OKACOM

Climate, Hydrology and Water Resources; Angolan Sector

Draft Translation

Specialist Report prepared by Fiesa Namibia for :

PERMANENT OKAVANGO RIVER BASIN COMMISSION

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*** *DRAFT TRANSLATION* ***

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1.1   Overall Description of the Basin

1.1.1   Geomorphology

The Cubango River starts in the Bié plateau, Angola's hydrographic centre, to the South of Vila Nova, at an altitude of 1800 m, and in its initial track, it runs North-South until Menongue, from where it heads Northwest-Southeast. Downstream Cuangar, its course evolves West-Eastwards and it continues to the Southern Angola/Namibian border until Mucusso, at a length of 975 Km, in the Angolan territory. In the territory of Namibia, the river is known as the Okavango river, its length does not exceed 55 Km. The river crosses the Caprivi strip in Caprivi Region as it enters the territory of Botswana, at a swampy area close to Ngami Lake, known as the Okavango Delta. Between its river and the Zambezi, there appears, still an unexplained mechanism, during flooding periods, the existance of a communication system through the Limyanti River, which, starts from Ngami Lake, and crosses the Botswana territory, towards the Zambezi.

Its basin in the Angolan territory covers between parallels 12° 20' South and 18° South (Figure 1.1) and between the meridians 16° East and 21°30' East, covering parts of Cuando Cubango, Huambo, Bié, Moxico, Cunene and Huíla Provinces. To the East it meets the Cuando River, the Zambeze River basin to the Northeast, the Cuanza River basin to the North and the Cunene to the West, including the drainage area not clearly defined and known as the Cuvelai Delta River.

In the Angolan territory the basin covers an area of 148 860 Sq. Km, of which 60 860 belongs to the basin of its main tributary, the Cuito River.

The basin is elongated (Figure 1.2) and its axis is greater in the direction Northwest-Southeast, and it is extended to the North, evolving itself in its almost entirety, at the left margin of the river. The right side area of the basin to the North and South reaches up to 40 Km wide, but it is narrow at the central area, and at times it decreases into a small strip, which in many areas, it reaches below 10 Km wide.

1.1.2   Orography

Orographically (Figure 1.3), it has to be considered at the Northwest side of the basin, North of the parallel that crosses the village of Chitembo, an uneven area with altitude higher than 1500 metres and increasing to the Northeast reaching heights of 1800metrs. . From this area, which include the counter act of heights which preceed the western strip of the Angolan highlands, altitudes decrease towards the South as well as Eastwards, although in that direction, the decrease is slight and is not lower than 1400 m. From the 1400 m curve, altitudes decrease rapidly to the South as far as 1200 m and this marks the transition to the plain area that covers the meridional part of the basin with altitudes higher than 1000 m, although this decreases slightly to the South.

This description shows that from the orographical point of view, the basin could be divided into four areas:

Figure 1.1 : Location of the Cubango River Basin

Figure 1.2 : Cubango River Basin

Figure 1.3 : Orography of the Cubango River Basin

Figure 1.4 : Geology of the Cubango River Basin

I   An uneven area with altitudes between 1500 m and 1800 m, covering the whole of the Northwest of the basin ;

II   The Northwestern region's relief is generally rippled, with altitudes higher than 1400 m, but not exceeding 1500 m of altitude, except on small and isolated nucleuses;

III   Transitional area, inclined Westwards with altitudes decreasing from 1400 m to 1200 m;

IV   The South of the basin is a plain area with a slightly uneven terrain and, although somehow steep Southwards, its altitudes are always higher than 1000 m.

1.1.3 Geological Features

The geological design of Figure 1.4, the three largest rock groups can be observed at the basin. The eruptive and metamorphic rocks confined to the relief region especially at the Northwest side of the basin, and the sedimentary rocks at the plained areas of the Northeast and South which constitute the rest of the basin.

Eruptive rocks cover part of that Northeastern region, and are represented by:

Ante-permian formations, include generally, granites, porphyries and porphyritic and, to Northwest of Cavango (Artur Paiva), one of the small types of syenites;

Undated ante-cambric formations, made up of granites, and granodiorites and quartzodiorites and, in Cubango region (Artur de Paiva), a small sport of dolerites.

