	40 %
P 0,99	=	920 mm	E	=	506 mm	Ke	=	55 %
P 0,01	=	200 mm	E	=	40 mm	Ke	=	20 %

750 mm isoyet :

median P	=	750 mm	E	=	300 mm	Ke	=	40 %
P 0,99	=	1 180 mm	E	=	650 mm	Ke	=	55 %
P 0,01	=	430 mm	E	=	108 mm	Ke	=	22 %

If the 300 mm curve is compared with that in fig. 15 corresponding with category II of the subdesert regimen, the Sahelian curve of GALMI 5 km^2 is clearly above that for category II which is normal since category II generally has steep slopes, but it comprises drift and eolian deposits. However, both curves meet for the 0,99 frequency. This stems from the fact that in the subdesert regimen the depth of exceptional rainfall is strongly influenced by a single rainstorm. Where centennial rainstorms are concerned our knowledge is not very reliable for the subdesert regimen and it is advisable to tread more warily than for the sahelian regimen for frequencies of this order. Therefore runoff for the hundred year wet year should be slighthy increased for when this value for runoff is calculated, it is not usually for water supply problems, but rather to check whether the dam will stand up to such exceptional hydraulic problems. In this case then in spite of what is to be done for the median year or the hundred year dry year, safety resides in taking over-estimated values.

Generally speaking, in the sahelian regimen we have, to all intents and purposes not taken a safety margin for the hundred year wet values

3.3.2.6 Conclusion : Procedure to follow in the evaluation in the sahelian regimen proper of runoff for basins with an area between 2 and 40 km²

3.3.2.6.1 Operations to be carried out

1°/ To determine the area of the drainage basin to be studied.

2°/ To determine the median depth of annual rainfall with the help of diagram n° 1.

3°/ Deduce from this the statistical distribution curve for annual depths of rainfall thanks to fig. 17. This operation is only to be carried out if one has to go on to make difficult interpolations between corresponding distribution curves, from the diagrams of 25 and 5 km^2 (basins with an area of 10 to 15 km^2), or between two curves which are widely spaced on figs. 21 or 23. In this case a knowledge of annual rainfall for the different frequencies in dry years and the control of the corresponding coefficents of runoff may be helpful.

Generally, this intermediate operation may be dispensed with.

4°/ To study on the ground or if necessary on aerial photographs the conditioning factors for runoff, or certain pointers which may allow them to be found. We will return to this operation later, which is the most important and the most difficult.

After this fourth operation, the basin may be classified within one of the categories studied in paragraphs 3.3.2.4.3 to 3.3.2.4.8 or in paragraphs 3.3.2.5.2 to 3.3.2.5.6 and may be attached to a basin-type, or classified within an intermediate position between two categories.

5°/ If, with S approaching 5 km^2 or 25 km^2, the basin presents the same characteristics as one of the reference basin-types, the distribution curve corresponding to the depth of median rainfall determined in 2°) is plotted by interpolation between two curves of the reference basin-type. In the instance of basins of the ABOU GOULEM or KADIEL type interpolation is easy since the curves are given for median precipitation which does not differ by more than 100 mm or 50 mm. If the interval is greater, in order to facilitate graphic interpolation one will be able to start from three points established from the depth of median rainfall of P 0,99 and of P 0,01 and values of Ke in relation with those mentioned in paragraphs 3.3.2.4.3 to 3.3.2.4.8 or 3.3.2.5.2 or 3.3.2.5.6.

6°/ If the characteristics of the drainage basin to be studied are intermediate between those of two basin-types from the same category, one will plot first of all, for the two reference basin-types, distribution curves corresponding to the depth of median precipitation determined in 2°). It will then be a simple matter to plot the distribution curve sought between the two reference curves, but its exact position will depend on the studies made in 4°). This exact position is defined by the depth of runoff for median P.

7°/ If the drainage basin does not form part of one of the categories studied, an attempt will be made to attach it to one of these categories by means of studies carried out within the framework of the operation 4°), studies which will be set out in detail in the following paragraph.

8°/ If the drainage basin is of an area distinctly different from 5 or 25 km^2, there will be the need to interpolate and extrapolate by following the recommendations given in 5°) and 6°).

9°/ If in the basin which is very permeable as a whole, a small zone of n km^2 to the downstream is impermeable, it would be necessary to proceed as though in the presence of a basin of n km^2, disregarding the remainder.

10°/ A study of annual volumes available for the different frequencies.

3.3.2.6.2 <u>A study of the factors conditioning runoff; permeability, slope, vegetation cover, hydrographic network.</u>

3.3.2.6.2.1 "Total permeability". It has been seen earlier that even if a drainage basin forms part of a characteristic formation it generally corresponds with a group of types of soils with very differing properties. In each category studied earlier every basin-type corresponds to very definite proportions of the different surface formations. It is therefore necessary to make for the basin, whose depth of runoff has to be determined, at least a summary chart of these varyied formations or to determine the relative importance of the areas which they cover on the ground and in aerial photographs.

For the 300 and 400 mm isohyets, one must always recognize the importance of windborne deposits on which runoff is practically nil.

As soon as there is a rocky massif involved, one must in every case identify the very weathered zones or zones of drift, in particular granites decomposed in balls which lead to very poor runoff. If the rock is in smooth slabs or domed, it is advisable to check whether the surface runoff which results is not absorbed at the base by the zones of drift or permeable terrains.

To review the categories of basins studied earlier :

- In sandy terrain, one needs to locate outcrop zones or even the lateritic shields which may lead to appreciable runoff (the example of the small basin of NIAMEY V) A check is made by examining the drainage network that this runoff goes as far as the outlet and only the area of the outcrop is taken into account by connecting it with the basin-type of ABOU GOULEM or of BARLO, according to the nature of the outcrop.

- On basins on *granite and granito-gneiss an inventory of the different types of* soils enumerated in paragraph 3.3.2.3.3 should be made to determine what the type of weathering of the granites is : decomposition in balls, drift or domes, and one should check that the runoff on surfaces, by reputation impermeable, reaches the outlet i.e. clay sand or sandy clay soils (solodised solonetz or naga), hydromorphic soils, granite domes, clay reg etc... This should be done by means of studying the drainage network. A clay reg soil to the upstream of the basin whose runoff does not reach the dam, will be of no use and it must not be considered. The same is true for a dome surrounded by a wide belt of arenaceous granitic and very permeable soils.

Even if they are made in the dry season, a series of MUNTZ tests on clay sand or sandy clay soils and on shallow or deeper sandy soils will be able to provide useful information, but it is far more difficult to carry these out than one might think at first sight. On this type of basin it is necessary to determine the drainage density on aerial photographs.

With a table of percentages of the area occupied by different types of soils, the drainage index and index of slope defined as will be seen later, these data will be compared with those from the three basin-types : ABOU GOULEM, BARLO and CAGARA-West, and one will be in a position to classify the basin one intends to manage in relation to these three basin-types.

On basins of the SEBIKOTANE type, the relative proportions of black clays, sands and lateritic shield will need to be defined and one will need to check the state of weathering of the latter.

On basins on sandstone it is necessary to ascertain the area occupied by denuded or almost denuded sandstones with very good surface runoff, that occupied by the more permeable lateritic formations, downstream regions covered with sands or other types of alluvium whose capacity for runoff is variable depending on their nature. One must also ascertain whether the sandstone is in good condition or very fractured . In this way, one will have some idea of the reduction to make submitted to the data obtained on the KOUMBAKA II basin where sandstones occupy nearly the whole area of the basin.

- On basin on schists, one must first determine the area of the rocky outcrops and their condition : solid or very fractured or changed into sedimentary deposits. In the second instance, they are permeable. If this area is appreciable in size (more than 10 %) it needs to be derived from the basin area, in the same way as for zones occupied by windborne deposits. Data from the KADIEL basin-type will only be applied to the surface reduced in this way.

On the ADER DOUTCHI basins, one must first determine the area of fractured sandstones which have low capacity for runoff : perhaps 10 % of that of marl-limestone soils, then the area of marl-limestone soils and clay colluvions which have a very good runoff coefficient, next that for brown red soils and their tendency to be more or less sandy, and finally that of hydromorphic soils in valley bottoms if there are any.

The proportions of these different types of soils will be compared with those from the GALMI and KOUNTKOUZOUT basin-types or those from ALOKOTO which is not a basin-type, but may serve as a guide in selecting the value of median Ke.

For basins which do not come within the studied categories one may nevertheless briefly estimate the proportions occupied by the different types of soils, for even if their origin is not the same, the may have simular properties. Rock drift may be considered permeable, whatever the type of rock, a very clayey soil may be considered as impermeable as the GALMI soils.

In every case, the drainage density must be determined, which is not enough to characterize the set of permeability gradients, but which does provide a further pointer.

3.3.2.6.2.2 Slope : The total index of slope will be determined :

$$I_g = \frac{\Delta D}{L}$$

- L length of the equivalent rectangle
- D difference between the extreme altitudes of the basin leaving aside 5 % of the area corresponding to the highest slopes, and 5 % of the area corresponding to the lowest slopes, this to avoid singular points.

However, if a very cracked mountain massif occupies more than 10 % of the area of the basin, it must not be taken into account in calculation. One will also determine the slope for the principal water course over at least the downstream half of its length.

3.3.2.6.2.3 Vegetation cover : Most important is vegetation cover in the bed of the watercourse at the downstream end. Cover of this kind absorbs a great deal of water and curbs runoff (unless it is drowned by the future dam), it must lead to reduction in the coefficient of runoff (see KOUMBAKA I). The vegetation cover over the basin itself, if it is dense, must likewise reduce the coefficient of runoff (especially in permeable soils; south of the OUADDAÏ).

3.3.2.6.2.4 Hydrographic network

It has been seen that in all cases there is the need to estimate drainage density. In addition, the nature of the bed must be examined, a check must be made to see if there is not an endorheic zone and to see whether in the middle of the basin there is no loss zone on the principal bed. This is most important for permeable basin.

The ideal thing would be to have at ones disposal a regression equation between the rate of mean maximum annual flood flow and the mean annual volume of runoff on one hand, and between the geomorphology of the bed and this rate of mean annual flood flow on the other. Regressions of this kind may be used but on larger watercourses, for 25 km^2 there would be many difficulties in disregarding local peculiarities. In any case all these regressions vary with the type of basin, but in this there is a path to be explored in the future and a well defined network with beds with marked profile is the sign of good capacity for runoff.

3.3.2.6.3 Realization of this study

The best solution would consist of examining together the terrain and aerial photograph ,but this is not always possible . In any case, one needs at least to study aerial photographs in order to distinguish the glacis of the rocky zones and of the zones under cultivation, to evaluate drainage density, etc.. In the Sahelian zone maps are not a great help.

3.3.3 Drainage basin of 40 to 300-500 km^2 in the Sahelian regimen

3.3.3.1 Generalities

Between 25 km^2 and 200 km^2 the slope of the basin and that of the bed decrease as a general rule, but the action resulting from the decrease in slope is less significant than that from degradation, which is moreover a decreasing function of the slope.

Generally speaking, hydrographic degradation is far less swift than in the subdesert regimen, but it varies a great deal according to the different types of basin.

As a general rule there will be practically no degradation on basins of the wadi GHORFA (KADIEL - DJADJIBINE) type or on those of the ADER DOUTCHI and of the MAGGIA. It will only occur further downstream when slope becames very low and very few tributaries feed the main watercourse.

In a region of granite or granito-gneiss substratum on the contrary, the basin almost always comprises a considerable part of permeable soils and as the slope decreases hydrographic degradation is greater, the influence of the regs or clay sandy soils is very little, especially if they are upstream of the basin. In this connection one could again mention what was said in 2.3.3.1, every case is a specific case, small basins of 2 to 40 km^2, situated immediately upstream of the outlet, in point of fact produce the major part or the total runoff if they comprise at least one section of their area covered by a soil which is impermeable or relatively impermeable.

Further on we have collected all available information.

3.3.3.2 Available information

It comes for the most part from the representative basins and data from regional studies (OUADDAÏ, GUERA, ADER DOUTCHI, BRAKNA, AFFOLE, Wadi GHORFA, North-DORI, DJIBO) however use may already be made of the results from some network stations and at least we have taken into account some figures stemming from the ORSTOM study of BAM Lake.

We have taken up the drainage basins on the limits of the subdesert zones to the North of the Sahelian zone, and on the tropical ones to the South. We have also quoted data connected with a certain number of water courses whose drainage basin is in clear excess of 500 km^2.

Pond GADEL (BRAKNA - Mauritania) median P : 300 mm

S = 410 km^2	1958 P = 400 mm	E = 44 mm	Ke = 11 %
	1959 P = 215 mm	E = 28 mm	Ke = 13 % (1)
		Mean year	Ke = 10 % ?

Wadi BOUDIENGAR (AFFOLE - Mauritania) median P : 300 mm

S = 930 km^2	1960 P = 190 mm	E = 2,4 mm	Ke = 1,25 %
Sandstone + eolian deposits		Mean year	Ke = 1,5 % ?
+ some clay deposits	For 140 km^2	Mean year	Ke = 7 to 10% ?

Pond CHOGGAR (BRAKNA - Mauritania) median P : 310 mm

S = 190 km^2	1958 P = 380 mm	E = 44 mm	Ke = 11,5 %
		Mean year	Ke = 10,5 % ?

(1) Most of annual P fell during two rainstorms.

Lake MAL (BRAKNA - Mauritania) median P : 320 mm

S = 900 km^2	1958 P = 280 mm	E = 21 mm	Ke = 7,5 %	
	1959 P = 200 mm	E = 2 mm	Ke = 1 %	
	1960 P = 370 mm	E = 26,2 mm	Ke = 7,1 %	
		Mean year	Ke = 8 %	

KARAKORO at LEHBILE (AFFOLE - Mauritania) median P : 320 - 330 mm

S = 143 km^2	1960 P = 210 mm (2)	E = 23,9 mm	Ke = 11,3 %	
Sandstone + clay desposits + some eolian deposits		Mean year	Ke = 15 %	?

AM NABAK (OUADDAÏ - Chad) median P : 330 mm

Reduced basin

S = 60 km^2	1965 P = 330 mm	E = 6,3 mm	Ke = 2 %
30 % clay reg on granite	1966 P = 380 mm	E = 25 mm	Ke = 6,6 %

Ouadi AMBAR at KAOUI (OUADDAÏ - Chad) median P : 330 mm

S = 52 km^2

Granite and arenaceous soils	1967 P = (800 mm)	E = (69 mm)	Ke = 8,6 %

Ouadi AMBAR at the confluence with Wadi ENNE (OUADDAÏ - Chad) median P : 330 mm

S = 83 km^2 Granite and reg	1961 P = (800 mm)	E = (126 mm)	Ke = 15,6 %

Ouadi ENNE at BILTINE (OUADDAÏ - Chad) median P : 330 - 350 mm

S = 527 km^2	1958 E intermediate between 1959 and 1961		
Granite and reg arenaceous soils and sands	1959 P = (330 mm)	E = 9,1 mm	Ke = 2,75 %
	1961 P = (850 mm)	E = 43,5 mm	Ke = 5,1 %
	1972	E almost normal	
	1973	E $\neq$ 0 a small flood	
	1974	E normal	

(2) a very good concentration of rainfall

Ouadi ENNE at MALAGI (OUADDAÏ - Chad) median P : 330 - 350 mm

$S = 270\ km^2$ 1961 P = (900 mm) E = 43,3 mm Ke = 4,3 %

Granite and reg
arenaceous and sands

GOSI at TOROU (OUADDAÏ - Chad) median P : 330 - 350 mm

$S = 60\ km^2$	Dd = 2,18	1961 P = (910 mm)	E = 28 mm ?	Ke = 3 to 4%
Granite, arenaceous soils and sands	Aug. and Sept.	1961 P = 199 mm	E = 14 mm	Ke = 7 %

KORI GIGE (ADER DOUTCHI - Niger) median P : 380 - 390 mm

$S = 50\ km^2$	1966 P = 480 mm	E = 60 mm	Ke = 13 %
	1967 P = 350 mm	E = 70 mm	Ke = 20 %
	decennial dry	E = 24 to 30 mm	Ke = 12 % ?
	decennial wet	E = 160 to 180 mm	Ke = 29 % ?

AGOULOUM (ADER DOUTCHI - Niger) median P : 380 - 390 mm

$S = 91\ km^2$	1967 P = 370 mm	E = 82,5 mm	Ke = 22 %
	decennial dry	E = 22 mm ?	Ke = 10 % ?
	decennial wet	E = 143 mm ?	Ke = 25 % ?

IBOHAMANE (ADER DOUTCHI - Niger) median P : 390 - 400 mm

$S = 117\ km^2$	1965 P = 470 mm	E = (80) mm	Ke = 17 %
	1966 P = 425 mm	E = 57 mm	Ke = 13 %
	1967 P = 450 mm	E = 101 mm	Ke = 22,4 %
	1971 P = 291 mm	E = 43,2 mm	Ke = 14,8 %
(dubious)	1972 P = 253 mm	E = 52 mm	Ke = 20,5 %
(dubious)	1973 P = 153 mm	E = 46,2 mm	Ke = 30 %

TEGUELEGUEL (ADER DOUTCHI - Niger) median P : 390 - 400 mm

$S = 157\ km^2$	1965 P = 470 mm	E = (90) mm	Ke = 19 %
	1966 P = 425 mm	E = 70 mm	Ke = 16,5 %
	1967 P = 440 mm	E = 76 mm	Ke = 17,3 %

JEJI SAMAE (ADER DOUTCHI - Niger) median P : 400 mm

$S = 575\ km^2$	1966 P = 425 mm	E = (41,5) mm	Ke = (9,8) %
Bed with slight slope, hydrographic degradation	1967 P = 425 mm	E = 33 mm	Ke = 7,8 %

Wadi BOUDAME at ECHKATA (GUIDIMAKA - Mauritania) median P : 440 - 460 mm

$S = 149\ km^2$	Dd = 2,80	1965 P = 430 mm	E = (35) mm	Ke = 8 %
	$I_g = 2,8$	1966 P = 443 mm	E = 39,6 mm	Ke = 8,9 %
		1967 P = 550 mm	E = 51 mm	Ke = 9,3 %

Wadi BOUDAME at BOUDAMA (GUIDIMAKA - Mauritania) median P : 450 - 475 mm

$S = 564\ km^2$	Dd = 2,67	1964 P = 467 mm	E = 97,6 mm	Ke = 20,8 %
	$I_g = 1,40$	1965 P = 409 mm	E = 39,2 mm	Ke = 9,6 %
		1966 P = 402 mm	E = 38,2 mm	Ke = 9,5 %
		1967 P = 560 mm	E = 107 mm	Ke = 19 %

DJAJIBINE (GUIDIMAKA - Mauritania) median P : 475 mm

$S = 148\ km^2$	Dd = 2,51	1964 P = 529 mm	E = 172 mm	Ke = 32,5 %
	$I_g = 2,02$	1965 P = 455 mm	E = 110,9 mm	Ke = 24,4 %
		1966 P = 417 mm	E = 71,1 mm	Ke = 17 %
		1967 P = 480 mm	E = 159 mm	Ke = 33 %

BOITIEK (GUIDIMAKA - Mauritania) median P : 450 - 475 mm

$S = 250\ km^2$	Dd = 1,47	1965 P = 473 mm	E = 105,4 mm	Ke = 22,4 %
	$I_g = 1,56$	1966 P = 443 mm	E = 49,8 mm	Ke = 11,2 %
		1967 P = 570 mm	E = 145 mm	Ke = 25,4 %

DOUHOUA (ADER DOUTCHI - Niger) median P : 460 mm

$S = 74\ km^2$	(1)	1969 P = 312 mm	E = 29,5 mm	Ke = 9,5 %
		1970 P = 473 mm	E = 121,5 mm	Ke = 25,7 %
		1971 P = 355 mm	E = 31,5 mm	Ke = 9 %

TAMBAS (ADER DOUTCHI - Niger) median P : 460 mm

$S = 284\ km^2$	(1)	1969 P = 336 mm	E = 34,2 mm	Ke = 10,2 %
		1970 P = 470 mm	E = 94,6 mm	Ke = 20 %
		1971 P = 324 mm	E = 20,3 mm	Ke = 6,3 %

KAORA ABDOU (ADER DOUTCHI - Niger) median P : 470 mm

$S = 234\ km^2$ (1)	1969 P = 321,5mm	E = 29,4 mm	Ke = 9,1 %
	1970 P = 459 mm	E = 42,1 mm	Ke = 9,2 %
	1971 P = 308 mm	E = 17,3 mm	Ke = 5,6 %

KATASAORA (ADER DOUTCHI - Niger) median P : 480 mm

$S = 104\ km^2$ (1)	1969 P = 356 mm	E = 28,4 mm	Ke = 8 %
	1970 P = 445 mm	E = 41,5 mm	Ke = 9,3 %
	1971 P = 297 mm	E = 14,7 mm	Ke = 5 %

MAGGIA at AYAOUANE (Niger) median P : 470 - 480 mm

$S = 270\ km^2$	1964	E = 50,7 mm	Ke = 9 to 10 %
	1965	E = 52,2 mm	Ke = 9 to 10 %

SABONGA (Niger) median P : 520 mm

$S = 79{,}9\ km^2$ Dd = 3,87 $I_g = 7{,}0$	1958 P = 607 mm	E = 60 mm	Ke = 9,9 %

Ouadi MANDJOBO at KASSINE (OUADDAÏ - Chad) median P : 500 - 520 mm

	1958 P = (500) mm	E = 4 to 8mm	Ke = 0,8 to1,5%

GOUDEBO at GUEMNI (OUDALAN - Upper Volta) median P : 550 mm

$S = 390\ km^2$	1964 P = 550 mm	E = 24,5 mm	Ke = 4,5 %
	1965 P = 500 mm	E = 19,0 mm	Ke = 3,8 %

FELLEOL (OUDALAN - Upper Volta) median P : 550 mm

$S = 400\ km^2$	1964 P = 550 mm	E = 36 mm	Ke = 6,5 %

(1) See runoff for the MAGGIA and BADEGUICHERI.

