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OUTLINE OF WATER RESOURCES DEVELOPMENT IN THE WEST AFRICAN SAHEL

FOREWORD

This paper must be regarded as a provisional working document whose sole aim is to contribute to a general study of water problems in the West African Sahel.

Some inaccuracies and perhaps certain errors must of course be expected in a general outline of this kind.

It is merely intended as a basis for discussion by national and foreign experts in order that the indicated estimates and targets can be better specified.

This paper was prepared jointly by the Technical Services of the Ministry of Co-operation and SCET-INTERNATIONAL.

OUTLINE OF WATER RESOURCES DEVELOPMENT IN THE WEST AFRICAN SAHEL

Summary

PART THREE:

OUTLINE OF WATER RESOURCES DEVELOPMENT IN THE WEST AFRICAN SAHEL

INTRODUCTION

METHODS, CONCEPTS AND LIMITS OF THE STUDY

The present outline of water resources development in the West African Sahel covers six countries

MAURITANIA SENEGAL MALI UPPER VOLTA NIGER and CHAD, with a total area of about 5,255,000 km^2 and a population of nearly 30,000,000.

The purpose of this study is to draw up a first inventory of the quantities of water of all categories available for humans, livestock and irrigation in the various regions of the Sahel, to locate them geographically, to compare them with requirements and to see how far their use is compatible with various constraints, such as the presence of grazings or irrigable land at a reasonable distance from the water resources, or an acceptable cost of harnessing.

Annually usable water resources of the Sahel comprise surface water and ground water. The former much greater in amount, constitutes the main resource available for irrigation. The latter is found in smaller amounts with extremely variable recovery costs. It is used by humans and animals, but not for irrigation, except in the case of a few ground water systems with particularly favourable characteristics.

Part One of the study gives particulars of per capita consumption for humans and livestock and water requirements per unit area for the various types of irrigated farming practised or possible in the Sahel. A first global estimate of water requirements for various hypotheses of population growth, livestock development and irrigation expansion is deduced from these unit figures.

Part Two contains an overall estimate of water resources in the Sahel in a year of average rainfall and in years of deficient rainfall with return periods every five and fifty years. A preliminary comparison of total resources and requirements is made.

Part Three is devoted to identifying feasibilities and means of adapting each type of resource to requirements.

Resources may be grouped into three categories:

1. The discharges of the main Sahelian river systems (Senegal, Niger, Chari-Logone-Chad, plus Gambia and Volta) which, apart from the White and Red Voltas, have a perennial flow, even if it is very low at certain stations and at certain times (this characteristic depends on the origin of inflows due to runoff in Guinea and Central Africa).

   These discharges can therefore be used without regulation, at least in a first stage, as they are at present.

   But this type of utilisation is approaching its limits, in particular in the case of the Logone, the Senegal and the Niger, and the development of modern perennial irrigation beyond the present level calls for the operation of first-generation reservoir dams to ensure partial interannual regulation.

   A much longer range total interannual regulation of the main Sahelian rivers should be envisaged and is probably feasible.

   Part Three of this memorandum states the irrigation potential of each of the three main rivers as follows:

   a) Present potential or, in other words, the irrigable area in "critical months" recurring every 5 years and every 50 years, the critical month being defined as the month when the ratio "available supply/irrigation unit requirements" is at its lowest.

   b) Potential corresponding to first-generation dams for interannual regulation.

   c) Potential corresponding to long-range total interannual regulation.

Potentials corresponding to interannual regulation were determined for all reservoirs of known specifications by "forward planning" or "simulated management" methods; discharges were represented either by observed discharges over long periods, as resulting from the ORSTOM's hydrological yearbooks, or by dummy runs obtained by random selection on the basis of a frequency function.

In applying the method, withdrawals taken into account were limited in general to evaporation on reservoir waters, spillway outfalls, and drawoff for irrigation according to a timetable compatible with modern intensive irrigation requirements.

The case of water for navigation and hydropower production was not systematically studied.

The results thus obtained therefore represent maxima which in reality could not be attained on multipurpose water reserves.

2. Middle-distance runoffs on Sahelian catchment basins, at least those which seem really active, were the subject of the same exercise, but treatment was necessarily more summary because it was based on less complete data. These catchment basins have practically no dry weather flow and can be used only under a regulation system. An evaluation was therefore made of their runoff in a median year and on this basis normative tables developed from typical cases gave an approximate idea of the quantity of water available for irrigation, with a guaranteed supply in 49 years out of 50.

The exercise was carried out on a dozen areas containing about 50 catchment basins with a minimum area of 1000 km^2.

Another possible approach to the use of the Sahelian catchment basins could also be envisaged by regulating a very large number of small basins, which in fact give a far better runoff per unit area than basins of over 1000 km^2. However, their total development raises enormous problems and Part Two of this report is therefore limited to an overall estimate of their potential without any breakdown by hydrological units.

3. Lastly, ground water can be used occasionally for irrigation and very frequently for humans and animals. Areas where both types of use are possible have been located on a 1:5,000,000 map with an approximation of corresponding quantities.

PART ONE

WATER REQUIREMENTS FOR HUMANS, LIVESTOCK AND IRRIGATION IN THE WEST AFRICAN SAHEL

1.1. WATER REQUIREMENTS OF THE POPULATION

Water requirements per head in the countries of the West African Sahel are both low in absolute value and very different according to the lifestyle of the individuals concerned.

Current daily average individual consumption (1975) is roughly as follows:

- Inhabitants of rural areas	40 to 50 litres per day
- Inhabitants of small towns (5,000 to 100,000)	70 to 100 " " "
- Inhabitants of large towns	150 to 200[1] " " "

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(1) This figure covers:

- domestic consumption	120 litres per head
- watering private gardens	50 " " "
- watering public gardens	7 " " "
- commerce	2 " " "
- air conditioning	11 " " "
- crafts and very small industries	10 " " "
	200 litres per head

Total

On the other hand, it does not cover the requirements of large industries as it is difficult to forecast their development; their case is mentioned below.

It is generally agreed that requirements per head will increase moderately in the future; by the year 2000 they might exceed current requirements by

+ 20% in rural areas
+ 30% in small towns
+ 40% in large towns

these percentages being merely orders of magnitude.

Account should also be taken of a seasonal fluctuation in requirements, which reach their peak towards the end of the dry season, i.e. April to June according to the latitude. By comparison with average daily requirements these peak consumptions represent an increase of

- 50% in rural areas
- 30% to 40% in medium-sized towns
- 40% in large towns

It therefore seems reasonable to predict that daily requirements per head in the year 2000 will be of the following order of magnitude:

	Average requirements	Peak requirements
Rural areas	55 litres	80 litres
Small towns	110 litres	150 litres
Large towns	250 litres	300 litres

Applied to the total population forecast for the year 2000 for the six Sahelian countries combined, these figures correspond to the total water consumptions shown below:

	Population (1)	Total water requirements per average day ('000 m^3)	Total water requirements per peak day ('000 m^3)
Rural areas	25,000,000	1,375	2,000
Small towns	5,000,000	660	900
Large towns	11,300,000	2,825	3,390
TOTAL	42,300,000	4,860	6,290

(1) Figures based on assumption of high population growth in capital cities.

Taking an order of magnitude of 5,000,000 m^3 of water per average day (for 300 days per annum) and 6,500,000 m^3 per peak day (65 days per annum), we have a total requirement of the order of

1,900 million m^3 of water

for the whole of the Sahel.

This figure would have to be increased by the water requirements of certain industries, in particular mining, which are either already or likely to be established in the Sahel and which may require substantial amounts of water (ARLIT uranium mines, for example).

It is difficult to assign an exact consumption figure at the date 2000. It seems reasonable, however, to expect a possible consumption of about 500 million m^3 per annum, so that total future requirements for humans and industry might well amount to

2,500 million m^3 per annum

around the year 2000.

While this volume is very small by comparison with irrigational needs, we shall see that it is by no means negligible in relation to the resources that can be drawn annually from ground water without endangering the water table balance.

1.2. WATER REQUIREMENTS OF LIVESTOCK

Requirements per head and overall

The cattle herd may be assumed to need 30 litres per head per day on average. This figure is sometimes considered inadequate, as it is forgotten that it applies to an average head of cattle.

Scientific norms of husbandry for these animals reckon a water consumption of 4 to 5 litres per kg of dry matter in the daily ration.

Consequently, an adult zebu of 350 kg live weight, consuming 2.7 to 3 kg of dry matter per 100 kg live weight, should drink each day an amount of water between

$$4 \times \frac{350}{100} \times 2.7 = \text{ca. } 38 \text{ litres}$$

and

$$5 \times \frac{350}{100} \times 3 = \text{ca. } 53 \text{ litres}$$

which are higher figures than those indicated above.

But the same calculation applied to a zebu of 200 kg live weight (which is probably slightly above the average of Sahelian herds, including young animals), gives figures of between 22 and 30 litres.

The figure of 30 litres per head per day therefore seems entirely justified.

The water consumption of sheep and goats is around 5 litres per head.

Finally, the livestock population in the Sahel countries at the year 2000 might, according to certain projections, amount to 30,000,000 head of cattle and 50,000,000 sheep and goats.

Their total annual consumption would therefore be of the order of 420 million m^3. To this should be added at least 20% for losses around watering-places, so that the figure must be raised to 500 million m^3 per annum.

This volume would be drawn mainly from surface waters[1] during roughly 7 months of the year and mostly from ground water during the last five months, from February to June.

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(1) Pools and marigots.

Maximum distance between watering-points and grazings

It is accepted that, in order to avoid overdriving the stock and possibly slowing down weight gain, the maximum distance from grazing to the watering-place should not exceed 6 km, corresponding to a 12 km round trip for one daily watering. This norm corresponds to an ideal range grid at the rate of one watering-place every 12 km, each point serving about 120 km^2.

In fact, in difficult cases one may envisage daily waterings with round trips of 30 km. The corresponding grid would have one watering-place every 30 km, each place serving 700 km^2.

However, this is an absolute maximum never to be exceeded.

Minimum discharge of watering-places

In addition, the discharge at the watering place must be adequate to water the stock on the area served.

For example, if the maximum area of 700 km^2, or 70,000 ha, is intended to feed one bovine per 10 ha, the discharge should be at least

$$\frac{70,000}{10} \times 0.03 = 210 \text{ m}^3 \text{ per day}$$

or 3 litres per second, for a guaranteed operation of 20 hours per day.

In fact, many wells or boreholes cannot provide such a discharge. Consequently if in a given region the watering places have a unit discharge of only 20 m^3 per day, they should be assigned an area corresponding to 700 cattle, i.e. about 7,000 ha or 70 km^2, which would make it necessary to multiply the watering-points. The minimum unit cost of bore-holes or wells certainly does not allow one to go below this last norm.

1.3. WATER REQUIREMENTS OF IRRIGATED FARMING SYSTEMS TIMETABLE AND UNIT REQUIREMENTS OF WATER.

Four main types of irrigation systems are feasible in the Sahel:

1/ Flood recession cropping. Cereals are sown (or transplanted) on flooded land once the floodwaters have receded. he water requirement is met from the soil moisture eserves.

.his type of system is practised above all in the main river valleys of the Sahel, especially the Senegal valley (millet), and sometimes in the bottom of certain marigots (bottom rice). The areas cultivated vary from one year to the next according to the flood mark reached, and yields depend on the date when the flood recession allows the farmers to sow or transplant (1).

In these circumstances it is difficult to give figures for areas and yields. but one may expect orders of magnitude of 350,000 ha for the six Sahel countries combined, with productions of 0,4 t (millet) to 0.8 t (rice). In a very dry year flood recession crops probably account for barely 100,000 ha.

A variant of this system consists of flood recession grazings, vast areas of which carry herds during the months following the withdrawal of floodwater.

The volume used by flood recession crops varies essentially according to the depth of flooding on the cultivated site in an average year. An average depth of about two metres may be assumed and this figure should be doubled to take account of the fact that only part of the flooded area is cultivated. Thus each hectare of flood recession crops would consume about 40,000 m^3 of water and in an average year such crops would consume about 12 billion m^3.

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(1) Early recession usually corresponds to a low flood and releases only a small amount of land; late recession mostly corresponding to a high flood releases large areas but at a date when vegetation starts too late.

In similar conditions flood recession grazings used in an average year perhaps represent 1,000,000 ha and would consume about 40 billion m^3 on the basis of the same calculation as above. These figures are very approximate and have not been taken into account in what follows.

In the long term there is no doubt that the survival of the Sahel peoples will largely depend on the replacement of these "irrigation" systems by more modern systems offering close to a 100% chance of an adequate water supply.

The introduction of such systems, which has already started, can be expected to promote the gradual disappearance of flood recession cropping, since they ensure stable yields 5 to 20 times higher than the average yields obtained with the old method.

Similarly, the gradual introduction of irrigated fodder crops will very probably lead to a substantial reduction in the use of flood recession grazings.

In a few decades flood recession crops and grazings are likely to likely to play only a marginal role, if any, in Sahelian agriculture, thus reducing the corresponding water consumptions to negligible figures(1).

2/ Basin check irrigation systems are based on the use of basins separated by non-floodable embankments over large areas; floodwater is let into the checks at low points through check gates in such a way that the level does not rise more than 3 cm per day, a rate compatible with the growth of certain rice varieties.

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(1) This development may take place with practically no damage to settled farmers and nomads living on flood recession crops and grazings, provided they are progressively afforded effective access to the modern irrigated zones.

The success of the system is possible only in areas where two constraints are respected:

- sufficient rainfall to guarantee the germination of "rainfed" rice by the time flooding takes place; respecting of this constraint means that effective application of the system is limited to areas with an annual average rainfall of 700 mm or over,

- water conditions guaranteeing submersion of the floodable parts of the checks throughout the rice growth period to a highly probable extent (98%).

In practice only the upstream valleys of the Niger and the Bani, the uppermost part of the Niger Central Delta, and certain parts of the Logone and Chari valleys are suited to this system, although perhaps involving several hundred thousand hectares.

Various check layouts may ensure relatively high stable outputs per hectare with the basin system:

- in the so-called "variety fringe" method, the various species of rice (erect, semi-erect, floating) are located in the parts of the basin where water conditions suit them best;

- in the so-called "ring" method, inner embankments divide the whole of each check into areas where the standing water can be maintained between upper and lower limits compatible with erect rice growing.

The water consumption of these systems is difficult to estimate and varies quite considerably from one check to another. It seems possible to assume that average consumption corresponds to:

- basin flooding to an average depth of 1 metre on sites effectively cultivated, i.e. 10,000 m^3 per ha;

- compensation for evaporation and seepage losses during the vegetation period, which partly coincides with rainfall periods; the portion of this compensation drawn on the floodwater discharge is probably fairly small - about 2,500 m^3 per ha.

Lastly, flooding the non-cultivable parts of the check basins (bottoms and upper fringes) represents very large volumes of water, probably twice the above figure; the uncultivated part of the basins represents less than 50% of their total geographical area, but the average depth of water on it is often over one metre.

Water consumption for the check basin system thus seems to be about 25,000 m^3 per ha effectively cultivated per annum.

In terms of quantities of rice produced, this consumption is relatively high; owing to inadequate control of water conditions, current yields are about 1.5 t of paddy per ha effectively cultivated and they seem unlikely to exceed 2 t in future, corresponding to a water consumption of some 12,500 m^3 per t.

On the other hand, these consumptions are drawn from natural floodwaters and the introduction of the system is therefore not limited in the first phase by the low stream flows of Sahelian rivers.

3/ Intensive irrigation with complete water control in the Sahel countries generally calls for flood protection works, a drainage network and a separate gravity or lift irrigation network. Irrigation can be practised with a view to obtaining one or two annual crops.