Metamorphic rocks form near the Northwest of the basin, where these are represented by formations of the Base Complex, made up of gneisses of different kinds, metamorphic schists, quartzites, quartzite schists and crystalline calcareous. On the metamorphic formations of the Upper Group of Oendolongo System scattered spots of eruptive rocks emerge, consisting of rocks of a weak metamorphism, namely ferruginous quartzites (of "banded-ironstone" type - *itabiritos*), quartzites and sandstones, which are crossed by felsites and porphyry dikes.

Sedimentary formations, which cover most of the basin area, certainly constitute its most striking feature, resulting in inevitable consequences in the water course regime as well as in the economic potential.

These are Upper Kalahari formations of Pleistocene, or even recent and essentially sandy, with some gravel levels and laterite deposits, resting on "polymorph sandstones", quartzites, sandstones and *millicified* calcareous of the lower Kalahari.

Still unknown are the mineral potential of the region. Rare occurrences are located at the older formations, but no signs of any Kalahari, or recent formations, which cover most of the Cubango basin, were identified.

Cupriferous impregnations of Menongue area can be identified which, under the current circumstances, neither correspond to a real economically exploring copper deposit, nor to the existence of manganese in Bela Vista region. This appears to be as a result of the laterite process, although there are no elements which allows us to ascertain its importance.

It has also been observed throughout Southern Angola the existence of alluvial gold, most of which has already been explored, although not always under profitable technical and financial conditions.

1.2   Climate and Superficial Water Resources

1.2   Climate

1.2.1   Overall Features of the Basin's Climate

The three most important climatic factors in the region are the altitude, the influence of the centre for dispersing the Kalahari desert dry winds, and the latitude, all of them pushing in the same direction, this is decreasing the latitude and increasing the altitude thus pushing it away from that dry area. As a result of the activities of these factors, there forms in the region a climatic differentiation characterised by an increase, from South to North in the humidity and rainfall.

In Figures 1.5 and 1.6, Tornthwaite's climatic classification is shown, and in Figure 1.5 shows the region divided according to the hydric index, and Figure 1.6, shows the region divided according to the thermic efficiency index.

Based on the referred classification, the Northern and Southern extremes can be located into two climatic zones which can be clearly identified as different:

I   The Septentrional extreme is comprised of higher altitude areas with annual rainfalls ranging between 1100 mm and 1300 mm, (Figure 1.7) of mesothermic and humid climate with diversified degrees determined by altitude variations;

II   And the Meridional extreme, to the South of a line which, generally, can be identified through parallel 17° South, including lower altitude areas and subjected mostly to the Kalahari desert influence. This area has an average annual rainfall ranging between 550 mm and 700 mm of megathermic climate, or closer, and of semi-arid features;

III   Marking the transition between these two extreme zones is the central area of the basin, with intermediate climatic characteristics, average annual rainfall ranging between 900 mm and 1100 mm, mesothermic climate, from sub-humid-humid to sub-humid-dry.

Having done this synthesised description of the basin's climate, a separate and detailed analysis of some climatic features, such as rainfall, evaporation, temperature, humidity and winds will be given.

Figure 1.5 : Climatic Classification of the Cubango River Basin (Wetness Index)

Figure 1.6 : Climatic Classification of the Cubango River Basin (Thermal Efficiency)

1.2.2   Rainfall

Rainfall will be studied separately, but three important features on how the rainfalls occur within the basin will now be indicated. The annual rainfalls (Figure 1.8) increase from the South, to an average 600 mm and to the North, they have an average of 1300 mm. Concerning the annual distribution, rainfalls are predominant in the rainy season covering October to March or April, and an absence of rains throughout the dry season, which includes the months of May through to August. April or May and September are usually transitional months. Usually, rainfall takes the form of showers, which may reach high intensities. The feature has important consequences, either from the erosion point of view or with regard to the rains/discharges.

1.2.3   Evaporation

The free area evaporation records are very scattered and insufficient. However, it was possible to identify average figures which indicate an annual evaporation of around 1900 mm at the Septentrional zone of the basin increasing to the South up to close to 2000 mm at the meridional region. The months with greater evaporation are those pertaining to the end of drought, and the lower evaporation month is February, during the peak of the rain season.