GOUDEBO at YAKOUTA (Upper Volta) — median P : 550 - 560 mm

S = 1640 km^2

1957		E > E 1961	
1958		E ≠ E 1959	
1963	P = 635 mm	E = 35 mm	Ke = 5,6 %
1964	P = 600 mm	E = 31,5 mm	Ke = 5,25 %
1965	P = 565 mm	E = 29,2 mm	Ke = 5,2 %
1969	P = 560 mm	E = 57,7 mm (1)	
1970	P = 350 mm	E = (18,3) mm	Ke = (5,25 %)
1971	P = 375 mm	E = 25,3 mm	Ke = 6,7 %
1972		E > E 1971	

E close to median : 1963 and 1964 (see DOLBEL)

Wadi TOURIME at TOURIME (GUIDIMAKA - Mauritania) — median P : 550 - 575 mm

S = 484 km^2

1964	P = 585 mm	E = 99,4 mm	Ke = 5,9 %
1965	P = 759 mm	E = 95,6 mm	Ke = 7,9 %

VENDO MENA (Upper Volta) — median P : 600 mm

S = 990 km^2

Calco-alkaline granite, a little schist, downstream permeable soils, slight slopes

1963	P = 650 mm	E = 0	Ke = 0
1964	P = 600 mm	E = 1,5 mm	Ke = 0,25 %

BA ADA (Upper Volta) — median P : 610 mm

S = 500 km^2

Calco-alkaline granite, permeable soils, slight slopes

1961		E = 5,6 mm	
1963	P = 700 mm	E = 3 mm	Ke = 0,4 %
1964	P = 620 mm	E = 2 mm	Ke = 0,3 %

KOUMBAKA I (Mali)

S = 87 km^2 Dd = 0,84 I_g = 9,35

1955	P = 600 mm		
1956	P = (587) mm	E = 57,8 mm	Ke = 9,8 %
1957	P = 710 mm	E = 69,8 mm	Ke = 9,8 %

(1) Overestimated value : calibration of the station, but in any case E is clearly higher than average.

PANETIOR (Senegal)	median P : 620 mm		
S = 93,2 km^2	1962 P = 620 mm	E = 42,7 mm	Ke = 6,9 %

Lake BAM (Upper Volta, principal tributary)		median P : 630 - 650 mm	
S = 1478 km^2 (440 km^2 endorheïc)	1966	E = 2,4 mm (3,4) mm	
	1967	E = 1,75 mm (2,5) mm	
	1968	E = 1,9 mm (2,7) mm	
	1969	E = 5,2 mm (7,4) mm	
	1972 P = 406 mm	E = 3,9 mm (5,6) mm	Ke = 1 %
	1973 P = 426 mm	E = 4,3 mm (6,15) mm	Ke = 1 %
	1974	E = 13,5 mm (19,3) mm	Ke = 1,7 to 2%

median E = 3,5 to 4,5 mm for (1 478 km^2)
5 to 6 mm for (1 038 km^2)

BIDJIR (GUERA - Chad)		median P : 850 mm		
S = 74,2 km^2	Dd = 3,07	1963 P = 684 mm	E = 2,4 mm	Ke = 0,35 %
		1964 P = 1079 mm	E = 146 mm	Ke = 13,6 %
		1965 P = 750 mm	E = 2,8 mm	Ke = 0,37 %
		1966 P = 752 mm	E = 14,5 mm	Ke = 1,93 %

TAYA (GUERA - Chad)		median P : 850 mm		
S = 167 km^2	Dd =(2,85)	1963 P = 631 mm	E = 0,6 mm	Ke $\#$ 0
	I_g = 6,5	1964 P = 1078 mm	E = 72 mm	Ke = 6,7 %
		1965 P = 800 mm	E = 3,6 mm	Ke = 0,4 %
		1966 P = 726 mm	E = 4,0 mm	Ke = 0,54 %

TOUNKOUL (GUERA - Chad)		median P : 850 mm		
S = 61,3 km^2	Dd = 3,86	1963 P = 678 mm	E = 3,2 mm	Ke = 0,48 %
	I_g = 6,0	1964 P = 951 mm	E = 146 mm	Ke = 15,5 %
		1965 P = 829 mm	E = 65 mm	Ke = 7,8 %
		1966 P = 655 mm	E = 17 mm	Ke = 2,6 %

BARLO V (GUERA - Chad)		median P : 835 mm		
S = 528 km^2	Dd =(3,1)	1963 P = 680 mm	E = 9,9 mm	Ke = 1,56 %
	I_g = 3,5	1964 P = 1025 mm		
		1965 P = 735 mm		
		1966 P = 724 mm	E = 19,9 mm	Ke = 2,6 %

MAZERA (GUERA - Chad)		median P : 835 mm		
S = 316 km^2	Dd =(3,3)	1963 P = 647 mm	E = 1,7 mm	Ke = 0,27 %
	I_g = 4,3	1964 P = 875 mm	E = 92 mm	Ke = 10,6 %
		1965 P = 778 mm		
		1966 P = 705 mm	E = 10,6 mm	Ke = 1,5 %

3.3.3.3 Median values for the coefficient of runoff

Naturally one encounters the same basin categories as for paragraphs 3.3.2. We have, after a fashion, estimated the values for the coefficients of runoff which, applied to the median value of precipitation for each basin, lead to the median value for depth of runoff. It is essentially the connection between the central value of the various figures for E corresponding to annual rainfall approximating on median rainfall and this median rainfall.

Granite or granito-gneiss subsoil :

AM NABAK	median P : 330 mm	S = 60 km^2	Ke = 2 %
Wadi AMBAR at KAOUI	median P : 330 mm	S = 52 km^2	Ke = 3 to 5 %
Wadi AMBAR	median P : 330 mm	S = 83 km^2	Ke = 5 to 7 % (reg)
Wadi ENNE at MALAGI	median P : 330-350 mm	S = 270 km^2	Ke = 1 to 2 %

Wadi ENNE at BILTINE	median P : 330-350 mm	S = 527 km^2	Ke = 2 %	
GOSI at TOROU	median P : 330-350 mm	S = 60 km^2	Ke = 1 to 2 %	
Wadi MANDJOBO at KASSINE	median P : 500 mm	S = 240 km^2	Ke = 0,8 to 1,5 %	
GOUDEBO at GUEMNI	median P : 550 mm	S = 390 km^2	Ke = 3 to 4 %	
FELLEOL	median P : 550 mm	S = 400 km^2	Ke = 5 to 6 %	
VENDO MENA	median P : 600 mm	S = 990 km^2	Ke = 0,25 %	(1)
BA ADA	median P : 610 mm	S = 500 km^2	Ke = 0,3 %	(1)
Lake BAM	median P : 630-650 mm	S =1038 km^2	Ke = 0,8 to 0,9 %	
BIDJIR	median P : 850 mm	S = 74,2 km^2	Ke = 1 %	?
TAYA	median P : 850 mm	S = 167 km^2	Ke = 0,6 to 0,8 %	
TOUNKOUL	median P : 850 mm	S = 61,3 km^2	Ke = 6 %	
BARLO V	median P : 830 mm	S = 528 km^2	Ke = 3 to 4 %	
MAZERA	median P : 830 mm	S = 316 km^2	Ke = 2 %	

SEBIKOTANE region :

PANE TIOR	median P : 620 mm	S = 93,2 km^2	Ke = 4 to 6 %

Sandstone "dogons" (KOUMBAKA) :

KOUMBAKA I	median P : 570 mm	S = 87 km^2	Ke = 10 %

Sandstone + clay deposits of the AFFOLE :

KARAKORO	median P : 320-330 mm	S = 143 km^2	Ke = 15 %
BOUDIENGAR	median P : 300 mm	S = 930 km^2	Ke = 1,5 % (eolian deposits, (degradation)

B R A K N A

GADEL	median P : 300 mm	S = 410 km^2	Ke = 10 %
CHOGGAR	median P : 310 mm	S = 190 km^2	Ke = 10,5 %
MAL	median P : 320 mm	S = 900 km^2	Ke = 8 %

(1) permeable, very slight slope

Clay on schist of the Wadi GHORFA

BOUDAME	median P : 450-475 mm	S = 564 km^2	Ke = 9 %
ECHKATA	median P : 440-460 mm	S = 149 km^2	Ke = 8 to 9 % (scree and eolian deposits)
DJAJIBINE	median P : 450-475 mm	S = 148 km^2	Ke = 19 %
BOITIEK	median P : 450-475 mm	S = 250 km^2	Ke = 15 %
Wadi TOURIME	median P : 550-575 mm	S = 484 km^2	Ke = 5 to 6 %

ADER DOUTCHI - MAGGIA :

Kori GIGE	median P : 380-390 mm	S = 50 km^2	Ke = 16 %
AGOULOUM	median P : 380-390 mm	S = 91 km^2	Ke = 18 %
IBOHAMANE	median P : 390-400 mm	S = 117 km^2	Ke = 16 %
TEGUELEGUEL	median P : 390-400 mm	S = 157 km^2	Ke = 17 %
JEJI SAMAE	median P : 400 mm	S = 575 km^2	Ke = 9 % (bed with slight slope)
DOUHOUA	median P : 460 mm	S = 74 km^2	Ke = 12 %
TAMBAS	median P : 460 mm	S = 284 km^2	Ke = 10 to 11 %
KAORA ABDOU	median P : 470 mm	S = 234 km^2	Ke = 9 to 10 %
KATASAORA	median P : 480 mm	S = 104 km^2	Ke = 8 to 9 %
MAGGIA AYAOUANE	median P :	S = 270 km^2	Ke = 9 to 10 %
SABONGA	median P :	S = 79,9 km^2	Ke = 9 %

Many values comparable with those from basins of between 2 and 40 km^2 are found, but of course in granitic regions one no longer meets with the high coefficients of surface runoff for argillaceous regs or clay-sandy soils and in the ADER DOUTCHI and on the MAGGIA, the even higher figures for argillaceous limestone and argillaceous colluvions since basins of 100 to 500 km^2 are no longer constituted solely by these types of soils, and in other respects CAGARA-West and GALMI basin-types would present mean slope greater than that usually found on these basins of between 100 and 500 km^2.

3.3.3.4 Statistical distribution curves for annual runoff

3.3.3.4.1 Generalities

For drainage basins of these dimensions, it is almost impossible to make distribution curves for amounts of runoff from relations between observed rainfall-flow figures and from rainfall distribution curves. The correlation between rainfall and flow is really too loose. Only with difficulty may one find the coefficient for runoff between a median value for rainfall and value for runoff.

The simplest procedure to follow is to look for the frequency for the years observed by referring to the results from a network station observed for 15 to 20 years and, if possible, situated downstream. Only in a very few cases is it possible to make use of rainfall-flow models as that has been done for the KADIEL basin.

For OUADI ENNE, it will be seen that it was possible to employ another procedure. Fortunately a certain number of exceptional years figured among the few years of observation, for example 1961 in the OUADDAÏ where both rainfall and runoff are exceptional, but there are instances where rainfall is near of the median and runoff exceptionally heavy. In this case the study of daily precipitation and flood flows which resulted are very useful. Very typical of this last instance is the year 1970 on the TAMBAS (ADER DOUTCHI), runoff is abnormally high as the result of a succession of heavy rainstorms. In the same way the observation year at DAMBOUSSANE is clearly exceptional for the same region.

Nevertheless coeffients of runoff will be calculated because, related to the median value of the depth of annual rainfall, they permit the relative importance of runoff from one basin to the next to be estimated. Likewise, in some simple cases, they permit reasonable extrapolations when calculations are made for the different frequencies, in particular for F = 0,01 and F = 0,99 or F = 0,1 and F = 0,9 when for the same frequency relating runoff to the corresponding depth of annual precipitation.

In what follows no attempt will be made to give for each type of basin a set of distribution curves of runoff for different values of median depth of rainfall, since it is nearly always impossible to give simple rules for calculation in the case of drainage basins with this area. We will content ourselves with choosing a certain number of cases within the various types of basin and for each case a single distribution curve will be given which corresponds exactly to this basin, except in the case of the BAM BAM (Chad) median P : 835 mm, for which the results are transposed for a depth of median precipitation of 750 mm.

The slope of the main bed and the state of its degradation play a principal part in runoff.

Later we will again take up essentially the same types of basins as for basins of 2 to 40 km^2.

3.3.3.4.2 Basins on granite or granito-gneiss

Hydrographic degradation is very frequent especially in the North and if the general slope of the basin is not too great.

It has already been seen how heterogeneous these basins are; we will encounter no basin of more than 150 km^2 of the BARLO or CAGARA-West type, 75 % covered with clay-sandy soil or argillaceous reg, except perhaps just in North-DORI where the CAGARA basins are situated where clay-sandy soils and relatively impermeable vertic clays largely predominate but slope is slight.Basins are also found with rocky massifs weathered into ball formations, granitic arenaceous soils and deep sandy soils with a very low coefficient of runoff. This is often the case in the GUERA and the OUADDAÏ.

In any case, a basin of more than 100 km^2, on a granitic subsoil reacts very differently depending on the nature of the varying formations of which it is constitued (rocky massifs weathered into ball formations, or domes, arenaceous granitic soils, deep or shallow sandy soils, clay sandy soils or vertic clays, hydormorphic soils from valley bottoms, not forgetting in the North argillaceous regs and eolian coverings, together with their position in relation to the bed and the observation station, and depending on the nature and slope of the bed or principal beds and not forgetting the basin's general slope.

When the basin is complex,especially in the North,annual runoff varies according to frequency in a quite fantastic way and this for reasons which are easily explained.This will be seen from the example of the OUADI ENNE at BILTINE : 527 km^2.

On its right bank this receives the OUADI AMBAR, 83 km^2, with not too much degradation and which in the downstream area of its basin presents zones of regs with good surface runoff. In fact the OUADI AMBAR is actually the principal watercourse for the OUADI ENNE, which presents relatively poor runoff, is very degraded before the confluence and only one of its arms joins the OUADI AMBAR. This arm shows no runoff in a year with a slight deficit. In the dry year, only the regs of the 29 km^2 downstream give rise to runoff. The basin has been thoroughly studied in 1961 and more briefly in 1969.

The year 1959 which was slightly exceptional, gave rise to reasonable runoff on the basin (527 km^2) equal to 9,1 mm. In the median year 6,6 mm was admitted, corresponding to Ke = 2 % for Pe = 330 mm. The contribution of the OUADI ENNE above the confluence is nil for this 0,5 frequency.

In the centennial year E = 40 mm was admitted, a value slightly lower than runoff in 1961 = 43,5 mm. But depth of rainfall in 1961 in this region, close on 800 mm, is clearly higher than the rainfall in the centennial year = 680 mm.

In the ten year dry year, only the regs of the 30 km^2 downstream give rise to runoff.

For f = 0,9, the diagrams of the basins of 25 to 40 km^2 lead to a depth of water of the order of 1,75 mm.

Assessed on 527 km^2 one finds :

$$E = \frac{1,75 \times 29}{527} \# \quad 0,1 \text{ mm}$$

Finally, the distribution curve depends on the three following points :

median P	= 330 mm	E = 6,6 mm	Ke = 2 %
P 0,01	= 680 mm	E = 40 mm	Ke = 6 %
P 0,90	= 190 mm	E = 0,1 mm	Ke = 0,05 %

It presents a rather bizarre aspect, the left extremity seems relatively flat in fact the contributions from the OUADI ENNE, even in the hundred year wet year are less significant than those from the OUADI AMBAR whose downstream section gives very important surface runoff and which presents very normal contributions. If one were to isolate this basin and relate its contributions to its 83 km^2 instead of adding them to those of the OUADI ENNE, in order to ascribe them to 527 km^2, one would probably find definitely more than 100 mm instead of 40 mm and the slope of the curve would be normal. In the same way, it must not be forgotten that for the five-year dry year, only the 30 km^2 downstream give rise to runoff and their contributions are distributed over 527 km^2, and thus a steeper curve than usual on its right section whereas the left section is too flat, but runoff is nil for a very low frequency. There was runoff in 1973 ! This curve will be found on diagram 25. It was not put on diagram 24 as not too overload it.

The Wadis encountered on the way from ABECHE to ADRE have still lower median runoff, perhaps Ke = 1 % to 2 %, in spite of the heavier rainfall, a median value of 450 to 600 mm, for here there is no longer argillaceous reg and slope is not very steep, with soils very permeable. The elements at ones disposal are still completely inadequate for the plotting of a distribution curve. The neighbouring watercourses of DJIBO which, if one may say so, drain from permeable, granitic soils of the same type and have very slight slope, present coefficients of runoff which are even lower VENDO MENA Ke = 0,25 %, BA ADA 0,3 %; runoff in this case may cancel itself out one year in five or one year in ten.

