AN ABSTRACT OF THE THESIS OF

Fatima Zahra Abba for the degree of Master of Science in Civil Engineering presented on December 19, 1995. Title: Requirements for Successful Irrigation Systems in the Senegal River Basin (Mauritania).

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Implementation of a small-scale irrigation project in southern Mauritania is analyzed in this report. The main objective is to demonstrate that small-scale irrigation farming is the best suited solution for Mauritania's agriculture. To reach this objective different steps are taken in this study. The first step highlights the different aspects affecting the development of agriculture in the Senegal River basin such as climatic, environmental, and socio-economic constraints. The next step is the design of a small-scale irrigation system for a small region in the middle valley of the Senegal River called the Dirol plain. Finally, analysis and discussion of the design is made. This discussion centers on the problems faced during the design and the different assumptions made to implement it. The conclusion section addresses the feasibility of the design and gives recommendations that will help improve the design process for future work in the Senegal River basin.

Requirements For Successful Irrigation Systems

in

the Senegal River Basin

(Mauritania)

by

Fatima Zahra Abba

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Fatima Zahra Abba, Author

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I would like to dedicate this thesis to my mother, who has been my ultimate role model of perseverance and self confidence; and to my husband, whose patience and respect enriched my personal understanding of this fascinating culture, and whose help in the editing process was invaluable.

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Requirements for Successful Irrigation Systems in the Senegal River Basin (Mauritania)

1 Introduction

1.1 Introduction and Objective

Over the past thirty years, due to the green revolution, the world's per capita food production has increased overall by 25 percent, with a 47 percent increase in the developed countries, but only a 15 percent increase in the developing ones. In fact, in sub-Saharan Africa, per capita food production has actually declined during the past two decades (ref. 1). The Sahel drought of these past few years has transformed as much as 650,000 km^2 of productive lands to desert areas adding to the misery of the African people.

African governments, having no other solutions but to develop an agricultural plan to help stop the spread of hunger in the Sahel region, asked for the help of international development agencies. Some international specialists in African development suggested that while the production of more food is needed to end hunger in the African Sahel, modern agricultural techniques currently in use are not the solution. They felt that a more appropriate and simplistic technology should be employed (ref. 2, and 3). This technology should be ecologically and environmentally sound, sustainable over a long period of time, and potentially as productive as more mechanized forms of farming.

Implementation of a small-scale irrigation project in southern Mauritania is analyzed in this report. The main objective is to demonstrate that small-scale irrigation farming is the best suited solution for Mauritania's agriculture. To reach this objective different steps are taken in this study. The first step highlights the different aspects affecting the development of agriculture in the Senegal River basin such as climatic, environmental, and socio-economic constraints. The next step is the design of a small scale irrigation system for a small region in the middle valley of the Senegal River called the Dirol plain. Finally, analysis and discussion of the design is made. This discussion centers on the problems faced during the design and the different assumptions made to implement it. The conclusion section addresses the feasibility of the design and gives recommendations that will improve the design process for future work in the Senegal River basin.

1.2 Senegal River Basin, General Information

The Senegal River is one of the most important waterways in west Africa and forms the southern border of the Islamic Republic of Mauritania with its neighbor Senegal (Figure 1). Mauritania has 1.7 million people scattered over a vast territory. The demographic growth rate, although among the lowest in west Africa, seems fairly high compared to the economic growth potential of Mauritania. The devastating droughts that began in 1968 have driven many Mauritanians from the rural areas that could no longer feed them. As a consequence, the nation's urban population has grown rapidly to include more than 30% of all Mauritanians. Nouakchott alone, the capital city, now holds nearly a quarter of the country's people; people who do not farm but must eat. Their needs have led to Mauritania's exaggerated dependence on international food aid for its basic survival.

Several important social and economic aspects of Mauritania need to be discussed here to understand the background for this project. Mauritanian society is

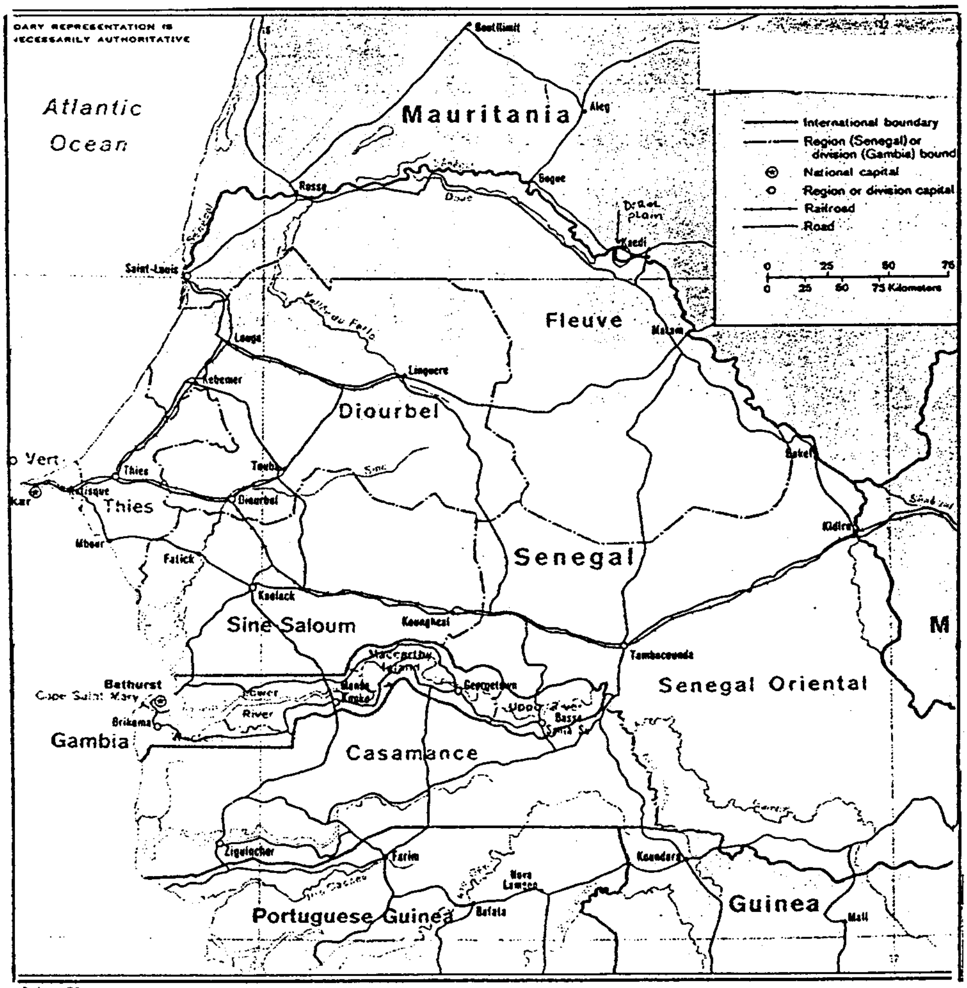
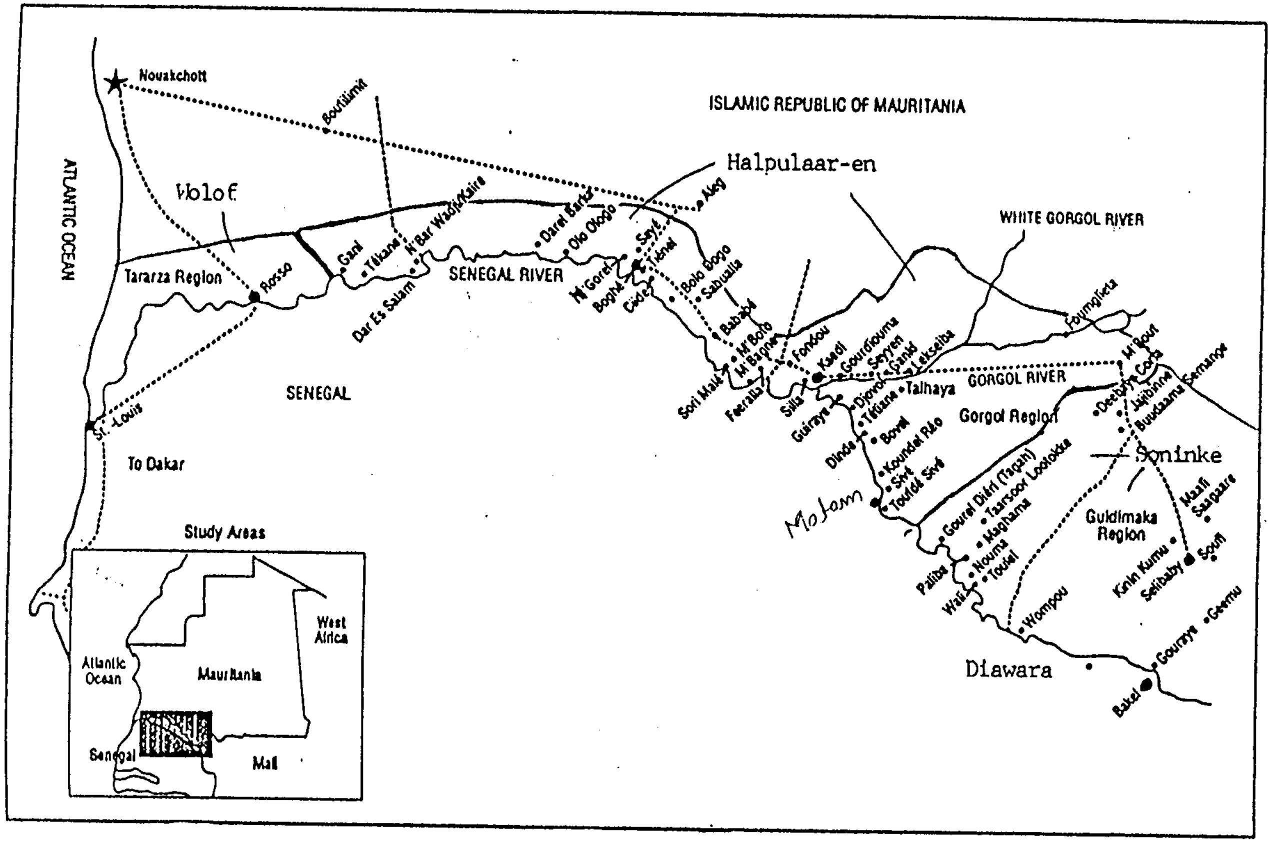


Figure 1. Map of the Senegal River Area.

composed of four major ethnic groups, each with its own dialect and customs. These groups are: 1) the Beidan, whose name means "white", who are the descendants of the Arab conquerors who began coming in the seventh century (they are known popularly in the west as "Moors"); 2) Haal Pulaar, with two subgroups - Sedentary Toucouleur and Nomadic Peul; 3) Wolof, and 4) Soninke (Figure 2).

The last three groups listed above are all pure black Africans. Each of these groups have a hierarchy or caste system in which there are four social classes; nobles, artisans, griots ("singers") and slaves. Slavery was allowed in Mauritanian society until the 1980's when the government was finally able to prohibit its practice. Even though slavery was abolished, the slaves were, and are still, considered socially inferior to the other groups. As with other Sub-Saharan African nations, Mauritanian society is divided into urban dwellers, nomads, transnumants, and cultivators.

Before the Sahel drought of the late 1960's and 1970's livestock herding was the major economic activity. This can be seen in that before the drought forty percent of the livestock was raised along the Senegal River, but just after the drought this livestock, which had supported seventy percent of Mauritania's population, could then support only thirty percent. To understand the importance of this development it is important to understand that the majority of livestock production used to be, and still is, done by the uppermost classes of each of the four ethnic groups. Traditionally local elite were both large land holders and herd owners. It is also important to understand that dry land farming and flood recession agriculture, which were predominant in the Senegal River basin before irrigated agriculture, could not compete with possible returns from livestock production. This is why the upper classes preferred pastoral activities and left the labor of cultivation to the lower social stratums. The upper classes then took no direct interest in their land other than to maintain legal ownership. After the drought reduced the returns on livestock, and with the introduction of irrigation, the upper class began to re-new interest in their lands. They have now begun charging rent and taking profits



(Slightly modified from map developed by OALS, Tucson, AZ.)

Figure 2. Map of the different villages and ethnic groups in the Se middle valley (George Eaton, 1987).

away from the cultivators, which has caused severe problems for the Mauritanian government and development agencies who had been treating the cultivators as if they were land owners. These complications will be discussed later in the section on land tenure issues and their effect on agricultural development in the area.

Mauritania's major economic component is rural development. Sixty five percent of the country's population live in rural areas, but rural development is under tremendous constraints due to the recurring droughts and increasing desertification. The remarkably poor edaphic environment has also created very fragile soils. The rural sector also suffers from its lack of transportation routes for the main vegetable and animal products. The proper design of irrigation schemes is of real concern because of the shortage and unreliability of statistical data. Institutional, financial, and tenure issues are all additional constraints that hinder the development of agriculture in Mauritania (ref. 4, 5, and 6).

The energy sector in Mauritania does not possess many resources. There is wind and solar potential, but they are still poorly managed and little utilized. The main constraints in this sector may be summarized as follows:

- Lack of exploitable fossil energy sources, which makes the country dependent on foreign supplies, with a resulting balance of payment problem
- Deforestation due to drought, over-exploitation by an unaware population, as well as due to development projects, is causing increased desertification
- Organizational and financial problems of many different villages

The construction of the Manantali dam on the Senegal River was supposed to store water for irrigation purposes, and also provide the area with hydroelectric power, thus relieving its energy problem (ref. 6). In fact it has accomplished the former, but the hydroelectric power will not be available until the end of the decade at the earliest.

2 Agricultural Development in the Senegal River Basin Literature Review

2.1 Need for Agricultural Development in the Senegal River Basin

A large part of the population in the Senegal River basin is engaged in agriculture. Approximately 33% of the gross national product of the three basin countries (Mali, Mauritania, and Senegal) comes from agriculture. Agricultural production in this region faces climatic, edaphic, and technical constraints. The drought of the past several years has increased the deficiencies of food and foreign exchange in these countries.

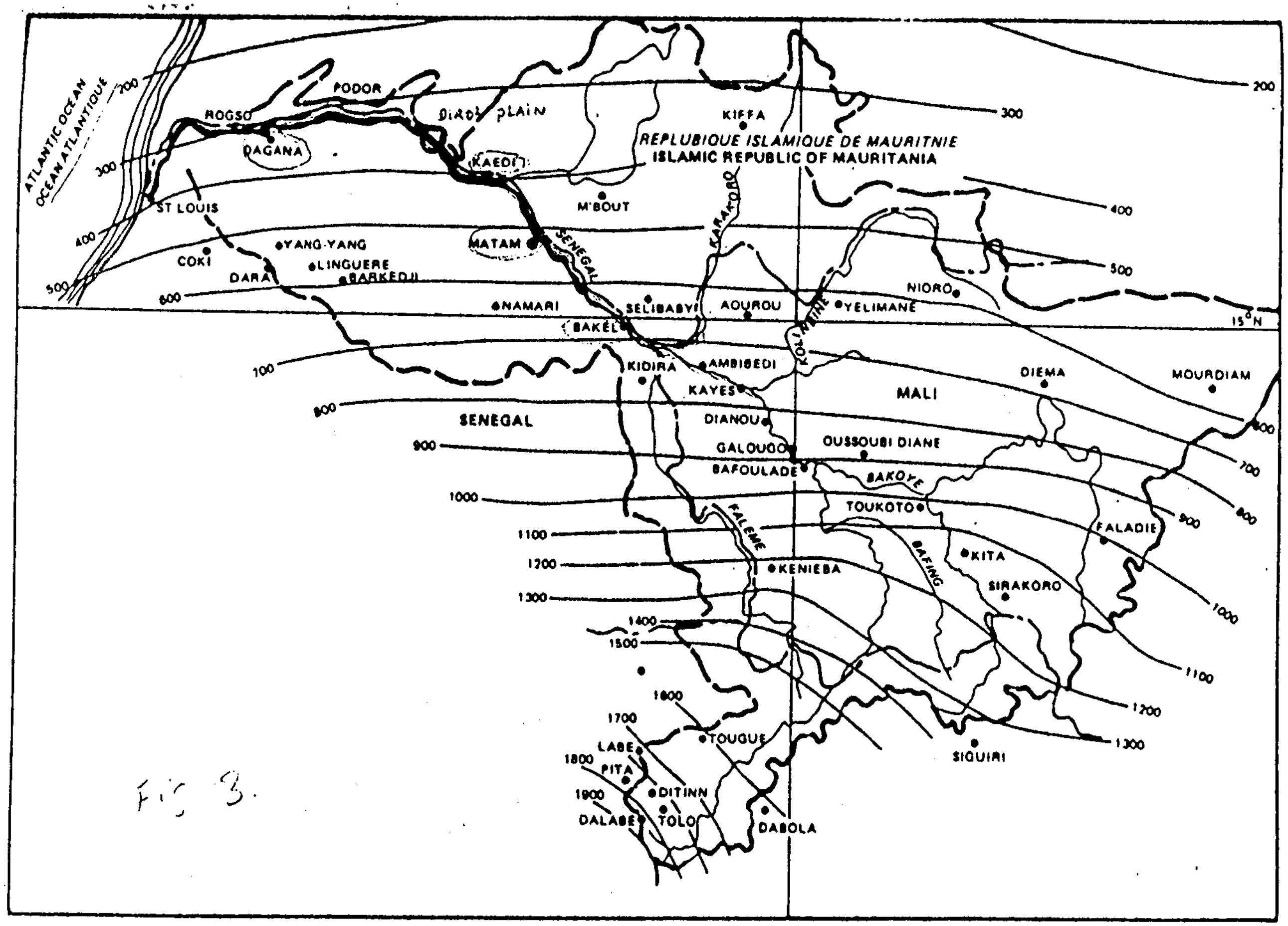
Looking to the future, the development of agriculture could become very important as the development of land and water resources in the Senegal River basin continue. Up to 430,000 ha of irrigated land could be in crop production compared to 10,000 - 20,000 ha from traditional agriculture (ref. 6). Flood recession land (low lands dependent on flood waters for agriculture) will diminish, but a larger irrigated area with substantially higher yield would result in considerably more production.