The first case is at present the most frequent, owing to the indadequacy of available stream flows in the "critical months". But this situation is bound to change quite soon, as experience shows it is almost impossible to write off costly engineering works with only one crop per year.

For this reason we shall not give further consideration here to the water requirements of single-crop intensive irrigation systems; conversely, the water requirements of double-crop intensive irrigation are examined in detail.

4/ Double-crop intensive irrigation systems

The annexed tables (1.1 to 1.5) describe the method of calculating water requirements per irrigated ha for 5 intensive irrigated crop systems (i.e. 2 crops per annum) which are feasible in the Sahel countries (map attached). These 5 systems are defined in terms of climatic and hydrological data.

Calculations are based on the crop timetables and provide the water requirements expressed for each month in DPET or Mean Daily Potential Evapotranspiration for the month in question.

Converting these results into m^3 of water per month and per day means calculating the D PET at various stations and multiplying the results by a coefficient taking account of water loss between the headgate and plant roots.

This coefficient is between 1.4 and 2 according to the surface area.

For areas of over 5,000 ha (coefficent 2) the results of applying the method give the volumes of water to be delivered each month in m^3 per ha at the headgate (see table on page.... below).

The five intensive systems considered are the following:

1 - Two successive rice crops close together (isotherm 17° and over);

2 - Two successive rice crops at $2^1/2$ months interval (between isotherms 17° and 15°). As the mean temperature for December and January is unfavourable to rice vegetation, the start of the second rice crop has to be postponed till February;

3 - A rice crop followed by a wheat crop (isotherm 15° and over).

4 - A rice crop in the rainy season followed by a vegetable crop in the dry season (isotherm 15° and over, with low, irregular hydro conditions);

5 - A sorghum or maize crop with supplemental irrigation in the rainy season, followed by an irrigated vegetable crop in the dry season (isotherm 15° and over, with low, irregular hydro conditions).

It should be noted that the water requirements given in Table 1 according to the timetable and D PET figures shown in Tables 1 to 5 in the Annex do not allow for the possibility of adopting the "transplanting" technique for irrigated rice.

This technique has numerous advantages:

Higher yields can be expected, other things being equal, while weeds and rhizomes can be better controlled.

In addition, with this technique it is possible to economise considerable quantities of water since during part of its growth rice is kept in nurseries covering some 10% of the area of ricefields. In the System 2 hypothesis at St. Louis (see Table 1 below), by using this technique 2 months of irrigation could be saved on one tenth of the area, i.e. approximately

$$(7,800 + 5,700) \times \frac{9}{10}$$

or 11,250 m^3 water for a total consumption of about 37,000 m^3 per year, or again 25 to 30% of the estimated consumption.

However, it is difficult to know exactly what the scope of this technique will be in 1985 or 2000, especially since it is rather hard to use in the case of two irrigated crops close together (Systems 1, 3 and 4).

We have therefore kept the figures of Tables 1 to 6 below as a precaution, since they may make up for many inaccuracies in the basic data.

In the context of detailed water development projects, it would however be essential to keep a strict account of economies made possible by the adoption of transplanting.

The totals given in the last column of Table 1 show that water requirements per ha vary quite considerably from region to region and from system to system, since they range from 22,000 m^3 per ha to 42,100 m^3 per ha.

INTENSIVE IRRIGATED FARMING SYSTEMS - WATER REQUIREMENTS

(m3. per ha.)

Systems & Stations	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Ap.	May	Total
System I: Kayes 2 rice crops close together	-	7800	3900	4300	1500	-	7900	5100	5300	6300	-	-	42100 m3
System I. Yagoua 2 rice crops close together	-	5800	2700	3000	1100	-	6300	3600	4200	4300	-	-	31000 m3
System 2: St Louis 2 rice crops at well-spaced intervals	-	-	7800	4200	4200	1400	-	-	5700	4800	4900	4000	37000 m3
System 2: Yagoua 2 rice crops at well-spaced intervals	-	-	5500	3000	3200	1200	-	-	4300	4400	4000	2900	28500 m3
System 3: N'Guigme Rice/Wheat	5700	4300	3800	3600	-	1000	3500	3400	2200	-	-	-	27500 m3
System 4: Niamey Rice/Vegetables	-	7200	4000	4300	2500	500	3700	3200	3300	4200	-	-	33400 m3

INTENSIVE IRRIGATED FARMING SYSTEMS - WATER REQUIREMENTS ctd

(m3. per ha.)

Systems & Stations	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Ap.	May	Total
System 5: Maradi Irrigated Sorghum/ Vegetables		1900	1500	1700	2200	500	3400	2900	3800	4100	-	-	22000 m3

These theoretical consumption figures seem very close to overall consumption observed in the field, in the few cases where they could be measured, e.g. at Yagoua (see attached graph).

It should be noted, however, that the water consumption figures worth knowing are those expressed per ton of product. In this connection it may be noted that the adoption of increasingly efficient irrigation systems leads to a decline in consumption per ton of cereals produced, as shown in the table below, which is valid to the extent that the figures for yield and water consumption can be regarded as roughly correct, at least in relative value:

CROPS	Water Consumption per ha. in m3.	Cereal Yield in t/ha.	Water consumption in m3. per t. of cereal
Flood recession cereals	40,000 m3.	0.6 t.	70,000 m3.
Basin check irrigation cereals: present situation	25,000 m3.	1.5 t.	16,000 m3.
Basin check irrigation cereals: future situation	25,000 m3.	2.0 t.	12,500 m3.
Intensively irrigated cereals: one crop per year	17,600 m3.	3.0 t.	7,900 m3.
Intensively irrigated cereals: two crops per year (1st crop: 3 t/ha 2nd crop: 3.5 t/ha)	Mean: 37,000 m3.	6.5 t.	5,700 m3.
	Max.: 42,000 m3.	6.5 t.	6,500 m3.
	Min.: 27,500 m3.	6.5 t.	4,200 m3.

PRESENT AND FUTURE CONSUMPTION OF IRRIGATION WATER

On the basis of these figures it is possible to obtain a rough picture of present and future requirements of irrigation

Probable consumption around 1975-1980

Engineering works in construction are assumed to be completed and flood recession crops to be maintained at approximately their current level, which should represent the situation around 1978.

Water requirements for flood recession grazings are too imprecise and have not been taken into account.

COUNTRY	Irrigated crops	Area in ha.	Unit consumption in m3/ha.	Total Consumption in millions of m3. (M m3.)
MAURITANIA & SENEGAL	-Flood recession cropping	100,000 ha.	40,000 m3/ha.	4,000 M m3.
	-Intensive irrigation, 2 crops per year	30,000 ha.	40,000 m3/ha.	1,200 M m3.
TOTAL MAURITANIA & SENEGAL				5,200 M m3.
MALI, UPPER VOLTA & NIGER	-Flood recession cropping	150,000 ha.	40,000 m3/ha.	6,000 M m3.
	-Basin checks	150,000 ha.	25,000 m3/ha.	3,750 M m3.
	-Office Niger: single-crop irrigation	60,000 ha(?)	20,000 m3/ha.	1,200 M m3.
	-Niger Niger: in principle, double-crop irrigation	10,000 ha(?)	33,000 m3/ha.	330 M m3.
TOTAL MALI, UPPER VOLTA & NIGER				11,280 M m3.

CHAD (& North CAMEROON)	-Flood recession cropping	40,000 ha.	40,000 m3/ha.	1,600 M m3.
	-Intensive irrigation, double crop	10,000 ha.	28,000 m3/ha.	280 M m3.
TOTAL CHAD(& North CAMEROON)				1,880 M m3.
GRAND TOTAL				25,910 M m3.

Irrigation systems in existence or in construction therefore represent an overall consumption of some 26 billion m3.

Probable long-range consumption of irrigation (e.g. around 2000 or 2050)

Hypotheses:

- Intensive project development aiming at the installation by 2000 or 2050 of 750,000 ha. double-crop area equivalent, basin checks being included in this figure at one-third of their area.

- Disappearance of flood recession crops.

- Natural grazings not taken into account.

COUNTRY	Irrigated crops	Area in ha.	Approximate Unit consumption in m3/ha. rounded to '000 m3/ha.	Total Consumptic in millior of m3. (M m3.)
MAURITANIA & SENEGAL	-Intensive irrigation, 2 crops per year	320,000 ha.	40,000 m3/ha.	12,800 M
MALI, UPPER VOLTA & NIGER	-Basin checks	500,000 ha.	25,000 m3/ha.	12,500 M
	-Intensive irrigation, 2 rice crops per year	180,000 ha.	40,000 m3/ha.	7,200 M

	-Intensive irrigation, 2 crops per year rice & wheat	30,000 ha.	28,000 m3/ha.	840 M m3
	-Intensive irrigation, 2 crops per year rice & wheat or rice & veg.	50,000 ha.	33,000 m3/ha.	1,650 M m3
TOTAL MALI, UPPER VOLTA & NIGER				32,190 M m3
CHAD (& North CAMEROON)	-Basin checks	50,000 ha.	25,000 m3/ha.	1,250 M m3
	-Intensive irrigation, 2 rice crops	50,000 ha.	31,000 m3/ha.	1,550 M m3
	-Intensive irrigation, 2 crops, rice & wheat	50,000 ha.	28,000 m3/ha.	1,400 M m3
TOTAL CHAD (& North CAMEROON)				4,200 M m3
GRAND TOTAL				49,190 M m3

It is plausible that irrigation consumption around 2000 - 2050 might approach 50 billion m3 if the desirable development programmes are in fact carried out.

These figures are well below the annual average discharges of the main Sahelian rivers:

- Senegal, at Dagana	22 billion m3.
- Niger, at Dire	36 billion m3.
- Chari, at N'Djamena	38.5 billion m3.
TOTAL	96.5 billion m3.

However, the situation is very different if the following constraints are taken into account:

- Existence of "critical months", defined as months when the ratio

$$\frac{\text{Volume of unregulated river water available}}{\text{Monthly unit consumption}}$$ is at its lowest.

- Need to maintain an adequate permanent discharge to supply water to riparian populations (especially large towns) and to ensure survival of fish (fishing is a very important resource for part of the population living along the banks of the main Sahelian rivers.)

- Interannual irregularities.

It will be seen that these constraints considerably limit the possibilities of drawing irrigation water from most of the rivers and streams in the Sahel and that in many cases the small areas already cultivated under intensive irrigation cannot be increased appreciably without constructing major engineering works to ensure interannual regulation.

1.4. GENERAL RECAPITULATION OF WATER REQUIREMENTS

The water requirements of the Sahel may be summarised as follows:

ORIGIN OF WATER REQUIREMENTS	REQUIREMENTS AROUND 1975-80 in billions of m3.	REQUIREMENTS AT 2000-2050 in billions of m3.	Multiplier
POPULATION (1)	0.75	2.5	3.3
LIVESTOCK (2)	0.25	0.5	2
IRRIGATED FARMING (3)	26.00	50	1.9
TOTAL	27.00	53	Practically 2

IN SHORT, WATER CONSUMPTION IN THE SAHEL WILL BE ROUGHLY DOUBLED.

(1) Water requirements of current populations were calculated on the basis of 30,000,000 persons, of whom 2,500,000 in the capital cities, 2,500,000 in small towns and 25,000,000 in rural areas; requirements in the year 2000 were calculated on page et seq. above.

(2) As regards livestock, the calculation at the year 2000 is given on page et seq., and the calculation for the current period was carried out on the same unit basis for 25,000,000 cattle and 30,000,000 small ruminants.

(3) The calculation of irrigation water requirements is given on page et seq. for the periods 1975-80 and 2000-2050.

PART TWO

WATER RESOURCES IN THE WEST AFRICAN SAHEL

II.1. RAINFALL IN THE SAHEL

Rain characteristics in the Sahel, resulting from the thunder storm formations produced when two air masses --the Saharan anticyclone and the monsoon-- met in the inter-tropical front, are well known.

It needs merely be pointed out that the outstanding features are:

- their occurrence in time - from April to October in the south of the Sahel countries and from 10th July to 10th-15th September in the desert fringe area; and

- their irregularity in space and in time --irregular annual totals and a skewed distribution within a given season.

We wanted to obtain at least an approximate idea of the volume of precipitation in the Sahel countries during an average year or during a dry year with a return period of some 50 years.

For purposes of rough calculation, the Sahel countries have been divided into six geographical areas:

PRECIPITATION IN THE SAHEL COUNTRIES

GEOGRAPHICAL AREAS	MEAN ISOHYETS ANNUAL EXTREMES	ISOHYET USED AS A BASIS FOR CALCULATION	AREA UNDER CONSIDERATION	VOLUME OF PRECIPITATION IN BILLIONS OF M^3
DESERT AREA: Northern part	5 mm - 100 mm	Average: 50 mm Dry year: 6,5 mm	1,500,000 km2	Average: 75 Dry year: 9.75
DESERT AREA: Southern part	100 mm - 200 mm	Average: 150 mm Dry year: 30 mm	700,000 km2	Average: 105 Dry year: 21
NOMADIC SAHEL	200 mm - 400 mm	Average: 300 mm Dry year: 80 mm	1,400,000 km2	Average: 420 Dry year: 112
SEDENTARY SAHEL	400 mm - 600 mm	Average: 500 mm Dry year: 230 mm	700,000 km2	Average: 350 Dry year: 161
SUDANI-SAHELIAN AREA	600 mm - 800 mm	Average: 700 mm Dry year: 420 mm	500,000 km2	Average: 350 Dry year: 210
SUDANIAN AREA	1,500 mm	Average: 1,100 mm Dry year: 900 mm	400,000 km2	Average: 440 Dry year: 360
TOTAL:				Average: 1,740 Dry year: 873.75

TABLE SHOWING VOLUME OF RAINFALL IN THE SAHEL COUNTRIES

GEOFRAPHICAL AREAS	VOLUME OF RAINFALL IN BILLION OF M3 - in an average year - in a dry year recurring every 50 years	UTILISATION
DESERTS	180 average year 30 dry year	-Rainfed agriculture: none. -Runoff: negligible and practically unusable -Infiltration into ground: very slight -Natural range lands: use very limited Nearly all evaportes
NOMADIC SAHEL	420 average year 110 dry year	Rainfed agriculture: none -Runoff: very slight and practically unusable -Infiltration into ground:very slight -Natural rangelands: extensive use Much evaporates
SEDENTARY SAHEL and SUDAN-SAHELIAN AREA	700 average year 370 dry year	-Rainfed agriculture: substantial use -Little runoff, approx. average 5% i.e. perhaps around 35 billion m3, short distance runoff. Long distance runoff probably amounts only to some 1%, 7 billion m3 in an average year.

.../...

		-Substantial infiltration into a small number of water tables only; -Natural rangelands: very extensive use
		a moderate amount evaporates
SUDANIAN AREA	440 average year 360 dry year	-Rainfed agriculture -Natural rangelands and recharging of major Sahelian rivers

In sum, rainfall in the Sahel countries amounts to 1,740 billion m3 in an average year and some 870 billion m3 in a very dry year.

These figures show that the water-supply in the Sahel is not one of the total precipitation but rather of geographical distribution, which varies too much from area to area, and of amounts which can be used by man, animals and agriculture.

Out of 100 units of water reaching the ground as rain, thus only the following can be said to be used:

- the evapotranspiration part from cultivated plants and natural fodder actually used for grazing. Cultivated plants, however, occupy only some 1% to 2% of Sahel territory and the natural rangelands actually grazed probably less than 40%.

- runoff, provided it is harnessed by irrigation installations. But runoff only accounts for between 0 and 20% of the precipitation, a figure in the neighbourhood of 5% being fairly common. Much of this amount again evaporates in marigot and river beds and in the inner deltas of the major Sahelian rivers.