The basin of the principal tributary of Lake BAM at PASPANGA is nearly as interesting as that of the OUADI ENNE. The basin on permeable soil with slight slope covers 1 478 km^2. At least 19 years in 20 and perhaps 49 years in 50 one section of the basin remains endorheic: the secondary basin of the BOURZANGA lake(440 km^2), but in the course of the exceptional year in 1974 this lake flooded and the flood joined the main watercourse upstream of PASPANGA. In this case, all the runoff should be ascribed to 1 478 km^2, but nearly always it is better to ascribe it to 1 038 km^2. However, for 1974 the depth of runoff coming from the BOURZANGA basin is certainly far less than that from the rest of the basin. Nevertheless one should remain convinced that even over these 1 038 km^2, only one section combines with runoff.

For this study, the endorheïc basin will be eliminated. It is advisable to remember that the figure of 19,3 mm for 1974 is too high.

When comparing runoff amounts at PASPANGA with those from Lake BAM which are spread out over a longer period, and keeping in mind the fact that the correlation is rather loose between the two runoffs in consequence of surface runoff on the clays round the lake, the following conclusions are reached for values of E :

median P = 640 mm	E = 6 mm	Ke = 0,94 %
P 0,10 = 870 mm	E = 15 mm	Ke = 1,73 %
P 0,90 = 455 mm	E = 2,4 mm	Ke = 0,53 %

From this one gets the curve which appears on diagram 24.

It is possible to trace probable distribution curves for the two other basins which are relatively permeable but with markedly steeper slope; those of TAYA and TOUNKOUL, both tributaries of the BAM-BAM (GUERA - Chad). The total index of slope is nearly the same but the TOUNKOUL basin is clearly smaller and the slopes, steep upstream, swiftly lead to a concentration of flow into a single watercourse, whereas on the TAYA basin the hydrographic network is in a fish bone style and the slope more progressive, which is unfavourable. Taken as a whole, TAYA is probably more permeable than TOUNKOUL. The following conclusions are reached: simplifying all the results to a depth of precipitation of 750 mm instead of 850 mm, almost the same coefficients of runoff are preserved except for dry years when they are appreciably reduced :

TAYA	median P	= 750 mm	E = 5,25 mm	Ke = 0,7 %
750 mm	P 0,10	= 1 000 mm	E = 60 mm	Ke = 6 %
	P 0,90	= 550 mm	E = 0,4 mm	Ke = 0,07 %
TOUNKOUL	median P	= 750 mm	E = 45 mm	Ke = 6 %
750 mm	P 0,20	= 900 mm	E = 117 mm	Ke = 13 %
	P 0,90	= 550 mm	E = 8 mm	Ke = 1,4 %

Values of E must be considered as orders of size, however, despite their lack of precision, it has to be admitted that the difference in behaviour of the two basins is considerable in spite of comparable slope index and pedological maps which show very little difference. However the difference in area plays a big part; for 61,3 km^2 (TOUNKOUL), conditions of runoff are not much worse than for 25 to 40 km^2. For 167 km^2 (TAYA), losses in the bed play a much greater part than for 61,3 km^2. The hydrographic network and the basins morphology likewise play a most important part, the form of the TOUNKOUL network is far more favourable. Finally, an examination in depth of the most permeable zones and their implantation would show more favourable conditions for surface runoff on TOUNKOUL. This shows that a priori determination of the runoff curve in a cristalline permeable or relatively permeable zone is very difficult and that the determination of the classic indexes of slope, and the examination of the classic pedological maps are inadequate. One has to proceed to a thorough examination of aerial photographs and of the terrain (basin soils and the nature of beds) in order to plot a distribution curve.

The two curves for TAYA and TOUNKOUL are reproduced on diagram 24.

Some basins on granite or granito-gneiss have a considerable part of their area occupied by clay soils or clay-sandy soils. This is often the case in North-DORI (Upper Volta), and especially on the basin of the FELLEOL which includes the small basin of CAGARA-West. Vertic clays become impermeable when the shrinkage cracks have disappeared after the first significant rainfalls, but slope is slight and the beds which are poorly defined are covered with vegetation. The coefficient of runoff varies little and particularly is not very high in a year with exceptional rainfall (1969), but it must be reduced very plainly in the 50 year or one hundred year dry years which did not occur during the dry period of 1970 - 1973 on this basin.

The FELLEOL, at the crossing point of the DORI road ($S = 400\ km^2$) was only properly observed in 1964, but one does know runoff amounts for the nearly water-courses of the GOUDEBO at YAKOUTA over a period of almost ten years, and those for the GOROUOL at DOLBEL, which allows the frequency of runoff in 1964 to be located and permits us to have some idea of the variations of runoff.

The distribution curve would depend on the three following points :

median P	= 550 mm	E = 33 mm	Ke = 6 %
P 0,90	= 370 mm	E = 17,5 mm	Ke = 4,7 %
P 0,10	= 760 mm	E = 55 mm	Ke = 7,2 %

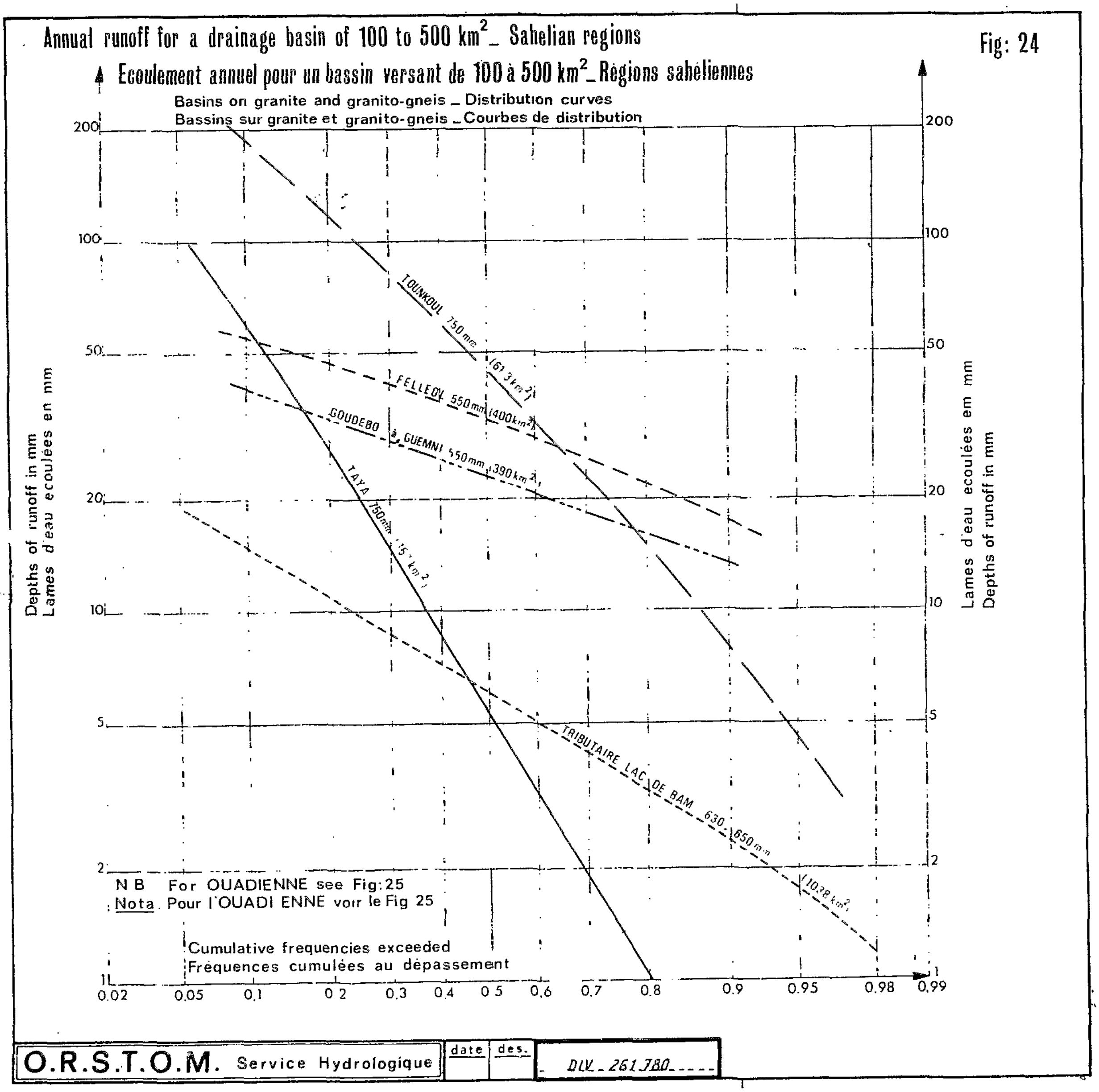
The GOUDEBO at GUEMNI ($S = 390\ km^2$) has lower runoff, in spite of a steeper slope. This is probably because the basin contains more permeable terrains. The distribution curve also takes into account data from the YAKOUTA station and from the DOLBEL station on the GOROUOL, both situated further downstream.

A curve may be plotted which would depend on the three following points :

median P	= 550 mm	E = 24 mm	Ke # 4,4 %
P 0,90	= 370 mm	E = 13,5 mm	Ke # 3,6 %
P 0,10	= 760 mm	E = 40 mm	Ke = 5,25 %

The two curves are given on diagram 24.

This set of diagrams may give some pointers on the plotting of the distribution curve for other basins on granite or granito-gneiss, but it is a long way from covering all the cases one may encounter in these types of basins, and prudence is imperative. Especially in the instance of true mountain basins such as are found in the North-CAMEROUN, South of the 750 mm isohyet with a bed with quite marked slope for basins up to 1,000 km^2; for these one must expect runoff coefficients which are higher, even in the dry year (see basins of 2 to 40 km^2). However there are a few north of the 750 mm. The watercourses of the GUERA quickly reach the plain and are almost always degraded before the basin attains 300 to 400 km^2.



Annual runoff for a drainage basin of 100 to 500 km² _ Sahelian regions
Ecoulement annuel pour un bassin versant de 100 à 500 km² _ Régions sahéliennes
Fig: 24
Basins on granite and granito-gneiss _ Distribution curves
Bassins sur granite et granito-gneiss _ Courbes de distribution
Depths of runoff in mm
Lames d'eau ecoulées en mm
TOUNKOUL 750 mm (61,3 km²)
FELLEOL 550 mm (400 km²)
GOUDEBO à GUEMNI 550 mm (390 km²)
TAYA 750 mm (15 km²)
TRIBUTAIRE LAC DE BAM 630-650 mm (10,38 km²)
N B For OUADIENNE see Fig:25
Nota. Pour l'OUADI ENNE voir le Fig 25
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
200
100
50
20
10
5
2
1
0.02
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.98
0.99
O.R.S.T.O.M. Service Hydrologique
date
des.
DLV_261 780

3.3.3.4.3 Basins on marls, sandy soils and lateritic crusts (SEBIKOTANE)

Such groups of formations exist in the region of SEBIKOTANE, but in the SAHEL there are a large number of heterogeneous basins which must present the same reactions. The only basin studied is that of PANE TIOR which was observed regularly only in 1962, but we have some idea of the hydraulic nature of years near that and variations in the depth of annual rainfall are pretty well known, 1962 showed in a matter of a few days three consecutive rainstorms of 80 to 100 mm which gave rise to clearly exceptional runoff for a depth of runoff approaching the mean. An examination of rainfall-flow relations on the scale of the storm, led to the admission of the values of annual runoff E which are found below :

median P	= 620 mm	E = 30 mm	Ke $\neq$ 5 %
P 0,90	= 440 mm	E = 3,8 mm	Ke = 0,86 %
P 0,10	= 860 mm	E = 90 mm	Ke = 10,5 %

The corresponding distribution curve has been given on diagram 25. It has only an indicative value.

3.3.3.4.4 Sandstone "dogons"

Data from KOUMBAKA are inadequate for making generalization. For KOUMBAKA I median runoff borders on 55 mm for an area of 87 km^2. Certainly it decreases (everything remaining the same elsewhere), if the area of the basin increases, because, to the downstream, areas occupied by the permeable products of erosion of sandstone increase appreciably, and the forest zones of the valley bottoms which appear when the area of the basin exceeds 25 - 50 km^2, curb runoff and absorb a great deal of water. One might perhaps compare the shape of the curves to that of ECHKATA which will be seen later on. The position of the curve is a little bit more high, because of the difference of the median precipitations and it does perhaps drop a little less towards the right but everything depends on the bed of the main watercourses and on the proportion of sandstone, and on the nature of the shields over the basin. They may be impermeable to a greater or lesser extent as a matter of fact.

3.3.3.4.5 Basins of the BRAKNA

Only the few observations made on the volume contributed to the GADEL pool allow the plotting of a distribution curve (rainfall : 300 mm), S = 410 km^2. The runoff is fairly representative of neighbouring watercourses :

median P	$\neq$ 300 mm	E = 30 mm	Ke = 10 %
P 0,80	= 200 mm	E = 12 mm	Ke = 6 %
P 0,20	= 395 mm	E = 44 mm	Ke = 11,2 %

The curve is shown on diagram 25.

3.3.3.4.6 Basins on sandstone of the AFFOLE (sandstone + eolian deposits)

For the basin of the type of the upstream portion of the KARAKORO, with few eolian deposits in the centre of the AFFOLE massif, one may consider the distribution curve for the GADEL pool and raise it from 60 to 80 %.

For basins in the North invaded by eolian sands such as the Wadi BOUDIENGAR, runoff recalls that for the basins on granite, one must reduce by at least 30 % the runoff amounts from the curve for the GADEL pool.

3.3.3.4.7 Basins of the ADER DOUTCHI - MAGGIA

Disintegrated argillaceous sandstones give little surface runoff, but the colluvions which result and the marl-calcareous products have good surface runoff. Watercourse of 200 to 600 km^2 have comparable behaviour; the proportion of surfaces occupied by sandstones and the materials of the slopes differ far less from one basin to the next than for very small basins, but the nature of the bed of the principal watercourse or its slope play an important part.

One may find oneself in the presence of a true wadi with steep slope as at IBOHAMANE, TEGUELEGUEL or at SABONGA (handicapped by a considerable proportion of sandstone on the basin), or a bed with slight slope cluttered with vegetation, or a bed with slight slope and quite degraded as at JEJI SAMAE or downstream of the KAORA ABDOU station, before the confluence of TAMBAS. For the runoff coefficient in the median year this is expressed by means of variations in the interval of 18 to 8 %.

To all intents and proposes there are no more basins without a plateau of sandstone like those of GALMI, with the result that maximum values for the runoff coefficients for the median year are much lower than those for basins of 2 to 40 km^2.

For Ke coefficients bordering on 10 % for the median value curves approximating on those for BOUDAME or ECHKATA may be adopted as will be seen later, according to the state of degradation and the slope of the principal bed. Two curve-types will be shown for basins which have best surface runoff : those of TAMBAS and IBOHAMANE.

The TAMBAS basin which flows into the KORI of BADEGUICHERI not very far from the gauging station of this last mentioned watercourse, plays a most important part in the formation of the flow rates at this station of the network. The principal arm which comes from KAORA ABDOU has, in fact, already undergone hydrographic degradation to a certain extent. Correlation must be good between runoff amounts at the TAMBAS station (284 km^2) and those of BADEGUICHERI (825 km^2), as is shown by the three years of observations they have in common. The modules at BADEGUICHERI have been observed for eight years and have been reconstituted, for a longer period from rainfall data, with the result that, finally, one has at ones disposal a sample of 37 years including the eight observed years. The median value for flow at BADEGUICHERI is of the order of 0,81 m^3/s.

The year 1969 with 0,58 m^3/s presents a frequency of 0,78; 1970 with 1,54 m^3/s a frequency of 0,175, and 1971 with a module of 0,31 m^3/s a frequency of 0,93. A linear regression will be used between the modules at BADEGUICHERI and annual runoff amounts in millimetres at TAMBAS. In these conditions, the median value of runoff at TAMBAS may be calculated by interpolation between the 1970 and 1969 results. From this comes runoff of 48,7 mm rounded up to 49 mm. It is admitted that 1970 at TAMBAS corresponds to a frequency equal to 0,2 (0,175 was found for BADEGUICHERI), runoff at TAMBAS corresponding to this frequency has been rounded up to 95 mm.

For discretions sake, we have admitted for the frequency 0,9, runoff of 18 mm, less than the 20,3 mm found in 1971 (frequency of between 0,9 and 0,93).

Consequently, the distribution curve at TAMBAS is defined by means of the following points :

median P = 460 mm	E = 49 mm	Ke = 10,5 %
P 0,90 = 285 mm	E = 18 mm	Ke = 6,3 %
P 0,20 = 590 mm	E = 95 mm	Ke = 16 %

It has been shown on diagram 25.

For IBOHAMANE we have been able to locate frequencies for the most reliable years: 1965 - 1966 - 1967, by examining details of the modules at the two nearest stations in the network. That of BADEGUICHERI, already mentioned and that of the MAGGIA at TSERNAOUA.

1965 was a little above the median, 1966 was a little below the median, 1967 was very exceptional with a frequency in excess of the order of 0,25. The deficit years of 1971 to 1973 one knows little about, but it is possible to admit depth of runoff of 40 mm for the frequency 0,8 approximating to the frequency for 1971 in the region (from the point of view of runoff).

The following figures have been deduced for three points of the distribution curve :

median P	= 400 mm	E = 66 mm	Ke = 16,5 %
P 0,80	= 280 mm	E = 40 mm	Ke = 14 %
P 0,25	= 485 mm	E = 100 mm	Ke = 20,5 %

It has been extrapolated towards the extreme frequencies by taking as a guide line the curves for TAMBAS and DJAJIBINE which are best known. It is shown on diagram 25.

With the quite steep slope of the basin, sparse vegetation cover and a fairly high proportion of impermeable soils IBOHAMANE represents runoff little less than the maximum for the region, in spite of a depth of median, annual rainfall less than that for the basins of BADEGUICHERI and of the MAGGIA further south.

The curve is valid for areas of 100 to 150 km^2, it would be a good thing to alter it downwards by 15 to 20 % for basins of 500 km^2.

3.3.3.4.8 <u>Clay basins on schist</u> (Wadi GHORFA)

As long as there is no degradation, runoff coefficients are very high and nearly those found for the basins of 25 to 40 km^2. However, as soon as the slope of the principal bed decreases, the major bed becomes covered with natural vegetation or crops, it becomes degraded and the depth of runoff is considerably reduced.

Wadi DJAJIBINE, for 148 km^2, escapes this degradation. Conditions of runoff are exactly the same as those for KADIEL (see earlier), thus the same proved curve is taken, however the runoff coefficient in the hundred year wet year has been slightly reduced.

The three characteristic points correspond to the following values :

median P	= 450 mm	E = 86 mm	Ke = 19 %
P 0,98	= 200 mm	E = 22 mm	Ke = 11 %
P 0,01	= 850 mm	E = 365 mm	Ke = 43 %

The corresponding curve is shown on diagram 25.

Hydrographic degradation begins practically at the gauging station, and if one goes further downstream the runoff coefficient decreases noticeably, moreover, it seems that even for the region Wadi DJAJIBINE presents very favourable conditions of runoff. Wadi ECHKATA has far less plentiful runoff.

A very rapid examination was made of what the distribution curve might be for Wadi BOUDAME at ECHKATA ($S = 149\ km^2$) whose basin over the upstream section, with sandstone screes and sand coverings, is far more permeable than the DJAJIBINE basin.

The quality of the measurements is only fair, but it is sufficient to give an appropriate idea of conditions of runoff for this kind of basin.