In three localities of the basin, it was possible to identify average records of evaporation and of potential evaporation-transpiration, calculated both through Thornthwaite and Penman methods, as follows:

Pan Evaporation (mm)

Meteorologic Centre	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	97	88	91	106	141	157	189	251	294	250	142	118	1924	53/67
Cuito Cuanavale	117	101	109	124	158	164	181	243	295	246	147	126	2011	51/67
Mavinga	131	95	139	174	200	183	199	266	360	319	179	139	2384	53.65
Cuangar	208	174	177	211	262	265	284	404	411	414	329	265	3404	55/67

Evaporation-Transpiration Calculated Potential (mm) (Thornthwaite)

Meteorologic Centre	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	100	86	93	77	55	37	37	54	81	111	103	103	937	51/70
Cuito Cuanavale	96	84	90	77	56	40	42	55	89	109	100	103	941	51/70
Mavinga	112	95	100	81	53	34	34	51	86	118	111	113	988	53/70
Cuangar	122	103	105	90	58	31	31	48	83	125	125	133	1054	55/67

Calculated Potential Evaporation-Transpiration (Penman)

Meteorologic Post	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue		161	138	147	134	115	93	101	130	156	182	165	165	1687 53/65
Mavinga		177	156	162	145	117	94	101	130	168	199	178	181	1808 54/65

Figure 1.7 : Mean Annual Precipitation over the Cubango River Basin

1.2.4 Temperature

The annual average figures for daily temperatures, range throughout the region at an average of 20° celcius, and a slight increase from North to South, not beyond four degrees celcius, can be observed, as per isothermic map of Figure 1.9. The temperature variations throughout the year have a weak amplitude and reach as high as 22°-24°C, of the monthly averages of daily temperatures, during October and January, during the rain season, and as low as 15°-17°C, during June, July and August, of the driest season of the year.

The daily maximum temperatures reaches 30°-32° C during the months of October through January and the minimum reaching 3° to 8° C in June, July and August. The daily fluctuations of temperature can be observed, and between the monthly average figures of temperature, maximum and minimum daily differentials reaching maximum figures the amount to 20° C during the colder season of the year as well as minimum figures ranging 12°C during the months of January, February and March.

1.2.5 Humidity

There is no record which allows for detailed characterization of the basin related to relative humidity. However, figures available give an idea, although a merely qualitative one, of the variations in space and time of this climatic feature.

As a result of the altitude and distance of the maritime influence, the monthly average figures of relative humidity are varying throughtout the year, and the amplitudes of this annual variation range 40% in the whole of the basin. The maximum figures are observed during rain season (February or March) and the minimum figures are seen during dry season (July or August). With respect to the space variation, a North-South decrease of the annual average figures is obvious, reaching around 60% in the North and 50% in the South.

As a result of the daily variations in temperatures, with influence in the degree of saturation of the air in the atmosphere, fluctuation in the relative humidity during the day are great, reaching maximum figures during less hot hours of the day. The amplitude in the daily variation can be estimated at 15 or 20%. The decrease in the degree of air saturation during hotter hours, added to the disturbance in the atmosphere caused by daily variations in the temperature, contribute to the evaporation that reach considerable figures in this area.

Relative Average Humidity at 09 hours (%)

Meteorologic Post	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year	Period
Menongue	75	76	78	71	64	59	55	44	38	48	67	71	62	51/70
Cuito Cuanavale	79	76	79	71	67	66	71	64	60	65	71	76	70	51/70
Mavinga	71	73	70	58	44	40	37	30	27	37	60	68	51	53/70
Cuangar	69	69	69	60	54	41	45	41	27	33	49	63	52	55/67

Figure 1.8 : Mean Annual Temperatures in the Cubango River Basin

1.2.6   Wind

There is very little record on the wind's intensity and direction in the region. In a very general characterisation, it could be said that in the interior regions of Angola, where the whole of the Cubango basin is located, the winds are usually weak and prevalence of winds from the Eastern quadrant directions.

Sometimes there are quick strong blasts of winds reaching up to 100 km/h of speed, of varying direction and usually linked to such phenomenas of atmosphere instability such as showers and thundershowers.

For the two localities of the basin it was possible to find average records of winds at 2 m above the ground, which records are indicated as follows:

Meteorologic Post	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year Period
Menongue	3,63,3	2,8	2,8	2,9	3,1	3,6	3,9	4,3	4,2	4,1	3,8	3,5	53/65
Mavinga	4,7	4,7	4,2	4,3	4,0	4,1	4,4	4,8	5,9	5,9	5,0	4,9	4,7	54/65

1.3   Hydrology and Surface Hydraulics

1.3.1   General

The following is a simple summary of the material discussed in Volume 3 - Hydrological Study of the Overall Scheme of Hydraulic Development of the Cubango River (1973). The most striking aspects which characterize the Cubango Basin Hydrology are underlined. It was not possible to consult the referred Book, which is crucial for a complete clarification and addressing of these issues, because no copy of this report appears to be available in Angola.