2.2 Factors Affecting Agricultural Development.

2.2.1 Physical Factors.

2.2.1.1 Climate

The Sahel is that area lying south of the Sahara desert located between the isohyets of 100 to 600 mm of precipitation per year. It is a vast region that is 400-800 km wide, around the latitude 15 degrees north, and 5,000 km long, from 16 degrees west to 35 degrees east. This region is known for its dry climate and scarcity of rainfall (ref. 7). High pressure zones occurring at tropical latitudes lead to high pressure anti-cyclones. Some of these affect the Sahelian climate, such as the anti-cyclones centered on the Azores, on Libya, and over St. Helena in the southern hemisphere. These anti-cyclone zones create tropical air streams on the surface of the Earth. The locations where these air-streams meet are called the "inter-tropical front " or ITF. The climate in the Senegal River basin is affected mainly by the inter-tropical front created by the meeting of dry, warm air from Libya and cold, humid air from St. Helena, called the continental inter-tropical front. It is characterized by low moisture content, and therefore low rainfall, particularly in the region of the Senegal River. As we go south the humid air masses from St. Helena become more important. Rainfall goes from as low as 200 mm/y at the Senegal River basin, to as much as 1500 mm/y in the Casamance region in the south of Senegal (Figure 3). The average rainfall in the Senegal River basin is about 494 mm/y, 84% of which occurs in July, August, and September. Tables 1, 2, and 3 show respectively annual rainfall values in mm/y at Kaedi for the period 1931 to 1959 and 1970 to 1974, average monthly rainfall for the period 1920 to 1975 at Matam region, and actual and effective precipitation in the Matam region.



Figue 3. Isoyetal map of the Senegal River Basin (Bechtel Inc., 1976).

Table 1. Annual Rainfall in mm/y at Kaedi for the period 1931 to 1959 and 1970 to 1974. (Larry Boersma, 1980)

	June	July	August	September	October	Total for Year
	....	....	....	....	....	....
1931	4	83	130	124	50	393
1932	9	155+	212	37	0	419+
1933	36	171+ (81)	213	73	19	515+
1934	39	73	100	22	0	235
1935	28	198	104	156	10	501
1936	120	262	196	91	1	730
1937	5	98	230	68	4	406
1938	26	21	119	76	77	323
1939	16	93	264	96	34	514
1940	17+	41	282	35	33	409+
1941	0+ (2)	37	27	139	3	203+
1942	9	88	112	64	20	292
1943	26	89	196	185	5	537
1944	7	39	109	71	61	300+
1945	–	301	80	122	0	503+
1946	4	99	95	43	7	248
1947	1	35	203	135	0	415
1948	66	81	196	62	7	419
1949	5	84	86	12	4	202
1950	18	48	276	141	27	510+
1951	18	90	145	78	–	330+
1952	60	52	162	163	27	486
1953	21	81	154	61	20	337
1954	13	56	121	55	7	346
1955	33	147	144	63	15	402
1956	12	46	157	184	66	467
1957	44	26	164	102	15	351
1958	11	132	284	33	0	461
1959	134	66	273	72	0	545
1970	57	60	145	98	0	418
1971	4	26	133	83	0	267
1972	27	9	60	10	0	108
1973	36	24	135	60	0	255
1974	17	119	215	75	20	445

\+ = questionable data

– = missing data

Table 2. Average monthly rainfall (1920-1975) at Matam (Bechtel Inc., 1976)

Month	Maximum	Minimum	Average
January	13	0	0.7
February	20	0	0.9
March	4	0	0.2
April	36	0	0.7
May	100	0	3.0
June	168	1	45.1
July	276	11	115.9
August	473	36	186.9
September	297	25	114.1
October	118	0	23.4
November	41	0	1.6
December	41	0	1.4
		Total Average/year	493.9

Table 3. Actual and effective precipitation at Matam (1920-1975) (Bechtel Inc., 1976)

Month	Actual Precipitation (mm)	Effective Precipitation (r_e) (mm)
January	0.7	0
February	0.9	0
March	0.2	0
April	0.7	0
May	3.0	0
June	45.1	42
July	115.9	91
August	186.9	102
September	114.1	90
October	23.4	23
November	1.6	0
December	1.4	0
Annual	439.9	348

The temperature is warm throughout the year, with only 12 degrees variation between the average temperature of the warmest month (May, 35 ^{0}C) and the coldest month (January, 23 ^{0}C). Frost never occurs, the minimum temperature ever recorded in the area of the Senegal River basin was 7 ^{0}C. The average number of hours of sunshine at the surface is very long, and in the middle and lower valleys the annual average number of sunshine hours exceeds 8 h/d. The solar radiation on the surface of the Earth ranges from 194 W/m^2 to 291 W/m^2. Table 4 shows different values of temperature, relative humidity, sunshine hours and evaporation for the Dirol plain.

Table 4. Average monthly values of temperature, relative humidity, sunshine hours, and evaporation in Kaedi for the period 1970 to 1981 (George Eaton, 1987)

J	F	M	A	M	J	J	A	S	O	N	D	Year	
32.2	34.8	36.9	40.2	41.3	40.4	36.6	35.2	36.0	38.5	35.7	32.0	36.7	**Max T**
17.4	9.0	21.8	5.0	26.7	25.5	25.3	25.5	25.2	24.3	20.8	18.0	22.9	**Min T**
24.8	26.9	29.4	32.6	34.0	33.4	31.1	30.3	30.6	31.4	28.3	25.0	29.8	**Mean T**
24	23	20	20	26	38	52	62	59	40	26	27	35	**% (R H)**
260	269	279	291	264	258	264	202	255	267	249	248	3106	**(Sun hrs)**
9.4	11.5	13.6	16.2	16.7	14.3	12.2	8.7	7.8	9.2	9.5	8.6	11.5	**E (mm/d)**

Note: Max T, Min T, and Mean T are respectively maximum, minimum, and mean temperatures in °C. RH is relative humidity in percent. The last two parameters are sunshine hours and evaporation which is in mm/d.

2.2.1.2 Hydrology of the Senegal River

2.2.1.2.1 Introduction

The Senegal River originates in the Fouta Djalon highlands of northern Guinea with the northward flowing Bafing River. This river is joined by two other principle tributaries, the Bakoye river in Mali and the Faleme river in Senegal, to become the Senegal River. This river forms the border between Mauritania and Senegal from the Bakel region downstream to the Atlantic Ocean. The Senegal River is 1800 km long and drains an area of 289,000 km^2. There is an average rainfall of 1100 - 1400 mm on the Bafing River. This amount decreases to 300 - 400 mm at the lower end of the middle valley of the Senegal River.

The flow at Bakel at the upper end of the middle valley, below which no tributaries significantly augment the flow in the Senegal River, is of particular interest. Based on a review of hydrological records covering the period 1903 - 1968 done by the United States Agency for International Development (USAID) mission in 1983, the average annual flow rate at Bakel is 771 m^3/s or an annual discharge of 24,300 million cubic meters (ref. 8). This is said to be equivalent to 40% of the annual flow of the Nile, which is not inconsiderable. Unfortunately there are extreme fluctuations of annual discharge at Bakel, plus or minus 60%, between wet and dry years. Monthly fluctuations are even more significant. In the hot-dry season (March - June) river flows decrease to 10 m^3/s or less and occasionally stop entirely; in September flood flow reaches 7,200 m^3/s.

Downstream from Bakel the Senegal River flows through a large alluvial valley which varies in width from 10 to 25 km. At Richard Toll, which is about 80 km from the ocean, the river enters the extremely flat delta region in the Gorgol River which is dry most of the year.

The general slope of the valley is almost flat (ref. 7). The average slope of the terrain is on the order of 5 cm/km or 0.005%. At Podor, some 265 km from the river mouth, the average monthly water surface elevation is only 0 - 5.5 m above sea level so that in low stages water quality is threatened by the saline water moving upward from the Atlantic Ocean.

2.2.1.2.2 Existing Water Resource Projects: Diama and Manantali

The disastrous drought in the Sahel of the 1970's badly affected food production in the Senegal River basin. Because of these conditions, the member states of the Senegal River valley; which include Senegal, Mauritania and Mali, with the help of international development agencies, decided to take joint steps toward development of the water resources in the Senegal River basin. These countries formulated a long term development plan, including construction of two dams to deal with the two most important problems of the Senegal River, the widely fluctuating river flows and the salt-water intrusion from the Atlantic ocean. The projected cost was $750 million. The two dams constructed were:

Diama dam. Located about 30 km upstream from the mouth of the Senegal River. Its primary function is to prevent the intrusion of the sea water from the Atlantic Ocean to the delta and lower valley. The dam is a low-gated structure that provides a salt water barrier and a reservoir at normal elevation 2.50 m above sea level. This will allow the irrigation of the delta region and will feed two natural lakes (Guiers and R'Kiz) which provide water to urban centers in Mauritania and Senegal. The dam was completed in 1986.

Manantali Dam. Located in the Bafing River in Mali about 1200 km from the sea, and 400 km above Bakel. The 65m high dam will store water from a 27,800 km^2 basin with an average annual inflow of 12,000 million cubic meters (equivalent to a constant flow of 380 m^3/s). At full reservoir level of 208 m (above sea level) the reservoir will have a gross storage capacity of about 11,000 million cubic meters. The majority of the inflow occurs in the flood period from July to November. In periods of drought the flow falls to near zero.

The operation of the Manantali Dam is designed to provide a minimum flow of 300 m^3/s at Bakel throughout the year. This minimum flow is sufficient for year-round navigation and irrigation of 300,000 ha in the upper and middle valleys and the delta. The storage capabilities of Manantali will also provide flood attenuation, serving to reduce downstream flood stage levels, but will not "control" floods in that the drainage basin between Manantali and Bakel contributes an average annual inflow to the Senegal River approximately equal to the inflow above the dam. In addition studies are being made of potential power markets. The Manantali dam was completed in 1989.

2.2.1.2.3 Hydrology of the Senegal River

A comprehensive review of hydrological data was made by USAID mission for project development of the Mauritania River Valley (ref. 6). This mission was able to give the latest perspectives on future development of the Senegal River valley, before and after the Manantali Dam. Measurements of the water level were made at the intermediate valley, called the Dirol plain, in addition to other water measurements from the Bakel station for the period 1903-1983.

2.2.1.2.3.1 Monthly Flow Distribution.

The annual flow history of the Senegal River consists of a single flood event resulting from the rainy season. Over 80% of the annual flow occurs in the months of August, September, and October. The hydrologic water cycle in the basin is May 1st through April 30th. Mean monthly flows are shown in Table 5.

Table 5. Mean monthly discharges (1903-1973) (cubic meters per second) (Bechtel Inc., 1976)

Month	Maximum	Minimum	Average
May	31.1	1.6	8.6
June	223	2.5	72
July	1,358	184	495
Aug	3,569	748	2,047
Sept	7,411	1,030	3,357
Oct	4,236	587	1,970
Nov	1,850	194	645
Dec	521	75	264
Jan	251	28.7	143
Feb	151	11.0	82
Mar	80	9.8	45
Apr	41	6	19
Annual Average	1,394	314	764

2.2.1.2.3.2 River Flow Patterns before Manantali Dam

Table 6 gives adjusted maximum and typical water levels for various flood frequencies and the corresponding submerged areas in the Senegal River basin middle valley in the Dirol plain for duration of 5 to 45 days.

Table 6. Adjusted maximum and typical water levels for various flood frequencies and the corresponding submerged area in the Dirol Plain for duration of 5 to 45 days (George Eaton, 1987).

Frequency (%)	Max Level (meters)	45 day level (meters)	Area Inundated for 45 days (ha)
1	12.5	11.8	6700
5	12.3	11.5	6400
10	11.9	11.2	6050
50	11.1	10.3	5400
90	9.9	9.0	3400
95	9.2	8.5	2500
99	7.8	7.2	-

From Table 6 the following analyses were made:

- Every two years the peak water level reaches 11.1 m, stays above 10.3 m for 45 days submerging approximately 5400 ha in the northern zone of the plain.
- The 100 year flood reaches 12.5 m and would stay above 11.8 m for 45 days.

2.2.1.2.3.3 River Flow Pattern after Manantali Dam.

The filling of the Manantali Reservoir started sometime in 1988. Because of the lack of information about the management of the Manantali Dam, the following data were taken from the results of the study done by USAID mission using a mathematical model to simulate future water levels in the Senegal River middle valley at Kaedi.

The average water levels at Kaedi computed for the artificial flood generated by the Manantali Dam are shown in Table 7 below.

Table 7. Water level at Kaedi in meters (George Eaton, 1987)

Month:	J	F	M	A	M	J	J	A	S	O	N	D
level (m) :	5.90	5.90	5.80	5.65	5.65	5.90	6.45	9.25	11.5	10.8	8.45	6

The levels of water in the Senegal River basin are measured by reference to the I.G.N. network, (Institute Geographique Nationale reference level network where 0 is equal to mean sea level at the mouth of the Senegal River at St. Louis).

The maximum water level at Kaedi of 11.5 m corresponds to water levels of 10.59 m at the Dirol plain. The 100 year flood controlled by Manantali Dam would produce the following water levels at Kaedi and the Dirol plain see Table 8 below (ref. 6):

Table 8. The 100 year flood water level at Kaedi and the Dirol (George Eaton, 1987)

Station meter	Natural conditions	After Manantali Dam	
		Mid-term development	Long-term development
Kaedi	13.70	13.85	14.85
Dirol	12.97	13.13	13.84

On average, the optimal flood should reach 10.59 m on the Dirol plain and inundate 5,800 ha in the northern part of the region. The design project in this report will use this value of 5,800 ha as the overall area for flood recession agriculture.

2.2.1.3 Soils in the Senegal River Basin

The soil characteristics in the project area of the Senegal River Middle Valley are determined by the hydrology of the basin, particularly the annual cycle of flooding of the Senegal River. The periodic flood, which is common to most rivers flowing through delta areas or areas of negligible slope, produces a levee along the bank of the flow channel made up of sandy material and little silt or clay (Figure 4). These soils are called "Falo soils" in the Senegal valley. Behind the levee are the depressions where water becomes stagnant and deposits finer material which is clay and silt . This second sediment forms heavy textured soils that are called "Hollalde soils" which contain more than 50% clay. As one goes further from the river beyond the flood plain, another type of soil is found (Dieri soil). This soil is coarse and has less than 15%clay (ref.7 and 8).

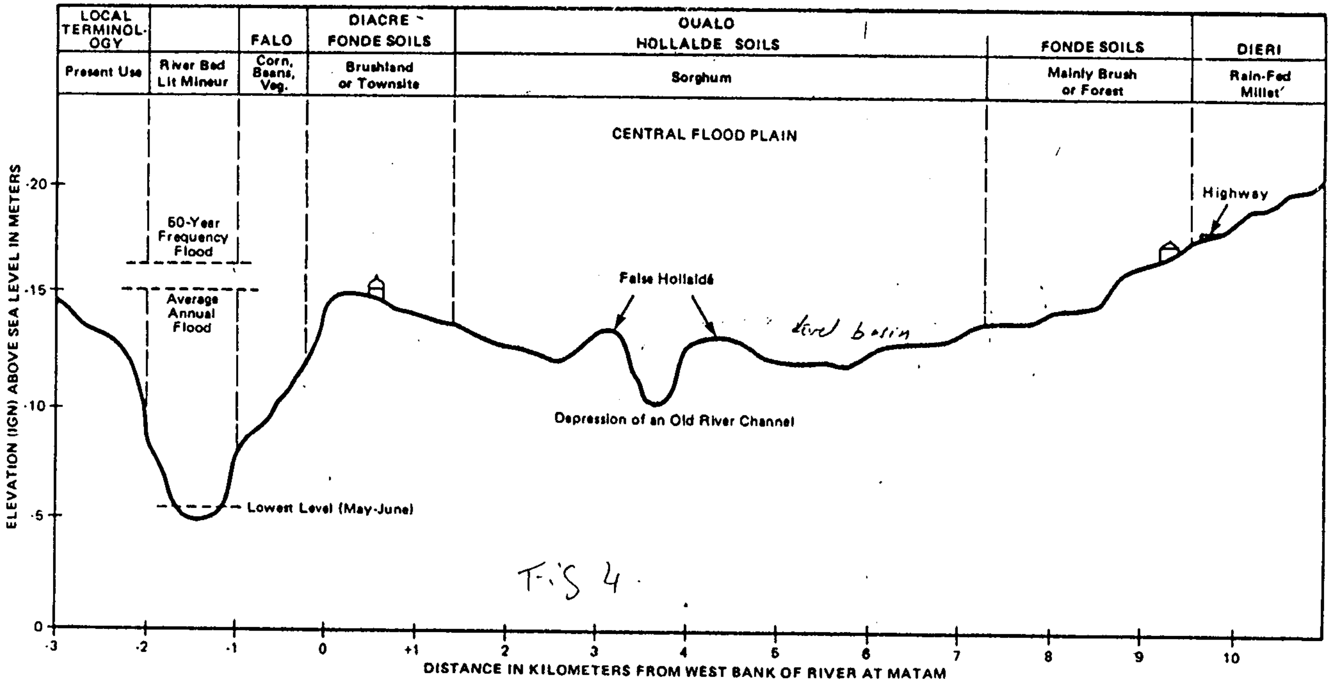


Figure 4. Soil profile at the Matam region (Bechtel, 1976).