The determination of depth of median runoff presents some difficulties, because the respective frequencies of the years 1965 and 1966 are not the same at ECHKATA as at DJAJIBINE; in fact, annual rainfall and runoff amounts are higher in 1966 than in 1965, the median year is close to the average of the values for runoff corresponding to these two years. E = 38 mm will be adopted which is perhaps a little pessimistic, it is not entirely out of the question for E to be equal to 40 mm. This value of 38 mm agrees with what will be found later for Wadi BOUDAME at BOUDAMA. In the same way it is possible to draw inspiration from the data from this last mentioned station in order to determine the depth of runoff in the exceptionally wet year. The poor depth of runoff for the year of heavy rainfall, 1967 at ECHKATA, leads to a low value for runoff in the hundred year wet year - 130 mm to be compared with 250 mm, for the same frequency, from Wadi BOUDAME at BOUDAMA (slightly more than double, as occurred more or less in 1967).

With regard to dry years, for a depth of annual rainfall of 300 mm, a runoff coefficient of 5 % has been estimated, clearly lower than that for 1965.

In these conditions, the distribution curve may be plotted from the three salient points as follows

median P = 440 mm	E = 38 mm	Ke = 8,6 %
P 0,87 = 300 mm	E = 15 mm	Ke = 5 %
P 0,01 = 830 mm	E = 130 mm	Ke = 15,7 %

It has been shown on diagram 25.

Basins of the order of 500 km^2 present a mixture of basins with good surface runoff and others which do not have such a good surface runoff. In addition hydrographic degradation has its part to play, a considerable part of flood crests is lost in the major bed. The drainage basin of Wadi BOUDAME at BOUDAMA ($S = 564\ km^2$) comprises a basin with poor surface runoff, that of ECHKATA and further downstream zones comparable with those of Wadi DJAJIBINE.

The years 1965 and 1966 showed a slight deficit, this is why a depth of median runoff equal to 40 mm was admitted. The year 1964 showed a definite excess, as was the case all over the SAHEL. 1967 is clearly exceptional in this part of MAURITANIA. For DJAJIBINE, the frequency for 1967 corresponds to 0,16, that for 1964 to 0,14. For Wadi BOUDAME at BOUDAMA it is probably the opposite. It has been estimated that E = 100 mm, comprised between runoff amounts for 1964 and 1967, corresponded to the frequency 0,15.

For the ten year dry year E = 12 mm is admitted.

The distribution curve for runoff amounts would therefore pass through the following three points :

median P	=	450 mm	E	=	40 mm	Ke	$\neq$	9 %
P 0,90	=	280 mm	E	=	12 mm	Ke	=	4,3 %
P 0,15	=	600 mm	E	=	100 mm	Ke	=	16,7 %

It is reproduced on diagram 25.

Between 110 km^2 and 500 km^2, a fair number of basins of the Wadi GHORFA type must exist which show conditions of surface runoff midway between those for ECHKATA and DJAJIBINE.

Unfortunately it has not been possible to taken into account the influence of the slope of the principal beds which is essential because the data relating to this particular morphological characteristic are lacking for most of the basins quoted in paragraph 3.3.3.2, and this will make the transposition of data difficult.

3.3.3.5 Procedure to follow for the evaluation of the depth of runoff in the Sahelian regimen for basins of 40 to 300 - 500 km^2.

The operations to be carried out are effectively the same as those in paragraph 3.3.2.6.1.

1°/ - To determine the area of the basin to be studied.

2°/ - To determine the median depth of annual rainfall with the help of diagram n° 1.

3°/ - To deduce from this the statistical distribution curve for annual depths of rainfall. This operation is only necessary for difficult interpolations or to control runoff amounts in very dry years.

4°/ - to study on aerial photographs or on the ground the conditioning factors for runoff. This study brings to mind the one described in paragraph 3.3.2.6.2. It rests on the total permeability, taking into account different formations encountered in every category of basin-type, on slope, vegetation cover, hydrographic network, but it presents two important differences :

1) - it is a great deal more extensive;

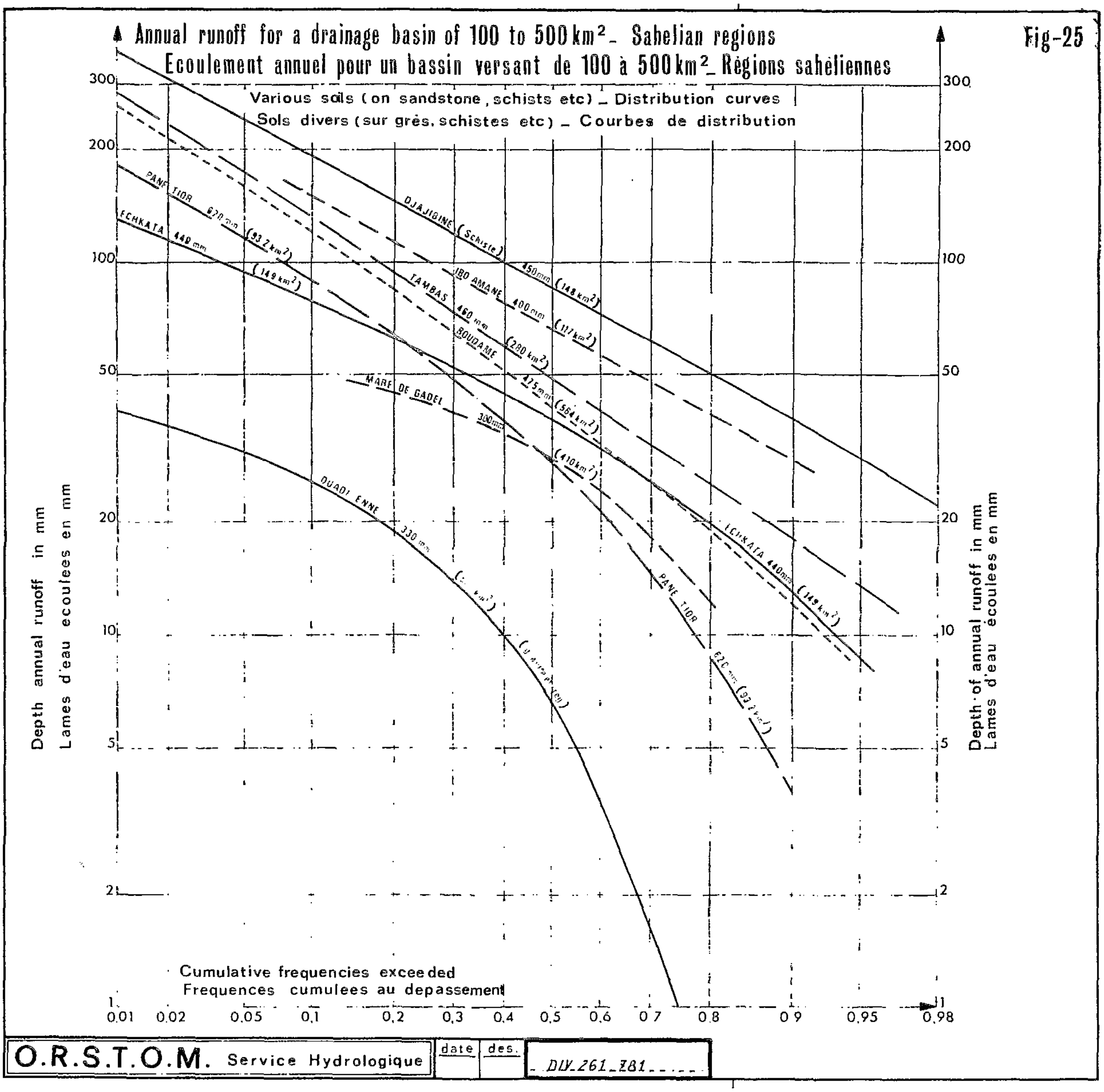
2) - the characteristics of the principal beds have to be carefully examined : slope, nature of the bed, importance and look of the major bed, the eventual existence of loss zones.

After this study has taken place, the basin may be attached to one of the cases studied in the preceding paragraph, however there is no clearest grouping for the variety in behaviour is far greater than is the case for basins of 2 to 40 km^2. Besides, the characteristics of the principal bed of the basin-types described earlier are not always clearly determined, especially slope. Each time it is advisable for one to be able to determine this slope for the basin-type one has selected.

5°/ - To study thoroughly, as in paragraph 3.3.2.6.2 the basin tributaries closest to the site where one wishes to determine runoff and especially when the principal basin has poor runoff. In the same way one will be trying to determine endorheic zones.

6°/ - If the area of the basin is definitely less than 100 km^2, one will interpolate between the results found for the same kind of basins for areas of between 25 km^2 and 40 km^2, and the results still for the same type of basin provided by the preceding paragraph.

7°/ - If the basin is on granite or granito-gneiss, and it is permeable with not very great slope, everything will depend on those regions situated in the downstream part of the basin. One will proceed as was done for OUADI ENNE; it will be necessary to deduct impermeable zones and inquire under which conditions surface runoff arising from them may reach the site to be studied.


Annual runoff for a drainage basin of 100 to 500 km²- Sahelian regions
Ecoulement annuel pour un bassin versant de 100 à 500 km²_ Régions sahéliennes
Fig-25
Various soils (on sandstone, schists etc) _ Distribution curves
Sols divers (sur grés, schistes etc) _ Courbes de distribution
Depth annual runoff in mm
Lames d'eau ecoulees en mm
Depth of annual runoff in mm
Lames d'eau écoulees en mm
300
200
100
50
20
10
5
2
1
DJAJIGINE (Schiste) 450 mm (148 km²)
IBO AMANE 400 mm (117 km²)
TAMBAS 460 mm (280 km²)
BOUDAME 425 mm (564 km²)
MARE DE GADEL 300 mm (410 km²)
PANE TIOR 620 mm (93.2 km²)
ECHKATA 440 mm (149 km²)
OUADI ENNE 330 mm
Cumulative frequencies exceeded
Frequences cumulees au depassement
0.01
0.02
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.98
O.R.S.T.O.M. Service Hydrologique
date
des.
DIV. 261_181

8°/ - If the basin is sandstone, as on the ADER DOUTCHI, or clay on schist as Wadi GHORFA, on one hand, the importance of impermeable and permeable zones needs to be examined ; this will permit the basin to be classified between the DJAJIBINE category and the ECHKATA category for basins of the Wadi GHORFA type; and on the other hand, one must study the principal bed. This will permit the distribution curve to be plotted above or below that for Wadi BOUDAME at BOUDAMA, if it is a matter of a basin of 300 to 600 km^2. The same may be done for a basin of the ADER DOUTCHI, MAGGIA type, or a basin of the FELLEOL kind.

9°/ - If the basin is granitic, not too permeable and with steep slope, even for the principal bed, and if the depth of annual rainfall is considerable, degradation is of little importance (as is the case for the Mayos of North CAMEROUN). In this case the results found for basins of the same kind of 25 to 40 km^2 will be slightly reduced, but everything depends on the slope of the principal bed. There are few basins of this type in the Sahelian zone, whereas they are more numerous in the subdesert zone (KORI TELOUA, for instance).

10°/ - To determine annual volumes for the different frequencies

Generally speaking it is necessary to try to understand the way in which runoff is brought about before attaching it to a known type and to interpolate or extrapolate , especially when it is a question of determining volumes in dry years, for all distribution curves do not have the same shape. It should be observed that the extremely slight nature of annual rainfall in dry years with a return period of 50 or 100 years, for the 300 or 400 mm isohyets, leads perforce to very poor runoff, except in the case of very impermeable basins. Also, for areas of 200 to 600 km^2, hydrographic degradation seriously reduces flow rates in this case.

3.3.4 Drainage basins of 1,000 to 10,000 km^2 in the Sahelian regimen

3.3.4.1 Generalities

The lessening of the slope of the principal bed and hydrographic degradation play an even more significant part than in basins of 40 to 300 - 500 km^2, all the more so as in a certain number of cases watercourses whose basin is in excess of 1,000 km^2 arrive in very flat zones corresponding to very large lakes or large rivers from the last major rainy period. The clearest examples are given by wadis or "riguils" which flow into the Chad basin. When they are well supplied by the upstream area with depths of rainfall close on or slightly higher than 750 mm, they succeed in preserving a well defined bed over a good distance, but when the basin receives between 300 and 400 mm (and it is not impermeable) for more than 1,000 km^2 it is almost a fossil watercourse which only presents generalized runoff every 100 or 1,000 years. It has to be realized that even the large tropical rivers coming from wet tropical regions sustain enormous losses in the Sahelian zone, the most characteristic examples are those of the NILE and the NIGER.

Even impermeable not degraded basins up to 500 km^2 present marked degradation as in the case of certain tributaries of the Wadi GHORFA and the watercourses of the ADER DOUTCHI - MAGGIA.

In all cases, the existence of a very active tributary just upstream of the site one wishes to study, plays a large part in the hydrologic regime of the principal watercourse although this is not the essential part.

In the instance of a mountain massif, with strong relief, and covering a considerable area having valleys with steep slope, as the mountain of the MANDARA in North CAMEROUN, watercourses of 1,000 km^2 and more in the sahelian zone would be real torrents, as is the case for the TSANAGA and the Mayo LOUTI in North CAMEROUN. However, only the northern part of the mountains of the MANDARA penetrate into the sahelian zone and this northern point covers an area too small to permit the existence of watercourses whose basin would cover 1,000 km^2. The massif of the GUER in CHAD is at the southern limit of the sahelian zone and the morphology of its northern slopes is such that with a basin of 1,000 km^2, the watercourses are already in the CHAD basin. The OUADDAÏ is too far north and its valleys are flat. On the contrary, the example of the KORI TELOUA, in the subdesert zone, shows that even for the 300 and 400 mm isohyets one would find very active watercourses if the morphology permitted it. There is no massif of this kind between the Atlantic Ocean and the frontier of the SUDAN, between the 300 mm and 750 mm isohyets. On the other hand there is the DJEBEL MARRA in the SUDAN for which we have only very indirect indications furnished by the BAHR AZOUM, but it must present watercourses with a high runoff coefficient.

Also in this case, watercourses on granite and granito-gneiss will often be characterized by the extreme paucity of their runoff coefficient.

It has to be observed that for basins of this importance the relation between depth of annual rainfall and depth of annual runoff is very loose. One may only say that a very marked annual rainfall measurement most probably leads to a high annual runoff and that a year with very poor annual rainfall presents at least low runoff. The distribution in time of storms plays a far more important part than on small basins and even on drainage basins of median area.

This is a drawback for the study of runoff but it is compensated for by the fact that a large number of these watercourses are observed in the hydrometric networks and that there are acceptable correlations for this area between annual runoff amounts of neighbouring rivers.

Later one will find all the information available for use. Results from certain stations have been excluded which are not yet calibrated or whose quality of observations is really too poor. Very unusual cases from which nothing may be extracted have been left out, the most typical being that of BELI (Upper VOLTA) which are will be talking about later.

3.3.4.2 Available information

For the most part this comes from the networks. The contribution of regional studies, especially those of the ADER DOUTCHI, of the BRAKNA and of the Wadi GHORFA, is important, that from the representative basins is small. Where data coming from the networks is concerned, since it is a question of difficult networks, the quality of observations is sometimes very inferior to that of results from the representative basins and regional studies. However, fortunately, the inter-station correlations permit the elimination of too inconsistent values especially when it is a question of stations on the same watercourse.

Results from drainage basins on the border of the subdesert regimen have been taken in the North and on the border of the tropical zone in the South. We have also quoted a certain number of results relating to watercourses whose drainage basin is a little less than 1,000 km^2.

Finally, in some cases, concerning stations in the network, the annual depth of rainfall, has not been given for the various years of observation for it would be too difficult to evaluate it, taking into account the low density of the rain gauges.

Wadi BOUDIENGAR (AFFOLE - Mauritania) median P : 300 mm

S = 930 km^2	1960 P = 190 mm	E = (2,4 mm)	Ke = 1,25 %
Sandstone + eolian deposits + some argillaceous zones		mean year	Ke = 1,5 %

WHITE GORGOL at AGUEIBAT (BRAKNA-Mauritania) median P : 300 - 320 mm

S = 8370 km^2	1958	P = 450 mm	E = 24 mm	Ke = 5,3 %
	1959		E = 10,7 mm	
	1971		E = 6,7 mm	
		mean year	E = 10 to 12 mm	Ke = 3,5 %

LAKE MAL (BRAKNA-Mauritania) median : 320 mm

S = 900 km^2	1958	P = 280 mm	E = 21 mm	Ke = 7,5 %
	1959	P = 200 mm	E = 2 mm.	Ke = 1 %
	1960	P = 370 mm	E = 26,2 mm	Ke = 7,1 %
			mean year	Ke = 8 %

BLACK GORGOL at FOUM GLEITA (Mauritania) median P : 380 - 390 mm

S = 8950 km^2	1958	P = (550) mm	E = 63 mm	Ke = 11,5 %
	1959	P = (370) mm	E = 36,5 mm	Ke = 9,8 %
	1960	P = (400) mm	E = 37 mm	Ke = 9,2 %
	1961		E = 27 mm	
	1964		E = 57 mm	
	1965		E = 39 mm	
	1970		E = 43 mm	
	1971		E = 33 mm	

OUADI FERA at KOURNELIA (OUADDAI - Chad) median P : 400 - 450 mm

S = 5600 km^2 - 60 km^2	1965	P = 350 mm	E = 0	Ke = 0
Local runoff	1966	P = 400 mm	E ≠ 0	Ke ≠ 0

Wadi GHORFA at GHORFA-Downstream (Mauritania) median P : 450 - 475 mm

S = 5020 km^2	1964	P = 498 mm	E = 67,2 mm	Ke = 13,5 %
	1965	P = 527 mm	E = 64,2 mm	Ke = 12,2 %
	1966	P = 447 mm	E = 33 mm	Ke = 7,4 %

Wadi BOUDAME at OULOMBOME (Mauritania) median P : 450 - 475 mm

S = 2500 km^2	1964	P = 474 mm	E = 46,8 mm	Ke = 9,9 %
	1965	P 554 mm	E = 40,6 mm	Ke = 7,3 %
	1966	P 464 mm	E = 16,7 mm	Ke = 3,6 %

Wadi GHORFA at NDAWA (Mauritania) median P : 475 mm

$S = 1850\ km^2$		1965 P = 570 mm	E = 8,7 mm	Ke = 1,5 %
		1966 P = 450 mm	E $\#$ 0	Ke $\#$ 0

Wadi BOUDAME at OULED ADDET(GUIDIMAKA-Mauritania) median P : 450 - 475 mm

$S = 1125\ km^2$	Ig = 1,10	1964 P = 490 mm	E = 95,4 mm	Ke = 19,4 %
	Dd = 2,23	1965 P = 438 mm	E = 78,2 mm	Ke = 17,8 %
		1966 P = 404 mm	E = 41,7 mm	Ke =(10,3) %
		1967 P = 541 mm	E = (115) mm	Ke = 21 %

BADEGUICHERI KORI (ADER DOUTCHI-Niger) median P : 470 mm

$S = 825\ km^2$	1966	E = 28,3 mm	
	1967	E = 43,2 mm	
	1968	E = 6,9 mm	(dubious)
	1969	E = 22,2 mm	
	1970	E = 59 mm	Median calculated over : 37 years E = 31 mm
	1971	E = 11,8 mm	
	1972	E = 17,6 mm	
	1973	E = 27,2 mm	

MAGGIA at the TSERNAOUA BRIDGE (Niger) median P : 475 - 500 mm

$S = 2525\ km^2$	1954	E = 10,9 mm	
	1955	E = 1,3 mm	(very dubious)
	1956	E = 9,5 mm	(dubious)
	1957	E = 3,3 mm	
	1959	E = 32 mm	
	1960	E = 2,9 mm	
	1962	E = 32,3 mm	
	1963	E = 16,6 mm	
	1964	E = 41,7 mm	
	1965	E = (16,8) mm	
	1966	E = 12,7 mm	
	1967	E = 22,4 mm	
	1968	E = 5,6 mm	
	1969	E = 21,8 mm	
	1970	E = 29,3 mm	
	1971	E = 8,3 mm	
	1972	E = 13,7 mm	
	1973	E = 22 mm	

MAGGIA at BIRNI NKONI (Niger) median P : 475 - 500 mm

S = 2800 km²	1954 to 1971	very difficult calibration	
	1972	E = 7,1 mm	
	1973	E = 11,7 mm	

MAGGIA at TIERASSA (Niger) median P : 475 - 500 mm

S = 2775 km²	1970	E = 17,6 mm	
	1972	E = 10 mm	
	1973	E = 13,5 mm	

GOROUOL at KORIZIENA (Niger) median P : 500 mm

S = 2500 km²	1964 P = (500) mm	E = 24 mm	Ke = 4,8 %
	1965 P = (500) mm	E = 25,4 mm	Ke = 5,1 %
	1970 P = 410 mm	E = 29 mm	Ke = 7,08 %
	1971 P = 250 mm	E = 17,7 mm	Ke = 7,1 %
	1972 P = 325 mm	E = 20 mm	Ke = 6,1 %

OUADI MANDJOBO at MOURRAH (OUADDAÏ - Chad) median P : 520 - 540 mm

S = 3500 km²	1959 P =520-530 mm	E = 3 to 6 mm	Ke =0,5 to 1,2 %
	1956 : maximum flow 250 m³/s	E = 25 mm ?	