- the part that infiltrates the deeper strata, provided it is recovered by sinking wells.. Infiltration into the deeper layers is very limited (3% perhaps), and only a very minute part of this water is recovered.

In sum, most of the rainwater evaporates where it falls or after running off for some distance, or after being thrown off by plants of no direct agricultural or pastoral value.

II.2. SHORT-DISTANCE RUNOFF HYDROLOGICAL DEGRADATION

Hydrological degradation

The geography of the Sahel countries has given rise to certain river system characteristics:

- gentle longitudinal slopes over most of the course;
- valleys are fairly flat in cross-section;
- impermeable soils generally prevail;
- very high degree of evaporation;
- the river system generally runs from south (humid and rainy) to north (where there is little rainfall and a dry climate[1].

Because of these conditions all Sahelian watercourses are affected by so-called "hydrological degradation; in other words, the specific flow rate (i.e. the flow rate per unit of the catchment basin area) decreases as one moves downstream.

In certain cases (the most striking example being Lake Chad, although there are others), the watercourses flow into closed basins, where the level is maintained between certain limits depending on evaporation as related to recharge; this is known as "endorheism".

Therefore the runoff coefficients --defined as the ratio between precipitation in some given area and the volume of water flowing downstream from this area- declines substantially, depending on whether the catchment basin is taken as an entity or as the sum of all small component catchment areas.

Thus, the Goroul, Upper Voltan branch of the higher portion of the Niger River, whose basin receives an average annual precipitation of some 460 mm, has the following mean runoff coefficients along its course:

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(1) There are a few exceptions, the best known are the Volta Rivers and the Niger portion of the Niger River.

Catchment basin	runoff coefficients	Depth of runoff in an average year
- Small upstream basins of about 25 km2	around 15%	around 70 mm
- Partial catchment basin at Dilbel: 7,500 km2	8%	36 mm
- Total catchment basin at Aliongui: 44,850 km2	less than 1%	4 mm

This explains the importance of differentiating short-distance runoff from long distance runoff in all estimates of surface water resources in the Sahel countries.

By short-distance runoff is here meant the runoff into catchment basins whose surface area is big enough to provide enough recharge water to justify the development of some small elementary irrigated areas. It is assumed that the water from the small hill dam can irrigate at least 10 hectares, on which a surghum-legume type of crop can intensively be grown each year from July to March. This means that about 16,000 m3/ha(1), or 160,000 m3 of water for all 10 hectares, will be needed.

It will later be seen that the hill pond thus formed is of varying effectiveness in preserving the natural water supply depending on the shape of the reservoir, the recharge capacity during the rainy season and the climatic features (rain and evaporation) recorded at the particular geographical location. In general, however, a small hill pond of fairly unfavourable shape in a Sahelian rainfall area of ±500 mm, with a water recharge between 500,000 and 1 million m3 yields a volume of water downstream amounting at least to 20-25% of the water it originally receives.(2)

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(1) This is system 5 shown in the table of intensive agricultural systems, but with a water requirement coefficient of 1.5 or 2.

(2) The rest of the water input, i.e. 75%, either evaporates in the reservoir or, during heavy flooding, spills out too violently to be of any use in the farmed area.

To water a minimum area, therefore, takes

$$160{,}000 \times \frac{100}{25} = 640{,}000 \text{ m}^3$$ of recharge during a dry year with a 5-year return period.

If the average rainfall is about 500 mm, the rainfall during a dry year is about 350 mm with a 5-year return period which corresponds to runoff coefficients ranging from 0 to 30% and in most cases amounting to some 8-10%. Even assuming that the runoff coefficient is 5% (1) during the recurring dry year, the runoff depth measures 25 mm.

Some 25 km^2 are therefore required to obtain 640,000 m^3 of recharge with such an amount of runoff.

It can thus be assumed that a catchment basins of over 25 km2 is potentially worth while for irrigation development in the Sahelian area. It should be noted, however, that this standard applies when the average annual rainfall is about 500 mm, and that, all things being equal, a potentially worthwhile area will be greater north of the 500 mm isohyèt and smaller south of it.

The fact that a basin is potentially worthwhile will moreover not always justigy the use of an irrigation facility from a hydrological standpoint. The topography and the geology must also lend themselves to the construction of a hill-type dam at a cost compatible with the anticipated gains, while, douwnstream the soil must be suited to irrigation The latter requirement can fairly often be met, however, owing to the small size of the areas involved.

The economic advantage of such a facility can only be determined by undertaking a feasibility study in each individual case.

Short-distance runoff coefficient

ORSTOM studies show the runoff position in catchment basins of some 25 km2 and the following diagram shows annual frequencies of equivalent of greater runoff in the three "desert", "sub-desert", and "Sahelian" climatic zones.

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(1) The actual figure is equal or higher in 90% of cases.

These three tables can be summed up as follows:

- Desert climate: Graphs 7 and 8
  (between 0 and 100 mm average annual rainfall)

With an average annual rainfall of 50 mm, approximately 8 mm of runoff is obtained once every two years.

<u>But runoff is next to nil one year out of five</u>.

In a desert climate, short-distance runoff may be assumed to be valueless for irrigation purposes.

- <u>Sub-desert climate</u>: graphs 13 and 14.
  (between 100 and 300 mm average annual rainfall'.

When the average annual rainfall approaches 200 mm, runoff fluctuates around the following figures:

- impermeable basins with steep slopes; about 57 mm.
- relatively impermeable basins with fairly steep slopes; about 27 mm.
- relatively impermeable basins with gentler slopes; about 10 mm.

It should however be noted that the median category with fairly steep slope and relatively impermeable basin has a runoff of only 12 mm in a dry year with a 5-year return period and practically nil for one with a 50-year return period.

In the final analysis, in a sub-desert climate, short-distance runoff is of marginal value to irrigation except when groundwater dams are built to harness underflow.

- <u>Sahelian and Sudani-Shelian Climate</u>
  (Average annual rainfall betwee 300 and 800 mm).

When the average annual rainfall approaches 500 mm, runoff fluctuates around the following figure in a median year:

TYPE OF BASIN	Depth of run-off in a median year with rainfall of some 500 mm	Depth of run-off in a year with chance of at least an 80% following depth	Depth of runoff in a year with a 98% chance of at least the following depth
1- Sandy basins	2,2 mm	1 mm	0
2- Basins overlying sand and marl			
3- Basins overlying granite and gneissose granite			
3.1-Permeable soils with fairly steep slopes(12 to 14 m/km)	17,5 mm	10 mm (?)	5 mm (?)
3.2-Less permeable soils with steep slopes (20 to 30 m/km) with at least 25% of the surface composed of more compact sandy soils and shallow sandy soils	35 mm	30 mm(?)	10 mm(?)
3.3-Soils barely permeable with moderate slopes (4m/km)	70 mm	35 mm(?)	15 mm(?)
4- Basins overlying relatively fissureless sandstone, excluding the Aderdoutchi Basin in Niger	70 mm	35 mm(?)	15 mm(?)
5. Basins overlying schist	98 mm	50 mm(?)	25 mm(?)
6-Ader Doutchi Maggia sandstone basins			
6.1 With 40% red-brown soils and favily permeable areas	70 mm	35 mm	15 mm
6.2 80 to 90% alluvial clays and non-calcareous soils	175 mm	110 mm	40 mm

All these figures, especially those on the last two columns, are averages subject to confirmation, based on data taken from ORSTOM studies.

- Sudanian climate

Information on short-distance runoff in the Sudanian climatic areas of the Sahel countries is much scarcer and less accurate than preceding climatic zones.

Various sectorial studies, especially the SOGETHA studies on the harnessing of marigots in Central and Southern Upper Volta, indicate that when the average annual rainfall is about 1,000 mm the runoff depth is about 150 mm at least in the moderately sloping gneissose granite areas and for catchment basins some 25 km^2, in area [(1)].

Similarly, the height of the runoff in a year when the frequency of excess flow is 80% is approx. 70 mm and when it is 98% the runoff is about 40 mm[(1)].

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(1) These figures vary greatly from one year with an average rainfall of 1,000 mm in the granite-gneiss area, for instance, may range between 50 and 300 mm.

Use of Short-distance Runoffs for Irrigation

The degree of utilisation cannot be accuratly evaluated until individual studies have been made of thousands of small component basins, which is beyond the purview of this paper.

In the absence of such an evaluation, a rough estimate can probably be made, probably indicating the lowest potential.

Using the above information and more specific studies carried out as part of a survey of drought-control strategy for the West African Sahel, it is possible to work out ratios for the major climatic zones of the Sahel countries as follows:

1. The fraction of the total area occupied by small catchment basins (ranging from 2 km^2 to some tens of km^2, with the average located somewhere around 25 km^2) with appropriate locations for hill dams and irrigable soil.
2. Mean annual depths of runoff.
3. Ratio of mean recharge water which can be recovered downstream for irrigation purposes.
4. Water consumption requirements per irrigated hectare.

- The first ratio depends on topography, and generally decreases as one moves from south to north in the Sahel countries; general magnitudes of 1% in the Nomadic Sahel, 10% in the Sedentary Sahel and Sudani-Sahel area, and 12% in the Sudanian area are likely according to maps on the scale of 1:250,000.

- The second ratio could be calculated very roughly on the basis of the above runoff data:

  20 mm in the Nomadic Sahel
  50 mm in the Sedentary Sahel and the Sudani-Sahel area, and
  120 mm in the Sudanian area.

  These figures do not seem exaggerated as averages for large area units.

- The third ratio depends on evaporation and average mean annual rainfall in the water reservoirs.

  The various management forecasting studies for small dams carried out as part of the survey on drought-control strategy in the West African Sahel suggest that 20%, 30% and 50% of the average annual recharge could be used for irrigation in the Nomadic Sahel, the Sedentary Sahel and Sudani-Sahel area and the Sudanian area respectively.

- The fourth ratio (irrigation water requirements) increases as one moves from south to north. Considering the high water utilisation coefficient over small areas, the figures might reach some 5,000 m^3 in the Sudanian area, 20,000 m^3 in the Sedentary Sahel and Sudani-Sahel area and 25,000 m^3 in the Nomadic Sahel for cereal and legume-type crops (rice/legumes in the south, sorghum or wheat/legumes in the north). The following table might hence provide some rough idea as to theoretically useable irrigation capacity by means of fully controlled short-distance runoff.

IRRIGATION CAPACITY PROVIDED BY SHORT-DISTANCE RUNOFF

Geographical area. Extreme and annual mean rainfall. Total area in km^2.	Useable areas: -as percentary of the total - and in km^2	-Mean annual depth of run-off in mm -Mean annual volume of run-off in millions of m^3	-Volumes of use to irrigation -as percentage of the average annual and -in millions of m^3	-Water requirements per unit area i.e. m^3/ha. -Potentially irrigable areas (in ha)
DESERT AREA 20 to 200 mm	SHORT-DISTANCE RUNOFF OF NO USE TO IRRIGATION			
NOMADIC SAHEL 200 to 400 mm 1,400,000 km^2	2% 28,000 km^2	25 mm 700 M m^3	20% 140 M m^3	25,000 m^3 6,000 ha approx.
SEDENTARY SAHEL AND SUDANI-SAHEL AREAS. 400 to 800mm 1,130,000 km^2	10% 113,000 km^2	50 mm 5,650 M m^3	30% 1,700 M m^3	20,000 m^3 85,000 ha
SUDANIAN AREA 800 mm 420,000 km^2	12% 50,000 km^2	120 mm 6,000 M m^3	50% 3,000 M m^3	15,000 m^3 200,000 ha approx.
TOTAL		12,350 M m^3	4,840 M m^3	291,000 ha

Four points are worth stressing:

1) - These figures are large ‹by open to doubt, and again can only be regarded as very approximate.

2) - Insufficient irrigable soils downstream of the dams constitute a constraint which may substantially reduce these figures, especially in the Sudanian Area.

For the 25 km^2 catchment basins, the average area size would be:

- NOMADIC SAHEL	6 ha
-SEDENTARY AND SUDANI-SAHEL AREAS	20 ha
- SUDANIAN ZONE	100 ha

One cannot be sure, moreover, that 100 ha. of irrigable soil could readily be found downstream of each 25 km^2 catchment basin considered suitable for development in the Sudanian Zone since the total irrigated area does not exceed 4% of the total basin area in this region.

3) - The table however probably gives an accurate picture as to <u>relative orders of magnitude</u> of the areas which potentially can be irrigated from short-distance runoff. Even in the absence of precise figures the potential can be summarised as follows:

- DESERT AREA AND NOMADIC SAHEL	Negligible potential
- SEDENTARY SAHEL AND SUDANI-SAHEL AREA	One third of potentials, i.e. perhaps 100,000 ha can be effectively irrigaged
- SUDANIAN ZONE	Two thirds of potential, i.e. perhaps 200,000 ha can be effectively irrigated.

4) - Developing the full potential, evaluated at 300,000 ha, would entail a titanic effort, since it would mean building some <u>7,000 hill dams</u>.

At an average cost of about 300 million CFA francs per dam (1), the investment would exceed 2,100 billion CFA francs, not counting installations in the irrigated areas.

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(1) This figure can vary greatly, depending on the topography and geotechnical conditions.

II.3 - LONG-DISTANCE RUNOFF

While the data in section II.2 enables potentially irrigable lands to be estimated provided all small catchment basins in the Sahel countries are equipped, the utopian character of such an endeavour is also apparent. Looking several centuries ahead, conceivably the Sahelian population could perhaps acquire such facilities, which would not nessarily be limited to crop irrigation alone (drinking water in rural areas, urban development, livestock production, quality of life, etc.).

Within the more foreseeable future of a few dozen years, the Sahel countries might perhaps achieve a small part of such irrigation development, but it is more likely that to begin with they would try to control long-distance runoff, which is possible with a much smaller number of projects, even though on a larger scale. This is an important consideration in countries where the shortage of skilled personnel calls for concentrated forms of effort.

A distinction will be made between:

- Long-distance runoff in catchment basins specific to the Sahel, whose surface areas range from a few thousands to a few tens of thousand km^2 i.e. medium-sized catchment basins; and,
- Long-distance runoff into major rivers flowing through the six Sahel countries but originating outside their political boundaries. These main watercourses, which are abundantly replenished by the heavy rainfall in the Guinean and Central African regions are:
  - . the SENEGAL
  - . the NIGER
  - . the CHARI-LOGONE-CHAD system,

  to which we have added the GAMBIA owing to the extensive volume of water it receives and the VOLTA rivers which, although completely within the Sahel size - are a substantial asset in UPPER VOLTA owing the size of their catchment basins.

II.3.1 - LONG-DISTANCE RUNOFF IN MEDIUM-SIZED CATCHMENT BASINS

General Characteristics:

A medium-sized basin is taken to mean a catchment basin of between 1,000 and 120,000 km^2 located entirely within the Sahel.

Three runoff features are of special relevance to utilisations:

1 - The Irrigularity of Runoff During a Given Year

Actually nearly all of these catchment basins yield no downstream flow during all or part of the dry season.

As an example, the ALIBORI, the Benin affluent of the Niger, whose greater and medium-sized catchment basins cover 8,150 km^2 in a region where the average annual rainfall is 1,090 mm (a very favourable figure compared with other basin averages), has no run-off even in a year of heavy rainfall from January through April. When rainfall is slight, this period extends from December to July. The attached charts give an idea of the irregularity of flow down-stream from the basin in years of both slight and heavy rainfall. The situation is worse in nearly all other medium-sized basins, which means that the unregulated flow of these streams cannot be relied upon to supply a modern, intensive perennial irrigation net-work watering two crops a year, as described in page and there-after. Even when intensive irrigation is used for only one crop a year the water supply is not reliable enough for irrigating areas of any appreciable size downstream from these basins.