2.2.1.4 Soils and Irrigation

According to studies made by the Bechtel consulting engineering firm (ref. 8), most soils in the valley are well suited for irrigation and the most serious limitation is heavy textured soils. This limitation applies particularly to the Hollalde soils and their high clay content which makes them hard to drain. Soils with high sand content like the Dieri soils are not recommended for irrigation because of their high water loss caused by drainage. Based on the U.S. Bureau of Reclamation land classes, Bechtel was able to classify the Senegal River basin soils as follows:

- Fonde - class 1
- False Hollalde - class 2
- Hollalde - class 3

Class 1 has the highest and class 3 the lowest suitability for irrigated farming. Very sandy land not suitable for irrigation is classified as class 6.

Bechtel suggested that class 3 Hollalde soils which have high clay content are better suited for the cultivation of rice in flooded paddies. If other crops such as wheat and corn were to be grown in this soil, seed bed preparation would be an arduous task due to the heaviness of the soil and drainage would be a problem. Fonde soils however, are suitable for any crop adapted to the climate including rice. Dierie soils have high sand content and are not recommended for irrigation because of the higher loss of water due to seepage.

2.2.1.5 Groundwater Resources

Under USAID contract, Bechtel developed an exploration program for ground-water monitoring in the Matam region of the river plain in 1979 (ref.9). The exploration found that the Senegal River flood plain in the study area is underlined to a depth of 150 meters by four stratigraphic units, which include in descending order:

- Uniform clay silt, gray brown, 7 to 15 meters thick
- Sand, tan, permeable, 46 to 66 meters thick, forms the upper aquifer
- Silty clay-sand, gray, with a red interbed, about 30 meters thick
- Sand, white, permeable, thickness greater than 50 meters, forms the lower aquifer

Both upper and lower aquifers are highly transmissive and can yield large quantities of water to wells. The ground water quality is acceptable for irrigation and for domestic use. No data were available to speculate on the possible connection between the lower and the upper aquifer, however, it was stated by the exploration team that the upper aquifer and the surface water, mainly the Senegal River, were connected. The upper and middle plain water table is low enough to not cause water impoundment in the farms. Unfortunately this is not the case in the Richard Toll area right on the intersection between the Senegal River and the Atlantic ocean where the water table of the upper aquifer causes water impoundment and drainage problems.

2.2.2 Social and Economic Factors

2.2.2.1 Traditional Way of Farming

There are three traditional farming methods used in the Senegal River basin: flood recession agriculture, rainfed agriculture, and animal husbandry (ref. 6, 7, and 8).

Flood recession agriculture: In this traditional way of agriculture, farmers wait for the flood to recede before they start farming. Work usually begins 15 to 20 days after the water has receded and the land is hard enough to walk on. This work can be started in late August or the end of October depending on the occurrence and recession of the flood. Farmers dig holes where they plant the seeds. The plants utilize the water stored in the soil during the flooding period. This system of farming works well for crops which have a short growing season such as sorghum and millet. After seeding, the area is guarded for about two weeks to prevent birds and rats from eating the seeds. Weeding then begins, it seems to be the most difficult and limiting factor to the size of the land production unit. On Hollalde (clay-like soils), the size of the current year flood and its pattern over a period of successive years seems to be an important factor in the difficulty of weeding. Apparently not only the quantity but the quality of weeds changes directly with the availability of water. Lands that receive more water develop weeds which are difficult to pull-up. As result of this problem, low Hollalde lands next to the river are generally more difficult to cultivate than high Hollalde soils. Thus in years of high floods, farmers tend to desert the low areas for the higher ones. When the plants are sufficiently developed, the task of guarding against birds, rats, wild boars, etc. continues. This task is in which everyone participates. At the end of the season the crop is harvested and transported to the village where it is used for local (human) consumption.

Rainfed agriculture: Like recession agriculture, this method of farming is practiced by a permanent population which lives in native villages. Farmers plant their crops shortly after the beginning of the rainy season. Little soil preparation is needed. After planting has been completed, the farmers wait for rainfall, which may or may not occur. This kind of agriculture provides an insecure source of food and income.

Animal husbandry: This method of agriculture is practiced mainly by the nomadic population of Mauritania. The livestock production has being drastically affected by the Sahelian drought of the past 10 years.

As can be observed, the traditional agricultural sector is very vulnerable. It relies on uncontrolled sources of water and according to studies done in the area, the agricultural lands are not fully exploited and the crop yield is very low, less than 1.0 T/ha.

2.2.2.2 Income and Migration

Based on studies done in 1976 in the Senegal River Middle Valley, an average family of 8 people with 3 working adults would have 1,200 kg of cereals from cultivating 3.0 ha. (2.0 ha. of millet and 1.0 ha of sorghum in the Hollalde lands). The estimated worth of 1,200 kg of cereals is below the living costs of the average family. It is assumed that it will not even supply the family's annual cereal grain requirements which are estimated to be 2,100 kg.

Farming alone can not provide families with their needs and most villagers look for other sources of income outside their lands. Officials in the area of the Senegal River have noted that the importance of migrant remittances as a source of regional income is evident from the receipt of postal money orders. It is estimated that a larger amount is brought directly by the migrant workers to their families. Apparently the general use of this money is:

- Subsidies of basic necessities for the families, particularly during poor years
- Gifts to family members to help with their marriages or other social or religious celebrations
- Construction of houses, and
- Investment in cattle

These are all economic and social reasons to expect the continuation of migration. In addition, the rigid social system encourages the departure of persons who find themselves locally at a disadvantage because of their low status at birth within the tribe or village hierarchy.

2.2.3 Land Tenure Issues in the Senegal River Basin

2.2.3.1 Traditional or Customary Land Tenure Systems

When dealing with economic strategies concerning land use, African farmers still base their acts and decisions on customary laws. Land tenure in the Senegal River region traditionally depends on the quality of the cultivated land (ref.6):

Flood recession or Hollalde lands are the most important lands in the traditional farming system in the Senegal River basin. They are generally held as common property by the extended family and passed from generation to generation. Ownership rights extend over the full flood plain. These lands are not fully accessible by all the cultivators in the area. Contractual arrangements are also common on these lands, but they are quite variable from year to year depending mainly on the availability of land. In a flood year, 20% or more of the cultivators, those who do not own the land but rent it for farming, find themselves at disadvantage, and this percentage is even higher in poor years. Control of these flood recession lands has been a source of competition and tension within or across communities and ethnic groups. Conflict between herders and cultivators have a long history in the area and can become a national issue, as seen during the 1989 political crisis between Mauritania and Senegal concerning land use (ref. 2, and 10). Flood recession lands are the most reliable assets, yet regularly in short supply. Each dominant group in the area wants to control them in an attempt to exercise authority that implies control over the regional population regardless of what side of the Senegal River they belong, the Mauritanian side or the Senegalese side.

Dieri lands have more open access than Hollalde lands though they need to be cleared and prepared for cultivation and are exposed to high risk (from birds and cattle) when isolated. Desirable Dierie fields tend to be grouped and located near settlements. For this reason Dieri lands often command what is called in the area a "loubel" or money paid to the village or settlement near the land in order for farmers to use it, even though there is no shortage of Dierie lands.

Concerning the farmers right to land and their ethnic background, the right to own the land is even more complex. Arabic speaking "Moors" include Beidans who are the land owners, and Haratine who work the land, often paying Beidan for the privilege. The Beidan do not themselves engage in cultivation.

The Halpulaar, due to the fact that they were the first ethnic group to settle in the Senegal River Valley, have traditionally held rights to lands in most of the middle

Senegal River basin. This allows them to impose payments of tithes on other farmers who are acquiring either full ownership of the land or temporary use only.

Among the Soninke, land is held as common property at the extended family level. The eldest male, called the Kagume, manages the property in two ways; by requiring all male members of the extended family to work the main fields from 0700 h to 1400 h during the farming season, and by allocating individual fields (Salumo) on an annual basis to male members of the family for their own use. Women can have access to the fields, but the possibility of owning the land depends on village acceptance and the marital status of the women. Unmarried women do not have the right to own land. In general women do not receive land directly from the Kagume. They may rent it from other farmers or inherit it from their own mothers

2.2.3.2 Land Policy in Mauritania since Independence

The government of Mauritania has established a great deal of legislation concerning land tenure since independence. The most important were the decrees of 1960 and 1983-1984. The decree of 1960 was one of Mauritania's earliest pieces of legislation. It maintained the legality of customary law and established both the right of the state to take land for the public good and the right of any person whose land is expropriated by the state to just compensation. This legislation also established the principle, based on the Islamic Law (Maliki Law), that lands which are empty for ten years become the property of the state (ref. 11). The tenure legislation of 1983-1984 removed the legislative backing for traditional tenure rights (ref.11,and 12). The purpose behind this new legislation was to facilitate the development of state-backed irrigation projects in order to increase national production. This tenure legislation created major problems in the Senegal River basin because the traditional land owners felt that the government of Mauritania enacted the 1984 legislation in order to favor some groups over others, such as the Biedan, by providing them with lands in the development sectors that traditionally did not belong to them.

2.2.3.3 Water Right Practices in the Senegal River Basin

There are two main practices of water rights in the Senegal River Valley those inherited from the former French colonial administration and those based on Islamic Law. Former French colonies in "West Africa" inherited from their colonizers a number of legal procedures dealing with water rights. Almost all waters, surface or underground, are part of the public domain of the state. Private waters are considered to be any water source, springs, wells, etc., located outside the public domain in private lands (ref.11).

Based on the Islamic Sharia and on the words of the Prophet, the general principles concerning water rights include that high lying areas should be irrigated before low-lying ones. This can lead to presumption that upstream owners may take water for irrigation regardless of the effects on downstream ones (ref.11). The Islamic Sharia also recognizes the right to quench one's thirst, and surplus water must be provided to others for domestic and animal use regardless of individual or tribal ownership.

2.2.4 Environmental Issues.

2.2.4.1 Health Problems in the Senegal River Basin

Domestic water supplies for villages are from open hand-dug wells varying in depth from 15 to 30 meters. Water is taken from the majority of these wells manually by ropes and buckets.

Experts from USAID have occasionally noticed the occurrence of high nitrate levels in these wells, possibly due to the oxidized products of animal or human wastes in the region. The river water while generally acceptable for drinking, has a high nitrate level for a surface water source indicating the presence of pollutants in the river and the need for chlorinization and filtration. Open wells are subject to pollution and are a public health hazard. The provision of sanitary seals and some kind of hand-pumps should be a goal of any development project. No waste treatment or sewage collection system exists in the region, thus adding to the danger of contamination of water supplies and the incidence of cholera, salmonelloses, and other diarrheal diseases.

Shistosomiasis (Bilharzia) is a serious public health problem in the Senegal River basin where the prevalence of this disease is quite high. The delta area reports an incidence of 10 percent with rates increasing up the river valley to over 40 percent at the Mali border. This disease is caused by two species of small worms living in the capillaries of the bladder or bowel. The eggs of the worms are passed into water via urine or feces. The eggs hatch and produce larvae that invade an intermediate tract: snails of the family of Bulinus. The larval forms multiply in the snails, emerge, and enter the water from which they penetrate the skin of persons working or swimming in the contaminated water. Worms develop in the infected person's liver and migrate into small veins around the intestine or bladder. Eggs are produced which work their way into the bowel or bladder where they are passed to complete their vicious life cycle.

Malaria is the most common infectious disease of man in the tropics and is present throughout Senegal with an infection rate of 56 percent in the river basin. The principal vector is the Anopheles sp. mosquito. Mosquito breeding occurs during the July to September rainy season, which corresponds to the flood period of the Senegal River. High incidence of malaria have not been reported in the region because of the inability of the Anopheles to survive the dry heat occurring in the other months. Likewise, Trypanosomiasis (sleeping sickness) is not a serious problem in the middle valley as a result of the lack of survival of its vector insect the tsetse fly in this region's dry heat (ref. 6, 7, and 13)

2.2.4.1 Soil Degradation Problems

The African Sahel is characterized by a very fragile edaphic system where the soil is subject to erosion. This erosion, which increases desertification, is believed to be caused by the growing influence of humans and domestic animals. Some of the activities that contribute to desertification are as follows:

- increase of cultivated areas
- overgrazing
- destruction of ligneous woody species
- wild fires
- inconsiderate development of irrigation that causes solute deposit in soils,
- soil compaction due to stock use resulting in a high runoff coefficient

3 Proposed Irrigation Design in the Senegal River Basin

3.1 Project Location and Population Characterization

The project area is located in the Dirol plain which is part of the Senegal River middle valley. The Dirol plain is located north of Kaedi (Figure 5) and consists of 13 villages (Table 9) of Pulaar and Haratine (Black Moors) farmers whose traditional combination of rainfed and flood recessional farming has been affected by drought over the last two decades.

Among the 13 villages of the plain only three villages belong to the Haratines. These villages are Debayel Doubel, Boubou Aoudi, and Hijaj. They were all settled by tribes liberated from the Beidan (white Moors) slave masters and thus there are no Beidans claiming any share of their crops. The Haratines function as independent households, with a village chief and elder but no lineage organization.

The Pulaar society is more complex and is based on a caste system. This results generally in an inegalitarian access to the means of production (land). It results also in narrow control of the decision making which is left in the hands of a minority of Pulaar upper class. The lower class groups in the area account for about 80 % (ref. 6) of the total households living in the 13 villages potentially affected by the project.

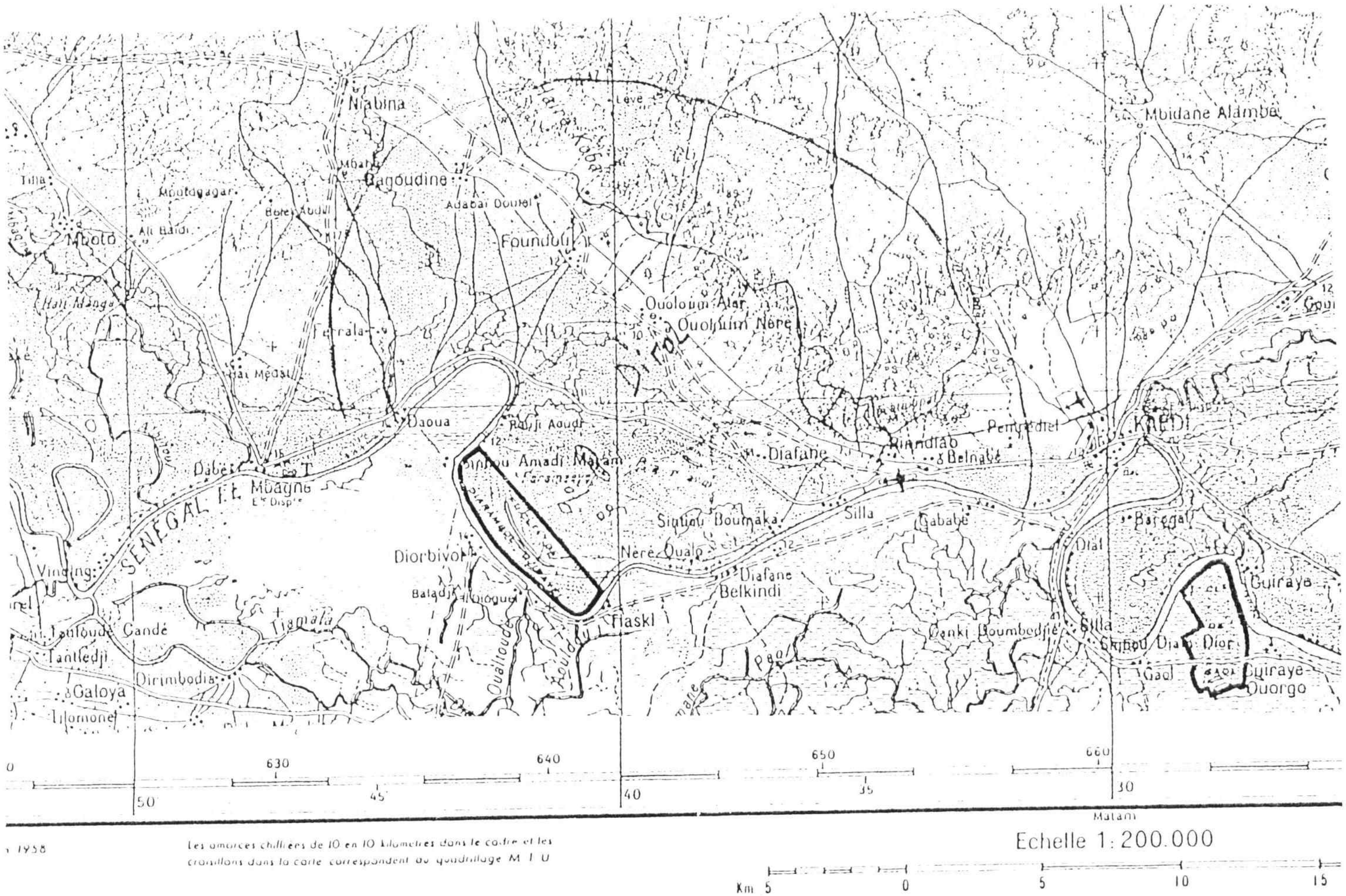


Figure 5 Map of the project area

Table 9. List of villages traditionally using the Dirol plain (George Eaton, 1987).