BA THA at AM GUEREDA (OUADDAÏ - Chad) median P : 550 mm

S = 7900 km²	1957 P = (575) mm	E = 12,3 mm	Ke = 2 %
	1958 P = 520 mm	E = 19,5 mm	
	1959 P = 600 mm	E > E 1958	

BA THA at AM DAM (OUADDAÏ - Chad) median P : 530 - 550 mm

S = 10500 km²	1957 P : (600) mm	E = 13,3 mm	
	1958 P : 493 mm	E = 15,2 mm	

GOUDEBO at YAKOUTA (Upper-Volta) median P : 550 - 560 mm

S = 1640 km²	1957	E > E 1961	
	1958	E ≠ 1959	

GOUDEBO at YAKOUTA (Upper Volta) median P : 550 - 560 mm

S = 1640 km^2

1963	P =	635 mm	E =	35 mm	Ke =	5,6 %
1964	P =	600 mm	E =	31,5 mm	Ke =	5,25 %
1965	P =	565 mm	E =	29,2 mm	Ke =	5,2 %
1969	P =	560 mm	E =	57,7 mm (1)		
1970	P =	350 mm	E =	(18,3)mm	Ke =	5,25 %
1971	P =	375 mm	E =	25,3 mm	Ke =	6,7 %
1972			E > E	1971		

GOROUOL at DOLBEL (Niger) median P : 520 mm

S = 7500 km^2

1961	E =	54,7 mm
1962	E =	25,7 mm
1963	E =	34,4 mm
1964	E =	36,5 mm
1965	E =	27,7 mm
1966	E =	44,6 mm
1967	E =	36,9 mm
1968	E =	18,7 mm
1969	E =	45,9 mm
1970	E	31,3 mm
1971	E =	26,1 mm
1972	E =	24,3 mm
1973	E =	34,5 mm
	median E =	34,4 mm

DARGOL at TERA (Niger) median P : 550 mm

S = 2750 km^2

1959	E =	16 mm (very dubious)
1961	E =	82 mm
1962	E =	25,6 mm
1963	E =	41,9 mm
1964	E =	92,8 mm
1965	E =	23,5 mm
1966	E =	21,3 mm
1967	E =	47,3 mm
1968	E =	10,9 mm

(1) Value probably a little overestimated on account of calibration of the station

DARGOL at TERA (Niger) — median P : 550 mm

$S = 2750\ km^2$

	1969	E = 50,5 mm
	1970	E = 32,7 mm
	1971	E = 25,5 mm
	1972	E = 21,1 mm
	1973	E = 32 mm

DARGOL at KAKASSI (Niger) — median P : 550 - 575 mm

$S = 6940\ km^2$

	1957	E = 10,2 mm
	1958	E = 25,8 mm
	1959	E = 31,7 mm
	1960	E = 7,8 mm
	1962	E = 21,7 mm
	1963	E = 21,6 mm
	1964	E = 58 mm
	1966	E = 9,6 mm
	1967	E = 32 mm
	1968	E = 4,17mm
	1969	E = 17,7 mm
	1970	E = 19,2 mm
	1971	E = 21 mm
	1972	E = 15,9 mm
	1973	E = 19,4 mm

The KORAMA at KOUTCHIKA (Niger) — median P : 550 - 650 mm

$S = 750\ km^2$ approx.

	1958	E = 96,5 mm
	1961	E > E 1958
	1962	E = 59,4 mm
	1963	E = 39,5 mm
median E =18 to 20 mm ?	1964	E = 74 mm
	1968	E = 18 mm
	1969	E = 7,55mm
	1970	E = 4,2 mm
	1971	E = 5,5 mm
	1972	E = 0,8 mm
	1973	E = 0

Wadi NIORDE at HARR (Mauritania) — median P : 575 - 600 mm

$S = 1550\ km^2$

1964	P = 608 mm	E = 67,8 mm	Ke = 11,1 %
1965	P = 688 mm	E = 63,9 mm	Ke = 9,3 %

VENDO MENA (Upper Volta) median P : 600 mm

$S = 990\ km^2$	1963	P = 650 mm	E = 0	Ke = 0
	1964	P = 600 mm	E = 1,5 mm	Ke = 0,25 %

LAKE BAM (Upper Volta) median P : 630 - 650 mm

$S = 1478\ km^2$	1966		E = 2,4 mm	E = 3,4 mm
($440\ km^2$ endorheïc)	1967		E = 1,75 mm	E = 2,5 mm
	1968		E = 1,9 mm	E = 2,7 mm
	1969		E = 5,2 mm	E = 7,4 mm
	1972	P = 406 mm	E = 3,9 mm	E = 5,6 mm
	1973	P = 426 mm	E = 4,3 mm	E = 6,15 mm
	1974		E = 13,5 mm	E = 19,3 mm

median E 3,5 to 4,5 mm or 5 to 6 mm

LAM of BAM (Upper Volta)

(Entire basin)	1966	E = 5,4 mm
$S = 2606\ km^2$	1967	E = 5,75 mm
($440\ km^2$ endorheïc)	1968	E = 2,26 mm
	1969	E = 6,13 mm
	1970	E = 3,18 mm
	1971	E = 11,5 mm
	1972	E = 5,75 mm
	1973	E = 11,9 mm
	1974	E = 38,3 mm

GOULBI of MARADI at NIELLOUA (Niger) median P : 750 - 800 mm

$S = 4800\ km^2$	1957	E = 10,3 mm	
	1958	E = 23,7 mm	(dubious)
	1959	E > E 18,7 mm	
	1961	E = 90 mm	
	1962	E = 24,2 mm	
	1963	E = 35,4 mm	
	1964	E = 27 mm	(very dubious)
	1965	E = 20,6 mm	
	1966	E = 17,3 mm	
	1967	E = 53,5 mm	
	1968	E = 12,3 mm	
	1969	E = 17,5 mm	
	1970	E = 55,8 mm	

GOULBI of MARADI at NIELLOUA (Niger) median P : 750 - 800 mm

S = 4800 km^2	1971	E = 39,4 mm
	1972	E = 20,6 mm
	1973	E = 27 mm

GOULBI of MARADI at MADAROUNFA (Niger) median P : 750 - 800 mm

S = 5400 km^2	1956	E = 42,7 mm
	1957	E = 19,5 mm
	1958	E = 36 mm
	1961	E = 79,5 mm
	1962	E = 19,3 mm
	1963	E = 27,4 mm
	1964	E = 58,9 mm
	1965	E = 25 mm
	1966	E = 24,5 mm
	1967	E = 49,8 mm
	1968	E = 14,3 mm
	1969	E = 25,2 mm
	1970	E = 63 mm
	1971	E = 29 mm
	1972	E = 16 mm
	1973	E = 25,1 mm

GOULBI of MARADI at GUIDAM ROUJI (Niger) median P : 750 - 800 mm

S = 8800 km^2	1956	E = 24,7 mm
	1957	E = 16 mm
	1958	E = 21,8 mm
	1960	E > E 12,2 mm
	1961	E = 88 mm (1)
	1962	E = 14,7 mm
	1963	E = 21,5 mm
	1964	E = 40,8 mm
	1965	E = 18,4 mm
	1966	E = 11,1 mm
	1967	E = 36,1 mm
	1968	E = 5,98 mm
	1969	E = 9,7 mm

(1) Very marked extrapolation for the calibration curve, value greatly overestimated

GOULBI of MARADI at GUIDAM ROUJI (Niger) median P : 750 - 800 mm

$S = 8800\ km^2$		1970		E = 31,5 mm
		1971		E = 17,9 mm
		1972		E = 5,94 mm
		1973		E = 7,4 mm

MELMELE at DELEP (Chad) median P : 750 - 800 mm

$S = 1750\ km^2$		1959		E = (20,3) mm
		1960		E = (7,5) mm
		1962		E = (25,8) mm
		1964		E = (36,4) mm
provisional calibration		1965		E = (6,5) mm
		1966		E = (11,1) mm
		1967		E = (18,2) mm
		1968		E = (8,3) mm
		1969		E = (13,6) mm
		1970		E = (28,8) mm
		1971		E = (16,8) mm
		1972		E = (4,7) mm
		1973		E = (16) mm

KOULOUOKO at NIEGHA (Upper-Volta) median P : 775 mm

$S = 1010\ km^2$	Ig = (1,53)	1960	P = (650) mm	E = 15,6 mm	Ke = 2,4 %
	Dd = 1,10	1961	P = (840) mm	E = 29,7 mm	Ke = 3,5 %
		1962	P = (1150) mm	E = 105,5 mm	Ke = 9,2 %
			median	E = 30 mm	Ke = 3,9 %

BAM BAM at TIALO ZOUDOU (GUERA-Chad) median P : 800 - 835 mm

$S = 1200\ km^2$	Ig = 3,4 mm	1958		E > 1964 ?	
	Dd = 3,20 mm	1959	P = 720-750 mm	E = 75 mm	Ke # 10 %
		1960		E = 33 mm	
		1961		E > E 1959	
		1962		E < E 1959	
		1963	P = 690 mm	E = 8,7 mm	Ke = 1,3 %
		1964	P = 995 mm	E = 92,9 mm	Ke = 9,3 %
		1965	P = 716 mm	E = 8,1 mm	Ke = 1,1 %
		1966	P = 723 mm	E = 14,1 mm	Ke = 1,9 %

For these basins of 1,000 to 10,000 km^2, one will not be trying to determine median variations of runoff from observations of rainfall. On the contrary, and in a far more systematic way than on basins of 60 to 500 km^2, distribution curves will be established by use of runoff data from the network stations, and only from these curves will the values of Ke be reconstructed. To a distribution curve of annual runoff amounts there corresponds a distribution curve of annual rainfall, and the value of E, for a given frequency, simply represents the central value of all the values of the depth of runoff which correspond to annual precipitations of the same value but with different time distributions during the year.

The classification of these different types of basins has been described earlier, but it will be observed that in this case basins often cover zones very different in types, for example the greater part of the GOULBI of MARADI is on granite, whereas the stations are on residual terrains.

3.3.4.3. <u>The completion of statistical distribution curves for runoff for drainage basins of 1,000 to 10,000 km^2</u>

3.3.4.3.1 <u>Generalities</u>

It is even more difficult to give precise, general directives than is the case for basins of 100 to 500 km^2. The only thing possible is to give some examples and some qualitative indications. It is fortunate that the basins given as an example on the whole cover non-negligible areas in the Sahelian zone except for the KOLIMBINE zone where there is no station.

As stated earlier, the most reliable part of our data is furnished by the networks and the period of observation takes in both very exceptional years like 1961 or 1964 depending on the regions (their frequency is often decisively lower than the ten year frequency), and exceptional deficit years such as 1968, or 1971, or 1972.

Rainfall/flow models have been completed for the representative basins but it is no longer a question of comprehensive models, and the utilization of point rainfall series in these models pôses problems which have not been completely resolved. Somehow or other, one will establish the frequency of rainfall observed by comparison with the data from neighbouring stations. The same will be done for stations observed in the course of regional studies.

It is seen that between the 300 and 400 mm isohyets, (and sometimes between the 400 and 500 mm isohyets) on flat, permeable terrains, basins of 1,000 km^2 and above show very slight runoff in the median year. The most frequent instances are basins on granitic soil(OUADI FERA at KORNELIA, Wadi BOUNDIENGAR).

3.3.4.3.2. Basins with subsoils constituted by granite or granito-gneiss

As stated earlier, the Northern basins: OUADDAÏ, the DJIBO region, North of the basin of Lake BAM, permeable and with slight slope, have nil runoff at least one out of two years.

Further South, still for permeable terrains, runoff is again very poor : OUADI MANDJOBO (S = 3,500 km^2) at the crossing of the ABECHE-ADRE road, shows a depth of median runoff of the order of 3 mm (Ke = 0,5 %), median P = 520 - 540 mm.

The other tributaries of the OUADI BITEA, tributaries of the BA THA, do not flow copiously. We observe that in these basins there are small watercourses with noteworthy runoff, as in the case of the ABOU GOULEM stream.

The VENDO MENA at DJIBO, for 990 km^2, shows median runoff of 1 to 2 mm.

For slightly heavier rainfall and on basins of this kind, the tributary of Lake BAM, for example, (S = 1,038 km^2), the hydrographic network becomes much clearer. It has been possible to plot a distribution curve for the basin of this tributary after making allowance for the Lake BOURGANZA basin which is almost endorheic (except in 1974).

The curve is determined by the following three points :

median P	= 630 mm	E = 6 mm	Ke = 0,95 %
P 0,10	= 850 mm	E = 13 mm	Ke = 1,53 %
P 0,90	= 440 mm	E = 0,5 mm	Ke = 0,11 %

It is given on diagram 26.

Runoff amounts should be reduced by 30 % if the endorheic zone is taken into account.

If the general slope is a little more marked or the soils less permeable, one may find watercourses such as the BA THA at AM GUEREDA (S = 7,900 km^2), for which no distribution curve has been plotted because it is almost the same as the one for the GOULBI of MARADI or of the DARGOL at KAKASSI. It would pass through the following three points :

median P	= 550 mm	E = 18 mm	Ke = 3,3 %
P 0,10	= 770 mm	E = 60 mm	Ke = 7,8 %
P 0,90	= 355 mm	E = 6 mm	Ke = 1,7 %

Still among formations on granite comprising a considerable proportion of permeable soils, with marked slopes upstream and vast flood plains downstream, in CHAD one finds the MELMELE for which a very brief calibration curve has been plotted which gives flows to 25 or 30 % approx. In the interpretation of data inspiration was drawn from the flows from BA THA which are in good correlation with those for the MELMELE at DELEP (S = 1,750 km^2).

The curve which is found on diagram 26 may be defined by the three following points :

median P	= 750 mm	E = 16 mm	Ke # 2,1 %
P 0,05	= 1050 mm	E = 49 mm	Ke = 4,7 %
P 0,95	= 502 mm	E = 4,9 mm	Ke # 1 %

One may attach to this sort of basin the GOULBI of MARADI at NIELLOUA (S = 4,800 km^2) whose general slope is more slight, but which has not yet undergone hydrographic degradation.The observations are very irregular, but those for 1961 are good and those for 1968 likewise, the distribution curve is very similar to that for the MADAROUNFA station situated a little further downstream, the only difference consists in the runoff for very wet years for which there are appreciable losses between the two stations :

Slope 1 m/km	median P =	775 mm	E = 28 mm	Ke = 3,6 %
	P 0,05 =	1080 mm	E = 76 mm	Ke = 7 %

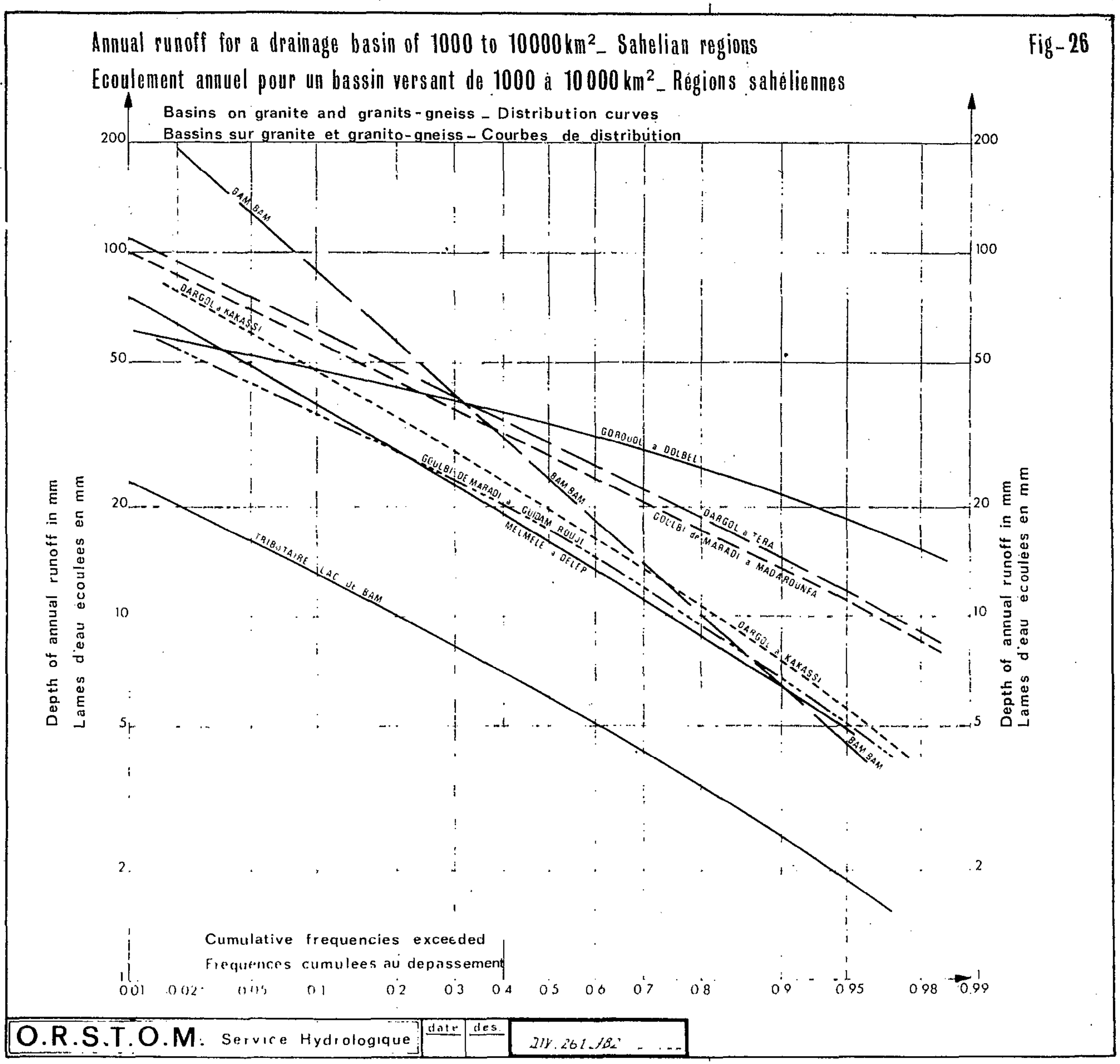
Further downstream, for the MADAROUNFA station (S = 5,400 km^2), on the same watercourse the distribution curve has been plotted which passes through the three following points :

Slope 0,5m/km	median P =	775 mm	E = 28 mm	Ke = 3,6 %
	P 0,05 =	1080 mm	E = 70 mm	Ke = 6,5 %
	P 0,95 =	450 mm	E = 11 mm	Ke = 2,45 %

This is represented on diagram 26.