1.3.2   Rainfall

After a number of analyses, the study has adopted the period of 12 months as the hydrological year starting on October 1.

The pluviometric network of the basin could not be considered for a judicious study of the rainfall. In reality, only in the Northern and Northwestern parts there is a sufficient number of centres, and these become rare towards the South and East making it difficult to have an idea of the distribution of the rains at this area.

Records were obtained regarding the annual rainfall as from 1943/44, but only after 50/51 their utilization was considered advisable, because they became increased. It should however be pointed out that the last years of the period are again have no data, which has made the analysis difficult, mainly with regard to the possible relationships between rains and drainage.

The annual rainfall study was carried out based on the isothyetal method, which has allowed for two sections considered to be typical, namely Cubango, at the border, and Cuito at the junction with Cubango, to obtain over 20 years the annual rainfall figures.

Although considered to be of problematic reliability, a statistical study of these rainfalls were undertaken, having concluded that, for the Cubango, the full average annual rainfall was 953 mm, while for Cuito it was 839 mm. Certain discrepancies were registered as far as coincidence of humid, medium and dry years is concerned between the two basins, which could be justified partly by the degree of proximity with which the isohals were drawn, due to shortage of records in most of the basin.

The study on the progress of rainfall throughout the year has shown the normal distribution in these regions - dry season, with absence of rainfalls from May until September, humid season from October until April, being April, May, September and October the transitional months. As a feature, there is a dry period during rainy season, usually in February. The drought period is more prolonged Southwards.

Rainfalls usually occur in the form of strong and localized showers accompanied by thundershowers.

1.3.3   Discharges and Drainage

Hydrometric occupation of the Cubango basin could be considered as reasonable, taking into account that this is an inhospitable region and due to transport difficulties. 18 of the 28 centres established measured discharges and, although the network was recent, they enabled a very approximate study of the drainage, and subsequent definition of a number of features of the water course regime that runs through the basin.

At the time, the Republic of South Africa also undertook discharge measurements in a segment of the international strip they occupied, where their records dated back 25 years; but unfortunately, due to indications by the South African authorities, these figures cannot be considered reliable. Concerning the National network, despite previous irregular records, only from 65/66 did their systematic measuring start. Figure 1.10 gives an idea of the basin's current hydrometric network.

The annual drainage study was conducted separately for Cubango and Cuito, due to different regimes of these two rivers. Having obtained some missing drainage, by correlation, it was possible to fill in Table 1.1 where the overall and specified annual drainage figures are summarised.

Regarding Cubango, it is immediately observed that the most humid year of the period was 67/68, being 66/67 the driest. Specific drainage study enables, for each year, to underlie a variation law with the draining basin, thus leading to the knowledge of the annual drainage at any point of the river.

These figures increase generally to the Cuatir mouth and decreases downstream afterwards, due to the considerable losses in the larger waterbed and muddy areas and due to lack of intermediate contribution during almost the entire year, since that section until the Cuito junction.

Regarding Cuito, the drainage is basically independent from the period years, having been able to conclude the degree of regularity of the drainage and self-regularization of the basin, which

Figure 1.9 : Hydrometric Gauging Network of the Cubango River Basin

could go even beyond the annual, which fact is not to be admired, considering its geological nature and the physiography of the river and its tributaries.

The quantitative study of the drainage for Cubango was conducted with the support of the figures supplied by South Africa for Rundu section. Even though these are not considered as entirely worth of reliability, they exist for a considerably long period, so that they allow a statistic study which, at least, characterizes the years in which there are records during the national seasons. Therefore, having admitted the probability of occurrence indicated by study at Rundu section, it was possible to define the drainage of the medium, dry year and critical period at any point of the basin, also making use of the specific drainage variation laws mentioned previously.