Village	Location	Households 1977	Households 1987	Population 1977	Cultivator	Herders
Bagoudine	plain/N	185		1158	211	4
Dbaye Doubel	plain/NE	133	2444	826	81	8
Devalel	R. bank/SE	102	230	661	61	3
Hijaj	plain/N	56	105	418	30	4
Boubou Aoudi	plain/NW	185	434	1045	213	10
Rindiaou	plain/NE	138		865	83	16
Silla Rindiao	R bank/NE	117		750	101	7
Sintiou Boumaka	R bank/W	103		664	219	4
Dabbe	R bank/SE	180		602	156	
Dia Wout	R bank/SE	14		37	8	
Dior Bivol	S.R. bank					
Dioguel	S.R. bank					
Diafane Beltindi	S.R. bank					

From Table 9 the total number of households of 3,261 in 1987 will be used to determine the minimum size of land needed per household (see paragraph 3.6).

3.2 Cropping Seasons

Three cropping seasons are recognized in the Senegal River basin; one hot-dry season from mid-March to mid-July, one hot-wet season when the rainfall occurs from mid-July to mid November, and one cold dry season from mid-November to mid-March see Table 10.

Table 10. Cropping seasons in the Senegal River basin before irrigation (Larry Boersma 1980).

January	
February	
March	--
April	
May	**Hot, dry, season (Contre-saison chaude)**
June	
July	--
August	
September	**Hot, wet, season (Hivernage)**
October	
November	--
December	
January	**Cold, dry, season (Contre-saison froide)**
February	
March	--
April	

The hot-wet season is the most important in the traditional way of farming. It is the season when rainfall occurs followed by the flood of the Senegal River which allows the practice of rainfed agriculture in the Dieri soils, and flood recession agriculture in the Hollalde soils and, in some seasons of high floods, the Fonde soils.

With the availability of irrigation water, growing crops during all three seasons becomes possible. In this report, use of two cropping seasons is chosen over three because it allows farmers more flexibility and more time between cropping seasons to take care of other needs and responsibilities.

3.3 Choice of Crop and Cropping Patterns

Based on farming experience in the region and the recommendations of the Food and Agriculture Organization (FAO) of the United Nations (ref. 14, and 15), the choice of crops for arid areas with limited water supply that seem to be the most suitable to grow are as follows:

- Sorghum and millet because they are drought resistant and the farmers are already familiar with their methods of cultivation
- Wheat which can be grown during the cold season
- Maize which can be grown once or twice a year
- Rice which has been introduced in the basin as a cash crop
- Tomatoes and onions which are used for both local consumption and as a cash crop

On the basis of the position of the soil on the landscape, three landscape designations are used in this analysis:

1. Low-land / Hollalde or clay landscape
2. Mid-land / Fonde or silt loam landscape
3. Up-land / Dieri or sandy loam landscape

Hollalde soils that are heavy textured and slowly permeable are recommended for growing rice, but they are best suited for growing sorghum and millet using the flood recession method of farming. The lighter textured Fonde soils can grow any kind of crop and are highly recommended for irrigated agriculture because they are unreachable by flood water which eliminates the need for protection systems and makes irrigation farming less costly in the area. False Hollalde soils have intermediate characteristics that make them suitable for either the Hollalde or Fonde crop production. Dierie or sandy loam soils are highly permeable and excessively well drained and they are not inundated by the Senegal flood because they are located at an elevation of 13 m and above. These soils are not well suited for recession agriculture, but irrigation can be used in combination with rains to grow sorghum and millet.

. Based on a USAID study on a scale of 6, with 1 being excellent and 6 being useless, the soils of the three major landscapes of the plain would be ranked on a general basis as follows see Table 11 (ref.8):

Table 11. Ranking of the three major landscapes in the Dirol (Bechtel Inc., 1976)

Landscape	Elevation	Irrigation	Recession
Low-land / Hollalde	7-10 m	4	1
Mid-land / Fonde	10-13 m	1	3
Up-land / Dirie	13 m +	5	6

3.4 Crop Calendar

The crop calendar in this case will help determine the quantities of irrigation water needed to meet the crop water requirement at different crop stages and in the different type of soils. Figure 6 shows the crop calendar for the chosen crops. The crop

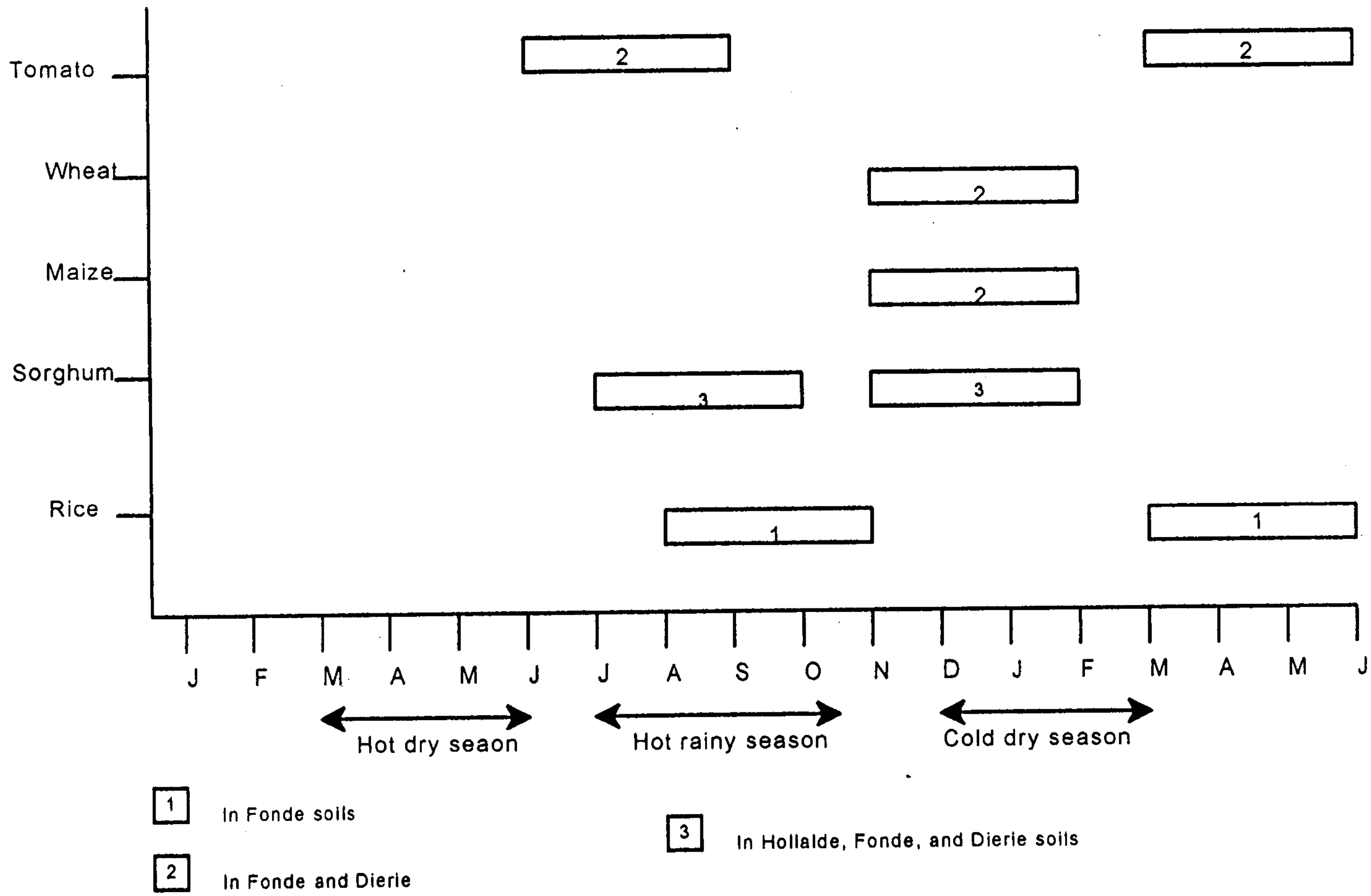


Figure 6. Crop calendar in the Dirol Project .

calendar in this study has been defined in order to realize optimal production levels within the limits of the soil potential, water availability and climatic hazards in the area.

Rice requires average temperatures of 20-30 °C for optimal production, therefore, rice should not be cultivated between December and February in the Dirol plain. Sorghum can resist all kinds of weather conditions in the area. As stated, two cropping seasons are recommended instead of three to allow more flexibility for the farmers. Sorghum is grown in the three types of soils including the Hollalde soils in the flood recession season. Maize is sensitive to heavy and wet lands in addition to temperatures above 35 °C. Maize can be grown in well drained soils, such as Dierie soils between November and February. Wheat needs low temperatures for vernalization in addition to well drained soils. November through February seems to be a suitable growing season for wheat in Fonde and Dierie soils.

3.5 Labor Availability

One of the main potential constraints on agricultural development in many parts of the Senegal River basin is labor shortage due to high migration. The Dirol plain is also affected by this problem. However there are eleven villages that cultivate directly on the Dirol plain. An estimate of 40% of the heads of households work outside the Senegal River basin in other parts of Mauritania or Senegal. Their families live in villages to which they return during the recessional season to cultivate and assure food security for the household. There are at least 711 heads of household who come back to farm each year (ref. 8). Table 12 shows the distribution of tasks and the importance of heads of households in farming in the Dirol plain.

Table 12. Farm labor in the Dirol plain, distribution of tasks (George Eaton, 1987).

Person	Clear	Hoe	Sow	Weed	Pesticide	Harvest	Transport	Total person	%
Men	43	45	45	45	2	45	45	270	44.1%
Women	9	8	40	12	0	37	35	141	23.0%
Sons	14	15	21	17	0	22	23	112	18.3%
Daughters	4	4	22	6	3	18	19	76	12.4%
Relatives	2	2	8	2	0	8	6	28	4.6%
Villagers	0	0	0	0	0	0	3	3	0.5%

3.6 Plot Size

The size of the flooded Hollalde land, after the operation of the Manantali Dam, will be about 5800 ha. In this report this flooded land will be used for the traditional flood recession agriculture. Irrigated farming will be performed in the Fonde lands only preferably those close to the river bank (Figure 4). The size of Fonde lands is about 1000 ha. Dieri lands are about 2000 ha in size in the area of the Dirol plain, however it is recommended to use them for rainfed agriculture only because of their high water seepage. By adding the three types of land together, the overall size of the agricultural land is 8800 ha. As shown earlier, the total number of households in the Dirol area is 3,261. With an overall area of 8800 ha of farm lands, an area of 2.69 ha will be allocated to each household. This value can easily supply the recommended 2100 kg of crops per family per cropping season mentioned earlier in this report. The intended double cropping seasons, encouraged by irrigation, will provide the farmers with even more crops that can become a source of additional cash for each household.

The 2.69 ha per each household will be allocated as follow:

- 0.3 ha in the Fonde soils which corresponds to the minimum size of an irrigated field
- 1.77 ha in the Hollalde flooded soils
- and 0.61 ha in Dierie rainfed soils.

3.7 Crop Water Requirements

The FAO Blaney-Criddle method was used to compute the crop water requirements. It is recommended for areas where climate data cover only temperature (ref. 14, 15, and 16). Based on the FAO Blaney-Criddle method, using measured temperature data as well as general levels of humidity, sunshine and wind speed, obtained from Table 4 listed earlier in Chapter 2, an estimation of evapotranspiration can be obtained. The recommended relationship using mean values over the given month is as follows:

$$ET_o = P(0.46\,T+8) \qquad (1)$$

ET_o = reference crop evapotranspiration for the month considered, mm/d

T= mean daily temperature over the month considered, °C

P= mean daily percentage of total annual daytime hours obtained from Table 1 (Appendix A) for a given month, percent

ET_o is estimated graphically from Figure 1 (Appendix A) using calculated values of P(0.46T+8). The value of P(0.46T+8) is given on the X axis and the value of ET_o can be read directly from the Y axis. Relationships are presented in (Figure 1 Appendix A) for:

(i) three levels of minimum humidity (RH_{min})

(ii) three levels of the ratio of actual to maximum possible sunshine hours (n/N)

(iii) three ranges of daytime wind conditions at 2 m height (U_{day})

After determining ET_o, ET_{crop} can be predicted using the appropriate crop coefficient (K_c):

$$ET_{crop} = K_c . ET_o \qquad (2)$$

Tables 13 to 17 show calculations of crop evapotranspiration using the FAO Blaney-Criddle method.

A value of 120 days was taken as the length of the growth period for each crop except for rice for which 150 days was assumed to be the length of the growing season. Adjustment for the crop coefficient K_c was made for each crop based on the assumption that each growth period starts exactly at the beginning of the month, and that there are four growth stages per each growth period of sixteen weeks (120 days); an initial stage of two weeks, a development stage of four weeks, a mid-season of six weeks, and a late season of four weeks.

Table 13. Calculation of evapotranspiration (ETc) for rice using FAO Blaney-Criddle method.

Calculation of ETcrop using FAO Blaney-Criddle Method (1).							
Month	T mean C	p %	ETo (1) mm/d	ETo f(RH,n/N, mm/d	Kc(Rice)	ET (Rice) (2) mm/d	ET (Rice mm/mon
JAN	24.80	0.26	5.08	4.8			
FEB	26.90	0.26	5.33	6.1			
------MAR	29.40	0.27	5.85	8.4	1.15	9.66	299.46
APR	32.60	0.28	6.48	9.7	1.15	11.15	334.65
S(1) MAY	34.60	0.29	6.97	12	1.35	16.20	486
------JUN	33.40	0.29	6.81	10	1.05	10.50	315
JUL	31.10	0.29	6.51	9.5		total/seas =	1435.11
------AUG	30.30	0.28	6.18	6.5	1.15	7.48	224.25
SEP	30.60	0.28	6.22	5.2	1.15	5.98	179.4
S(2) OCT	31.40	0.27	6.09	6	1.35	8.10	243
------NOV	28.30	0.26	5.50	5.3	1.05	5.57	166.95
DEC	25.00	0.26	5.10	4.2		total/seas =	813.6

Legend:

Tmean : average monthly temperatures in degree celsuis for Dirol plain

p : mean daily % of day time hours at latitude 15 degree north.

ETo : evapotranspiration using Blaney-Criddel method

(1) : equation (1); $ETo = P(0.46T + 8)$

(2) : equation (2); $ETcrop = Kc \cdot ETo$

RH : average monthly relative humidity for the Dirol plain.

n/N : ratio of actual to maximum sunshine hours, fraction.

U : average monthly wind speed.

Kc : crop coefficient (e.g. FAO paper #24, table 28).

ET(rice) : maximum evapotranspiration for rice obtained by multiplying Eto by Kc. mm/d or mm/month.

S (1) : Crop season 1.

S (2) : Crop season 2.

Table 14. Calculation of evapotranspiration (ETc) for sorghum using FAO Blaney-Criddle method.

Calculation of ETcrop using FAO Blaney-Criddle Method.							
Month	T mean	p %	ETo (1) mm/d	ETo f(RH,n/N,U2'	Kc(Sorg)	ET (Sorg' (2) mm/d	ET (Sorgh) mm/month
JAN	24.80	0.26	5.08	5.1			
FEB	26.90	0.26	5.33	5.3			
MAR	29.40	0.27	5.85	7.2			
APR	32.60	0.28	6.48	8.4			
MAY	34.60	0.29	6.97	8.8			
JUN	33.40	0.29	6.81	8.5			
-----------JUL	31.10	0.29	6.51	8.5	0.487	2.07	62.09
AUG	30.30	0.28	6.18	7.6	1.05	3.99	119.70
S(1) SEP	30.60	0.28	6.22	8	1.15	9.20	276.00
-----------OC	31.40	0.27	6.09	6.3	0.975	6.14	184.28
						total/season	642.07
-----------NO	28.30	0.26	5.50	6	0.487	1.46	43.83
DEC	25.00	0.26	5.10	5.2	1.05	2.73	81.90
S(2) JAN	24.8	0.26	5.08	5.1	1.15	5.87	175.95
-----------FEI	26.9	0.26	5.33	5.3	0.975	5.17	155.03
						total/season	456.71

Legend:

Tmean : average monthly temperatures in degree celsuis for Dirol plain.
p : mean daily % of day time hours at latitude 15 degree north.
ETo : evapotranspiration using Blaney-Criddel method (e.g. FAO Paper #23).
(1) : equation (1); ETo = P(0.46T + 8)
(2) : equation (2); ETcrop = Kc . ETo
RH : average monthly relative humidity for the Dirol plain.
n/N : ratio of actual to maximum sunshine hours, fraction.
U : average monthly wind speed.
Kc : crop coefficient (e.g. FAO paper #33, table 18).
ET(Sorg) : maximum evapotranspiration for sorghum obtained by multiplying ETo by Kc, mm/d or mm/month.
S (1) : Crop season 1.
S (2) : Crop season 2.