Further downstream, the GOULBI of MARADI becomes degraded, and the distribution curve at GUIDAM ROUJI for a basin of 8,800 km^2 is defined by the three following points (diagram 27).

Slope 0,7m/km	median P =	750 mm	E = 17 mm	Ke = 2,26 %
	P 0,05 =	1050 mm	E = 44 mm	Ke = 4,2 %
	P 0,95 =	502 mm	E = 5 mm	Ke # 1 %



Annual runoff for a drainage basin of 1000 to 10000 km² _ Sahelian regions
Ecoulement annuel pour un bassin versant de 1000 à 10 000 km² _ Régions sahéliennes
Fig - 26
Basins on granite and granits - gneiss _ Distribution curves
Bassins sur granite et granito-gneiss – Courbes de distribution
Depth of annual runoff in mm
Lames d'eau ecoulees en mm
BAM BAM
DARGOL a KAKASSI
GOROUOL a DOLBEL
GOULBI DE MARADI a GUIDAM ROUJI
MELMELE a DELEP
DARGOL a TERA
GOULBI de MARADI a MADAROUNFA
TRIBUTAIRE LAC de BAM
Cumulative frequencies exceeded
Frequences cumulees au depassement
O.R.S.T.O.M. Service Hydrologique
date
des.

The readings for 1961 have been disregarded as the calibration curve will not permit the correct translation into flow amounts.

To conclude on these basins on granite with a considerable proportion of permeable soils and fairly marked slope, we show the distribution curve for the BAM BAM whose higher portion may be satisfactorily proved thanks to data from the exceptional year of 1964.

The area of the BAM BAM basin is 1,200 km^2.

median P	= 800 mm	E = 24 mm	Ke = 3 %
P 0,10	= 1030 mm	E = 90 mm	Ke = 8,7 %
P 0,90	= 605 mm	E = 6,5 mm	Ke = 1,1 %

If runoff is high in the wet year thanks to the slope, it is low in the dry year because of the high permeability.

The median and ten year dry runoff amounts are extremely low compared with those of the mayos of North-CAMEROUN, but it must not be forgotten that the general slope is far less and that the tributaries of the BAM BAM lose considerable quantities of water in their major bed, whereas on the TSANAGA degradation only becomes very marked to the downstream of MAROUA (for TOUNKOUL we found a median runoff coefficient of 13 %).

If one now considers basins on granite with argillaceous soils going first from North to South, one finds the GOROUOL at KORIZIENA (S = 2,500 km^2) (Slope = 0,50 m/km) whose distribution curve might be represented by reducing by 20 % the ordinates of the curve for the GOROUOL at DOLBEL which we will be considering later :

<u>median E = 27 mm</u>

<u>The GOUDEBO at YAKOUTA</u> (S = 1,640 km^2) is a tributary of the GOROUOL, with quite slight slope like the GOROUOL, its distribution curve seems to be the same as the one for the GOROUOL at DOLBEL .

Slope is perhaps of the order of 0,10 m to 0,15 m/km.

<u>The GOROUOL at DOLBEL</u> offers the better series of data for the region. The area of the basin is 7,500 km^2.

The distribution curve represented on figure 27 passes through the following three points :

median P	= 520 mm	E = 34,5 mm	Ke = 6,65 %
P 0,10	= 740 mm	E = 49 mm	Ke = 6,65 %
P 0,90	= 325 mm	E = 21,5 mm	Ke = 6,65 %

In fact the runoff coefficient certainly does not remain strictly constant, but this characteristic of Ke reflects the influence of clays which cover an important part of the basin.

To the South of the GOROUOL one finds the DARGOL with its two stations of TERA and KAKASSI, but as the rainfall regime on this basin is more homogeneous than on the GOROUOL the basin's behaviour is more normal : for the same frequency, E decreases from upstream to downstream. The slope of the valley is quite slight : 0,30 m/km.

The distribution curves for the TERA station (S = 2,750 km^2) (fig. 27) pass through the three following points :

median P	= 560 mm	E = 30 mm	Ke = 5,3 %
P 0,10	= 780 mm	E = 61 mm	Ke = 7,8 %
P 0,90	= 360 mm	E = 14,3 mm	Ke = 4 %

<u>The one for KAKASSI</u> (S = 6,940 km^2) (fig. 27) passes through the three following points :

median P	= 560 mm	E = 20 mm	Ke = 3,6 %
P 0,10	= 780 mm	E = 47 mm	Ke = 6 %
P 0,90	= 360 mm	E = 7,5 mm	Ke = 2,1 %

The SIRBA flows South of the DARGOL : one of its tributaries, the KOULOUOKO, has been studied at NIEGHA near BOULSA (Upper Volta) (S = 1,010 km^2) slope of bed 0,25 m/km; thanks to a really exceptional rainstorm in 1962 one has fairly good knowledge of the upper part of the distribution curve, the depth of median runoff may be estimated at 30 mm.

This curve might be plotted from the three following points :

median P	= 775 mm	E = 30 mm	Ke = 3,9 %
P 0,01	= 1220 mm	E = 110 mm	Ke = 9 %
P 0,90	= 580 mm	E = 14 mm	Ke = 2,4 %

It has not been plotted on diagram 27 so as not to overload it, it is very easy to put in as it is almost intermingled with the one for the DARGOL at TERA, it has been established that the slight slope is compensated for by the impermeability of the soil.

Before leaving the basins of the North-east of UPPER VOLTA, a few words may be said about the BELI a tributary of the GOROUOL which receives 400 mm to 450 mm per year (median value), but the principal bed has very slight slope,even in a natural state it comprised many pools, and on its left bank it receives several tributaries with appreciable runoff. The southern part of the basin is very silted up. Generally speaking, the water from the left bank tributaries is reserved in the pool immediately upstream; this is for example, the case for the FADAR FADAR pool without there being any communication with "downstream". Even the GOROUOL at the confluence of the BELI begins to send its waters into the pool of the BELI closest to the upstream area.At the end of the rainy season this pool restores its waters tc the GOROUOL.It happens that all the pools of the BELI valley join up,and there is generalized runoff towards the downstream area, that is to say towards the NIGER. This occurred in 1963.

3.3.4.3.3 Clay basins on schists

One takes up again the basins of MAURITANIA studied in various earlier paragraphs or chapters.

The watercourses of the BRAKNA show considerable endorheic zones, further south runoff is a little more important,attempts have been made to plot the distribution curve for the GORGOL NOIR at FOUM GLEITA ($S = 8,950\ km^2$). Median E must be close on 35 mm.

By comparison with BADEGUICHERI which will be seen further on, we have been able to estimate :

E 0,10 at 70 mm

and

E 0,90 at 10 mm

The curve next to that for BADEGUICHERI has not been plotted, it would pass through the three following points :

median P	=	390 mm	E	=	35 mm	Ke	=	9 %
P 0,10	=	580 mm	E	=	70 mm	Ke	=	12 %
P 0,90	=	215 mm	E	=	10 mm	Ke	=	4,4 %

It only corresponds to a simple indication as it rests on very few data.

Data for the basin of the Wadi GHORFA are difficult to utilize for basins of this size, for only three or four years of observation are at our disposal. Only rainfall/flow relations which are well known for each year,storm by storm, may serve as guide for the evaluation of frequencies for the observed runoff amounts.

The heterogeneous character of this basin is most interesting. If the Wadi DJAJIBINE corresponds to runoff conditions close to optimum conditions, other tributaries like the Wadi GHORFA at NDAWA whose basin ($S = 1{,}850\ km^2$) reminds one a little of the ECHKATA basin, and whose bed, flat and very choked with vegetation, present nil median runoff.

<u>The Wadi GHORFA at OULOMBOME</u> ($S = 2{,}500\ km^2$) is fed by the tributaries of the downstream part of the basin. Somehow taking as guide the curves for the other stations of the Wadi GHORFA, it has been possible to plot a distribution curve which passes through the three following points :

median P	=	460 mm	E	=	35 mm	Ke	=	7;6 %
P 0,20	=	600 mm	E	=	55 mm	Ke	=	9,2 %
P 0,80	=	325 mm	E	=	16 mm	Ke	$\#$	4,9 %

The curve is shown on diagram 28.

The Wadi BOUDAME at OULED ADDET ($S = 1{,}125\ km^2$) receives the Wadi DJAJIBINE but this is one of its most outstanding tributaries.

By combining the curves for these tributaries of less than 1,000 km^2 and data collected directly, it has been possible to plot the distribution curve for runoffs which passes through the three following points :

median P	=	460 mm	E	=	65 mm	Ke	=	14,1 %
P 0,15	=	625 mm	E	=	105 mm	Ke	=	16,8 %
P 0,90	=	270 mm	E	=	20 mm	Ke	=	7,4 %

This is the basin-record for runoff amounts on basins of 1,000 km^2 in the SAHEL. The whole difference is measured with surface runoff on the DJAJIBINE basin.

Further downstream, the Wadi GHORFA with a drainage basin of 5,020 km^2 received yield from the Wadi BOUDAME and some small tributaries which very appreciably reinforce its rather mediocre contributions at OULOUMBOME.

It has been possible to plot an approximate curve passing through the three points here defined :

median P	= 460 mm	E = 48 mm	Ke = 10,4 %
P 0,15	= 625 mm	E = 75 mm	Ke = 12 %
P 0,90	= 270 mm	E = 15 mm	Ke = 5,5 %

South of the Wadi GHORFA, the Wadi NIORDE at HARR (S = 1,550 km^2) would give a distribution curve defined as follows :

median P	= 600 mm	E = 50 mm	Ke = 8,3 %
P 0,10	= 820 mm	E = 130 mm	Ke = 15,8 %
P 0,90	= 400 mm	E = 16 mm	Ke = 4 %

3.3.4.3.4 <u>Basins of the ADER DOUTCHI and the MAGGIA</u>

Three watercourses may be classified in this category : the KEITA valley, the BADEGUICHERI valley and the MAGGIA valley. The KEITA valley only comprises stations on the upstream tributaries (IBOHAMANE, TEGUELEGUEL etc..)

On the other hand, those of the BADEGUICHERI and the MAGGIA have been studied since 1954 for the MAGGIA and since 1966 for the BADEGUICHERI valley.

For the BADEGUICHERI station (S = 825 km^2) a flow/rainfall study over 37 years has facilitated the plotting of the distribution curve. The three characteristic points are found as follows :

median P	= 470 mm	E = 31 mm	Ke = 6,6 %
P 0,02	= 825 mm	E = 90 mm	Ke = 10,3 %
P 0,95	= 235 mm	E = 7,5 mm	Ke = 3,2 %

For the valley of the MAGGIA the two stations of the TSERNAOUA bridge and BIRNI N'KONI present several difficulties.

For the first, the years 1954 to 1957 furnish data which are of little use. Several correlations with neighbouring stations tend to show that the values are underestimated: either the flood crests have been disregarded by the reader, or the destruction of the natural vegetation in the valley after 1957 has increased runoff, or both factors at one and the same time. Data for these four years have not been considered in the drawing up of the distribution diagram.

For BIRNI N'KONI, the first station was almost impossible to calibrate, the readings only give a qualitative idea of the variations of the frequencies, since 1972, observations have been made downstream of the bridge and the station has been rated , the annual modules for 1972 and 1973 have furnished two points of reference for the plotting of this curve, but little is known about runoff amounts for wet years.

The distribution curve for the TSERNAOUA bridge (fig. 28) ($S = 2{,}530\ km^2$) passes through the three following points :

median	P = 480 mm	E = 15 mm	Ke = 3,15 %
P 0,02	= 835 mm	E = 46 mm	Ke = 5,5 %
P 0,95	= 250 mm	E = 3,7 mm	Ke = 1,48 %

In spite of slightly more copious rainfalls, the coefficient of runoff is lower than at BADEGUICHERI. This is due to a more extensive basin, in the absence of a basin with good surface runoff in close proximity to the station, like that of TAMBAS for BADEGUICHERI and perhaps a greater extent of sandstone plateaux which have low surface runoff.

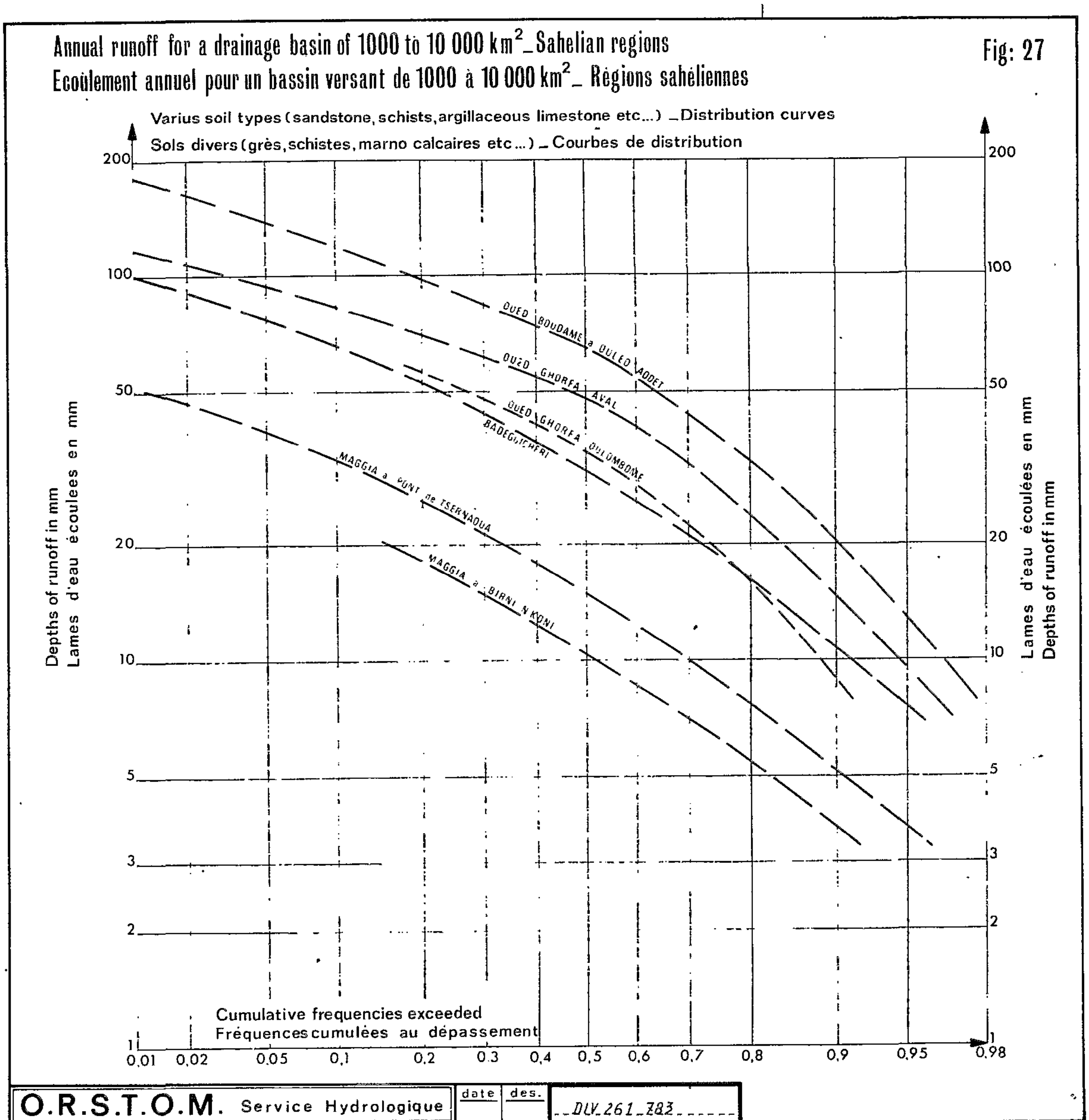
Whatever the case, the difference between runoff on these basins of more than 1,000 km^2 and those of 200 km^2 is considerable.

Further downstream the hydrographic network quickly becomes degraded. On the MAGGIA at BIRNI N'KONI, for an area of 2,800 km^2 runoff amounts are clearly lower than at the TSERNAOUA bridge.

For median	P = 480 mm	E = 10,5 mm	Ke = 2,2 %
P 0,80	= 380 mm	E = 5,4 mm	Ke = 1,4 %

For P 0,80 at the TSERNAOUA bridge, we found E = 7,6 mm

To the downstream of BIRNI N'KONI and of the BADEGUICHERI bridge, runoff amounts decrease very rapidly. Let us recall that it is on this type of basin that we found the GALMI streams which presented the highest runoff for the 25 km^2 category.


Annual runoff for a drainage basin of 1000 to 10 000 km^2 _ Sahelian regions
Ecoûlement annuel pour un bassin versant de 1000 à 10 000 km^2 _ Régions sahéliennes
Fig: 27
Varius soil types (sandstone, schists, argillaceous limestone etc...) _ Distribution curves
Sols divers (grès, schistes, marno calcaires etc...) _ Courbes de distribution
Depths of runoff in mm
Lames d'eau écoulées en mm
OUED BOUDAME à OULED ADDET
OUED GHORFA AVAL
OUED GHORFA OULOMBONE
BADEGUICHERI
MAGGIA à PONT de TSERNAOUA
MAGGIA à BIRNI N'KONI
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
200
100
50
20
10
5
3
2
1
0,01
0,02
0,05
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
0,95
0,98
O.R.S.T.O.M. Service Hydrologique
date
des.
DLV.261_783

3.3.4.4. <u>Conclusion</u> - <u>Some directives for the evaluation of depth of runoff in the Sahelian regimen for basins of between 1,000 km^2 and 10,000 km^2</u>

It is even more difficult to generalize results than it is for basins of 40 km^2 to 300-500 km^2, that is why the gaps in our information are of greater consequence. Except for the vast plains with vertisols and the zones covered with sand deposits where watercourses of this importance do not exist or are moribund, the most serious gaps are in the zone between the central delta of the NIGER and the massif of the AFFOLE and Wadi GHORFA. Here the study of runoff presents serious problems. In fact, it is only really possible to transpose results from the preceding paragraph in these two instances :

1°/- If the station under consideration is upstream or downstream of a station studied in paragraph 3.3.4.3;

2°/- if the basin whose runoff characteristics one wishes to determine is located in a homogeneous hydrologic zone with similar principal valleys and with a well known basin in this homogeneous zone on another watercourse, but not too far away from the station which is to be studied.

Even in these two instances the transposition of results is difficult.

It is fortunate that with the group of basins,distribution curves have been established earlier, a considerable area is covered so that it is not improbable that one of these two instances may be encountered.