Table 1.1

Overall and Specified Annual Drainage

Draining Area Km2	1962 / 1963		1963 / 1964		1964 / 1965		1965 / 1966		1966 / 1967		1967 / 1968		1968 / 1969	
	Annual drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specified Drainage hm3/km2	Annual Drainage hm3	Specif Drainage hm3/k...
1799			670.0	0.372	853.0	0.474	569.0	0.316	415.0	0.231	1.083.1	0.602	828.9	0.
7185			1.838.0	0.242	2.056.0	0.271	1.533.0	0.202	914.0	0.127	2.502.0	0.348	2.212.6	0.
38486			5.024.0	0.131	6.159.0	0.16	4.801.0	0.125	2.422.0	0.063	8.105.2	0.211	6.912.1	0.
50135			4.892.0	0.098	7.101.0	0.142	6.461.0	0.129	3.130.0	0.062	9.236.1	0.184	7.382.5	0.
68357							5.984.0	0.088	3.487.0	0.051	9.681.5	0.142	7.715.3	0.
92250	98993	0.107	5. 383.6	0.058	6.951.2	0.075	6.394.0	0.069	3.785.6	0.041	9.612.9	0.104	7.789.3	0.
93475			4.680.0	0.050	5.858.0	0.063	5.493.0	0.059	3.268.0	0.035	9.606.3	0.103	7.547.6	0.
3683			858.0	0.233	850.0	0.231	793.0	0.215	395.0	0.106	1.332.7	0.362	1.211.7	0.
9214			1.822.0	0.198	1.926.0	0.209	2.045.0	0.222	676.0	0.073			2.471.4	0.
5839									424.0	0.073				
976					65.0	0.067	53.0	0.054	36.0	0.037			86.2	0.
4295			777.0	0.181	676.0	0.157	649.0	0.151	584.0	0.136	99.2	0.102	728.2	0.
9758					724.0	0.074	732.0	0.075	647.0	0.066	827.6	0.193	1.037.4	0.
							72.0	0.135	69.0	0.129				
1122					128.0	0.114	120.0	0.107	128.0	0.114				
1769							254.0	0.144	248.0	0.14				
15193							2.810.0	0.185	2.607.0	0.172				
22198									3.344.0	0.151				
25351			3.836.0	0.151	3.982.0	0.157	4.201.0	0.166	3.972.0	0.157				

Indeed, having observed that the period 63/70 had medium features, it was considered an average year, which would correspond to the average of this period's drainage.

Concerning the dry year, the study has shown that 66/67 could be considered as representative of the average of the most unfavourable dry period, 56/60.

According to this reasoning, Cubango's average annual drainage in the junction with Cuito would be 6 200.106 m3, while the average of the dry year would range half of this figure.

For Cuito, the task was made difficult by lack study elements as well as by the impossibility of correlations with Cubango. The approximate study conducted enables to us to state that the Cuito drainage, although subjected to future confirmation, will not vary yearly and it will be slightly lower than the figure of the Cubango drainage average of the same section. Under these conditions, the annual average drainage of the whole basin in Mucusso, would be 11 200 106 m3.

In Cubango, the running time of the drainage was studied from the characteristic discharges of Caiundo to the Cuatir Mouth and from there to Zâmbio. It could be concluded that, between the first two sections, the running time is basically independent from the discharge and it is close to 4 to 5 days (50 km a day), while between Cuatir Mouth and Sâmbio, time increases with the decrease in discharge and varies between 4 to 10 days (75 to 30 km a day). In Cuito, the study was made difficult by the absence of records of small variations of discharge, but a 70 km a day speed could be evaluated. The drainage progress throughout Cubango was evaluated by comparing Artur de Paiva (Cuvango) and Sâmbio monthly drainage for the year 66/67, as the driest of the period. It was concluded that drainage always increases from Artur de Paiva to Cuatir Mouth, as a result of the permanent contribution of the intermediate attributes and waterbed physiography, but from here to Sambio this increase only exists during drought, as during humid season there is always a monthly decrease. This was as result of the spillover for the margins of the waterbed which recover the volumes to the river during drought increasing subsequently, the discharges downstream. However, there is a corresponding annual loss to evaporation and to infiltration. Most of the year, at this strip, there is no intermediate contribution.

In Cuito, despite the shortage of figures, it can be concluded that the phenomenon is similar to the international segment of Cubango with a drainage decrease downstream during flooding and a drainage increase during drought.