The supply must be regulated at least annually if it is to be used for intensive irrigation.

The KOMADOUGOU, a southeastern tributary of Lake Chad, is the only exception, one moreover of limited extent.

2 - Rates are also Very irrigular from year to year.

As an example, the ALIBORI flow rates, expressed in continuous year round terms, ranges from 13.5 m^3/sec. in a decennial dry year to 65 m^3/sec. in a decennial wet year (39.5 m^3/sec. in an average year). And this is an especially favourable case.

The flow rate of the BAM-BAM as it leaves the GUERA mountains in CHAD varies between 9 million m^3 in a decennialdry year to 108 million m^3 in a decennial wet year, (20 million m^3 in an average year).

If any considerable proportion of the runoff supplied by these catch-ment basins is to be used for intensive year round irrigation, annual regulation of the flow will therefore not be enough.

Flow regulation facilities must be fairly substantial for regulating the flow between years, even if infrequent flows are to be regulated (i.e. water supplied during wet centennial years, partly discharged through the dam, spillway, and the supply in dry centennial years, where a moderate loss in quantity can be tolerated).

3 - Hydrological degradation reaches some considerable proportions in these basins and the average annual runoff coefficients are still relatively small.

They vary greatly from one catchment basin to another. The following paragraph gives a very general idea of the main types of runoff, as described by the ORSTOM.

Runoff in Medium-sized Sahelian Basins

According to ORSTOM, a distinction should be made between the 1,000 to 10,000 Km^2 catchment basins and those of over 10,000 km^2.

1 - Catchment Basins of 1,000 to 10,000 km^2

a) - In desert and sub-desert climates, with an average annual rainfall reaching some 300-400 mm, average annual recharge rates are negligible; the supply mainly depends on the tributary closest to the station where flow rates are measured. Thus "the Fero Wadi catchment basin at AM NABAK has a surface area of 5,600 km^2 and 19 years out of 20, or perhaps even 49 years out of 50, the runoff comes from a 50 km^2 zone immediately upstream of AM NABAK". (Source: ORSTOM).

The only noteworthy exceptions are the catchment basins lying mainly in well-developed mountain areas where the terrain is fairly permeable and the slopes of the main valleys are fairly steep.

The KORI TELOUA in the AIR mountains, thus with an average annual rainfall of 160 mm has the following runoff depths:

- Median year 25 mm (runoff coefficient: 15%)
- Decennial dry year 8 mm (runoff coefficient: 8%)

In the absence of mountain catchment basins, catchment basins where the ground is fairly impermeable and slopes are substantial can yield coefficients between 2 and 5 % in a median year, provided runoff conditions downstream are adequate.

When the slope is too gentle and the soil permeable, these coefficients drop to some 1% or even 0.

b) - In a strictly Sahelian climate, a distinction should be made between:

b.1 - Catchment basin overlying granite or gneissose granite formations, where runoff may be as follows:

- very gentleslope permeable soil	Approximate depth of runoff: nil in median year
- fairly gentle slope permeable soils	Approximate depth of runoff: - 6 mm in median year and - 2 mm in decennial dry year
- fairly steep slope high percentage of permeable soil	Approximate depth of runoff; - 24 mm in median year and - 7 mm in decennial dry year
- moderate slope, high percentage of clayey soil covering the granite	Approximate depth of runoff: - 35 mm in median year and - 22 mm in decennial dry year

b.2 - Clayey basins overlying schist or the intercalated continental formations where runoff is far better than on the former:

- basins with good runoff conditions (steep slopes very few permeable soils)	Approximate depth of runoff: - 65 mm in median year and - 20-25 mm in decennial dry year
- Basins with moderate runoff conditions (medium slopes, high percentage of impermeable soils)	Approximate depth of runoff: - 30 mm in median year and - 10 mm in decennial dry year
- basins with poor runoff conditions (fairly gentle slopes, considerable percentage of permeable soils)	Approximate depth of runoff: - 15 mm in median year - and slightly under 5mm in decennial dry year

An overall estimate runoff based on the above data would have no meaning. An estimate has therefore been made in Part IV based on data from 50 catchment basins grouped into 12 hydrological areas covering some 500,000 km^2. These basins supply most of the usable recharge water for medium-sized catchment basins in the Sahel proper.

2 - Catchment basins over 10,000 km^2 in area :

According to ORSTOM only a few catchment basins with a surface area of over 10,000 km^2 can avoid total degradation.

They fall into two groups:

Group 1:

This group is composed of rivers with "gentle slopes, with very little runoff over much of their surface area or a heavy loss of water in certain areas", e.g. the WHITE VOLTA, THE GOROUOL and the KOMADOUGOU.

The depth of annual runoff is some 5 mm in a mdeian year, i.e. the runoff coefficients range from 0.7 and 1.2% of precipitation.

Group 2:

This group is composed of "rivers in basins with better runoff either because slopes are generally appreciable, or because of clayey soils", e.g. The BATHA and the BAHR AZOUM in CHAD, and the SIRBA a Voltan affluent of the Niger portion ofthe Niger river.

The depth of annual runoff is some 15 mm. in an average year, i.e. the runoff coefficients range from 2 to 3% of precipitation.

It should be noted that in both groups the depth of runoff in a dry year with a 50-year return period is 2 mm.

The KOLOMBINE and the KARAKORO, right-bank affluents of the SENEGAL River in Mali and in Mauritania, whose regimers are ill-known, seem to belong to this group, with runoffs of some 20 to 25 mm in a median year.

II. 3. 2 - FLOW RATES IN BASINS OF SAHEL RIVERS

Three hydrological characteristics of the major Sahelian Rivers should be taken into consideration:

1 - Highly variable discharge rates within a given year

As, according to ORSTOM, in the following cases:

-Senegal River at Bakel in 1973 (upon entering the Sahel area):

. maximum flow rate	2,550 m3/sec
. average flow rate for the year	355 m3/sec
. low stream flow rate	0.25 m3/sec

-Niger River at Koulikoro in 1973 (upon entering the Sahel area):

. maximum flow rate	4,140 m3/sec
. average flow rate for the year	903 m3/sec
. low stream flow rate	16 m3/sec

-Niger River at Niamey in 1973 (after crossing the Sahelian area):

. maximum flow rate	1,560 m3/sec
. average flow rate for the year	605 m3/sec
. low stream flow rate (1974)	0.6 m3/sec

Variability is less marked for the Logone and the Chari, at least as regards low stream flow:

-Logone River at Lal in 1973 (upon entering the Sahel area):

. maximum flow rate	1,420 m3/sec
. average flow rate for the year	265 m3/sec
. low stream flow rate (1974)	21,4 m3/sec

-Chari River at N'Djamena in 1973

. maximum flow rate	2,130 m3/sec
. average flow rate for the year	572 m3/sec
. low stream flow rate	38,6 m3/sec

2 - Highly Variable discharge rates as between years, as shown in the following table:

	Average annual discharge (billions of m3)	Discharge in 1973 (billions of m3)
Senegal River at Bakel	23,6	11.2 (20-year return period)
Niger River at Koulikoro	67,0	29.2 (50-year return period)
Logone and Chari where they enter the Sahelian Zone	46,2	18,0 (40-year return period)
TOTAL	136 8	58 4

It is important to note that the considerable average amounts annually discharged, i e 136.8. billion m3, which before entry into the Sahel exceeds the total average discharge of the White Nile and the Blue Nile, which, according to ORSTOM, 121 billion m3

3 - The major Sahelian Rivers suffer from very serious hydrological degradation as they flow through the Sahel, as shown by the following ORSTOM data:

	Average annual discharge upon entering the Sahel (billions of m3)	Average annual discharge upon leaving the Sahel (billions of m3)	Average annual loss (billions of m3)	Average loss in ratio to average annual discharge
SENEGAL	23,6	22 (Dagana)	- 1,6	- 7%
		18 (St-Louis)	- 5,6	-23%
NIGER + BANI	67,0	36 (Diré)	-31	-47%
		31,2 (Niamey)	-36,8	-55%)
CHARI + LOGONE	46,2	38,5 (N'Djamena)	-7,7	-17%
		0 (TCHAD)	46,2	-100%
TOTAL	136,8	49,2 (St-Louis + Niamey+TCHAD)		-65%

To develop the major Sahelian rivers to any considerable extent, a first step must be substantial interannual river training before they enter the Sahelian area proper.

II.4 - GENERAL LOCATION OF GROUNDWATER RESOURCES

The study dealing with the productivity of water tables, average cost of recovery and suitability of ground water for irrigation in the Sahel countries, carried out by the Bureau de Recherche Geologique et Minière, to which we shall frequently refer, claims that a distinction should be made between:

- GENERALIZED AQUIFERS, showing some continuity in their spatial characteristics, and generally containing plentiful reserves owing to their huge size.

The B.R.G.M. classified under this heading "sedimentary formations with interstitial porosities (sand, sandstone) or fissures, showing some general permeability, (dolomite, limestone, karstified calcareous, marl, highly diaclastic rocks, etc.).

- DISCONTINUOUS AQUIFERS, "intrinsically impermeable geological formations having acquired, secondarily and very locally, by deterioration or fracturing, a certain permeability".

The B.R.G.M. has classified in this category "all formations belonging to the eruptive and metamorphic rock foundation (granite, gneiss, schists, intrusive rocks), and also certain sedimentary formations, e.g. indurated sandstone, quartzite, etc."

II.4.1. - GENERALIZED AQUIFERS

Going from West to East, the principal GENERALIZED AQUIFERS are as follows:

II.4.1.1. - GENERALIZED AQUIFERS IN THE WEST OF THE SAHEL COUNTRIES

These underlie SENEGALESE AND MAURITANIAN territory and comprise four major water tables:

Dune sands:

These are quaternary sands extending over some thousands of square kilometres behind the Atlantic Coast, from Cape Verde to the AOUKER-CHECAT region.

The static level lies at about 10 to 50 metres under the surface, and the depth of the aquifer is normally from 20 to 30 metres.

The sands are permeable, but the productivity of installations is too often limited by their lack of depth. If this were extended to the substratum, unit yields of up to 1,000 or 1,500 m3 per day could be obtained, and would be useful for local irrigation of fruit, vegetables and fodder crops.

The capacity of the water table, which is interspersed with some sterile areas, is not known. Although it is to some extent replenished by rainwater, it may be doubted whether more than a few hundred million m3 per year, enabling some 10,000 ha to be irrigated, can be safely drawn off without gradually exhausting the supply.

.../...

Continental Terminal

This is a vast aquifer consisting of heterogeneous argilaceous sand or sandstone, or sometimes eocene limestone.

It seems at first sight to be a free table, its static level lying some 50 to 70 m underground, the depth of the aquifer varying from 20 to 200 m (generally between 20 and 50 m).

In the West, the water table takes up the greater part of the Senegal -Mauritanian geographical basin, over about 40,000 km2 the exploitable volume being somewhere around 50 billion m3. Replenishment seems to be assured, within reasonable limits, by rainwater and by the Senegal, but the balance has not been worked out and the usable annual yield is somewhat uncertain.

The specific yields are highly variable, ranging from those in SENEGAL, where they may reach 1,800 m3 per day (for a drawdown of 10 m) to those in the neighbourhood of MAURITANIA (300 m3 per day for the same drawdown).

The water table could be tapped for irrigation purposes at least in South-East Senegal.

Maastrichtian sand and sandstone:

This is far and away the largest aquifer in SENEGAL, underlying the previous formations nearly everywhere.

It consists of a confined, rising structure 200 to 400 metres deep (usually 200 to 250 metres). It covers nearly 100,000 km2 and its usable volume is considerable, possibly amounting to 3,000 billion m3.

There is a little information about replenishment, although this seems probable, and the specific yields of the installations exceed 1,500 m3 per day for a drawdown of only some 30 m (in the best areas, yields may exceed 6,000 m3 per day).

SENEGAL Alluvia:

The B.R.G.M. claims that these alluvia are "highly permeable locally and may yield up to 30 m3 per hour for a drawdown of 2 m. Above BOGHE, the water is brackish and unusable".

In fact, the land which could be served by this water table can usually already be irrigated from rivers, on the whole move cheaply.

Other water tables in the West of the Sahel countries:

The other generalised water tables underlying the West of the Sahel countries are less well known or less extensive. They include:

the palaeocene limestone and karstified dolomite formations on the northwestern edge of the Senegal basin and in the southern part of the Mauritanian basin, the usable volume of which is not known, but which may give considerable yields (of something like 100 m3 per hour, for a drawdown of 10 m especially on the Senegal side).

- the "intensely karstified palaeocene limestone of Cap Verde drains the Maastrichtian water table laterally", with very high yields in some places (up to 300 m3 per hour, for a drawdown of 10 m).

- the TAOUDENI water table, the existence of which seems probable and might be a boon for MAURITANIA.

II.4.1.2. - GENERALIZED AQUIFERS IN THE CENTRAL PART OF THE SAHEL COUNTRIES.

The three principal generalised aquifers in the central region (MALI, UPPER VOLTA and NIGER territory) are:

The water tables in continental formations of varying age in MALI:

These extend over about 130,000 km2. around the loop of the Niger, from upstream of SEGOU (South AZOUAD) to downstream of GAO (North AZOUAD), mainly in argilaceous sandstone of the Continental Terminal or in alluvia of the Niger River.

Usable amounts seem to approach 30 billion m3., the aquifers generally being not very deep, stretching downwards for a few metres, or more often for a few decametres, with a static level some 25 to 100m down.

It is not known what yields could be used annually without endangering the water table balances but they are probably rather low, notwithstanding the fact that they are replenished by the Niger or by some of its tributaries, e.g. the Faguibine.

The specific yields are generally low, even in the Niger alluvia, where they do not exceed 360 m3/day for a drawdown of 10 metres.

The Western water table of the Continental Terminal in the NIGER Republic:

Extends over some 20,000 km2., south of the Sudanian channel and the Niger Basin.

It lies in argileaceous sandstone, and in some places in sand; it often comprises more than one water table (at least two) which communicate with the free standing ground water above.

The static level of the aquifer lies some 30 to 60 m underground, and its depth varies from 30 to 60m.

.../...

Usable quantities amount to some 15 billion m3; the annual maximum has not been determined, but must be favily high, in view of replenishment by the Niger.

Specific yields vary from 150 to 3,000 m3 per day for a drawdown of 10 metres.

The Tegama sandstone water table:

This is the largest underground water table in the central region.

Geographically speaking, it belongs to the Intercalated Continental formation and the Continental Rock Plain series.

It extends from the South of the AIR region to the Nigerian frontier and from the TENERE to the NIGER, covering several hundred thousand km2 at depth down to 30 to 50 m (it is, however, confined with a static level at + 15m. in the Southeastern part of the NIGER Republic. This water table, which is 500 to 700 m. deep, made up of sandstone, argileaceous sandstone, sand and clay, has a usable volume of several hundred thousand m3, and the maximum annual draw-off might well amount to several billion m3 with replenishment by the Niger).

The specific yields are very high in the part of the water table close to the frontiers of NIGERIA (1,000 to 3,500 m3 per day for a drawdown of 10 metres or sometimes more).

In other parts of the water table the specific yields are well below 1,000 m3 per day for the same drawdown.

Other generalized aquifers in the Central SAHEL region:

Two of these are of some interest:

- The AGADES sandstone water table in Western and North-western AGADES, covering 10,000 km2, is under pressure, and sometimes wells up; its water is fresh, but becomes brackish towards the western boundary of the water table.

The aquifer is some 90 m deep, and the total usable volume must approach 10 billion m3.

However, no more than a few tens of million m3 can be used owing to the low intake and the danger of swamping by salt water from the West.