Table 15. Calculation of evapotranspiration (ETc) for wheat using FAO Blaney-Criddle method.

Calculation of ETcrop using FAO Blaney-Criddle Method (1).

Month	T mean c	P %	ETo (1) mm/d	ETo f(RH,n/N,U2)	Kc(whe)	ET (wheat) (2) mm/d	ET (Wheat) mm/month
JAN	24.80	0.26	5.08	5.1			
FEB	26.90	0.26	5.33	5.3			
MAR	29.40	0.27	5.85	7.2			
APR	32.60	0.28	6.48	8.4			
MAY	34.60	0.29	6.97	8.8			
JUN	33.40	0.29	6.81	8.5			
JUL	31.10	0.29	6.51	8.5			
AUG	30.30	0.28	6.18	7.6			
SEP	30.60	0.28	6.22	8			
OCT	31.40	0.27	6.09	6.3			
---------NOV	28.30	0.26	5.50	6	0.50	1.50	45.00
cold DEC	25.00	0.26	5.10	5.2	1.00	2.60	80.60
seas. JAN	24.8	0.26	5.08	5.1	1.20	6.12	189.72
---------FEB	26.90	0.26	5.33	5.3	0.98	5.17	144.69
						total/season	460.01

Legend:

Tmean : average monthly temperatures in degree celsuis for Dirol plain.

p : mean daily % of day time hours at latitude 15 degree north.

ETo : evapotranspiration using Blaney-Criddel method (e.g. FAO Paper #23).

(1) : equation (1); ETo = P(0.46T + 8)

(2) : equation (2); ETcrop = Kc . ETo

RH : average monthly relative humidity for the Dirol plain.

n/N : ratio of actual to maximum sunshine hours, fraction.

U : average monthly wind speed.

Kc : crop coefficient (e.g. FAO paper #33, table 18).

ET(whea) : maximum evapotranspiration for wheat obtained by multiplying ETo by Kc, mm/d or mm/month.

cold seas. : cold season for wheat

Table 16. Calculation of evapotranspiration (ETc) for maize using FAO Blaney-Criddle method.

Calculation of ETcrop using FAO Blaney-Criddle Method (1).

	Month	T mean c	P %	ETo (1) mm/d	ETo f(RH,n/N,U2)	Kc(maize	ET (maize) (2) mm/d	ET (Maize) mm/month
	JAN	24.80	0.26	5.08	5.1			
	FEB	26.90	0.26	5.33	5.3			
	MAR	29.40	0.27	5.85	7.2			
	APR	32.60	0.28	6.48	8.4			
	MAY	34.60	0.29	6.97	8.8			
	JUN	33.40	0.29	6.81	8.5			
	JUL	31.10	0.29	6.51	8.5			
	AUG	30.30	0.28	6.18	7.6			
	SEP	30.60	0.28	6.22	8			
	OCT	31.40	0.27	6.09	6.3			
---------	NOV	28.30	0.26	5.50	6	0.60	1.80	54.00
cold	DEC	25.00	0.26	5.10	5.2	1.12	2.91	90.27
seas.	JAN	24.8	0.26	5.08	5.1	1.20	6.12	189.72
---------	FEB	26.90	0.26	5.33	5.3	1.18	6.23	174.37
							total/season	508.36

Legend:

Tmean : average monthly temperatures in degree celsuis for Dirol plain.
p : mean daily % of day time hours at latitude 15 degree north.
ETo : evapotranspiration using Blaney-Criddel method (e.g. FAO Paper #23).
(1) : equation (1); ETo = P(0.46T + 8)
(2) : equation (2); ETcrop = Kc . ETo
RH : average monthly relative humidity for the Dirol plain.
n/N : ratio of actual to maximum sunshine hours, fraction.
U : average monthly wind speed.
Kc : crop coefficient (e.g. FAO paper #33, table 18).
ET(maize) : maximum evapotranspiration for maize obtained by multiplying ETo by Kc, mm/d or mm/month.
cold seas. : cold season for maize

Table 17. Calculation of evapotranspiration (ETc) for tomato using FAO Blaney-Criddle method.

Calculation of ETcrop using FAO Blaney-Criddle Method (1).

Month	T mean c	P %	ETo (1) mm/d	ETo f(RH,n/N,U2	Kc(toma	ET(tomat (2) mm/d	ET (Tomat mm/month
JAN	24.80	0.26	5.08	4.8			
FEB	26.90	0.26	5.33	6.1			
---------MAR	29.40	0.27	5.85	8.4	0.58	4.83	149.73
APR	32.60	0.28	6.48	9.7	1.38	13.34	400.125
S (1) MAY	34.60	0.29	6.97	12	1.25	15.00	450
---------JUN	33.40	0.29	6.81	10	1.10	11.00	330
						total/seas =	1329.855
---------JUL	31.10	0.29	6.51	9.5	0.58	3.74	112.125
AUG	30.30	0.28	6.18	6.5	1.38	7.15	214.5
S (1) SEP	30.60	0.28	6.22	5.2	1.25	7.50	225
---------OCT	31.40	0.27	6.09	6	1.10	5.83	174.9
NOV	28.30	0.26	5.50	5.3		total/seas =	726.525
DEC	25.00	0.26	5.10	4.2			

Legend:

Tmean : average monthly temperatures in degree celsuis for Dirol plain.
p : mean daily % of day time hours at latitude 15 degree north.
ETo : evapotranspiration using Blaney-Criddel method (e.g. FAO Paper #23).
(1) : equation (1); $ETo = P(0.46T + 8)$
(2) : equation (2); $ETcrop = Kc \cdot ETo$
RH : average monthly relative humidity for the Dirol plain.
n/N : ratio of actual to maximum sunshine hours, fraction.
U : average monthly wind speed.
Kc : crop coefficient (e.g. FAO paper #33, table 18).
ET(tomat): maximum evapotranspiration for tomato obtained by multiplying ETo by Kc, m/d or mm/month.
S (1) : Crop season 1.
S (2) : Crop season 2.

3.8 Water Supply for Crop Water Requirements

Natural precipitation is known to contribute to the needed crop water requirement. However, some precipitation runs off, and some percolates below the reach of the roots. What is left of precipitation after runoff and percolation loss is used by the crop. This reminder is called effective rainfall. Subtracting effective rainfall, r_e, from maximum crop evapotranspiration, ET_m, gives the value of the amount of water needed by the crop in (mm). It is also the amount of water necessary to deliver to the farm, assuming irrigation is 100 percent efficient. Since this is not a valid assumption, the amount of water delivered to the farm must be enough for the crop use plus any losses. To account for these losses, different kinds of efficiencies were proposed for irrigation systems (Cuenca, 1989) (ref. 16) and (ref. 17). Two of these efficiencies were chosen for surface irrigation systems suggested in this project:

Conveyance efficiency

$$e_c = \frac{\text{volume delivered to application devices}}{\text{volume delivered to distribution system}} \times 100 \tag{3}$$

Distribution pattern efficiency

$$e_d = \frac{\text{volume stored in crop root zone}}{\text{volume delivered to application surface}} \times 100 \tag{4}$$

The conveyance efficiency in this project is assumed to be equal to 80% while, the distribution pattern efficiency is taken to be equal to 65% for furrow irrigation.

It will be noted that requirements for rice provide additional amounts of water for soaking, filling, and percolation losses. These are estimates of amounts of water required to saturate the topsoil, flood the paddy, and replace percolation losses while maintaining the flooded condition throughout the growing season. These requirements do not apply to non-flooded crops. In the case of rice, irrigation efficiency does not apply since percolation loss (inefficiency) is estimated directly. The suggested value of percolation loss in this project for crops other than rice is about 20%.

Tables 18 to 22 show the farm delivery requirement for each crop, together with the various factors used in the computation.

3.9 Source of Water Supply

The projected value of the average discharge of the Senegal River after operation of the Manantali Dam is 300m^3/s. This average value is estimated to provide water for irrigation of about 300,000 ha in the middle and lower valley of the Senegal River. In this project, water for irrigation of the Fonde lands will be taken directly from the river. Tables 23 to 27 give an estimate of the percentage of water diverted from the average monthly discharge of the Senegal River. Taking the example of rice which is the crop that requires the most of the water for irrigation, the peak water demand for rice in the dry season (season (1)) is estimated to be 7290 m^3/ha for the month of May (Table 18). This value corresponds to 0.91% of the average flow in the Senegal River (Table 23) which is low enough knowing that the average discharge of the river after operation of the Manantali Dam will be 300m^3/s which will allow for irrigation of other areas of the basin outside the Dirol plain.

Table 18. Farm water delivery for rice.

Water Requierement per rice field							
Month	ETm mm/month	Effective Rain (1920-1975) re mm	water for crops ETm - re mm	Required water for fill & soak mm	water for percolation loss mm	Farm water delivery assuming conveyance efficiency ec=80% mm	m^3/ha
JAN		0					
FEB		0					
-------MAR	299	0	299	120	60	599	5992
APR	335	0	335		67	502	5020
(1) MAY	486	0	486		97	729	7290
---------JUN	315	42	273		55	410	4095
JUL		91					
--------AUG	224	102	122	120	24	333	3334
SEP	179	90	89		18	134	1341
(2) OCT	243	23	220		44	330	3300
-------NOV	167	0	167		33	250	2504
DEC		0					
tot/yr	2249	348	1992	240	398	3288	32876

Note:

Requirements for rice provide additional amounts of water for soaking, filling and percolation losses.

A 40%water for soaking and filling, and 20% for percolation loss need to be considered.

Legend:

ETm: maximum crop evapotranspiration

re : effective rainfall.

(1) : season 1.

(2) : season 2.

ec : conveyance efficiency

Table 19. Farm water delivery for sorghum

	Water Requierement for sorghum				
Month	ETm mm	Effective Rain (1920-1975) re mm	water needed for crops ETm - re mm	Farm water delivery assuming: ed = 65% and ec = 80% mm	m^3/ha
JAN		0			
FEB		0			
MAR		0			
APR		0			
MAY		0			
JUN		42			
---------JUL	62	91	0	0	0
AUG	120	102	18	34	340
(1) SEP	276	90	186	358	3577
---------OCT	184	23	161	310	3102
--------NOV	44	0	44	84	843
DEC	82	0	82	158	1575
(2) JAN	176	0	176	338	3384
--------FEB	155	0	155	298	2981
tot/yr	686		822	1580	15802

Legend:

ETm: maximum crop evapotranspiration
re : effective rainfall.
ed : distribution pattern efficiency
ec : conveyance efficiency

(1) : season 1.
(2) : season 2.

Table 20. Farm water delivery for wheat

Month	Water Requierement for wheat				
	ETm mm	Effective Rain (1920-1976) re mm	water needed for crops ETm - re mm	Farm water delivery assuming: ed = 65% and ec = 80%	
				mm	m^3/ha
JAN		0			
FEB		0			
MAR		0			
APR		0			
MAY		0			
JUN		42			
JUL		91			
AUG		102			
SEP		90			
OCT		23			
--------NOV	45	0	45	87	865
cold DEC	81	0	81	155	1550
seas JAN	190	0	190	365	3648
---------FEB	145	0	145	278	2782
tot/yr	460	348	460	885	8846

Legend:

ETm: maximum crop evapotranspiration

re : effective rainfall.

ed : distribution pattern efficiency

ec : conveyance efficiency

cold seas : cold season

Table 21. Farm water delivery for maize

	Water Requierement for maize				
Month	ETm mm	Effective Rain (1920-1975) re mm	water needed for crops ETm - re mm	Farm water delivery assuming: ed = 65% and ec = 80% mm	m^3/ha
JAN		0			
FEB		0			
MAR		0			
APR		0			
MAY		0			
JUN		42			
JUL		91			
AUG		102			
SEP		90			
OCT		23			
-------NOV	54	0	54	104	1038
cold DEC	90	0	90	174	1736
seas JAN	190	0	190	365	3648
---------FEB	174	0	174	335	3353
tot/yr	508	348	508	978	9776

Legend:

ETm: maximum crop evapotranspiration
re : effective rainfall.
ed : distribution pattern efficiency
ec : conveyance efficiency

cold seas : cold season

Table 22. Farm water delivery for tomato

Water Requierement.					
		Effective Rain (1920-1975)	Required water	Farm water delivery assuming: ed = 65% and ec = 80%	
Month	ETm mm/month	re mm	ETm - re mm	mm	m^3/ha
JAN		0	0		
FEB		0	0		
-----MAR	150	0	150	288	2879
APR	400	0	400	769	7695
(1) MAY	450	0	450	865	8654
------JUN	330	42	288	554	5538
------JUL	112	91	21	41	406
AUG	215	102	113	216	2163
(2) SEP	225	90	135	260	2596
------OCT	175	23	152	292	2921
NOV		0	0		
DEC		0	0		
tot/yr	2056		1708.38	3285.3	32853

Legend:

ETm: maximum crop evapotranspiration
re : effective rainfall.
ed : farm distribution efficiency
ec : conveyance efficiency

(1) : season 1.
(2) : season 2.

Table 23. Percent of water diverted from the Senegal River for rice field.

Water requirement per rice field				Senegal River mean monthly discharges		Diverted water for irrigation as percentage of average flow (Q) of the Senegal River	
Month	ETm	Farm water delivery assuming conveyance efficiency ec=80%		Before Manantali Dam average Q	After Manantali Dam average Q	Before Manantali Dam	After Manantali Dam
	mm/month	mm	m^3/ha	m^3/s	m^3/s	%	%
JAN				143	300		
FEB				82	300		
------MAR	299	599	5992	45	300	4.97	0.75
APR	335	502	5020	19	300	9.86	0.62
(1) MAY	486	729	7290	8.6	300	31.65	0.91
---------JUN	273	410	4095	72	300	2.12	0.51
JUL				495	300		
-------AUG	122	333	3334	2047	300	0.06	0.41
SEP	89	134	1341	3357	300	0.01	0.17
(2) OCT	220	330	3300	1970	300	0.06	0.41
----NOV	167	250	2504	645	300	0.14	0.31
DEC				264	300		
tot/yr	1992	3288	32876	9148	3600	49	4

Legend:

ETm: maximum crop evapotranspiration

(1) : season 1.

(2) : season 2.

ec : conveyance efficiency

Table 24. Percent of water diverted from the Senegal River for field of sorghum.

Month	Water Requierement. ETm - re mm	Farm water delivery assuming: ed = 65% and ec = 80% mm	m^3/ha	Senegal River mean monthly discharges: Before Manantali Dam Q (m^3/s) Average	After Manantali Manantali Dam Q (m^3/s) Average	Diverted water from the Senegal River @ ed = 65 % & ec = 80%: Before Manatali %	After Manatali %
JAN				143	300		
FEB				82	300		
MAR				45	300		
APR				19	300		
MAY				8.6	300		
JUN				72	300		
---------JUL	0	0	0	495	300	0.00	0.00
AUG	18	34	340	2047	300	0.01	0.04
(1) SEP	186	358	3577	3357	300	0.04	0.46
--------OCT	161	310	3102	1970	300	0.06	0.40
--------NOV	44	84	843	645	300	0.05	0.11
DEC	82	158	1575	264	300	0.23	0.20
(2) JAN	176	338	3384	143	300	0.91	0.44
--------FEB	155	298	2981	82	300	1.40	0.38
tot/yr	409	1580	15802				

Legende:

ETm: maximum crop evapotranspiration
re : effective rainfall
ed : farm distribution efficiency
ec : conveyance efficiency

(1) : season 1.
(2) : season 2.