There are still two gaps to be pointed out : the KORAMA (Niger) with a very special regimen has been discarded, the EL BEÏD (North-Cameroun) which is in actual fact a watercourse flowing out of the LOGONE has not been studied (reference may be made to the Monograph on Lake CHAD by P. TOUCHEBEUF de LUSSIGNY - 1969), for this present study does not consider the hydrological problems of the big tropical rivers arriving in the SAHEL, among whose number are the CHARI and the LOGONE, these problems are examined in the corresponding monographs.

In any case, operations to be carried out which aim at a good knowledge of both the reference basin and the one which it is desired to study are practically the same as those described in paragraph 3.3.3.5.

1°/- The area of the basin is determined : although this element is not of great importance.In the case of a basin with a station already studied in paragraph 3.3.4.3, one will rather study in the principal bed everything which may allow the provision of an index on the slopes between the station and the site which is to be studied, and large endorheic zones.

2°/- The median depth of annual precipitation will be determined.

3°/- From this one will deduce the statistical distribution curve for the depths of annual precipitation which may be of service.

4°/- As in paragraph 3.3.3.5 one will study the conditioning factors for runoff on the basin, tributary by tributary , including the characteristics of the principal beds. This study leads to the selection of one or more reference basins from paragraph 3.3.4.3.

5°/- Tributary basins closest to the station to be studied (the case for BADEGUICHERI and the TAMBAS)should not be neglected.

6°/- Proceed to the same study on the reference basin or basins. The study of the principal bed is of prime importance. Data is lacking for proper calculation of the influence of the slope of this principal bed, this influence is significant but seems to play different parts depending on the basin's permeability.

7°/- If the basin area is between 500 km^2 and 1,000 km^2 one will take into account runoff amounts which are intermediate between those of paragraph 3.3.3. and of paragraph 3.3.4.

8°/- After carefully selecting the reference basin and collecting some indications on the corrections to apply to the data from the reference basin in order to reduce them to terms of what may be runoff on the basin to be studied, one will then determine the distribution curve. It may be useful to consider two reference basins .

9°/- Annual volumes for the different frequencies will be determined.

One must not lose sight of the fact that in 10 or 20 km, or sometimes only a few kilometres, the watercourse may become completely degraded. The hydrologist gradually finds himself in a more difficult province.

3.3.5. Drainage basins with an area of more than 10,000 km^2

3.3.5.1. Generalities

Few sahelian watercourses still show runoff every year or almost every year where a basin exceeds 10,000 km^2. There are only seven or eight up to the frontier with the SUDAN, from West to East.

The KARAKORO, a tributary of the SENEGAL (whose upstream basin has been mentioned previously), the KOLIMBINE, likewise a tributary of the SENEGAL, the WHITE VOLTA, the GOROUOL a tributary of the central NIGER, the SIRBA tributary of the central NIGER, the KOMADOUGOU YOBE tributary of Lake CHAD, the BA THA which flows into Lake FITRI, and the BAHR AZOUM very theoretical tributary of the CHARI which comes from the DJEBEL MARRA in the SUDAN. GOROUOL, SIRBA and KOMADOUGOU are situated at the southern limit of the sahelian regimen, which explains the fact that they are able to flow over such an extent.The BAHR AZOUM comes from a mighty mountain massif and disappears practically downstream of the main station of AM TIMAN. The KARAKORO and the KOLIMBINE come from the North fed by tributaries some of which perhaps flow over soils comparable with those of DJAJIBINE. The WHITE VOLTA also flows from North to South.

One knows almost nothing about the KARAKORO. On the KOLIMBINE we only have data from 1935 and 1936 with measurements which were certainly made with very few means available, but which were made conscientiously, a fact which compensates very considerably. For all the other watercourses there are at our disposal observations made over a long period and which are of pretty good quality. Of course there is occasionally a year which is rather freakish but not to the extent where the distribution curve might be inaccurate.

Needless to say that the depth of mean precipitation does not contribute much, but dry or wet years are almost the same everywhere with, however, appreciable variations from one basin to the next.

Further on will be seen all what is known about the annual runoff from watercourses within this category.

3.3.5.2. Available information

It comes from the network data, except for the KOLIMBINE where it stems from the study of a project.

Median precipitations are of no great significance as often it is the wettest part of the basin which influences the regimen most. For example, on the BA THA, it is the region where the depth of annual precipitation is equal to or greater than 600 mm/year.

The BAHR AZOUM at AM TIMAN   median P : (500 - 600 mm) ?

$S = 80{,}000\ km^2$

1953	E =	16,8	mm	1965	E =	4,08	mm
1954	E =	20,2	mm	1966	E =	4,78	mm
1955	E =	12,3	mm	1967	E =	11	mm
1956	E =	19,4	mm	1968	E =	6,5	mm
1959	E =	16	mm	1969	E =	10,8	mm
1960	E =	5,95	mm	1970	E =	22,2	mm
1961	E =	16,9	mm	1971	E =	11,7	mm
1962	E =	12,3	mm	1972	E =	3,55	mm
1963	E =	8,75	mm	1973	E =	5,45	mm
1964	E =	14	mm	1974	E =	18,1	mm

The BA THA at ATI (CHAD)   median P : 500 mm ?

$S = 45{,}290\ km^2$

Slope 0,29 m/km

1955	E =	12,5	mm	1965	E =	6,2	mm
1956	E =	20,8	mm	1966	E =	5,0	mm
1957	E =	8,3	mm	1967	E =	13,1	mm
1958	E =	10,1	mm	1968	E =	3,5	mm
1959	E =	21,6	mm	1969	E =	8,8	mm
1960	E =	2,6	mm	1970	E =	24,8	mm
1961	E =	46,2	mm	1971	E =	3,75	mm
1962	E =	24,8	mm	1972	E =	3,4	mm
1963	E =	3,0	mm	1973	E =	8,95	mm
1964	E =	34,7	mm	1974	E =	14,6	mm

The BA THA at OUM HADJER (CHAD) median P : 500 mm ?

$S = 32{,}950\ km^2$

Slope 0,60 m/km

1955	E =	24,8	mm (dubious)	1966	E =	7,58	mm
1957	E =	12,9	mm	1967	E =	17,3	mm
1958	E =	9,77	mm	1968	E =	8,57	mm
1959	E =	34,33	mm	1970	E =	27,10	mm
1960	E =	3,12	mm	1971	E =	8,55	mm
1961	E =	46,2	mm	1972	E =	4,30	mm
1962	E =	21,2	mm	1973	E =	22,10	mm
1963	E =	8,1	mm	1974	E =	31,6	mm
1964	E =	58,5	mm				

The KOMADOUGOU at BAGARA (Niger) median P : 750 mm ?

S = 115,000 km^2

1957	E =	4,1 mm	1967	E =	4,8 mm
1958	E > E	1962	1968	E =	5,0 mm
1962	E =	7,8 mm	1969	E =	5,1 mm
1963	E =	4,9 mm	1970	E =	5,6 mm
1964	E =	8,3 mm	1971	E =	4,7 mm
1965	E =	6,0 mm	1972	E =	3 mm
1966	E =	6,1 mm	1973	E =	2,28 mm

The KOMADOUGOU at GUESKEROU (Niger) median P : 750 mm ?

S = 120,000 km^2

1957	E =	4,3 mm (dubious)	1966	E =	4,2 mm
1958	E > E	1962	1967	E =	3,05 mm
1960	E < E	1961	1968	E =	3,2 mm
1961	E =	3,95 mm	1969	E =	3,2 mm
1962	E =	4,75 mm	1970	E =	3,50 mm
1963	E =	3,4 mm	1971	E =	3,15 mm
1964	E =	4,95 mm	1972	E =	2,2 mm
1965	E =	4 mm	1973	E =	1,55 mm

The GOROUOL at ALCONGUI median P : 550 mm ?

S = 44,850 km^2

1957	E =	2,23 mm	1966	E =	5,40 mm
1958	E =	6,23 mm	1967	E =	4,13 mm
1959	E =	4,45 mm	1968	E =	2,91 mm
1961	E =	5,24 mm	1969	E =	6,10 mm
1962	E =	2,1 mm	1970	E =	5,63 mm
1963	E =	2,8 mm	1971	E =	4,38 mm
1964	E =	5,38 mm	1972	E =	3,23 mm
1965	E =	2,76 mm	1973	E =	5,67 mm

The WHITE VOLTA at WAYEN median P : 650 - 700 mm ?

S = 20,000 km^2

Provisional data

1955	E =	(7,4) mm	1969	E =	5,52 mm
1965	E =	(16,8) mm	1970	E =	5,2 mm
1966	E =	(4,25)mm	1971	E =	5,0 mm
1967	E =	(11) mm	1972	E =	2,75 mm
1968	E =	3,5 mm	1973	E =	(12,6) mm

The SIRBA at GARBEY KOUROU median P : 700 mm ?

$S = 38,750\ km^2$	1956	E = 25,1 mm		1966	E = 5,53 mm
	1957	E = 3,8 mm		1967	E = 34,7 mm
	1958	E = 62,6 mm		1968	E = 2,16 mm
	1962	E = 28,1 mm		1969	E = 13,8 mm
	1963	E = 4,65 mm		1970	E = 8,12 mm
	1964	E = 26,9 mm		1971	E = 4,65 mm
	1965	E = 32,2 mm		1972	E = 4,85 mm

The KOLIMBINE on coming out of Lake MAGUI (Mali) median P : 600 - 650 mm ?

$S = 20,000\ km^2$	1935	E = (32) mm		1936	E = (35) mm
	1935	would have been a little exceptional.			

3.3.5.3. Distribution curves

There is no question of plotting this for the KOLIMBINE. It appears that median E is in the neighbourhood of 30 mm. The year 1935 seemed rather wet at that time. It would be a maximum for watercourses of this category. This value for the depth of runoff would correspond to Ke in the neighbourhood of 5 %. It should be added that runoff downstream of Lake MAGUI has already undergone evaporation losses on the lake (more than 2 m per annum). Runoff upstream of the lake would be definitely greater. This might be explained by runoff amounts on the schists or sandstones of the basin comparable with those observed at OULED ADDET on the BOUDAME.

The WHITE VOLTA at WAYEN, in spite of WAYEN's somewhat southerly situation (PK 55) on the way from OUAGADOUGOU to NIAMEY has a basin which clearly is sahelian. The North of the basin is practically endorheic, Lake BAM only flooded towards the WHITE VOLTA in 1974, after more than ten years without overflowing. The parts of the basin situated further West were studied in 1964 and 1965 at the same time as the représentative basins of TIKARE and ANSOURI, runoff there was not more copious than in the Lake BAM area. Most of the runoff thus stems from the Southern half of the basin. It will be understood that in a dry year it must be very poor by reason of the slight slope and the permeability of a large part of the basin. In an exceptionally wet year, runoff is far more abundant, it tends to become generalized.

Values of E have been determined concisely. They will be stated precisely later when, on the occasion of the elaboration of the VOLTA Monograph, the data from this station will form the object of a far more searching analysis.

The distribution curve given on fig. 28 might be defined by the three following points :

median P	= 675 mm	E	= 6 mm	Ke	= 0,9 %
P 0,05	= 965 mm	E	= 14,2 mm	Ke	= 1,47 %
P 0,95	= 480 mm	E	= 2,6 mm	Ke	= 0,54 %

The station for the GOROUOL at ALGONGUI is not excellent, low water flows are not properly known in consequence of backwash from the NIGER, but as a whole observations are of acceptable quality. Wet years are found which are well known : 1961, 1964, 1970, but 1966, 1958 and 1969 are also years of abundant flow. The year 1962 is the poorest before 1957 - 1965 and 1968 the well known years.

The curve passes through the three following points :

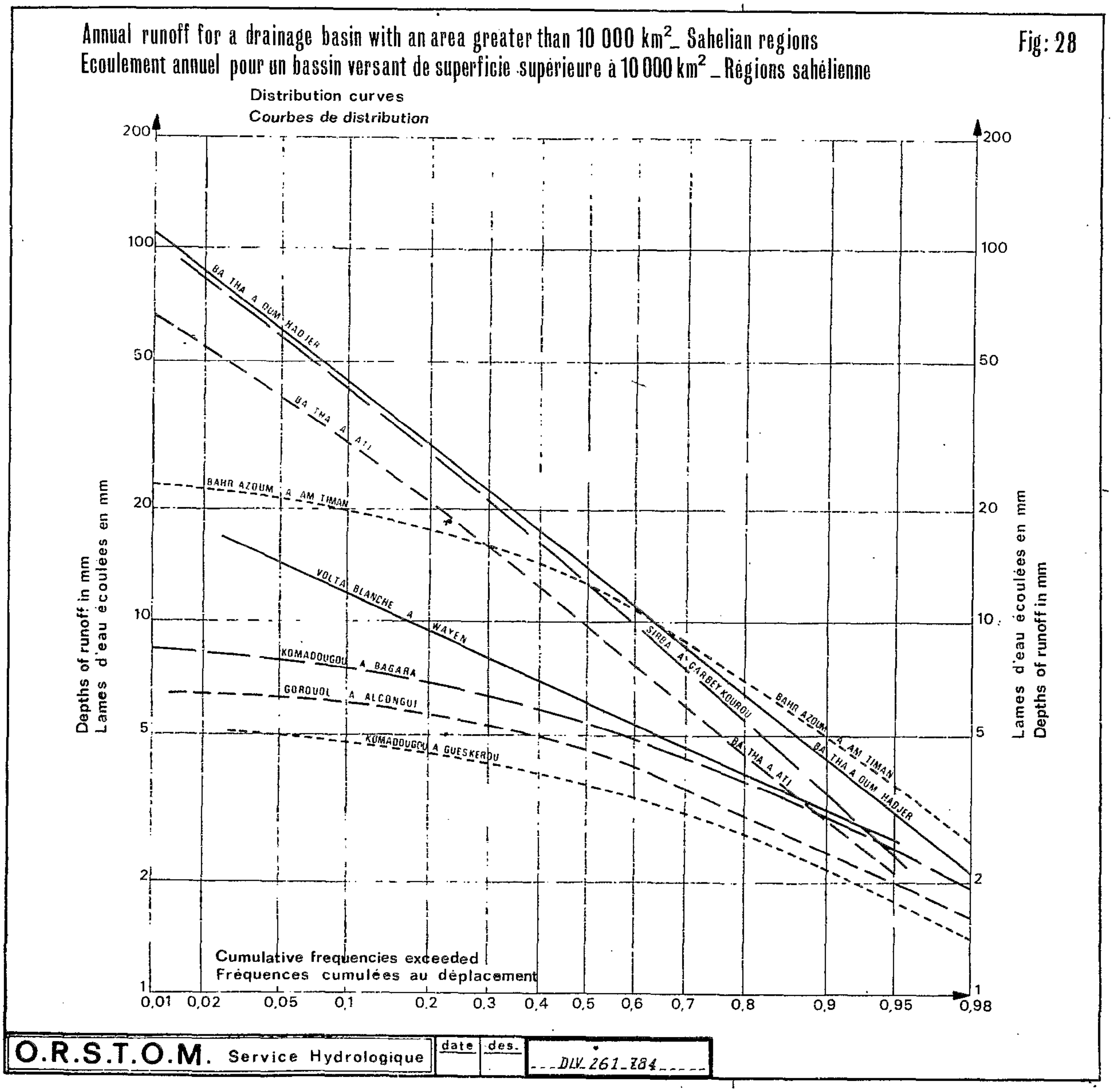
median P	= 550 mm	E	= 4,5 mm	Ke	= 0,82 %
P 0,02	= 910 mm	E	= 6,4 mm	Ke	= 0,7 %
P 0,98	= 270 mm	E	= 1,6 mm	Ke	= 0,59 %

It will observed that in wet years with the filling of the pools of the BELI losses are such that Ke is poorer than in the median year, a phenomenon of the same kind is encountered on the KOMADOUGOU and the BAHR AZOUM.

The curve is given on fig. 28.

The KOMADOGOU shows enormous losses in a flat and permeable basin, then in the flood plains of the CHAD basin. It may be seen through the losses between BAGARA and GUESKEROU.

Effectively we have plotted the two distribution curves for these two stations. Heavy years are found 1964 - 1962, dry years 1972 and 1973. The year 1968 shows a slight deficit.


Annual runoff for a drainage basin with an area greater than 10 000 km²_ Sahelian regions
Ecoulement annuel pour un bassin versant de superficie supérieure à 10 000 km² _ Régions sahélienne
Fig: 28
Distribution curves
Courbes de distribution
Depths of runoff in mm
Lames d'eau écoulées en mm
BA THA A OUM HADJER
BA THA A ATI
BAHR AZOUM A AM TIMAN
VOLTA BLANCHE A WAYEN
KOMADOUGOU A BAGARA
GOROUOL A ALCONGUI
KOMADOUGOU A GUESKEROU
SIRBA A GARBEY KOUROU
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
0,01 0,02 0,05 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 0,95 0,98
1 2 5 10 20 50 100 200
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The distribution curves plotted on fig. 28 pass through the following three points :

KOMADOUGOU at BAGARA :

median P	= 750 mm	E = 5,4 mm	Ke = 0,72 %
P 0,02	= 1070 mm	E = 8,2 mm	Ke = 0,77 %
P 0,98	= 460 mm	E = 1,9 mm	Ke = 0,41 %

KOMADOUGOU at GUESKEROU

median P	= 750 mm	E = 3,7 mm	Ke = 0,49 %
P 0,02	= 1070 mm	E = 5,2 mm	Ke = 0,48 %
P 0,98	= 460 mm	E = 1,4 mm	Ke = 0,30 %

In the median year, the KOMADOUGOU loses nearly 200,000,000 m^3 between BAGARA and GUESKEROU. In the 50 year wet year, it loses nearly 350,000,000 m^3.

The BAHR AZOUM benefits from the existence of several active tributaries : the OUADI AZOUNGA on the frontier with CHAD has appreciable flood flows, but at AM TIMAN, several arms have already left the BAHR on the right bank. We have to go up to MOURAIA in order to find a bed with little degradation or better still KOUKOU ANGARANA, but the station is not calibrated. So losses are still higher than for the KOMADOUGOU, which explains the shape of the distribution curve.

Heavy years are : 1954, 1956, 1959, 1961, 1964, 1970 and 1974. Dry years are : 1960, 1965, 1966, 1968, 1972 and 1973. The distribution curve ascertained over 20 years, is reproduced on fig. 28, it may perhaps be defined through the three following points :

median P	= 600 mm	E = 12,5 mm	Ke = 2,28 %
P 0,02	= 970 mm	E = 22,5 mm	Ke = 2,32 %
P 0,98	= 325 mm	E = 2,5 mm	Ke = 0,77 %

Here Ke really has no significance. P itself has not a great deal more. It will be noted that Ke is almost the same for P 0,02 as it is for median P.

The last two watercourses, less reduced perhaps, show much more dissymetric distribution curves and yet they are very different.

The SIRBA drains a flat, relatively impermeable basin, one of its tributaries was studied earlier : the KOULOUOKO at NIEGHA, the BA THA which is a more uneven basin but a far more permeable one. The two basins are at the southern limit of the sahelian zone. The BA THA network is probably more degraded than that of the SIRBA : one of its important tributaries, the BITEA, is practically endorheic. The bed of the SIRBA tributaries is perhaps a little less marked by reason of the slight slopes. But,finally,the influence of soil impermeability prevails, the median depth of runoff on the SIRBA is 30 % higher than that for the BA THA. On the SIRBA, the very wet years are : 1958, 1967, 1965, 1962 (exceptional flood flow on the upstream basin), unfortunately 1961 was not observed. 1962 is a typical example. Generally speaking, this year is not very heavy, but a single quite exceptional rainstorm on the KOULOUOKO sufficed for its frequency to be low on the SIRBA.