Although average specific yields only amount to some 500 to 1000 m3 per day, with a drawdown of 10 m this aquifer is of great importance for the local populations.

- The primary system water tables lie West of the AIR region.

These are sandstone or sandy aquifers enclosed by clay, with fresh water in the Nothern part, becoming brackish towards the South.

They cover several tens of thousand km2, and usable volume probably approaches 50 billion m3.

There seems to be little or no replenishment, so that the maximum annual draw-off is very low, but the specific yields are sometimes high.

The OTHER GENERALIZED AQUIFERS IN THE CENTRAL SAHEL REGION are of much les importance:

- The TAOUDENI water table seems to be the MALI extension of the (hypothetical) MAURITANIAN aquifer already referred to.

The ADRAR DES IFORAS marine series offers rather low specific yields (0 to 150 m3 per day for a drawdown of 10 m).

- The GONDO water table lies in argileaceous sandstone filling a basin formed by subsidence, straddling the UPPER VOLTA-MALI frontier, East of BANDIAGARA; the specific yields are low.

- The TELOUA sandstone water table West of the AIR region has not be fully explored; its productivity is considered to be low.

II.4.1.3. - GENERALIZED AQUIFERS IN THE EASTERN PART OF THE SAHEL STATES

The Eastern part of the Sahel states is defined in the B.R.G.M. study already referred to, as comprising the territory of the CHAD Republic and the part of the NIGER Republic lying east of the Zinder meridian.

Eight generalised aquifers appear to be of considerable importance; unfortunately as a rule they have been less fully explored than the generalised aquifers of the western and central regions of the Sahel countries.

1.- The TEGAMA sandstone in this region is an extension of the major aquifer of the same name in the central region. The sandstone extends from DAMERGOU, south of TENERE, to TALASSASSET, and is very similar in character to that found farther West.

2.- The UPPER CRETACEOUS sandstone series overlie the TEGAMA sandstone to the East, around TERMIT, AGADEM and BILMA (where the artesian springs well up at the rate of 1,200 m3 per day.)

Towards the South, various boreholes yield flows of around 400 to 1,000 m3 per day.

The particulars of this series are, on the whole, very imperfectly known.

3.- The KORAMAS water table stretches South of the Zinder mountain system to from 20 to 30 km. North of the NIGERIAN frontier.

There is little accurate knowledge of the total usable volume or specific yields, which seem to vary widely from 250 to 2,000 m3 per day, for a drawdown of 10m.

4.- The PLIO-QUATERNARY water tables extend North and East of Lake CHAD, in the MANGA and KANEM regions; they cover some 65,000 km2, with a total usable volume of some 30 billion m3.

They comprise an upper stage, a river-lake series and dunes, from 10 to 20 m. deep, sometimes separated by clay, the whole showing somewhat varied water features and fairly low specific flows of some 120 to 300 m3 per day, for a drawdown of 5 m.

This same series includes a lower water table enclosed in sand, known as the middle water table, it wells up in places around Lake CHAD. Specific yields are distinctly higher (500 to 2,500 m3 per day

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The B.R.G.M. refers to the following:

-The cretaceous sediments in southern CHAD

-The marine carboniferous sediment in southern CHAD

-The Nubian sandstone in the northernmost part of the CHAD Republic, which may prove highly productive.

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for a drawdown of 10 m.

5.- The CONTINENTAL TERMINAL, northern part, extends West of the OUADAI district, through the CHAD lowlands and the BATHA district. over about 40,000 km2. This is a shallow water table near the surface, but owing to its extent and water characteristics, the total usable volume seems to be considerable (somewhere between 10 and 40 billion m3.)

The specific draw-offs are highly variable, ranging from 120 to 1,200 m3 per day, for a drawdown of 5 m.

6.- The CONTINENTAL TERMINAL, southern part, still referred to as the KOROS water table, covers an area of some 100,000 km2, in the southern part of the CHAD Republic, south of BONGOR, and in the SALAMAT district. It is a water table with somewhat varied features, the static level lying between 5 and 80 down, having a depth of somewhere around 15 metres, with wide variations.

Its total usable volume, which is very imperfectly known, seems to be somewhere between 20 and 80 billion m3.

For a drawdown of 5 m. the specific yields of intake installations range from 250 to 1,800 m3 per day, generally much nearer the first figure.

The low general productivity of this water table is thought gradually to improve as it approaches the centre of the SALAMAT depression.

7.- The LOWER PLIOCENE water table is believed to cover some 25,000 km2 above the Continental Terminal, West of the OUADDAI district and the northern part of the Continental Terminal table. The land consists of generally rather unproductive sandy and clayey soil, yielding however, by and large, an appreciable usable volume (15 billion m3.)

8.- Lastly, in the northern part of the CHAD Republic, the CAMBRIAN-VISEEN water table around LARGEAU consists of coarse and kaolinic sandstones highly productive and largely unexplored.

Other generalized water tables are of less importance, and have been even less fully explored than those already described.

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II.4.2. - DISCONTINUOUS AQUIFERS

These aquifers cover most of the remainder of the Sahel countries. Their only conceivable function is to supply the population and their flocks and herds.

1. - First and foremost are the aquifers contained in the weathered or fissured parts of the crystalline or phyllocrystalline African bedrock.

They are located, in particular

- East of the Senegal-Mauritanian sedimentary basin, over vast areas;
- On the Voltan shield, over some 300,000 km2.;
- In the ADRAR DES IFHORAS mountain system;
- In the AIR mountain system;
- In the GOURMA region;
- In the ZINDER, OUADDAI and GUERA mountain systems.

Total usable reserves, annual usable amounts and specific drawoffs are invariably low in these formations (rarely exceeding 100 m3. per day.)

We find in addition:

2. - The discontinuous water tables of the HODH pelites, under the pasture land at the East-West frontier between MAURITANIA and MALI.

3. - Discontinuous water tables in the infra-Cambrian and primary sandstones in MAURITANIA, which may be slightly more productive, particularly in the ASSABAT and TAGANT areas.

II.5. - GENERAL RECAPITULATION OF GROUND WATER RESOURCES.

The attached map merely shows the boundaries plotted by the B.R.G.M. of the chief generalised aquifers briefly described above.

A very summary recapitulative table may be drawn up, restricted to aquifers, showing the ground water resources which technically can be harnessed for irrigation, hence also for supplying the needs of humans and livestock.

REGIONS OF THE SAHEL	Principal generalised aquifers	Total usable volume (in billions of m3.)	Annual draw-offs technically possible in millions of m3. (rough, purely tentative estimation) without endangering the equilibrium of the water table.	Specific draw-offs in m3 per day for a drawdown of 10 m. ------- Poor: 1,000 1,000 Medium: 1,000 2,000 Good: 2,000
WESTERN REGION	-Dune sands (coastal)	5	200	Medium
	-Continental Terminal	50	1,000	Poor to Medium
	-Maestrichtian sandstone	3,000(?)	5,000(?)	Medium & Good
	-Senegalese alluvia	50	300	Good
	TOTAL WEST	3,105(?)	6,500	
	-Continental formations in MALI	30	1,500	Medium
CENTRAL REGION	-Western Continental Terminal water table in the NIGER Republic	15	500	Poor to Medium
	-TEGAMA sandstone water table	300	3,000	Medium and Good
	TOTAL CENTRE	345	5,000	
EASTERN REGION	-TEGAMA sandstone	see Central Region	500	Medium & Good
	-Upper sandstone series	?	?	Poor
	-KORAMAS	?	?	Medium and Good
	-Plio-quaternary	30	500	Medium and Good
	-North Continental Terminal	10 to 40	300 to 600	Poor
	-KOROS	20 to 80	1,000 to 2,000	Poor & Medium
	-Pliocene	15	300	Poor
	-Cambrian-Visean	5(?)	100(?)	Good
	TOTAL EAST	100 to 200(?)	2,500 to 4,500(?)	
TOTAL SAHEL		3,550 to 3,650	11,500 to 15,000	

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No undue value should be attached to these figures, which are merely intended to provide the reader with some standard of reference.

The total usable volume of the leading generalised aquifers in the SAHEL amounts to several thousand billion m3 (perhaps between 3,500 and 4,000 billion), the bulk consisting of Maestrichtian sandstone. The annual drawoffs technically possible without endangering the equilibrium of the water tables are harder to calculate, but may be put at some 12 to 15 billion m3.

In actual fact, economic use for irrigation should be restricted to installations with 'medium' and 'good' specific yields (i.e. over 1,000 m3 per day or 12 m. per second), provided that the operating costs are reasonable and quality is satisfactory.

This being so it is probably impossible to draw off really large amounts from the SAHEL water tables for irrigation purposes.

Even if the maximum latitude were allowed, accepting for example, such conditions as:

- Minimum specific draw-off	500 m3 per day per borehole
- Maximum cost per m3 of water	CFA Fr. 20 per m3 (CFA Fr. 300,000 for 15,000 m3 per year of irrigation water, which could only be contemplated for double cropping of highly productive, quality vegetables or fruit.)
- Quality of water	Good, Medium, Poor under the California Department of Agriculture classification.

it may be doubted whether more than one to two billion m3 of ground water could be drawn off for irrigation (about 10 per cent of the yields technically possible), corresponding to between 60,000 and 120,000 irrigable ha used to grow highly productive and quality crops, supplied by 1,000 to 2,000 installations.

It seems reasonable to assume that the resources now capable of being used would supply little more than 10,000 to 20,000 ha within the next few decades.

PART THREE

ADAPTING RESOURCES TO REQUIREMENTS

III.1 REGULATED AND UNREGULATED USE OF THE MAIN SAHEL WATERCOURSE IRRIGATION

Utilisation without regulation

The areas which can be irrigated from the main Sahelian rivers without regulation of the flow have been calculated for quantities of water guaranteed by normal flow, four years out of five, and 49 years out of 50, during the critical months; the figures have been taken from the tables of monthly yields in the ORSTOM hydrological yearbooks, classified in inverse order of importance, with any needed extrapolation; quantities corresponding to the maintenance, during the same critical months, of a sufficient flow to cover water requirements of the riparian populations and insure survival of the aquatic fauna and flora have been deducted.

These minimum flows have been assessed as follows:

- for the SENEGAL, Upper NIGER and Middle NIGER (1), at about 20 m3 per second, or roughly 50 million m3 per month;
- for the LOGONE and the CHARI, at about 10 m3/second each (2), or roughly 25 million m3 per month;
- for the Upper BANI, at 5 m3 per second, or roughly 12 million m3 per month.

Regulated use:

The simulated management method mentioned in the introduction was applied to all reservoirs for the three main Sahel watercourses and the WHITE VOLTA, the dimensions of which were ascertained with an accuracy compatible with use of the mathematical model.

Assessments were based on information available regarding the GAMBIA water reserves.

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(1) For the Middle NIGER, account must also be taken of the necessity of maintaining a minimum flow in the "Nigerian" reach.

(2) Thus representing 20 m3 per second downstream of their confluence at N'DJAMENA.

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III.1.1. USE OF SENEGAL WATERS FOR IRRIGATION

III.1.1.1. UNREGULATED USE OF THE SENEGAL

Unregulated use of the valley land

The pedologically irrigable land in the Senegal Valley lies downstream of KAYES, and mainly downstream of BAKEL (1); it is subject to flooding by the river to a depth of about 1-4 metres, although this figure varies over the year and from year to year; in addition, the average annual rainfall at BAKEL is about 700 mm, while rainfall in the valley is equal to or below this figure.

Such rainfall conditions prevent development by a natural or controlled basin check system (see section 1.3 above, page..), and development by intensive irrigation would call for large basin checks protected from the river floods by a system of levees, and irrigated by pumping from the river. As the cost of such facilities per hectare is high, it is an economic necessity to practise the double cropping system, which is possible in those latitudes, either growing two rice crops with a long time interval between them (system 2, see page) in the northern part of the valley, or two rice crops in quick succession (system 1, page), in the South and upstream of the valley towards BAKEL, or more probably two rice/wheat crops (system 3).

Of these systems the one which seems likely to be most widely adopted in the river valley are system 1 (rice followed by rice) and system 3 (rice followed by wheat).

The critical month for system 1 is March, when irrigation of the second rice crop requires 6,300 m3 per ha, whereas the discharge of the Senegal at BAKEL in March amounts to 94 million m3 and 32 million m3 in years with an 80% or 98% frequency of at least this amount of discharge respectively. If the volume of water to be maintained in the river bed below BAKEL, i.e. 50 million m3 is deducted from these figures, the quantities available for irrigation are 44 million m3 and 0 respectively, depending on the frequency figure.

The irrigable areas bearing two crops of rice a year below BAKEL would thus amount to about 7,000 ha and 0 . Respectively, according to whether the aim is to practise irrigation four years out of five or 49 years out of 50.

(1) We shall refer henceforward to discharges at BAKEL, which have been the subject of more intensive analysis than those at Kayes, and which are also greater as the Senegal is fed by the KARAKORO and, still more important, the FALEME between the two points.

The critical month for system 3 is February, when irrigation of the second wheat crop requires 2,200 m3 per ha, whereas the discharge of the Senegal at BAKEL in February, in a dry year with a five-year return period is 157 million m3, and in a dry year with a 50-year return period 73 million m3. Deducting from these figures the amounts of water which must be maintained in the river bed below BAKEL , 50 million m3, it will be seen, that quantities actually available for irrigation in February are somewhere around 107 million m3 four years out of five, and 23 million m3 49 years out of 50.

The irrigable areas growing two crops a year (rice/wheat) immediately below BAKEL, without regulated use of the river, thus amount to some 49,000 ha or 10,000 ha, according to whether the aim is to guarantee irrigation four years out of five or 49 years out of 50.

In actual fact, these figures are probably somewhat pessimistic as field water application efficiency considered in the study on irrigation water requirements was taken to be 0.5, which is not necessarily accurate in a medium-sized system, if well managed. The systems corresponding to the areas recommended can in fact be regarded as medium-sized.

THE MAXIMUM IRRIGABLE AREAS GROWING TWO CROPS A YEAR BELOW BAKEL, WITHOUT REGULATED USE OF THE WATER THUS VARY ACCORDING TO THE NATURE OF THE SECOND CROP CYCLE AND THE IRRIGATION GUARANTEE REQUIRED, AS FOLLOWS:

	Crop Guaranteed 4 years out of 5	Crop guaranteed 49 years out of 50
Two rice crops	7,000 ha	0
Two crops: rice followed by wheat	49,000 ha	10,000 ha

It should be noted that the minimum irrigable areas with one crop per year, for which the critical months are July and October, are probably much larger, but as we have seen, they have no economic justification whatever in the case of the Senegal Valley.

Unregulated use for double cropping without regulated use of the delta land

Such utilisation is impossible with two irrigated crops a year; the discharge of the Senegal is, in fact so sluggish that during the greater part of the dry season the river is invaded by a tongue of salt water from the Atlantic nearly up as far as DAGANA.

In these circumstances, any attempt to irrigate the second crop would bring in salt water unusable for irrigation.

III.1.1.2. REGULATED USE OF THE SENEGAL

A. Regulation downstream: DIAMA GUIERS, R'KIZ and AFTOUT ES SAHEL

The most urgently needed regulation is in the delta, where the irrigated areas bearing one crop per year are now tending (1975) to reach their maximum extent, while those bearing two crops per year cannot be developed further owing to the presence of the "salt water tongue" in the river during the dry season.

There can be no question of creating a reservoir to ensure supplies all the year round on the Senegal downstream; as the reservoir would be extremely shallow, most of the valley would be flooded in the rainy season, while in the dry season evaporation would dry up the greater part of the water reserve.

The extremely high cost of the dam would not be offset by any advantages, and the drawbacks would be considerable.