Table 25. Percent of water diverted from the Senegal River for field of wheat

Month	Water Requierement.			Senegal River mean monthly discharges		Diverted water from the Senegal River @ ed = 65 % & ec = 80%	
	ETm - re	Farm water delivery assuming: ed = 65% and ec = 80%		Before Manantali Dam	After Manantali Manantali Dam	Before Manatali	After Manatali
	mm	mm	m^3/ha	Q (m^3/s) Average	Q (m^3/s) Average	%	%
JAN				143	300		
FEB				82	300		
MAR				45	300		
APR				19	300		
MAY				8.6	300		
JUN				72	300		
JUL				495	300		
AUG				2047	300		
SEP				3357	300		
OCT				1970	300		
-------NOV	45	87	865	645	300	0.05	0.11
cold DEC	81	156	1558	264	300	0.23	0.20
seas JAN	190	365	3654	143	300	0.99	0.47
---------FEB	145	279	2788	82	300	1.31	0.36
tot/yr	461	887	8865				

Legende:

ETm: maximum crop evapotranspiration

re : effective rainfall

ed : farm distribution efficiency

ec : conveyance efficiency

cold seas : cold season

Table 26. Percent of water diverted from the Senegal River for field of maize

Month	ETm - re	Water Requierement. Farm water delivery assuming: ed = 65% and ec = 80%		Senegal River mean monthly discharges Before Manantali Dam	Senegal River mean monthly discharges After Manantali Manantali Dam	Diverted water from the Senegal River @ ed = 65 % & ec = 80% Before Manatali	Diverted water from the Senegal River @ ed = 65 % & ec = 80% After Manatali
	mm	mm	m^3/ha	Q (m^3/s) Average	Q (m^3/s) Average	%	%
JAN				143	300		
FEB				82	300		
MAR				45	300		
APR				19	300		
MAY				8.6	300		
JUN				72	300		
JUL				495	300		
AUG				2047	300		
SEP				3357	300		
OCT				1970	300		
-------NOV	54	104	1038	645	300	0.06	0.13
cold DEC	90	174	1736	264	300	0.25	0.22
seas JAN	190	365	3648	143	300	0.98	0.47
--------FEB	174	335	3353	82	300	1.58	0.43
tot/yr	508	978	9776				

Legende:

ETm: maximum crop evapotranspiration

re : effective rainfall

ed : farm distribution efficiency

ec : conveyance efficiency

cold seas : cold season

Table 27. Percent of water diverted from the Senegal River for fields of tomato

Water Requierement.				Senegal River mean monthly discharges		Diverted water from the Senegal River @ ed = 65 % & ec = 80%	
		Farm water delivery assuming: ed = 65% and ec = 80%		Before Manantali Dam	After Manantali Manantali Dam	Before Manatali	After Manatali
Month	ETm - re mm/mont	mm	m^3/ha	Q (m^3/s) Average	Average Q (m^3/s)	%	%
JAN	0			143	300		
FEB	0			82	300		
-----MAR	150	288	2879	45	300	2.47	0.37
APR	400	769	7695	19	300	15.62	0.99
(1) MAY	450	865	8654	8.6	300	38.82	1.11
------JUN	288	554	5538	72	300	2.97	0.71
------JUL	21	41	406	495	300	0.03	0.05
AUG	215	412	4125	2047	300	0.08	0.53
(2) SEP	135	260	2596	3357	300	0.03	0.33
------OCT	152	292	2921	1970	300	0.06	0.38
NOV				645	300		
DEC				264	300		
tot/yr	1810	3481.5	34815				

Legend:

ETm: maximum crop evapotranspiration

(1) : season 1.

(2) : season 2.

ed : farm distribution efficiency

ec : conveyance efficiency

3.10 Design layout for Surface Irrigation, Furrow and Basin Systems

Furrow system design

Calculation procedures for furrow systems were done with the help of a computer program given in Cuenca (1989) (ref. 16). The following input data are required to execute the program:

(a) Intake Family constants a, b, c, f, and g

(b) Furrow length, m

(c) Furrow slope, m/m

(d) Furrow spacing, m

(e) Manning's roughness coefficient

(f) Net irrigation depth, mm

(g) Inflow rate, L/s

The Intake Family is calculated using Figure 7-31 and Table 3-3 Appendix B. The intake family for Fonde soils (silt loam) is found to be equal to 0.4. The furrow length is taken to be 100 m, the slope is 0.005 m/m, the furrow spacing is 0.65 m, and the roughness coefficient is 0.004. Net irrigation depth is obtained by multiplying the maximum evapotranspirtion ET_m for the month of August (critical month for sorghum) by number of days of irrigation which is 7 days in this project. Net irrigation depth is found to be equal to 65 mm. The maximum inflow rate that can maintain proper furrow shape and reduce sediment loss is found by using the following equation:

$$Q_{max} = \frac{C}{S} \tag{6}$$

S = ground slope down the furrow, percent

C = empirical constant equal to 0.6 for Q_{max} expressed in L/s

After entering the previous parameters, the program allows for iteration in length, slope, net depth of irrigation, or inflow rate and produces output for each iteration. The program output is as follows:

(a) Advance time, min

(b) Adjusted wetted perimeter, m

(c) Net infiltration time, min

(d) Design cut-off time, min

(e) Gross application depth, mm

(f) Average infiltration time, min

(g) Average infiltration depth, mm

(h) Surface runoff depth, mm

(i) Deep percolation depth, mm

(j) Distribution pattern efficiency, percent

The advance time for a stream of water moving down the furrow is calculated as follows:

$$T_t = \frac{x}{f}\exp\left[\frac{gx}{Q(S)^{0.5}}\right] \tag{7}$$

T_t = advance time, min

x = distance down the furrow, m

f = advance coefficient, Table 6-6 (Appendix C)

Q = volumetric inflow rate, L/s

S = furrow slope or hydraulic gradient, m/m

The adjusted wetted perimeter is as follows:

$$P = 0.265\left[\frac{Q_n}{S_{0.5}}\right]^{0.925} + 0.227 \qquad (8)$$

P = adjusted wetted perimeter, m

Q = volumetric inflow rate, L/s

n = Manning's roughness coefficient

S = furrow slope or hydraulic gradient, m/m

Net infiltration time:

$$T_n = \left[\frac{i_n\left(\frac{W}{P}\right) - c}{a}\right]^{1/b} \qquad (9)$$

T_n = net infiltration time, min

i_n = net irrigation depth, mm

W = furrow spacing, m

P = adjusted wetted perimeter, m

a, b, and c are advance coefficients, Table 6-6 (Appendix C)

Design cut-off time :

$$T_{co} = T_t + T_n \qquad (10)$$

T_{co} = design cut-off time, min

T_t = advance time, min

T_n = net infiltration time, min

Gross application depth, mm

$$i_g = \frac{60(Q)(T_{co})}{WL} \tag{11}$$

i_g = gross depth of application, mm

Q = inflow rate, L/s

W = furrow spacing, m

The average infiltration time is calculated as follows:

$$T_{0\text{-}L} = T_{co} - \frac{0.0929}{f(x)\left[\frac{0.305(\beta)}{L}\right]^2}\left[(\beta - 1)\exp(\beta) + 1\right] \tag{12}$$

$T_{0\text{-}L}$ = average infiltration time, min

T_{co} = cut-off time, min

$\beta = \frac{gx}{Q(S)^{0.5}}$

g = advance coefficient, Table 6-6 (Appendix C)

x = distance down the furrow (equal to L for maximum length), m

S = furrow slope, m/m

L = length of the entire furrow, m

The average depth of infiltration is determined by the following equation:

$$i_{avg} = \left[a(T_{0\text{-}L})^{b} + c\right]\frac{P}{W} \tag{13}$$

i_{avg} = average depth of infiltration, mm

a, b, and c are advanced coefficients, Table 6-6 (Appendix C)

$T_{0\text{-}L}$ = average time of infiltration, min

P = adjusted wetted perimeter, m

W = furrow spacing, m

The depth of surface runoff from the furrow is determined by subtracting the average depth of application from the gross depth of application:

$$d_{ro} = i_{g} - i_{avg} \tag{14}$$

d_{ro} = depth of runoff, mm

i_g = gross application depth, mm

i_{avg} = average application depth, mm

The equivalent depth of deep percolation is estimated as the difference between the average depth of application and the net depth of application:

$$d_{dp} = i_{avg} - i_{n} \tag{15}$$

d_{dp} = depth of deep percolation, mm

i_{avg} = average depth of application, mm

in = net depth of application, mm

The result of the calculations for furrow design using the computer program are shown in Appendix D. Table 28 and Figure 7 show a summary of the results of the furrow parameters in Fonde soils.

Basin system design

Table 6-3 (Appendix E) indicates suggested basin areas as a function of soil and water supply parameters necessary to reach a reasonable irrigation efficiency. This approach gives a general idea of the design criteria (Cuenca, 1989) (ref. 16).

Based on the previous information concerning the type of soil to be irrigated in the project area (silty loam) and the minimum plot size of 0.3 ha, Table 6-3 gives an estimate of the flow rate needed per plot of rice which is Q = 540 m^3/hr which equivalent to Q = 150 L/s.

3.11 Pumping System Design

Until electrical power is widely available in the Senegal River basin, diesel-driven pumps, placed on floating platforms at the river's bank are used (ref. 16,18,19, and 20). These pumps must discharge 150 L/s against a head of 4 to 16 meters up the bank, through light-weight pipe, to the irrigation canals. Such a pump unit is reasonably movable and can provide the water needed to irrigate a typical small unit of 20 ha gross area which consist of 66 farms of 0.3 ha each. Figure 8 shows a layout of the design.

Table 28. Table of parameters for varying flow rates for Fonde soils

Q (L/S)	Tco (min)	Ig (mm)	Dro (mm)	Ddp (mm)	Ed (%)	Run-off (%)
0.1	995.9	92	12	15	71	11
0.12	852.6	94	21	9	69	20
0.13	811.4	97	25	7	67	24
0.14	779.9	101	30	6	65	30
0.15	755	105	34	5	62	36
0.16	734.6	108	39	5	60	42
0.17	717.4	113	43	4	58	49
0.18	702.7	117	48	13	56	56
0.19	689.8	121	53	3	54	64
0.2	678.3	125	57	3	52	71
0.4	559.5	207	140	1	32	N/A
0.6	502	278	212	1	23	N/A
0.8	463.2	342	276	1	19	N/A
1	433.9	401	335	1	16	N/A
1.2	410.6	455	389	1	14	N/A

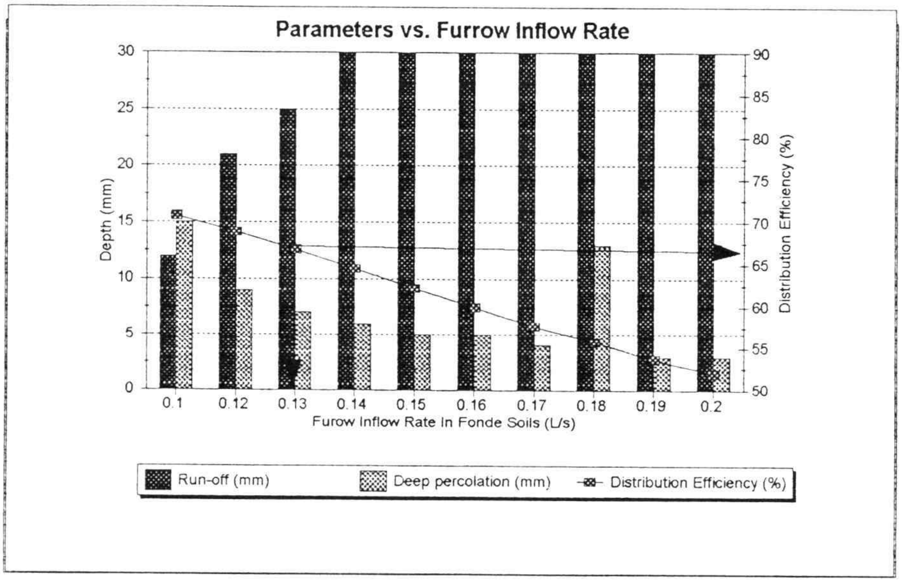


Figure 7. Run-off and deep percolation versus furrow inflow rate in Fonde soils

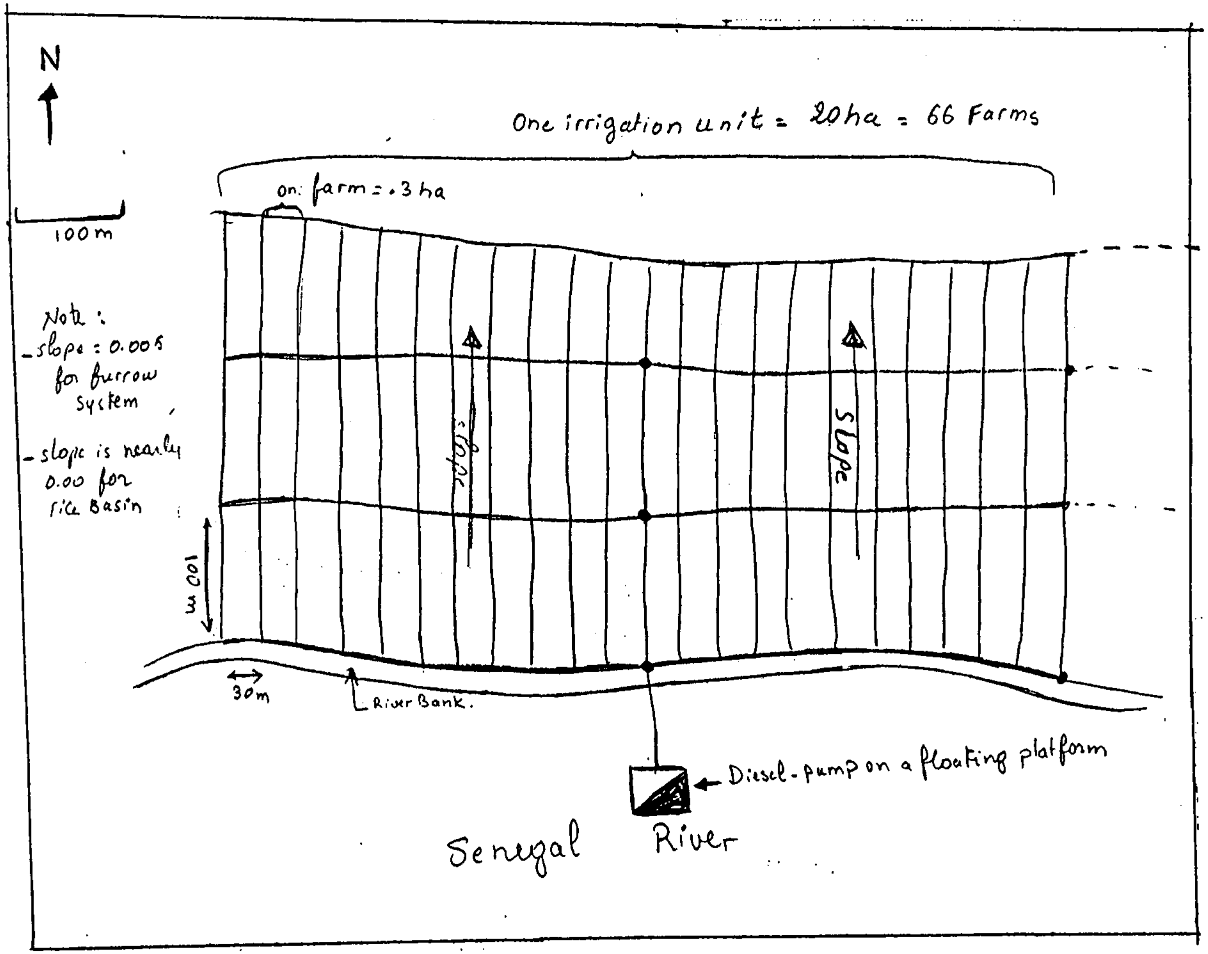


Figure 8. Layout plan of the Dirol irrigation design

Calculation of the required power of the pump

The required power of the pump should be calculated by reference to rice basins because of their high water demand. The flow rate needed to irrigate a rice basin of 0.3 ha in Fonde soils (silt loam) is Q = 150 L/s. For a discharge pressure head of 16 m and a pump motor efficiency of 80%, the required power is:

$$P = \frac{Q(H)(Sg)}{4634(E)} \qquad (16)$$

P = power, metric horsepower (mho)

Q = pump discharge, L/mine

H = discharge pressure head, m

Sag = specific gravity of water, dimensionless

E = pump motor efficiency, fraction

The calculated required power of the suggested pump is found to be:

P = 486 mhp.

3.12 Irrigation Schedule

In order for the farmers to get high crop yields, irrigation of the crop fields should be performed every 7 days. Knowing that one farming unit of 20 ha has 66 fields or basins, the irrigation schedule should be arranged in a way that allows the irrigation of

66 basins in 7 days. Calculations of irrigation schedule for rice basins and furrows were done as follows:

Irrigation schedule for rice basins

From Table 13, the maximum evapotranspiration for rice Et_m is equal to 16.2 mm/d. With the suggested 7 days period between each irrigation, the net irrigation depth i_n is:

$$i_n = 16.2 \text{ mm/d} \times 7\text{d} = 113.4 \text{ mm} \tag{17}$$

The gross irrigation depth i_g can be calculated using the following equation:

$$i_g = \frac{i_n}{\frac{e_d}{100}(\frac{e_c}{100})} \tag{18}$$

e_d = distribution pattern efficiency (assumed to be 80% for rice fields, i.e. deep percolation assumed to be 20%)

e_c = conveyance efficiency, percent (assumed to be equal to 80%)

i_g = 177 mm.

The rate of irrigation for rice basin is equal to:

$$\text{Rate of irrigation} = \frac{\text{Discharge / basin}}{\text{Area of basin}} \tag{19}$$

The discharge per basin is Q = 150L/s, and the area of the basin is 0.3 ha. Thus;

Rate of irrigation = 0.18 m/hr

The required time of irrigation for a rice basin is therefore equal to gross depth of irrigation i_g divided by the rate of irrigation:

$$\text{Time of irrigation} = \frac{i_g}{\text{rate of irrigation}} \tag{20}$$

$$\text{Time of irrigation} = \frac{177\ \text{mm}}{0.18\ \text{m/hr}} = \frac{177 \times 10^{-3}\ \text{m}}{0.18\ \text{m/hr}} = 0.98\ \text{hrs}$$

Therefore 10 basins of rice can be irrigated for 10 hrs which means it is feasible to irrigate 10 basins per day (assuming that working hours are between 8 to 10 hours per day).

Irrigation schedule for furrows

From the results of the computer program for calculation of furrow parameters, the inflow rate per furrow is taken to be equal to Q = 0.14 L/s. One basin of 0.3 ha, 30 m wide and 100 m long has a total number of 46 furrows (taking into consideration that one furrow spacing is equal to 0.65 m). Therefore, the inflow rate per basin is equal to Q/basin = 6.44 L/s, and Q for 10 basins is equal to 64.4 L/s. Concerning the time of irrigation, it was found equal to 12 hrs from the results of the computer program (Appendix F).