For the dry years, 1968 is well situated, as almost everywhere in the SAHEL, with 1957, 1971, 1963 and 1972. However the years 1971 and 1972 do not seem exceptionally dry, less in all cases than on the BA THA or the BAHR AZOUM.

The distribution curve is difficult to plot for even with the approximate value for runoff in 1973,only 16 years are available and there is great irregularity.

The distribution which does within a little approximate to a gaussian logarithm distribution may be defined by means of the three following points :

median P	=	700 mm	E	=	12,5 mm	Ke	=	1,8 %
P 0,05	=	990 mm	E	=	54 mm	Ke	=	5,5 %
P 0,95	=	460 mm	E	=	2,4 mm	Ke	=	0,52 %

At the ATI station on the BA THA,the years 1964 and especially 1961 are exceptionally heavy, they are followed by 1970, 1962, 1959, 1956. The years 1960 and 1963 are very dry years, more than 1972, 1968 and 1971. The years 1971 and 1972 presented the same severity as 1968.

The distribution curve is quite easy to plot, it corresponds with a law which is almost gaussian logarithmic and which recalls that for BAM BAM and its tributaries. This distribution is explained by the very low runoff amounts in a dry year on often permeable soils and by heavy runoff amounts in an exceptionally wet year, with rainfall of the order of 900 mm and nearly 1,000 mm for the southern most regions of the basin.

The curves passes through the following three points :

median P	= 500 mm	E	= 9,7 mm	Ke	= 1,94 %
P 0,01	= 920 mm	E	= 66 mm	Ke	= 7,2 %
P 0,95	= 270 mm	E	= 2,2 mm	Ke	= 0,82 %

It is shown on fig. 28.

It is extremely difficult to plot the distribution curve for frequencies higher than the ten years frequency as it seems that the decrease in runoff may be very slow when the frequency increases beyond 0,90. The curve has been stopped at the 0,95 frequency and even towards this frequency it perhaps overestimates runoff.

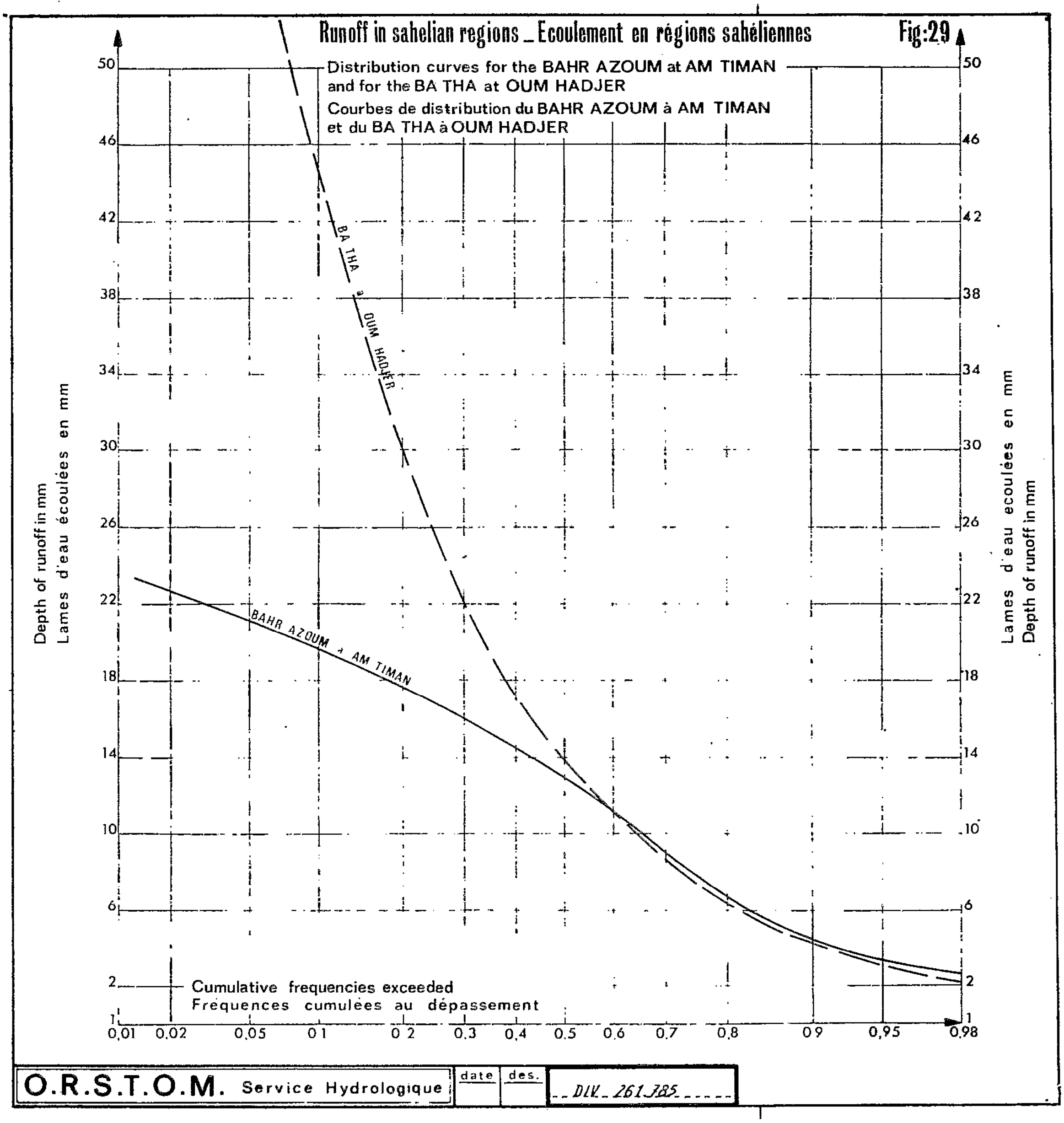
The correlation between data from OUM HADJER and that from ATI is good, particularly for the last years, which proves that the cross sections remained almost stable after the last, relatively old, control gaugings.

The distribution curve for annual runoff amounts given on fig. 28 passes through the three following points :

median P	= 500 mm	E	= 14 mm	Ke	= 2,8 %
P 0,01	= 920 mm	E	= 110 mm	Ke	= 11,9 %
P 0,95	= 270 mm	E	= 3,1 mm	Ke	= 1,15 %

3.3.5.4. <u>A few directives for the use of the distribution diagrams.</u>

Fig. 28 displays two families of curves : a first series whose depths of runoff in exceptional years tend to almost be bounded with distributions which on first approximation one might consider gaussian. This category takes in the KOMADOUGOU, the GOROUOL and the BAHR AZOUM. We have plotted in gaussian normal coordinates, representative points for the distribution for the BAHR AZOUM. From the fifty years dry year to the ten year wet year one might adopt GAUSS'law without making any appreciable error, but beyond, that the variation is far less rapid and this is most important for the dry years, a knowledge of which is essential for the exploitation of reservoirs. When one adapts to these experimental curves analytical relations for computer use, it will be necessary to respect the right part of these curves and not be content to take the three points which we give in the text in order to determine from these points the law which should be adopted.



Runoff in sahelian regions _ Ecoulement en régions sahéliennes
Fig:29
Distribution curves for the BAHR AZOUM at AM TIMAN
and for the BA THA at OUM HADJER
Courbes de distribution du BAHR AZOUM à AM TIMAN
et du BA THA à OUM HADJER
Depth of runoff in mm
Lames d'eau écoulées en mm
BA THA à OUM HADJER
BAHR AZOUM à AM TIMAN
Cumulative frequencies exceeded
Fréquences cumulées au dépassement
50
46
42
38
34
30
26
22
18
14
10
6
2
1
0,01
0,02
0,05
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
0,95
0,98
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A second category presents almost gaussian logarithm distributions : it comprises the BA THA, the SIRBA and the WHITE VOLTA; these are permeable basins with appreciable slope, except for the WHITE VOLTA,which present a low flow in a dry year and good runoff when a part of the permeable soils is saturated in an exceptionally wet year. Here one also encounters relatively impermeable basins such as that of the SIRBA, but they do not present, downstream, enormous regulating losses like the BAHR AZOUM, the GOROUOL (losses towards the BELI) and the KOMADOUGOU.

There is a shortage of relatively impermeable basins with appreciable slope, which is perhaps the case of the KOLIMBINE which nevertheless presents considerable endorheic portions, but it is highly probable that the curve for this watercourse would be located on diagram 28 above the one for the BA THA at OUM HADJER, a little like Wadi GHORFA if its basin was larger.

Curiously,in spite of the very artificial character of the depth of runoff on basins whose hydrologic regimen is as unstable, one finds a group of curves similar in shape with median depths of runoff which only vary between 3,7 mm and 14 mm, this probably because a basin of more than 10,000 km^2 already contains a considerable number of combinations of homogeneous hydrologic regions,and consequently, there is a certain tendency to homogenization.

This does not prevent the fact that the transposition from one basin to another is hardly recommended, all the more so because the two basins for which one would be tempted to do it: KARAKORO and KOLIMBINE, present geomorphological conditions different from those studied earlier. In this instance it is preferable :

- to divide the basin into various subbasins, comparable to those described in paragraph 3.3.4 whose depth of runoff will be determined,
- to eliminate all those which, in the median year, are endorheic,
- to make all the reductions which are necessary for losses in the principal bed and at arrival at the station where one wants to study runoff,
- to verify whether the result is not too improbable in relation to what the morphology of the cross-section may indicate on one hand, and in relation to data from diagram 28 on the other hand.

As for the calculation of data for one station of one of the six basins studied in paragraph 3.3.5.3., it is advisable to examine component contributions very closely, and above all the losses which occur for different frequencies between the reference station and the one being studied. The differences between the station of OUM HADJER and ATI on the BA THA and of BAGARA and GUESKEROU on the KOMADOUGOU give an idea of the modifications to the volume of annual runoff, even over relatively short distances. Likewise in this case, the examination of aerial photographs and ground level reconnaissances are indispensable. If one goes a little too far upstream it should not be forgotten that the behaviour of the different tributaries of 1,000 to 5,000 km^2 may be very different for a similar basin of 10,000 km^2, the geomorphological factors playing a more important part than the depth of median annual rainfall without it being disregarded (example : the North of the basin of the WHITE VOLTA or of the BA THA).

4 – CONCLUSION

The sahelian regimen presents serious difficulties for the determination of the various hydrologic characteristics. The depth of median runoff varies a great deal spatially for a similar depth of annual precipitation and hydrographic degradation seriously complicates the rules for runoff; statistical distributions are often very asymmetric and they can only be known properly with long series of observations.

It has been seen from the foregoing that the mass of informations collected with difficulty for twenty years is considerable and that it covers both very dry and very wet years.

We have done our utmost to put into play all available methodologies in order to produce the distribution curves. In some cases, the author found himself in the same position as the paleontologist who reconstructs a whole skeleton starting with a single bone. Fortunately in such cases , the simultaneous study of watercourses in the SAHEL allowed many errors to be avoided.

As for as the presentation of results is concerned, this memoir is a piece of work which owes a great deal to practical application and in particular, all scientific development on the results obtained has been avoided. An attempt has been made to provide data in a form which is capable of being turned to account, finally in each paragraph we did not hesitate to go on to make a certain number of repetitions so as to spare the reader interested in a basin of 300 km^2 the truble of constantly having to refer to other paragraphs concerning basins of other categories.

It appears necessary to draw attention to a certain number of gaps. Among the most important, let us mention the following :

1°/- For the exploitation of reservoirs instead of just considering the distribution curves it is useful to take into account historic or probable sequences. A supplement on this subject will be found.

It seems necessary to repeat at this point that the representation of experimentatl curves by analytical relations must take into account the lower part of the curves which is often above the curves representing the classic formulae.

2°/- For transpositions and interpolations, raw data concerning the possibility, for the principal bed, of permitting to some extent the passage of flood waves, are inadequate. One would need to be able to represent this by means of a small number of parameters, namely slope and characteristics of the apparent bed and major bed, but presence of tributary arms, swamps and secondary beds makes this study difficult.

3°/- On the geographical plane , a large area is unknown; the basins of the KOLIMBINE and of the KARAKORO. As a priority it is here that a few network stations ought to be installed (expensive and difficult to exploit) here likewise one ought to envisage two regional studies of three years' duration with representative basins exploited extensively as they were ten years ago.

4°/- There still remains the eternal problem of relations between surface runoff and soil structure. This is a question of fundamental research where progress is very slow. In the preceding pages we have only offered a very rough approach for this particular point.

To conclude, it must not be forgotten that this work is only a first essay and that a considerable effort on the hydrometric networks of the countries of the SAHEL is needed for a good many years, if one is to arrive at more reliable results than those which are offered here.

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APPENDIX

EXAMPLE OF A TIME SEQUENCE OF ANNUAL PRECIPITATION

This study has taken into consideration statistical distribution of annual runoff amounts which it is most useful to know, but a few ideas about sequences of annual runoff amounts for the same station over a long period would be especially useful for the study of future exploitation of a management scheme. In particular, should one anticipate series of consecutive dry or wet years and with what probability ? This may only be examined over series of 200 or 300 years at the very least.

The ideal solution would have lain in offering a large number of sequences of this kind, relative to various types of runoff in the sahelian zone. The establishing of such sequences was not impossible but it would have involved extensive work which would have delayed the completion of this work considerably, whithout resolving all the cases one might envisage.

We found it preferable to present a chronological series of annual precipitation which may be transformed into flow thanks to the diagrams contained in this memoir by looking through the frequencies again. These diagrams only give the mean value for all the depths of runoff corresponding to a depth of annual precipitation (these depths of runoff vary with the distribution of daily rainfall for a similar value of annual depth of precipitation P).Therefore,the methodology we propose is not absolutely correct, but it at least gives a first estimate of what a sequence of runoff may be. It will also be observed that in this operation the influence of runoff from one year on that of the following year is disregarded. In the sahelian region, if one year is wet the basin has plenty of time to dry up before the next rainy season but on the other hand, after a series of dry years, most of the vegetation has disappeared and surface runoff, from the first year of heavy or even mean rainfall which follows this drought is much greater than it should be, as was observed in 1974, but in that instance it was a matter of an error which did not in practice have serious consequences.

It remains to present some chronological series of precipitations. It is not possible to reproduce natural series. It would be necessary for these series to include the droughts of 1913, 1940 - 1945 and 1970 - 1973. The few stations observed throughout the period 1910-1974 are situated on the Atlantic littoral with a regimen which is rather special, or South of the sahelian strip,where as if by chance, they have been relatively spared by the drought : finally, no reading may be presented as an example. For this reason it is necessary to produce artificial series presenting the same statistical distribution. Then it remains to settle a problem that of persistence : should the depth of precipitation for one year be linked with that of the year before, or to put it another way does one given dry year involve a greater probability of finding a depth of annual precipitation in deficit the following year ? The study has just been carried out by Y. BRUNET-MORET in the South of the SAHARA for the group of francophone countries in West Africa, it is focused on the data from 179 raingauge stations. The results have been published in the following article : "Essay on the persistence of annual precipitations in West Africa". Cahiers ORSTOM, Hydrological Series, Vol. XII n° 4 - 1975.

If one calls z a random independent variable distributed according to a known or unknown distribution, the values x of observed precipitation, wich are not independent, are linked by the process :

$$X_{i+1} = Z_{i+1} + Ax_i$$

x_i corresponds to the year i; x_{i+1} to the following year; A is the coefficient of persistence. If A is nil, x is a random variable, there is no persistence.

For the sahelian zone Y. BRUNET-MORET found that A is significantly positive and in the neighbourhood of 0,24. From these results and by admitting for x the generalized, exponential, statistical distribution presented in paragraph 3.2.3.4., it is possible to create chronological series with effect of persistence by taking at random the values of z by means of the MONTE CARLO method in a law of distribution of z calculated from the law of distribution of x .

In this way we have reconstructed for the 500 mm isohyet a serie of 300 consecutive years. In order to determine this series we admitted at the outset a value for the coefficient of persistence equal to 0,24.

The statistical population of infinite dimension for the values of x certainly has a value for the coefficient of persistence equal to 0,24 and the values for the parameters of distribution equal to those of the generalized exponential law quoted earlier, but, naturally, for a sample of 300 years, a relatively small size for determining four parameters, slightly different values are found which is quite normal.

On the first attempt the results were as follows :

A	=	0,17	
mean x	=	466,7	
mean x	=	455,6	(median P)
x_o	=	110,3	
S	=	401,9	

Parameter of shape = 0,4137 (instead of 0,4)

All the figures in the series were corrected so as to find a median value of 500 mm instead of 455,6 mm for the sample of 300 years while of course keeping the same probalilities; x_o and S are in consequence modified (the values from paragraph 3.2.3.4. are found). The corrected values for annual precipitation have been shown on the attached table.

Where there is a different rainfall regime; for example for the annual 700 mm isohyet, one proceeds as follows :

From the generalized, exponential curve corresponding to the annual 500 mm isohyet, one determines the 300 values for frequencies corresponding to the 300 annual precipitation amounts given in the table. Next from these 300 frequencies and from the generalized, exponential curve corresponding to 700 mm, one determines the 300 annual consecutive precipitation amounts corresponding to the new rainfall regime (median P = 700 mm).

This operation may be carried out by computer. It is not very orthodox, but it leads to acceptable results.

In any cases, it is necessary to calculate the frequencies and to carry them on to the diagram which has already been completed for depths of runoff which concern the drainage basin being studied.

A SERIES OF 300 VALUES FOR CONSECUTIVE ANNUAL PRECIPITATION AMOUNTS

(Depth of median annual precipitation 500 mm
for a series of infinite duration)

YEARS	1	2	3	4	5	6	7	8	9	10
0	545	585	676	280	200	1 062	764	559	288	325
10	578	596	457	306	604	704	827	443	568	479
20	469	243	475	274	401	581	807	526	605	815
30	579	486	302	957	522	566	429	337	484	635
40	756	553	647	551	418	850	653	855	418	308
50	517	593	536	212	469	415	601	690	461	459
60	733	802	508	641	665	609	281	492	345	576
70	274	588	457	198	306	286	760	645	485	388
80	359	380	585	751	801	544	443	401	669	624
90	471	311	526	748	695	532	665	768	446	390
100	552	602	413	403	640	420	281	479	539	553
110	439	570	450	789	799	745	812	412	520	412
120	479	518	793	900	537	445	792	777	638	283
130	468	679	514	713	625	262	417	398	227	534
140	725	328	445	352	314	398	569	329	458	859
150	688	503	864	625	568	466	302	429	579	493
160	427	346	402	458	567	280	452	511	681	467
170	433	442	399	400	431	519	299	456	396	371
180	299	520	611	591	487	650	445	496	565	453
190	442	405	478	425	548	846	485	653	576	414
200	443	373	675	448	631	490	423	474	276	384
210	451	560	285	507	388	688	485	324	590	536
220	417	260	157	469	476	425	183	348	569	575
230	452	491	235	665	388	702	307	349	266	417
240	592	610	579	558	298	394	480	730	339	395
250	430	442	827	592	449	412	288	708	668	364
260	306	632	699	533	443	231	373	576	463	597
270	396	651	447	365	542	391	525	330	421	412
280	478	254	212	747	503	480	509	404	902	732
290	629	969	527	608	648	401	474	383	328	928

Coefficient of persistence 0,17

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