The method proposed would consist in building a dam with sliding sluice-gates storing a shallow depth of water (+1.5 or + 2.5m) letting through the main flow during the spate period from August to November, the sluice gates subsequently being closed so that the water would be at maximum height about 1st February.

The reservoir would thus allow a second rice or wheat crop to be grown, the first being irrigated by the flood water. The reservoir would not be called upon to discharge the minimum flow into the river below the dam in the dry season, as this would be invaded by the salt water tongue.

A reservoir limited to a depth of+1.5 or +2.5m would involve only slight drawbacks for pastureland. The potential was calculated on a forward planning basis for a decennial dry year, when the river discharges some 14.3 billion m3, with the following results:

- +1.5m
  - . amount used in a decennial dry year — 385 million m3
  - . irrigable area — 21,250 ha
- + 2.5 m
  - . amount used in a decennial dry year — 680 million m3
  - . irrigable area — 37,500 ha

These figures represent a very appreciable increase over the present maximum.

To these areas must be added those which could be irrigable from the three main distributaries downstream of the Senegal, i.e. AFTOUT ES SAHEL, Lake GUIERS and Lake R'KIZ:

1. THE AFTOUT ES SAHEL, a right bank distributary of the Senegal, has a capacity of about 1.4 billion m3 at + 1.5m

   The AFTOUT can be used up to about o.5m., to ensure that there no marine infiltration, as the river is separated from the oc only by a belt of dunes; the forward planning figures in a decennial dry year are:

   - Southern half:

     . amount used — 120 million m3
     . irrigated area — 10,000 ha

   - Totality:

     . amount used — 280 million m3
     . irrigated areas — 20,000 ha

   A detailed study of the SOGREAH for double cropping, but with other rotation courses, puts the cultivable areas at 14,000 ha in all. This is the figure we shall adopt.

2. Utilisation of GUIERS lake, a left-bank distributary of the Senegal, now provides for the irrigation of the RICHARD TOLL basins, switched to sugar cane cultivation over an area of about 5,000 ha. Several studies have mentioned the possibility of increasing this area to 10,000 ha by filling Lake GUIERS to a depth of 1.5 m from DIAMA.

3. Lake R'KIZ, a distributary on the right bank of the Senegal, would enable some 2,000 ha to be irrigated, provided it was filled to a depth of 1.5 m from DIAMA.

   Lastly, regulation downstream at what now seems to be the most likely depth of 1.5 m from DIAMA, would make it possible, in a decennial dry year, to irrigate:

   21,150 ha + 14,000 + 10,000 ha + 2,000 ha = 47,250 ha,

   amounting in practice to nearly 50,000 ha bearing two crops a year.

B. Regulation upstream

Regulation upstream has been considered on six of the main sites named, on a year-by-year system, based on actual flows during 66 years, with the following results:

Location	Dam	Dam height	Amounts regulated for irrigation purposes, (billions of m3	% of regulated discharge	Irrigable area under double cropping
On the BAING, working upstream	GALOUGO	46	12,2	70%	450,000 ha
	MANANTALI	38	8,6	75%	340,000 ha
	BOUREYA	60	8,6	77%	260,000 ha
	KOUKOUTAMBA	55	3,0	47%	120,000 ha
On the FALEME	GOURBASSI	22	2,4	46%	70,000 ha
On the BAKOYE	BADOUMBE	60	3,9	75%	150,000 ha

Drawoffs have been calculated for irrigating two crops per year throughout the river valley, from KAYES to the delta, the drawoff timetable being fixed to allow for the time required for the water to travel from the foot of the dam to the head of the irrigated area.

Furthermore, the drawoffs planned from GALOUGO and MANANTALI have been made subject to the constraint of a minimum flow for navigation (300 m3 per second), which would prove no great handicap, as it would mean drawing-off about 2% of the volume regulated at GALOUGO and of 14% for MANANTALI.

It can be seen from the above figures that it is theoretically possible to regulate the entire discharge of the Senegal at BAKEL (24 billion m3, yearly average) by a nicely calculated utilisation of only part of the above dams.

In actual fact, complete regulation is not necessary if it is desired to irrigate only the land which is clearly suitable for irrigation from the pedological aspect (alluvial soils in the valley and delta).

The geographical area of these soils is some 1,250,000 ha, consisting of 950,000 ha of alluvial deposits with no salinity problems (including 270,000 ha in MAURITANIA) and 350,000 ha of deposits with salinity problems (including 190,000 ha in MAURITANIA).

However, 50 to 60 per cent of the deposits without salinity problems should, according to the study made by the UNITED NATIONS SPECIAL FUND, be eliminated, for topographical reasons, or to allow the maintenance of permanent channels for fishing or navigation.

The alluvial soils with no salinity problems which are really suitable for development thus cover 360,000 to 450,000 ha.

Deposits with salinity problems actually suitable for development cover only 60,000 to 150,000 ha.

Finally, the irrigable areas cover between 450,000 and 600,000 ha, probably nearer the first figure than the second.

In those circumstances, the following combination seems to be attracting most attention:

- FIRST GENERATION DAMS (about [illegible]00 - 2050)

. 1st Phase; DIAMA (+AFTOUT ES SAHEL + GUIERS + R'KIZ)	50,000 ha
. 2nd Phase: MANANTALI	340,000 ha
. 3rd Phase: GOURBASSI	70,000 ha
Total First Generation	460,000 ha

- SECOND GENERATION DAMS (after 2000 - 2050)

. BADOUMBE, regulating the BAKOY would allow the area to be increased by 150,000 ha, giving in all	610,000 ha

Regulation would enable all the land actually suited to irrigation to be watered, with a regulated volume of some 15 billion m3 out of a discharge of 24 billion m3. Nine billion m3 would still not be regulated; the utilisation of this quantity is hardly conceivable unless it is planned to extend irrigation to largely unsuited soils such as "Dieri" which cannot reasonably be envisaged for a few more generations.

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III. 1. 2 - USE OF THE NIGER AND BANI WATERS FOR IRRIGATION

III. 1. 2.1 - UNREGULATED USE OF THE NIGER AND BANI

a) - Upper Niger and Bani Valleys

The utilisation downstream of the Upper Niger and the Bani, its tributary, for intensive double crop irrigation, involves a similar calculation to that made for the Senegal at Bakel, the critical month being March (second crop) for a type 1 system, with a water consumption of about, 4,300 m3 per hectare.

The results are as follows:

RIVER	DRY YEAR WITH A 50-YEAR RETURN PERIOD		DRY YEAR WITH A 5-YEAR RETURN PERIOD	
	Volume used in March (millions of m3)	Irrigable areas (hectares)	Volume used in March (millions of m3)	Irrigable areas (hectares)
NIGER AT KOULIKORO	36 (1)	8 500	110(1)	26 000
BANI AT DOUNA	8(1)	2 000	23(1)	5.500
TOTAL	44	10 500	133	31 500

Very small areas are thus involved, contrary to the opinion sometimes expressed, and in actual fact these areas are much smaller than those now cultivated in the Office du Niger area under the controlled basin check system

(1) Figures given after subtracting amounts of residual flow to be left in the rivers, i e 50 million m3 for the NIGER, below KOULIKORO, and 12 million m3 for the BANI, below DOUNA

The reason is that the Office du Niger almost invariably grows a single crop per year on the same land, the critical month being July for flooding, based on a drawoff of some 5,800 m3 per ha

Controlled flooding for the basin check system has to be effected from the July and August flows, those two months being required to furnish about 20,000 m3 per ha.

A similar calculation carried out for both types of irrigated crops naturally gives much higher figures than those already quoted i e:

FOR IRRIGATION OF A SINGLE CROP PER YEAR

RIVER	DRY YEAR WITH A 50-YEAR RETURN PERIOD		DRY YEAR WITH A 5-YEAR RETURN PERIOD	
	Volume used in July (millions of m3)	Irrigable areas (hectares)	Volume used in July (millions of m3)	Irrigable areas (hectares)
NIGER AT KOULIKORO	1.200	206 000	1.900	328.000
BANI AT DOUNA	135	24 000	320	57 000
TOTAL	1 335	230 000	2 220	385 000

FOR IRRIGATION BY CONTROLLED FLOODING WITH THE BASIN CHECK SYSTEM

RIVER	DRY YEAR WITH A 50-YEAR RETURN PERIOD		DRY YEAR WITH A 5-YEAR RETURN PERIOD	
	Volume used July/August (millions of m3)	Cultivable areas(ha)	Volume used in July/August	Cultivated areas (hectares)
NIGER AT KOULIKORO	4.400	220.000	10.000	500.000
BANI AT DOUNA	1.500	75.000	3.000	150.000
TOTAL	5.900	295.000	13.000	650.000

These tables make no allowance for amounts of residual flow, which are marginal by comparison with July and August discharges.

It is interesting to note the limits to progress imposed on short-term trends, which can probably be summed up as follows:

-maintenance of the Office du Niger area and extension to 60,000 ha, and introduction of double cropping as far as possible (for sugar-cane)

-rapid, large-scale development of the basin check system.

On this basis, the limits <u>without regulation</u> would be as follows:

<u>NIGER:</u>

60,000 ha under annual crops managed by the Office du Niger (of which 8,500 ha might be used for double cropping) and about 200,000 ha used for the basin check system	all guaranteed 49 years out of 50

or,

60,000 ha under annual crops managed by the Office du Niger (of which 26,000 ha might be used for double cropping and about 480,000 ha under the basin check system	all guaranteed 4 years out of 5

<u>BANI:</u>

75,000 ha under the basin check system	guaranteed 49 years out of 50
or 150,000 ha under the basin check system	guaranteed 4 years out of 5

In actual fact, the real figures are probably <u>lower</u>, if it is desired to maintain a minimum flow in the Niger for navigation and the downstream section of some 300 to 600 m3 per second, corresponding to a draw-off of about <u>1,600 million to 3,200 million</u> m3 for the months of July and August

If the Office du Niger area is maintained at 60,000 ha, this constraint would reduce the area of the basin check system guaranteed <u>49 years out of 50</u> to somewhere between 40,000 and 120,000 ha for the Niger valley alone, and to somewhere between 115,000 and 195,000 ha for the Niger and Bani valleys as a whole.

Having regard to the current basin check programmes, representing <u>150,000 ha</u> for the two valleys of the Niger and the Bani, the problem of inter-annual regulation would hence arise in the short-term.

(b) Unregulated Use of the Niger at the outlet from the lake basin

The Niger in the lake basin proper, i e from Mopti to DIRE, is now used for growing sorghum and rice crops sown when the flood has receded, and for after-flood pasturing In this area up-to-date irrigation systems ensuring complete water control would have to include large-scale flood protection and water diversion projects which could probably not be undertaken for some time to come. Their construction would call for exact prior knowledge of the topography, flood propagation in the lake area, and the influence of river training upstream.

At the tip of the central delta and the northernmost part of the river bend, consideration might be given to the institution of small to medium irrigation areas, drawing water from the river by pumping according to the time of year), and bearing two crops per year Any extension in the size of these areas would depend on the river flow.

Between DIRE and ANSONGO, three double cropping systems would be possible:

-two spaced out rice crops, on the lines of the "YAGOUA" system 2, perhaps with a slight time shift, for which May is the critical month (when irrigation of the second rice crop finishes);

-rice-wheat on the lines of the "N'GUIGMI" system 3 for which June is the critical month (flooding or the first rice crop);

-rice-vegetables on the lines of the "NIAMEY system 4", perhaps with a slight time shift to allow for the difference of latitude, the critical month being July (flooding or first rice crop).

A recent study by ORSTOM shows the probabilities of exceeding the monthly discharge at TOSSAYE, month by month, giving, after conversion into quantities 52, 13 and 26 million m3 guaranteed 49 years out of 50 for the months of May, June and July respectively. For the same months, amounts guaranteed 4 years out of 5 are 215,83 and 182 million m3 respectively

From the volumes guaranteed at TOSSAYE, quantities corresponding to a residual flow of 20 m3 per second for the riparian population of the Middle Niger have been calculated.

The results are then as follows:

	-Critical month - Unit discharge (m3 per ha)	Usable amounts during the critical month guaranteed 49 years out of 50 (millions of m3)	Irrigable areas bearing 2 crops per year guaranteed 49 years out of 50, in ha (area rounded to nearest 1000 ha)	Usable amounts during the critical month guaranteed 4 years out of 5 (millions of m3)	Irrigated area bearing 2 crops per year guaranteed 4 years out of 5 in ha (area rounded to nearest 1000 ha)
2 spaced out rice crops (marginal)	- May -2,900m3/ha	2	2,000	165	57,000
Rice/Wheat	- June - 5,700m3/ha	0 (-37)	0	33	6,000
Rice/Vegetables	- July - 7,200m3/ha	0 (-24)	0	132	18,000

Local food and farming habits, and the general economy of the region, are much more conducive to rice/wheat or rice/vegetable double cropping than to two crops of rice, which would in fact be marginally possible in this latitude.

It thus seems that the latter system would be little practiced, and the maximum figures similar to those advanced for the rice/wheat and rice/vegetable systems. The maximum irrigated areas for double cropping without regulation would thus be about 18,000 ha guaranteed 4 years out of 5, while the areas irrigated for rice/wheat or rice/vegetable double cropping could not be guaranteed 49 out of 50.

In actual fact, water depths observed during the critical months would substantially limit pumping capacity (inlets exposed) hence the areas theoretically irrigable, above.

c) - Unregulated use of the Middle Niger in the NIGER Republic, without regulation

For the Middle Niger, above and below NIAMEY, much the same problem arises as for the northern river bend. A similar calculation gives the following results:

	-Critical month - Unit discharge (per ha.)	Flow during critical month guaranteed 49 years out of 50 (millions of m3)(1)	Irrigable areas bearing 2 crops per year guaranteed 49 years out of 50 (hectares)	Flow during critical month guaranteed 4 years out of 5 (millions m3)(1)	Areas irrigated during critical month guaranteed 4 years out of 5 (hectares)
2 spaced out rice crops	- May - 2,900 m3/ha	50	17,000	220	76,000
Rice/Wheat	- June -5,700 m3/ha	0	0	50	9,000
Rice/ Vegetables	- July -7,200m3/ha	0	0	40	6,000

Finally, failing any incontrovertible assuption as to the distribution of the three systems in years to come, it would seem wise to adopt a figure closer to the maximum calculated for the rice/wheat and rice/vegetable systems, i.e. some 7,000 ha, for a two-crop system with the second crop guaranteed only four years out of five.

Attention must be drawn to the impossibility of practising irrigation for rice/wheat or rice/vegetable double cropping with any high degree of security if there is no prior regulation of discharge in the middle river valley.

Note that the unregulated drowffs in the Mali on reaach between DIRE and ASONGO cannot be added to those from the Nigerian reach, where the rate offlow is almost the same, with a timelag of a few weeks.

The irrigable areas for the two reaches cannot therefore be aggregated.

Double cropping areas irrigable without regulation along the Niger River up to the Nigerian frontier must therefore be taken as a rough indication, pendeng the possibility of calculating them with a mathematical model. The urgency of constructing such a model is underlined by the necessity of ascertaining the effects of the multi-purpose dam project dealt with below.

(1) After deducting amounts of residual flow to be left in the Middle Niger bed, i.e. some 50 million m3.

III.1.2.2. - REGULATED USE OF THE NIGER

At the present time only figures are available for the reservoirs of SELINGUE on the SANKARANI, an affluent on the right bank of the Upper Niger, and those of TOSSAYE and KANDADJI. They are only very roughly approximate in the case of these last two.

a) - Regulation by the SELINGUE Reservoir

The SELINGUE reservoir would hold slightly more than 2 billion m^3 at + 14.5 m above the present water level, subject to a mean annual discharge from the SANKARANI of some 12 billion m^3.