Calculation of the number of days for irrigation of the rice basins

Because of rice's high water demand, only 30% of the irrigated Fonde land will be used to grow rice. Thus, knowing that one unit of 20 ha has 66 basins (of 0.3 ha each) 20 basins only will be allocated as rice basins, the remaining 46 will be used to grow the rest of the crops using furrow systems. From previous calculations 1 hr is needed to irrigate one rice basin (taking into consideration the fact that the design pump delivers a discharge of Q = 150L/s) therefore, 20 hrs are needed for the irrigation of 20 rice basins which corresponds to approximately 2 days.

Calculation of the number of days for irrigation of the furrow basins

The projected 70% of Fonde lands used for furrow irrigation gives approximately 46 furrow basins. Previously in this report, the amount of inflow rate needed per furrow basin was found to be equal to Q = 6.44 L/s and the inflow rate for 10 basins is Q = 64.4 L/s. It is important here to emphasize that this Q = 64.4 L/s is less than half the amount of water delivered by the design pump for rice basin which is Q= 150 L/s. Therefore, two smaller pumps providing each a discharge of Q = 75 L/s are recommended for the irrigation of furrow basins (10 basins for each pump). Knowing that the design time cut-off is equal to 12 hrs (Appendix F) each pump will be able to irrigate 10 furrow basins per day so that the total number of 46 furrows will be irrigated in approximately 5 days. Therefore, the 66 basins of the projected irrigation unit will be irrigated in 7 days with 5 days of irrigation for 46 furrow basins using one pump with a discharge of 75 L/s, and 2 days of irrigation for 20 rice basins using the combined discharge of matching two pumps.

4 Analysis and Conclusion

Based on the environmental and socio-economic background of the project region, in an attempt to estimate the exact amount of water needed for irrigation, particular attention was given to:

(1) The choice of crops and cropping patterns.

(2) A well defined crop calendar that took into consideration the limits of soil potential, water availability and climatic hazards, all of wish have crucial impact on crops and their failure to reach their optimum production level.

(3) An adequate water supply that is economic, easy to operate and manage and that has the ability to supply the needed crop water requirements .

Table 29 gives a summary of the irrigation requirement with regard to the different crops and their cropping seasons, and the different type of soils.

Four major crops were chosen due the need for either local consumption such as sorghum, millet and maize, or, as cash crops such as rice. Like rice, tomatoes are new in the area and their introduction in this project report was done to show the needed requirements to sustain the growth and marketing of such crop in the Senegal River Valley. The water requirement for rice is higher than the other crops, especially flooded rice. An analysis of the results concerning the rice crop water requirement and field water requirement will give a good understanding of the project performance. Rice has two seasons, one from March to June and the other from August to November. In calculating the crop water requirement for rice, three major components had to be taken into consideration: 1) amount of water needed for the field preparation, 2) crop-specific moisture requirement, and 3) overall water use efficiency. An estimate of 40% additional water was included for field preparation and 20% additional water to compensate for deep percolation loss.

Table 29. Summary of irrigation requirements

Type of soil: Fonde (silt loam) Distribution efficiency : 65 % Conveyance efficiency:80% Deep percolation loss: 20%		Weighted Farm Delivery Requirement (mm of depth)												
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	annual
Type of crop														
Rice	**S (1)**			599	502	729	410							
	S (2)								333	134	330	250		
	total													**3288**
Sorghum	**S (1)**							0	34	358	310			
	S (2)	338	298									84	158	
	total													**1580**
Wheat	**(cold seaso**	365	278									87	155	**885**
Maize	**(cold seaso**	365	335									104	174	**978**
Tomato	**S (1)**			288	769	865	554							
	S (2)							41	216	260	292			
	total													**3285**
Total		1068	911	887	1271	1594	964	41	583	752	932	525	487	

s(1) : season 1. s(2) : season 2.

The size of the irrigated area was estimated to be about 1000 ha of Fonde land with a minimum plot size of 0.3 ha (30m wide and 100m long). Average gross water needs for rice cultivation in Fonde soils is estimated to be equal to 7290 m^3/ha. This value would be less in the Hollalde soils because of their high clay content. However the location of Hollade soils in the most flooded area of the river basin make them costly for irrigated agriculture because of the need for construction of a flood protection system that would increase the cost of irrigation for the farmers. Hollalde soils are reserved in this project for the practice of the traditional flood recession agriculture with sorghum as the main crop.

Water for rice fields is to be diverted from the Senegal River directly to the irrigated field two diesel pumps capable of a water discharge of 75 L/s each with a required head of 16m up the Senegal River bank. Table 23 shows the value of the diverted water as a percent of the average flow of the Senegal river. The results show that the percentage of the diverted water from the river is about 0.91% at peak water demand which corresponds to the month of May for the dry season of the rice crop. This value of 0.91% is very low compared to the average discharge of the river which is equal to 300m^3/s. One farm unit is considered to be equal to 20 ha with 0.3 ha as minimum size per farm. Diesel-driven pumps will be used for the irrigation of the field units. Tow pumps with a discharge of 150 L/s will irrigate 20 rice basins in a period of 2 days, while 46 basins of furrows will be irrigated by the two pumps in approximately 5 days, thus completing the irrigation of the entire 66 basins in 7 days which is the required schedule of irrigation for this project.

Clearly, water supply for irrigation is not a problem in the Senegal River Valley. However what can cause a real problem is the method of supply and distribution. Supply canals and distribution canals must be well constructed even if it requires more costly machine work, linings, or pipe to avoid loss of water due deep percolation, runoff and evaporation. Maintenance and repair is a crucial necessity for pump installation and distribution systems. If a pump goes out of service during the irrigation season for an appreciable period of time, crop production can be severely reduced or even lost. Much of this kind of experience can lead to discouragement among the farmers. Cultivators simply can not afford to make the inputs required and then watch their crops die for lack of water.

5 Other Conclusions and Recommendations

5.1 Land Tenure and Management

Concerning land tenure, the pattern of village and clan ownership is found useful for the development of small scale irrigation systems designed in this report. Such development can come from the bottom up: by a group of farmers having use of land under village control organizing themselves into an association to construct, operate and cultivate an irrigated land. Thus, one may be optimistic that with careful attention and respect to traditions and sociocultural norms of land use and ownership, a population of some 7,000 in the project zone, residing in 11 villages, needs no outside authority or interference in decision making.

Challenges will surface in large scale irrigation systems where group land use may have to be negotiated most of the time with the intervention of outside authorities. In order to give the farmers a better feel for irrigated farming, small scale design is recommended. It is also worth mentioning that a transition to a larger irrigation system by upgrading the small scale one can easily be made by this kind of farmer.

5.2 Economics and Marketing

It is not intended to make an economic analysis of the project. However, with the assumption that basic production constraints are reasonably well managed such as seed, fertilizer, water...etc., one may presume that the motivation of the cultivator to produce a second (dry season) crop is questionable. This is particularly true when the work is all done by hand under hot and rough weather conditions. There is little incentive to endure the expenses of crop inputs to produce more than one's family can consume, unless there is a substantial market for the product that will return a profit. Unfortunately, such conditions are still very limited in the area of the Senegal River basin. Thus the need for the government to intervene in order to set up a network of roads to local and city markets becomes a matter of crucial importance.

5.3 Government Support Funding

While maintaining the policy of maximum participation of farmer groups in the construction of irrigated fields (ref. 21, and 22), differentiation should be made between work that can be done by hand and work that can only be completed with machines. Hand work would include preliminary site preparations and individual plot work. Work restricted to heavy machinery would be excavations, compactions, load transports, contouring and leveling. It is recommended that the government make an important effort to help the farmers' association with loans necessary for the procurement of the needed farming equipment and machinery. It is also necessary to encourage the farmers to set up an effective pump maintenance and repair program done with the help of an experienced technician. The stocking of some individual pump units needed at critical times when there is a major breakdown is also recommended.

5.4 Health Issues

Calm, still waters, especially in the rice fields, are good breeding grounds for the snails that act as intermediate hosts for parasites which carry Shistosomiasis (Belharzia). They are also responsible for the increase of the breeding potential for Malaria vectors in the area. Since snails require fresh water rich in organic material, a measure of control can be achieved by keeping canals free of vegetation. In addition, treatment of water where it enters the fields with appropriate molluscides should be used as a direct control measure. An education program designed to acquaint local people with methods by which diseases are spread (via urine and feces of infected individuals in contact with water) should be undertaken.

It is finally required that a health surveillance program aimed at providing for early detection and treatment of diseases in agricultural workers should be organized and supervised by the government of Mauritania.

5.5 Summary of Recommendations for Successful Irrigation Design in Mauritania

The basic requirements to design an irrigation system in the Senegal River basin area, include:

- Size of field
- Type of water source
- Soil type
- Crop irrigated
- Physical topography
- Climate

However, other aspects of crucial importance in African context should be taken into consideration such as:

- Land tenure issues
- Rights to water
- Financial responsibility
- Political organization

- Political organization
- Health and environmental issues.

Finally a respect for traditional farming systems should be encouraged by agricultural engineers, and traditional farming methods should be kept alive if not improved. Farmers' autonomy, self-reliance, and self-esteem, will be increased by keeping their own traditional methods in addition to developing those for irrigation. This dual technology will allow the farmers to better understand irrigation principles and broaden their experience in agriculture.

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APPENDICES

APPENDIX A:

FAO Blaney-Criddle Method

- Table 1. Mean Daily percentage (p) of Annual Daytime hours for different latitudes.
- Figure 1. Prediction of ETo from Blaney Criddel f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

Table 1 Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes

Latitude North / South[1/]	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	.31*	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

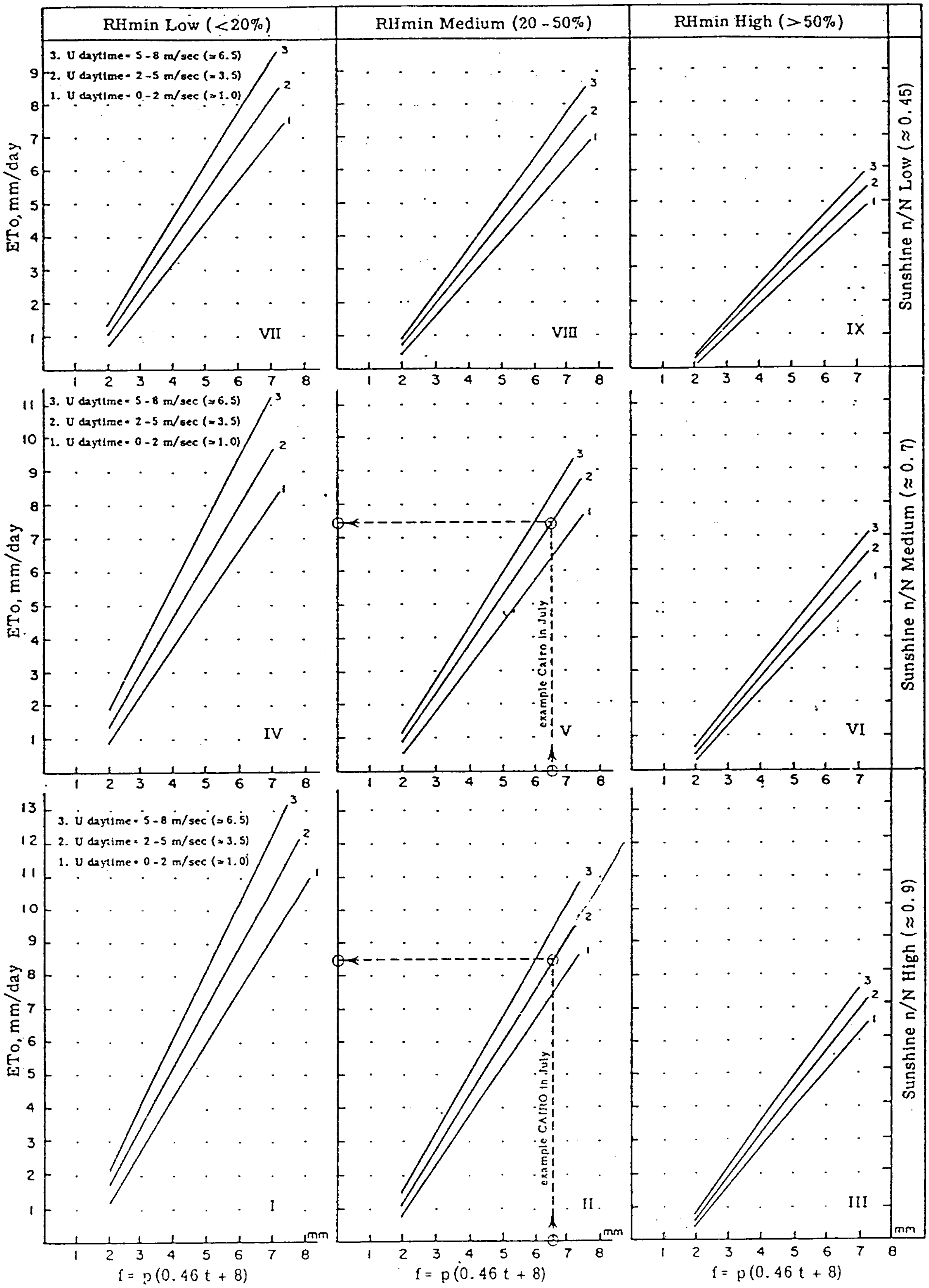

Fig. 1 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

APPENDIX B:

Intake Family

- Determination of the Intake Family for Fonde soils (silt loam) using Figure 7-3 and Table 3-3 (Cuenca, 1989).

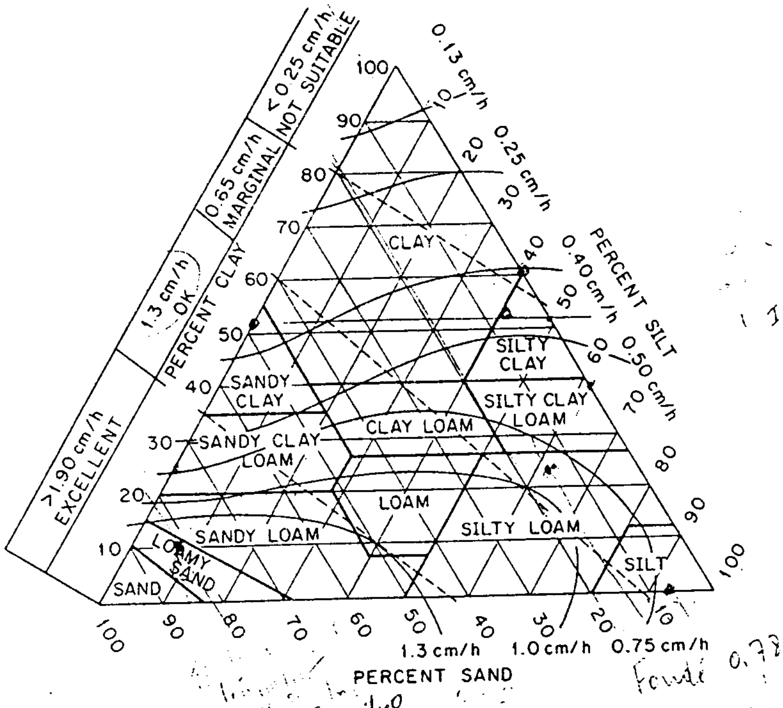

Figure 7-31 General infiltration rate contours superimposed on the USDA textural triangle. Adaptability of soil type to irrigation by center pivot indicated by dashed lines extending from the left of figure. (Adapted from USDA-SCS, 1983.)

where

Q = discharge required at the pivot, L/s
A = total area irrigated by the pivot system, ha
K = conversion constant

TABLE 3-3 Parameters for calculation of accumulated infiltration using the SCS intake family concept.

Intake Family	a (cm)	a (in)	b
0.05	0.0533	0.0210	0.6180
0.10	0.0620	0.0244	0.6610
0.15	0.0701	0.0276	0.6834
0.20	0.0771	0.0306	0.6988
0.25	0.0853	0.0336	0.7107
0.30	0.0925	0.0364	0.7204
0.35	0.0996	0.0392	0.7285
0.40	0.1064	0.0419	0.7356
0.45	0.1130	0.0445	0.7419
0.50	0.1196	0.0471	0.7475
0.60	0.1321	0.0520	0.7572
0.70	0.1443	0.0568	0.7656
0.80	0.1560	0.0614	0.7728
0.90	0.1674	0.0659	0.7792
1.00	0.1786	0.0703	0.785
1.50	0.2283	0.0899	0.799
2.00	0.2753	0.1084	0.808
3.00	0.3650	0.1437	0.816
4.00	0.4445	0.1750	0.823

APPENDIX C:

Advance Coefficients

Table 6-6 (Cuenca, 1989) representing the advence coefficients.

TABLE 6-6 Intake family and advance coefficients for depth of infiltration in mm, time in minutes, and length in meters.