Located in an area where evaporation is relatively slight (for Africa) and where rainfall over the reservoir area is considerable it has the advantage of being little subject to evaporation. On the other hand the amount of water evacuated by spillway would be substantial.

Forward management planning over a period of 66 years as regards discharges calculated from ORSTOM data and amounts of water used for two rice crops per year shows the following results:

- Amount lost through evaporation in an average year 0.33 billion m^3
- Amount discharges in an average year over spillway 8.26 billion m^3
- Amount regulated for irrigation purposes 3.40 billion m^3

Under these conditions, if alone used and solely for irrigation purposes, 110,000 ha of ricefields yielding two crops a year could be developed.

This figure is however given only for guidance, since the following constraint must be allowed for if a more realistic picture of future conditions is to be obtained.

The SELINGUE dam would have to be used for generating hydropower and for navigation, rather than for irrigation alone.

A study of dam capacity at SELINGUE from such a multipurpose standpoint shows that it would be possible to irrigate 62,000 ha of double-crop land from SELINGUE and moreover to obtain an extra crop on 40,000 ha of land in the Office du NIGER area. The degree of probability would be high: some 40 years out of 50.

These are the figures it is proposed to adopt.

It may be pointed out that the entire Upper Niger and the Bani would quite conceivably be trained by building reservoir dams in the valley upstream of this river, in Southern MALI and especially GUINEA as regards the Upper Niger, and in IVORY COAST or Southern MALI as regards the Upper BANI (actually the BAGOE and BAOULE, which join to form the BANI).

Various cursory feasibility studies suggest that such river training is possible, at least in the very long term, and that some three fourths of the average annual discharge of these two rivers could thus be made available for irrigation upon entry into the Sahel area, i.e. approximately 45 or 50 billion m^3 for watering over a million hectares of land yielding a double rice crop.

Lack of detailed information prevents any further analysis of these projects, which would require such a huge capital outlay that they could not be carried out before 2000-2050.

b) - Regulation at TOSSAYE

Training the Niger downstream from the lake area is a problem which arises owing to the small amount of land otherwise available for double cropping, based on the calculation of discharge amounts during the critical months at TOSSAYE (see III.1.2.1.b. above). It so happens that the area in the bend of the river is fairly under-privileged compared with the remainder of the Republic of MALI, so that the population might well suffer seriously from any recurrence of drought.

The need to afford access by the population to an agricultural output which is effectively guaranteed even during dry years has caused ambitious perennial irrigation targets to be set in the area; these may even exceed the strict requirements of the present population, in order that nomadic herders can be supplied in case of drought.

The exact dimensions of the TOSSAYE reservoir are not yet known, but various assumptions can be based on certain figures available regarding the longitudinal section of the NIGER.

The situation at TOSSAYE can be summed up as follows: taking low-water mark as + 252, by raising the water surface to + 260 a reservoir extending over a distance of 350 km upstream of TOSSAYE nearly as far as DIRE would be obtained.

This reserve amount of water would have the advantage of filling several lake basins which are offshoots of the Niger, where perennial irrigation now seems difficult owing to their irregular filling by the river.

Moreover, the riparian population in the northern bend could irrigate its fields by pumping.

On the other hand the reservoir, by flooding many grazings at BOURGOU, might seriously interfere with present stockfarming activities.

It is thus unlikely that the spillover figure at TOSSAYE can be put at + 260 upon completion of the project studies, and the forward planning quantities calculated for + 260 and + 259 (i.e. respectively 1500 and 800 million m^3) are given with serious reservations as to accuracy.

Nor could irrigation be limited to the use, whether by pumping or diversion, of water stored from April to July (low-water period) in the reservoir upstream of the dam.

It would seem only fair to reserve part of those quantities to the population living downstream from the dam. Hence forward planning calculations have been made by assuming that downstream from the TOSSAYE dam a flow of 100 m^3 per second would be maintained, of which 800 m^3 per second would be available for farmers using irrigation methods, the remainder, i.e. 20 m^3 per second, being maintained for "ecological reasons".

On such a basis, the forward-planning model yields the following results for a double rice/wheat crop:

	Irrigable from Reservoir	Irrigable below Reservoir	Total
At + 260	30,000 ha	36,000 ha	66,000 ha
At + 259	14,000 ha	36,000 ha	50,000 ha

and for a double rice/vegetable crop:

	Irrigable from Reservoir	Irrigable below Reservoir	Total
At + 260	20,000 ha	29,000 ha	49,000 ha
At + 259	10,000 ha	29,000 ha	39,000 ha

Owing to the uncertainty as regards the exact amounts of discharge from April to July and as regards the exact dimensions of the reservoir, and in view of amounts to be managed for hydropower generation, it would seem wiser to adopt a figure of some 20,000 or 30,000 ha, an area moreover appreciably matching the good irrigable soil potential available between Tossaye and ANSONGO (again for a double crop of the rice/wheat type and especially rice/vegetable.

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d) - Regulation by the KANDADJI Reservoir

Much as for DIAMA, the reservoir which could be built at TOSSAYE would only have a limited effect on annual regulation of the NIGER and none on interannual regulation, a fact foreseeable owing to the disparity between its volume (1.5 billion m^3 at + 260, which is probably too high a figure, and 0.8 billion m^3 at + 259, the most likely figure) and quantities discharged by the NIGER (annually averaging 30.2 billion m^3).

Owing to these conditions a dam would be absolutely needed downstream from TOSSAYE for training the Niger section of the NIGER river, whether for irrigation, navigation or hydropower generation.

While the dimensions of KANDADJI reservoir are not exactly known, with the information available it could be studied from a forward-planning aspect.

For a height of 30 m the volume of the reservoir would appear to reach some 9 billion m^3. a forward-planning model covering 37 years of quantities actually yielding the following results:

- Double cropping of the rice/wheat or rice/vegetable type:

. Average quantities discharged	30.2 billion m^3
. Amount discharged over spillway	6.8 billion m^3
. Evaporation	1.3 billion m^3
. Amount which can be regulated solely for irrigation	22.1 billion m^3

The volume of water trained for irrigation corresponds to a theoretical irrigation capacity of 560,000 ha for a double crop of the rice/wheat or rice/vegetable type and of 500,000 ha for the double cropping of rice

Areas suited to irrigation in the Niger section of the NIGER valley however probably amount to no more than 800,000 ha.

By making use of the KANDADJI reservoir to a height possibly under 30 m, irrigable land in the Niger section of the NIGER River could be completely watered, while navigation downstream could be improved, large amounts of hydropower generated and considerable regulated quantities of water supplied to NIGERIA.

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III.1.3 - USE OF CHARI-LOGONE-CHAD WATERS FOR IRRIGATION

III.1.3.1 - UNREGULATED USE OF THE LOGONE AND OF CHAD

The double cropping of rice can be practised in the lower plains of the LOGONE and CHARI: in the upper part of these plains rice crops can be grown at close intervals, and in the lower part toward N'DJAMENA, spaced rice crops or double crops of the rice/wheat type can be raised.

a) - The LOGONE

The critical month for irrigating a double crop of rice from the LOGONE is March, when the required discharge rate would be 4,300 m^3 per second for a guaranteed flow of some:

- 95 million m^3 49 years out of 50
- and 140 million m^3 four years out of five.

From these figures must be subtracted a quantity corresponding to a residual flow for the riparian population and for ecology of some 10 m^3 per second, i.e. 25 million m^3. Amounts available for irrigation in March would therefore have to reach some 70 million m^3 49 years out of 50 and 115 million m^3 four years out of five.

Irrigable surfaces would hence amount to some 16,000 ha guaranteed 49 years out of 50 and 27,000 ha guaranteed four years out of five.

It should be noted that the water of the river has begun to be used on a fairly extensive scale on the CAMEROON side, which has a right to half the discharge. Theoretically, therefore, North CAMEROON would be able to irrigate 8,000 ha for a closely spaced double rice crop. The actual figure is somewhat lower (5,500 ha), since a minimum water height must be available at pumping stations, while the recent extremely low stream flows with a return period of 60 to 70 years serve to highlight the limited irrigation capacity of the LOGONE without river training.

b) - The Lower CHARI

Unregulated development of the Lower CHARI can be planned:

b.1 - For raising a double crop of the rice/wheat type downstream from N'DJAMENA. The critical month is June, when the required flow would be 5,700 m^3 per ha.

Under those conditions, the irrigable areas without any regulation of flow would be:

- Guaranteed irrigation 49 years out of 50: a flow of some 470 million m^3 and of 445 million m^3 after deducting a residual flow of some 10 m^3 per second. This amount would enable 80,000 ha to be irrigated.

- Guaranteed irrigation four years out of five: some 570 million m^3 of flow and 545 million m^3 after deducting residual flow, enabling some 96,000 ha to be irrigated.

b.2 - For raising a spaced double crop of rice between SAHR and N'DJAMENA 4,000 m^3 per second would be needed in April, the critical month, i.e. an irrigation capacity after deducting 25 million m^3 for maintaining the residual flow, of:

- 210 million m^3 irrigating 53,000 ha 49 years out of 50, and
- 285 million m^3 irrigating 71,000 ha 4 years out of five.

It should be pointed out that these figures cannot be added together.

III.1.3.2 - THE CHARI AND LOGONE AFTER REGULATION

a) - Regulation of the LOGONE

In view of the foregoing facts it would seem indispensable in the short term to undertake regulation of the lower LOGONE, where any expansion of irrigation may well be "blocked" in the near future.

In the upper basin of the LOGONE two sites have been the subject of feasibility studies: GORE on the PENDE and KOUBAM on the VINA.

Forward planning exercises have been undertaken for a 32-year discharge sequence, yielding the following results in the case of a double crop of rice:

	GORE	KOUMBAM
Catchment basin	8,340 km2	11,680 km2
Height of dam	29 m	54 m
Volume of reservoir	ca.3 billion m3	ca 3,600 billion m3
Quantities used	ca. 2,500 million m3	ca 3500 million m3
Areas which can be irrigated by the reservoir	95 000 ha	ca 120,000 ha

Characteristics marking the use of these reservoirs are therefore well worth noting, owing to their shape and their location in a rainy area (1,200 to 1,500 mm).

One of these dams, particularly at GORE, where the cost per irrigated hectare would appear to be the lower, should therefore be promptly built, especially as irrigable soil is found over extensive areas on either bank of the LOGONE downstream.

In the short term, the problem which arises is whether it would not be well in a first stage to build dams of lesser capacity but at lower cost, which could ensure irrigation development during the next ten tofifteen years.

b) - Regulation of The CHARI

Regulation of the CHARI is by no means as urgent as that of the LOGONE, since the irrigation ceiling without river training is much higher, reaching some 70,000 to 80,000 ha.

The fact is that to our knowledge no topographical survey, even of a cursory kind, has been made of possible large-scale reservoirs on the CHARI and its affluents; while the creation of such reservoirs is believed quite feasible, it would be risky to extrapolate the shape of the basins. The geology and general topography at most suggest that a reservoir of no great height but considerable size could be created downstream from SAHR, provided a levee several kilometers long and extensive ancillary installations were built besides.

Within the next few decades no development project would seem to warrant such an undertaking.

On the other hand, use could be made of Lake Chad, where all the water brought in by the CHARI and LOGONE evaporates, as a reservoir for irrigating polders along the edge.

A forward planning exercise covering 39 years of discharge into Lake Chad shows that approximately each year 9 billion m^3 out of the 39 billion m^3 of water annually pouring on average into the lake could be withdrawn. Such withdrawals would enable 375,000 ha planted with a double crop of the cotton/wheat type to be irrigated.

Owing to these amounts withdrawn, the level of the lake would be maintained between narrower limits than it now is, since the approximate altitude recorded for maximum water level arount 1970 was + 285 m, whereas if the lake were used in this way the figure would not be above + 281.54m. In fact lowering of the water level would restrict pumping capacity for irrigable surfaces.

Another scheme for using Lake Chad is theoretically possible. This would consist in separating the north-eastern from the south-western section by means of a dyke one to eight metres high, built roughly at the site of the Great Barrier. The southwestern section would then be used as a reservoir for irrigating the northeastern section, which covers some one million hectares. Forward planning shows that discharges over a space of 42 years would enable 18,500 million m^3 of water to be drawn off for irrigating some 750,000 ha growing a double crop each year.

The maximum figure reached is some 283.73 m, without any spillover, suggesting that a levee suited to the system could be built to + 285m. No such work could be contemplated before the period following 2000-2050.

III.1.4 - USE OF THE VOLTA RIVERS AND THE GAMBIA FOR IRRIGATION

Neither the Voltas nor the Gambia can be compared to the three major Sahelian rivers, as much smaller auantities are discharged.

Yet their use for irrigation must be considered - the Voltas because they provide the leading water resource of a country largely devoid of any such assets, and the Gambia because its use would effectively add to the potential of the Senegal, which may well be used to full capacity within a few decades.

III.1.4.1 - UNREGULATED USE

Unregulated use of the Voltas for double cropping is impracticable, as the amount of discharge by the Black Volta is extremely small during the critical month and all the water must be used for drinking purposes in KOUDOUGOU and OUAGADOUGOU, while during the same month the White Volta has practically no flow and the Red Volta none at all from January to June.

Unregulated use of the Gambia is conceivable, since the flow is perennial. For irrigating two closely spaced rice crops the critical month in Gambia would be March, where the low amounts discharged (probably with a 50-year return period) would seem to approximate 8 to 9 million m^3. As the second rice crop during this month calls for 6,000 m^3 per ha, the irrigable area for double-crop purposes would be limited to 1,500 ha.

III.1.4.2 - REGULATED USE OF THE VOLTAS AND THE GAMBIA

a) - Regulated Use of the VOLTAS

The VOLTAS are the main water resource of the Republic of UPPER VOLTA.

Their regime is still not very well known; its special character has to do with the northwest/southeast orientation of these streams, with the exception of the upper branch of the Black Volta which is oriented southwest/northeast.

Because of this orientation the amounts discharged by those rivers increase rather rapidly, beyond isohyet 800 mm. North of this isohyet, low recharge and hydrological degradation limit the depth of runoffs to a few millimetres. South of this isohyet, the recharge is much heavier, hydrological degradation tends to disappear and depth of runoff amounts to several centimetres.

Their water regime may accordingly be presented as follows:

- **THE WHITE VOLTA AT WAYEN:**

  - Catchment basin 20,000 km^2.
  - Mean annual rainfall varying from 400 to 750 mm, with a geographic mean of about 675 mm.
  - Depth of runoff: 6mm, or 120 million m^3 recharge.

- **THE WHITE VOLTA AT BAGRE:**

  - Catchment basin 33,000 km^2.
  - Mean annual rainfall 400 to 950 mm.
  - The 13,000 km^2 of catchment basin from WAYEN to BAGRE receive 850 mm of rain on average and the runoff depth apparently corresponds to nearly 68 mm, or a recharge of some 884 million m^3. Added to the preceding figure, this gives a recharge of about one billion m^3.
  - The catchment area was multiplied by less than 1.7 and the recharge was multiplied by over 8.

The considerable advantage to be gained from regulating these rivers as far south as possible can hence be seen, particularly since, dimensions being equal, evaporation on reservoirs is much lower and rain inflow much higher.

Interannual management of the BAGRE reservoir would give the following results:

- Mean annual recharge	1,000 million m^3
- Spillover	60 million m^3
- Evaporation	200 million m^3
- Volume utilized	740 million m^3

This volume would make it possible to irrigate 25,000 to 30,000 ha with double-cropping.

- **THE RED VOLTA** is located in an area of relatively high rainfall - 880 to 1,000 mm - but its catchment basin on the southern frontier of UPPER VOLTA does not exceed 9,300 km^2. Mean annual runoff at the NOBERE station is about 250 million m^3. (Adequate irrigation of 5,000 ha with 180 million m^3 of water).

- **THE BLACK VOLTA** has two branches:

  - The upper branch oriented southwest/northeast as far as the SOUROU, is subject to heavy hydrological degradation, but receives abundant precipitations in the 1200-800 mm zone, giving rise to high runoff of the order of several hundred million m^3 from a few ten thousand km^2. As the upper BLACK VOLTA crosses extensive alluvial plains, it is reasonable to assume that a dam built near SAMANDENI, could irrigate between 10,000 and 15,000 ha, corresponding to a water consumption of 400 to 500 million m^3 (for 2 annual rice/rice, sorghum/vegetable or rice/vegetable crops).

  The upper BLACK VOLTA flows into the SOUROU which has its own catchment basin of 30,000 km2, but a rainfall of 400 to 800 mm, so that its own recharge is very small.

The use of the regulated effluent of the BLACK VOLTA would nevertheless make it possible to irrigate between 10,000 and 15,000 ha on the SOUROU.

The lower branch of the BLACK VOLTA starts with a low recharge due to losses from hydrological degradation in the northeastern part of the upper branch and on the SOUROU but recharge conditions become more and more favourable as it flows southward.

Unfortunately there is not much irrigable land in this lower valley. A dam is planned at NOUMBIEL, towards the GHANA frontier, but its reservoir can probably be used only to a very small extent - or not at all - for irrigation (0 to 5000 ha).

In short, the BLACK VOLTA, including the SOUROU, should make it possible to irrigate 20,000 ha at least, and 30,000 ha at most.

In all the irrigation capacity of the VOLTAS would be of the following order, the figures being subject to considerable reservations since the real capacity of the RED and BLACK VOLTAS is inadequately known:

	Maximum	Minimum
WHITE VOLTA	30,000 ha	25,000 ha
RED VOLTA	5,000 ha (?)	0
BLACK VOLTA	30,000 ha	20,000 ha
TOTAL	65,000 ha	45,000 ha

b) - Regulated Use of the GAMBIA

Discharge figures for the Gambia are only just beginning to be known.

According to a recent ORSTOM study, mean annual discharge varies from 2.540 million m^3 upstream towards KEDOUGOU to 5,050 million m^3 downstream towards GOULOMBO, the margin of uncertainty being ± 15%.

A preliminary study has been made of certain dam sites; one of the most interesting of these seems to be SAMBANGALOU, which for a storage level of 79 m would provide a reserve supply of about 4,500 million m^3.

In the absence of precise dimensional data, no forward planning has been attempted to this site, but it may be assumed that approximately 90% of the upstream flow could be regulated.

The reservoir would be located in an area of heavy rainfall and its total volume amount to nearly twice the mean annual discharge. In these circumstances it would allow the irrigation of 60,000 ha of double-crop rice, which is less than the irrigable area in the lower valley.

At very long range - beyond the years 2000-2050 - total regulation of the GANBIA seems feasible by building one or two additional dams, which would then make it possible to irrigate 150,000 ha on a double-cropping basis.

III.2 - USE OF THE SAHEL CATCHMENT BASINS FOR IRRIGATION

We have already noted the "potential" importance of the Sahel's own short-distance runoff for developing irrigation in the Sahel countries.

We have also mentioned that in the short and medium term long-distance runoffs (1) would probably prove the more advantageous to use.

A study of runoffs on 11 geographical areas in the Sahel itself yields the following approximate results:

AREAS	Catchment Basin Area in km^2	Mean Annual Discharge (millions of m^3)	Feasible Use Regulation (millions of m^3)	Irrigated Area Double-crop Suited to Geog. Region
Area 1: Left bank inflow to Sahelian Senegal (Ferlo)	26,800 km^2	10 (?)	5	Negligible (about 100 ha)(2)
Area 2: SALOUM Region	32,300 km^2	50 (?)	30	1,000 ha
Area 3: Right bank inflows to GAMBIA from NIOKOLO-KOBA to SANDOUGOU	25,000 km^2	710	525	12,500 ha
Area 4: Malian inflow to Senegal, from BAOULE to MORVAVIL	132,700 km^2	3,100 (1,550 without BAOULE)	2,090 (890 without BAOULE)	50,000 ha (2) (21,000 ha without BAOULE)
Area 5: Mauritanian inflows to Senegal, from KARAKORO to GUELOUAR	60,400 km^2	1,100	530	13,000 ha
CARRY FORWARD	277,200 km^2	4,970	3,180	76,500 ha (47,500 ha without BAOULE)

(1) In other words, the runoffs used downstream of catchment basins of at least 1,000 km^2 total area.

(2) In hydrological terms the Baoule is capable of irrigating 29,000 ha but it is doubtful whether there is that much irrigable land in its lower valley. It is therefore preferable to reserve its flow for the Senegal.

AREAS	Catchment Basin Area in km^2	Mean Annual Discharge (millions of m^3)	Feasible Use Regulation (millions of m^3)	Irrigated Area Double-crop Suited to Geog. Region
CARRY FORWARD	277,200 km^2	4,970	3,180 High 1,590 Low	76,500 ha (47,500 without Baoule)
Area 6: Voltan inflows to Niger, from GOROUOL to TAPOA	115,200 km^2	1,580	900 High 450 Low	30,000 High 15,000 Low
Area 7: Southeast Voltan marigots, from PENDJARI to BI?OU marigot	21,000 km^2	1,520	1,020 High 510 Low	34,000 High 17,000 Low
Area 8: Marigots of Central Upper Volta, except Red, Black and White Volta	49,000 km^2	850	440 High 220 Low	15,000 High 7,500 Low
Area 9: Left bank inflows to Niger, from NIAMEY to DALOL MAOURI	64,100 km^2	50	30	1,000
Area 10: Central rivers of the Republic of NIGER	91,400 km^2	420	190	6,000
Area 11: BA-TILA and BAHRAZOUM (CHAD)	135,000 km^2	1,410	590 (?)	20,000 ha (3,000 without BAHRAZOUM)
TOTAL	732,900 km^2	9,220	6,350	136,500 ha High (excluding 32,000 for BAOULE and BAHRAZOUM) 97,000 ha Low

The major uncertainty with regard to these results concerns the retention dams, the topography of which is now known but whose flat shape does not promote efficient use of the recharge.

"High" and "low" figures have therefore been suggested for Areas 6, 7 and 8.

Moreover, the interannual irregularity of recharge, the high level of evaporation on free water, and the difficulty of finding irrigable land urge caution in this type of calculation and the area effectively irrigable from Sahelian runoff may therefore be put at under 100,000 ha, excluding the potential of the BAOULE and the BAHRAZOUM given here for guidance and whose discharges would seem to be put to best use if allowed to rejoin the Senegal and the Chari.

III.3 - USE OF GROUND WATER FOR IRRIGATION

A map (scale 1:5,000,000) was prepared of areas in the Sahel where irrigation from ground water is technically and economically feasible. This map was drawn from three basic maps appearing in the above mentioned study by the Bureau des Recherches Géologiques et Minière on the ground waters of the African Sahel, i.e.

1 - Map of Ground Water Capacity

All areas where rates of flow as defined by the B.R.G.M. are less than 550 m^3 per day, or 6.5 litres per second per hectare, were disregarded.

Where this rate of flow is attained or exceeded, it is possible to put an area of at least 10 ha or so, under intensive fruit or vegetable cultivation, which seems to be a minimum figure.

2 - Map Showing Average Cost of Ground Water Catchment and Utilisation

All areas where the cost per m^3 of water (including depreciation and operating expenses) exceeds 20 CFA francs were disregarded.

Even on the assumption that half of this price would be borne by the State as depreciation, the other half, i.e. 10 CFA francs, would remain chargeable to growers, who would therefore have to look for enterprises likely to show a net profit after the allocation of 150,000 CFA francs each year for irrigation costs.

Only highly intensive fruit or vegetable growing would enable such expenditure to be written off, an amount which for the time being is an absolute ceiling for African farmers making use of irrigation.

3 - Map Showing Suitability of Water for Irrigation

All areas where ground water is not of excellent, good or acceptable quality for irrigation, as defined in the classification of the California Department of Agriculture were eliminated.

On the above bases the attached map shows that the areas where irrigation is "possible" (it would be better to say "conceivable" in view of the limite adopted) cover only limited geographical areas, i.e. approximately:

- 160,000 km^2 in the western part of the Sahel, possibly in the sand dunes the alluvial soils of the Senegal valley and the water tables of the Continental Terminal and Maestrichtian systems. Referring to the table on page , the available supply on this area will be seen to amount to several billion m^3 coming mainly from the Maestrichtian water table (the table on page shows 6,500 million m^3 "technically" possible each year; in fact, part of this amount is located outside the "technically and economically" feasible areas).

-180,000 km2 in the central part of the Sahel mainly on the alluvial soils of the Niger and the water tables of Tegama sandstones and the Niger Continental Terminal.

Annual availability (table page...) from the purely technical standpoint amount to some 5 billion m3. Barely half of these, mainly from the Tegama sandstone water table, are likely to be technically and economically usable.

- Lastly, about 100,000 km2 in the eastern part of the Sahel, mainly on the Koros water tables and the plio-quaternary water tables in the centre of the Chad Republic.

Annual availabilities (table, page...) are thought to be some 1,500 million m3, of which two thirds would come from the Koros water table in a region with relatively abundant rainfall and surface water.

Hence the annual volume effectively usable for irrigation from ground water in the eastern part of the Sahel presumably would barely exceed 500 million m3.

Areas where irrigation is technically and economically feasible, in the extremely wide sense, would therefore cover 440,000 km2, or less than 10% ofthe total area of the Sahel countries. Conceivably some 6 billion m3 might be drawn each year on these areas (3 billion in the West, 2½ billion in the Centre and ½ billion in the East).

In theory this figure is quite considerable and would correspond to 400,000 ha, for a mean annual irrigation volume of about 15,000 m3 per ha (1).

In view of the cost of the very many drillings that would have to be done, and the state of the market for very intensive crops (the only ones that could carry the accepted economic constraints) it seems likely that at best 100,000 ha might be developed by the year 2000-2050.

(1)
This figure may seem low. It corresponds to very high field water application efficiency, valid only for very small areas irrigated by modern methods: sprinklings, localised irrigation.

III.4. USE OF GROUND WATER FOR PEOPLE AND LIVESTOCK

A map was prepared of the areas where livestock could be supplied from ground water, according to the B.R.G.M. maps of water capacity and quality.

On this map four types of area were identified:

1) Areas where watering of livestock is impossible

- either because the operating flow of recovery installations is less than 20 m3 per day (and more often nil), so that not more than 600 to 700 cattle per day could be watered and it would therefore be necessary to increase the number of installations and raise the price of water;
- or because the quality of the water is not suitable for livestock.

These areas seem fairly limited in extent. They are mainly located in the Republic of Mauritania, where they appear in the form of "dry bevels" covering some 100,000 km2. The use of grazings in the souther part of these dry bevels therefore means that wherever possibl artificial ponds or else "feelers" from more productive watering places would have to be dug.

2) Areas where watering of livestock is difficult because the operating flow is between 20 m3 and 50 m3 per day, which limits the number of cattle to 1500 head.

These areas cover much larger tracts - several hundred thousand km2.

However, a distinction should be dragn here between:

- areas located well to the south (rainfall over 800mm) which should permit the watering of livestock without difficulty from artificial ponds;

- areas lying between isohyets 200 and 800 mm, which would make the use of artificial ponds feasible but less certain and involve greater cost;

- areas in regions with a rainfall of under 200mm. Here the use of artificial ponds to make up for inadequate ground water does not seem generally feasible. However, these areas contain only scanty pasture often of such poor quality that very few nomads come there and the watering of livestock should therefore raise fewer problems, especially since a good strategy of animal husbandry should promote the search for a more southerly location for nomads and their herds.

3) Areas where the presence and possible characteristics of ground water are still unknown. They cover more than 1,000,000 km2, mainly located in the North Sahara part of the Sahel. It would be well to know any groundwater resources in these areas, which might at least be used by their inhabitants, and possibly by mining installations and transit stations on the North African route. But as their use by livestock would normally be excluded, this gap would have no notable influence on the future development of animal husbandry.

4) Lastly, areas where the watering of livestock is considered "possible without special difficulty" because the unit flow of recovery installations is always above 50 m3 per day and the water quality is satisfactory.

These areas are marked in white on the attached map and will be seen to cover the greater part of the Sahel grazings.

It is difficult within the framework of this study to approach the problem of the annual water supply available for humans and livestock from ground waters.

We shall merely note that these requirements as determined in paragraphs I.1. and I.2. above and recapitulated in the table on page... represent 2,500 million m3 for humans and only 500 million m3 for livestock at the year 2000.

The water supply for the population will be obtained without difficulty from ground water. However, very large towns and notably some capital cities may draw their water from the major rivers of the Sahel, subject to prior treatment.

As regards livestock, there are possibilities of supply from continuous or intermittent water tables, as the case may be, except in certain regions where it would be necessary to use surface water collected in ponds or hill lakes, despite the disadvantages to health that careless use of this resource might cause.

III.5 - RECAPITULATION OF WATER RESOURCES UTILISATION

The prospects of using the water resources provided by the main Sahelian streams for double-crop irrigation may be summed up as follows:

	Unregulated flow. Double cropping guaranteed 49 years out of 50	First generation of dam and recovery facilities	Second generation of dam and recovery facilities beyond 2050
Senegal	Between 0 and 10,000 ha, depending on agr. system adopted	460,000 ha	610,000 ha
Upper Niger + Bani	10,500 ha	102,000 ha	600,000 ha ?
Middle Niger	7,000 ha	110,000 ha	110,000 ha
Logone	11,000 ha	95,000 ha	750,000 ha
Volta + Gambia	1,500 ha	105,000 ha	210,000 ha
	53,000 to 80,000 ha	100,000 ha (?)	750,000 ha
Total	83,000 to 115,000 ha	972,000 ha	2,495,000 ha

By also allowing for the prospects of using the water resources of specifically Sahelian catchment basins and aquifers, it is thus possible to estimate that:

- areas capable of irrigation at the 2000-2050 target date will amount to 1 million hectares;

- the overall irrigation potential of the Sahel amounts to between 2.6 and 2.7 million hectares.

CONCLUSION

Despite its shortcomings and approximations, the present survey shows that the overall rational use of potential water resources in the West African Sahel would enable the requirements of people and livestock to be met, as well as irrigation needs, over an extensive period well beyond the target date 2050.

In principle, therefore, the problem of water should be no obstacle to the economic and social development of these areas.

To carry out these programs will however be a considerable task lasting several generations, yet one so urgent that it should be undertaken as promptly as possible.

The building of wells, boreholes, dams and the establishment of irrigated areas will also call for substantial financial outlays.

Throughout this study the need to regulate the major Sahelian rivers has been emphasized in order that irrigation capacity can be rapidly developed.

The cost of building dams will certainly be high. For this reason in most cases the dams should be planned as multipurpose projects: for irrigation, generating hydropower and improving navigation.

The cost of irrigated areas will be higher still and their development will require many types of extremely complex supporting action to be undertaken: management, training and supervision of farmers, marketing of products, etc., which may ultimately prove to be the major constraint in achieving the proposed targets.

Lastly, it would be desirable for this preliminary study to lead to more specific programmes:

- at the level of the major river basins, through the preparation of master development plans such as that drawn up by the OMVS for the Senegal River;

at State level, for planning the use of the countries' water resources, which have been inventoried to a fair extent already, including all types of water utilisation: requirements of large towns, rural populations, livestock , agriculture and industry.