Intake Family	a	b	c	f	g
0.05	0.5334	0.618	7.0	7.16	1.088×10^{-4}
0.10	0.6198	0.661	7.0	7.25	1.251×10^{-4}
0.15	0.7110	0.683	7.0	7.34	1.414×10^{-4}
0.20	0.7772	0.699	7.0	7.43	1.578×10^{-4}
0.25	0.8534	0.711	7.0	7.52	1.741×10^{-4}
0.30	0.9246	0.720	7.0	7.61	1.904×10^{-4}
0.35	0.9957	0.729	7.0	7.70	2.067×10^{-4}
0.40	1.064	0.736	7.0	7.79	2.230×10^{-4}
0.45	1.130	0.742	7.0	7.88	2.393×10^{-4}
0.50	1.196	0.748	7.0	7.97	2.556×10^{-4}
0.60	1.321	0.757	7.0	8.15	2.883×10^{-4}
0.70	1.443	0.766	7.0	8.33	3.209×10^{-4}
0.80	1.560	0.773	7.0	8.50	3.535×10^{-4}
0.90	1.674	0.779	7.0	8.68	3.862×10^{-4}
1.00	1.786	0.785	7.0	8.86	4.188×10^{-4}
1.50	2.284	0.799	7.0	9.76	5.819×10^{-4}
2.00	2.753	0.808	7.0	10.65	7.451×10^{-4}

Appendix D:

Results of the Computer Program

Used for the Calculation of Furrow Parameters

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.15

RESULTS

BETA = 2.1025
Advance Time (min) = 105.1
Adjusted Wetted Perimeter (m) = 0.320
Net Infiltration Time (min) = 649.9
Design Cut-Off Time (min) = 755.0
Gross Application Depth (mm) = 105
Average Infiltration Time (min) = 725.9
Average Infiltration Depth (mm) = 70
Surface Runoff Depth (mm) = 34
Deep Percolation Depth (mm) = 5
Distribution Pattern Efficiency (percent) = 62.2

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.16

RESULTS

BETA = 1.9711
Advance Time (min) = 92.1
Adjusted Wetted Perimeter (m) = 0.322
Net Infiltration Time (min) = 642.4
Design Cut-Off Time (min) = 734.6
Gross Application Depth (mm) = 108
Average Infiltration Time (min) = 708.3
Average Infiltration Depth (mm) = 70
Surface Runoff Depth (mm) = 39
Deep Percolation Depth (mm) = 5
Distribution Pattern Efficiency (percent) = 59.9

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.17

RESULTS

BETA = 1.8551
Advance Time (min) = 82.1
Adjusted Wetted Perimeter (m) = 0.325
Net Infiltration Time (min) = 635.4
Design Cut-Off Time (min) = 717.4
Gross Application Depth (mm) = 113
Average Infiltration Time (min) = 693.3
Average Infiltration Depth (mm) = 69
Surface Runoff Depth (mm) = 43
Deep Percolation Depth (mm) = 4
Distribution Pattern Efficiency (percent) = 57.7

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.18

RESULTS

BETA = 1.7521
Advance Time (min) = 74.0
Adjusted Wetted Perimeter (m) = 0.327
Net Infiltration Time (min) = 628.7
Design Cut-Off Time (min) = 702.7
Gross Application Depth (mm) = 117
Average Infiltration Time (min) = 680.4
Average Infiltration Depth (mm) = 69
Surface Runoff Depth (mm) = 48
Deep Percolation Depth (mm) = 4
Distribution Pattern Efficiency (percent) = 55.7

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.19

RESULTS

BETA = 1.6598
Advance Time (min) = 67.5
Adjusted Wetted Perimeter (m) = 0.330
Net Infiltration Time (min) = 622.3
Design Cut-Off Time (min) = 689.8
Gross Application Depth (mm) = 121
Average Infiltration Time (min) = 669.0
Average Infiltration Depth (mm) = 68
Surface Runoff Depth (mm) = 53
Deep Percolation Depth (mm) = 3
Distribution Pattern Efficiency (percent) = 53.7

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.20

RESULTS

BETA = 1.5768
Advance Time (min) = 62.1
Adjusted Wetted Perimeter (m) = 0.332
Net Infiltration Time (min) = 616.2
Design Cut-Off Time (min) = 678.3
Gross Application Depth (mm) = 125
Average Infiltration Time (min) = 658.8
Average Infiltration Depth (mm) = 68
Surface Runoff Depth (mm) = 57
Deep Percolation Depth (mm) = 3
Distribution Pattern Efficiency (percent) = 51.9

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.40

RESULTS

BETA = 0.7884
Advance Time (min) = 28.2
Adjusted Wetted Perimeter (m) = 0.368
Net Infiltration Time (min) = 531.2
Design Cut-Off Time (min) = 559.5
Gross Application Depth (mm) = 207
Average Infiltration Time (min) = 548.5
Average Infiltration Depth (mm) = 66
Surface Runoff Depth (mm) = 140
Deep Percolation Depth (mm) = 1
Distribution Pattern Efficiency (percent) = 31.5

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.60

RESULTS

BETA = 0.5256
Advance Time (min) = 21.7
Adjusted Wetted Perimeter (m) = 0.394
Net Infiltration Time (min) = 480.3
Design Cut-Off Time (min) = 502.0
Gross Application Depth (mm) = 278
Average Infiltration Time (min) = 492.8
Average Infiltration Depth (mm) = 66
Surface Runoff Depth (mm) = 212
Deep Percolation Depth (mm) = 1
Distribution Pattern Efficiency (percent) = 23.4

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 0.80

RESULTS

BETA = 0.3942
Advance Time (min) = 19.0
Adjusted Wetted Perimeter (m) = 0.416
Net Infiltration Time (min) = 444.1
Design Cut-Off Time (min) = 463.2
Gross Application Depth (mm) = 342
Average Infiltration Time (min) = 454.8
Average Infiltration Depth (mm) = 66
Surface Runoff Depth (mm) = 276
Deep Percolation Depth (mm) = 1
Distribution Pattern Efficiency (percent) = 19.0

PROJECT: Furrow in Fonde soils

INTAKE FAMILY CONSTANTS

SCS Intake Family = 0.40

a = 1.0640
b = 0.736
c = 7.0
f = 7.79
g = 0.0002230

PHYSICAL DESCRIPTION

Furrow Length (m) = 100.0
Furrow Slope (m/m) = 0.0050
Furrow Spacing (m) = 0.65
Roughness Coefficient = 0.04
Net Irrigation Depth (mm) = 65
Inflow Rate (L/s) = 1.00

RESULTS

BETA = 0.3154
Advance Time (min) = 17.6
Adjusted Wetted Perimeter (m) = 0.435
Net Infiltration Time (min) = 416.3
Design Cut-Off Time (min) = 433.9
Gross Application Depth (mm) = 401
Average Infiltration Time (min) = 426.0
Average Infiltration Depth (mm) = 66
Surface Runoff Depth (mm) = 335
Deep Percolation Depth (mm) = 1
Distribution Pattern Efficiency (percent) = 16.2

APPENDIX E:

Rice Basin Parameters.

Table 6-3 for Calculation of Rice Basin Parameters

TABLE 6-8 Suggested basin areas for different soil types and rates of water flow. (Taken from Booher, 1974.)

A. Area in hectares

Flow rate		Soil type: Sand	Sandy loam	Clay loam	Clay
Liters per second	Cubic meters per hour	Hectares			
30	108	0.02	0.06	0.12	0.2
60	216	0.04	0.12	0.24	0.4
90	324	0.06	0.18	0.36	0.6
120	432	0.08	0.24	0.48	0.8
150	540	0.10	0.30	0.60	1.0
180	648	0.12	0.36	0.72	1.2
210	756	0.14	0.42	0.84	1.4
240	864	0.16	0.48	0.96	1.6
270	972	0.18	0.54	1.08	1.8
300	1080	0.20	0.60	1.20	2.0

B. Area in acres

Flow rate		Soil type: Sand	Sandy loam	Clay loam	Clay
Cubic feet per second	U.S. gallons per minute	Acres			
1	450	0.05	0.15	0.3	0.5
2	900	0.10	0.30	0.6	1.0
3	1350	0.15	0.45	0.9	1.5
4	1800	0.20	0.60	1.2	2.0
5	2250	0.25	0.75	1.5	2.5
6	2700	0.30	0.90	1.8	3.0
7	3150	0.35	1.05	2.1	3.5
8	3600	0.40	1.20	2.4	4.0
9	4050	0.45	1.35	2.7	4.5
10	4500	0.50	1.50	3.0	5.0

APPENDIX F:

Irrigation Schedule.

Calculation of Mean Evapotranspiration (ETa) over Time

after Irrigation for Different Values of (ETm).

Table 1 . Irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Sorghum
soil : Fonde (silt loam)
Root depth: 1.50 m.
Total available soil moisture: 225 mm.

month	ETm mm/day	Deplition P	ETa after 8days	ETa after 10days	ETa after 12days	ETa after 14days	ETa after 16days	ETa after 20days	ETa after 24days	ETa after 30days
Jan										
Feb										
Mar										
Apr										
May										
Jun										
Jul	2	0.875	2	2	2	2	2	2	2	2
Aug	4	0.7	4	4	4	4	4	4	4	4
Sep	9	0.425	9	9	8.9	8.7	8.5	7.9	7.4	6.6
Oct	6	0.55	6	6	6	6	6	6	5.9	5.4
total	21	2.55	21	21	20.9	20.7	20.5	19.9	19.3	18
Nov	1	0.875	1	1	1	1	1	1	1	1
Dec	3	0.8	3	3	3	3	3	3	3	3
Jan	6	0.55	6	6	6	6	6	6	5.9	5.4
Feb	5	0.6	5	5	5	5	5	5	5	4.9
total	57	7.925	57	57	56.8	56.4	56	54.8	53.5	50.3

Table2. Irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Sorghum.
Soil : Dieri (loamy sand).
Rooth depth:1.50 m.
Total available soil moisture:90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 2days	ETa after 4days	ETa after 6days	ETa after 8days	ETa after 10days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	2.04	0.875	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04
FEB	3.98	0.7	3.98	3.98	3.98	3.98	3.98	3.80	3.60	3
MAR	8.28	0.45	8.28	8.28	8.00	7.8	7.6	4.6	4	3.3
APR	6.72	0.5	6.72	6.72	6.72	6.72	6.72	5.2	4.7	4.1
MAY	4.84	0.6	4.84	4.84	4.84	4.84	4.84	4.50	4.3	4
wet										
dry season	775.74		775.74	775.74	767.34	761.40	755.40	604.20	559.20	493.20
JUL	2.55	0.875	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
AUG	5.32	0.6	5.32	5.32	5.32	5.32	5.12	4.40	4.00	3.40
SEP	8.00	0.45	8	8	7.9	7.5	6.9	4.6	4	2.8
OCT	4.73	4.73	4.73	4.73	4.73	4.73	4.60	4.00	3.8	3.2
NOV	3.00	0.875	3.00	3.00	3.00	3.00	3.00	3.00	2.90	2.60
dry										
wet season	708.00		708.00	708.00	705.00	693.00	665.10	556.50	517.50	436.50

Table 31. Irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Wheat
Soil : Dieri (loamy sand).
Rooth depth:1.50 m.
Total available soil moisture: 90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 2days	ETa after 4days	ETa after 6days	ETa after 8days	ETa after 10days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	2.04	0.8	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04
FEB	4.24	0.6	4.24	4.24	4.24	4.24	4.24	3.80	3.50	3.00
MAR	8.64	0.375	8.64	8.64	8.50	8.10	7.50	5.1	4	2.8
APR	6.30	0.45	6.30	6.30	6.30	6.20	6.00	4.50	3.6	2.7
MAY	2.20	0.8	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
Season1:	702.60		702.60	702.60	698.40	683.40	659.40	529.20	460.20	382.20
JUL	2.55	0.875	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
AUG	5.32	0.6	5.32	5.32	5.32	5.32	5.32	5.32	5.12	4.80
SEP	8.40	0.375	8.4	8.4	8.4	8.2	7.8	6.2	5.4	4.2
OCT	4.10	0.7	4.10	4.10	4.10	4.10	4.10	4.00	3.80	3.40
NOV	1.20	0.8	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Season2:	647.10		647.10	647.10	647.10	641.10	629.10	578.10	542.10	484.50

Table 32. irrigation schedule.
Case of limited soil water
Calculation of mean actual ET over time after irrigation for different ETm.

Crop: Maize
Soil: Dieri (loamy sand).
Root depth: 1.50 m.
Total available soil moisture: 90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 2days	ETa after 4days	ETa after 6days	ETa after 8days	ETa after 10days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	2.55	0.8	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
FEB	4.51	0.6	4.51	4.51	4.51	4.51	4.51	4.30	4.00	3.40
MAR	8.64	0.45	8.64	8.6	8.5	8.1	7.8	6.8	6.3	5.5
APR	7.98	0.45	7.98	7.90	7.80	7.50	6.9	4.6	4	3.3
MAY	5.28	0.6	5.28	5.28	5.28	5.28	5.28	3.8	3.4	2.8
Season1:	868.80		868.80	866.40	859.20	838.20	811.20	661.50	607.50	526.50
JUL	2.55	0.7	2.55	2.55	2.55	2.55	2.55	2.55	2.30	1.90
AUG	5.32	0.6	5.32	5.32	5.32	5.10	5.00	3.4	2.9	2
SEP	8.40	0.45	8.40	8.2	7.9	7.5	6.4	5.7	3.7	2.8
OCT	5.04	0.55	5.04	5.04	5.04	5.04	5.04	5.00	4.70	4.40
NOV	3.30	0.7	3.30	3.30	3.30	3.30	3.30	2.40	2.00	1.40
Season2:	738.30		738.30	732.30	723.30	704.70	668.70	571.50	468.00	375.00

Table 33. irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Beans
Soil:Dieri (sandy loam).
Rooth depth:1.50 m.
Total available soil moisture: 90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 8days	ETa after 10days	ETa after 12days	ETa after 14days	ETa after 16days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	2.04	0.875	2.04	2.04	2.04	2.04	2.04	2.04	2.00	1.60
FEB	4.24	0.7	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24
MAR	8.64	0.45	7.46	7.26	7.06	6.8	6.6	6.2	5.6	5
APR	6.30	0.5	6.30	6.30	6.30	6.30	6.30	6.30	6.30	6.30
MAY	2.64	0.6	2.64	2.64	2.64	2.64	2.64	2.64	2.64	2.64
Season1:	715.80		680.40	674.40	668.40	660.60	654.60	642.60	623.40	593.40
JUL	2.55	0.7	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
AUG	5.32	0.5	5.32	5.32	5.32	5.32	5.32	5.22	4.8	4.2
SEP	8.40	0.375	8.4	8.2	8	7.8	7.6	7.2	6.8	6.2
OCT	4.10	0.45	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10
NOV	1.50	0.45	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Season2:	656.10		656.10	650.10	644.10	638.10	632.10	617.10	592.50	556.50

Table 34. irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Tomato
Soil: Dieri (loamy sand).
Rooth depth:1.50 m.
Total available soil moisture: 90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 8days	ETa after 10days	ETa after 12days	ETa after 14days	ETa after 16days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	2.55	0.575	2.55	2.55	2.55	2.55	2.55	2.55	2.55	2.55
FEB	4.24	0.475	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24
MAR	9.00	0.25	8.8	8.6	8.4	8.2	8	7.6	7.2	6.6
APR	7.98	0.275	7.78	7.58	7.38	7.18	7	6.6	6.2	5.6
MAY	5.72	0.35	5.72	5.72	5.62	5.32	5.12	4.8	4.4	3.8
Season1:	884.70		872.70	860.70	845.70	824.70	807.30	773.70	737.70	683.70
JUL	3.40	0.6	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
AUG	5.32	0.5	5.32	5.32	5.32	5.32	5.32	5	4.6	4
SEP	8.40	0.375	8.2	8.0	7.8	7.6	7.4	7	6.6	6
OCT	5.04	0.45	5.04	5.04	5.04	5.04	5.04	5.04	5.04	5.04
NOV	3.60	0.6	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60
Season2:	772.80		766.80	760.80	754.80	748.80	742.80	721.20	697.20	661.20

Table 35. irrigation schedule.
Case of limited soil water
Calculation of mean actuel ET over time after irrigation for different ETm.

Crop: Onion
Soil: Dieri (loamy sand).
Rooth depth:1.50 m.
Total available soil moisture: 90 mm.

Months	ETm (mm/day)	Deplition P	ETa after 8days	ETa after 10days	ETa after 12days	ETa after 14days	ETa after 16days	ETa after 20days	ETa after 24days	ETa after 30days
JAN	3.06	0.425	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
FEB	4.24	0.35	4.24	4.24	4.24	4.24	4.24	4.00	3.60	3.00
MAR	7.92	0.275	7.72	7.52	7.32	7.12	7.00	6.60	6.20	5.60
APR	7.56	0.28	7.32	7.12	6.80	6.60	6.40	6.00	5.40	4.80
MAY	7.48	0.23	7.28	7.08	6.90	6.70	6.50	6.10	5.80	5.20
Season1:	907.80		888.60	870.60	849.60	831.60	816.00	772.80	721.80	649.80
JUL	3.40	0.3	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
AUG	5.32	0.3	5.32	5.32	5.32	5.32	5.32	5	4.6	4
SEP	7.60	0.275	7.4	7.2	7	6.8	6.6	6.2	5.8	5.2
OCT	5.36	0.35	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36
NOV	4.50	0.3	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Season2:	785.40		779.40	773.40	767.40	761.40	755.40	733.80	709.80	673.80