The maximum discharges for Cubango were analysed based on the Rundu records which, despite their small degree of reliability, are preferable to application of empirical formulae. The statistic study carried out through Gumbel method, led to 929, 1394 and 1850 m3/s for a period of decade, century and millennium, respectively. Thus relatively lower figures are observed, in the face of the draining basin area. As for definition of the floods in various sections of the river, it was possible to obtain a variation law of the specific discharge of flooding; if we are to admit the acceptable hypothesis that the figures of floods in Rundu are the same as those of Sâmbio and that the law would be applicable for floods of any magnitude, maximum discharges can be collected at any point for a given probability of occurrence. A five hundred years flooding would look like this:

Cuito Cuanavale Caiundo   Mucundi Cuatir Mouth   Sâmbio
        770   2.000   2.050   2.250   1.750

In m3/m the variation is easily explained by the physiography of the bedstead and existence of intermediate tributaries. In Cuito, it was impossible to carry out any similar reasoning and, due to uncertainty in the application of the empirical formulae, it was opted out not to go beyond a quantitative analysis, according which it could be concluded that the ends will surely be lower that those of Cubango for the same area of the draining basin.

Later on, Q. Góis *in* "O Regime de Cheias do Rio Cubango" undertook a study based on the statistical characterization of the floods through data available for Rundu, and the existing hydrometric records for the different seasons throughout Cubango River allow to determine the correlation between the basin specific discharges for various sections of the river and to characterize the regime of floods at any point.

The following table shows the century and millennium discharges, for various sections, collected through the use of correlation diagrams of the study.

Flood Frequency Analysis
Station Sâmbio Cuatir Mouth Mucundi Caiundo Menongue Chinhama

Station	Sâmbio	Cuatir Mouth	Mucundi	Caiundo	Menongue	Chinhama
1 in 100 year	2200	2520	2820	2460	950	280
1 in 1000 year	3000	3400	3800	3400	1300	390

The main conclusion to be drawn from the table and the study is the strong influence that the basin physiography has on the river bedstead, apart from the influence of rainfall distribution. As it can be observed, the flooding discharges of more downstream sections are much smaller than those upstream although the draining areas are vast, as the flood discharges decrease rapidly from Mucunde downstream. This phenomenon is explained by the regulatory effect of the surrounding waterbeds of floods.

Insofar as the minimum drought discharges are concerned, there was no further observation, but that of the existing records, with certainty that the year 66/67 has features of a great deal of dryness.

The comparison of the minimum discharges of the drought has indicated, once again, that the big difference between the Cuito and Cubango records, close to 4 times better in the former, and so are the records of transition observed in the basin rivers with mixed geological features. The minimum discharges of Cubango range 25m3/s, while Cubango are 100 m3/s, although the draining basin has a smaller area. The occurrence of minimum discharges is general during October, which confirms the existence of a prolonged drought.

1.3.4   Consistent Discharges

Besides a simple local observation there are no records of consistent transportation at the basin. The visual observation indicates, however, that while in Cubango River the widespread erosion is processed mainly in the upper area and concentrated during rains, at Cuito River the erosion is of a permanent nature the year through, which is translated into a constant instability of the bedstead given the erosion of the limit-lines. Bottom transport at Cuito River will as result be higher than that of Cubango.

2   Current Utilization of Water Resources

2.1   General

The region that consists of the Cubango River basin is one of the most unknown and least populated in Angola. In addition it should be stated that this very region is one of the most stricken by the past 22 year-war.

It is thus understood that the range of activities to be carried out in the light of the development of water resources is indeed small.

2.2   Irrigation

Until 1975 this activity was mostly private, and carried out through execution of small-size works of derivation to irrigation of some hectares of land to cultivate citrus and vegetables for local consumption. This activity was mostly focussed on the Northwest part of the basin. Other official activities were conducted in the right margin of Cuebe around 20 km South of Menongue.

2.3   Electricity

Until 1975 there were only two development projects, which were basically finalized, one in Menongue, in Cuebe River and with generators 1000 kW making use of a 6.70 m fall and this was the one which supply power to the Province's capital. Another development project was implemented in Cuvango with 560 kW, with the use of a 3,4 m3/s discharge and a 19,40 m fall which also supplied power to that settlement. Any development is based on trickles of water.

Moreover, there was only very little private initiative enterprise development at the basin. Like today, in all other settlements the supply to the various population centres was carried out by local diesel plants.

2.4   Water Supply

The uniformity of the hydrographic network, coupled with the good water quality, the prevailing drainage and the closeness of the population to the bedsteads of the water courses allow the relatively easy supply to all population centres.

Usually, this supply is undertaken through the water course pumping to a deposit and through a more or less complex distribution based on the beneficiary populations.

Currently, over 80% of the cost of water to the private consumer is Government subsidised.

3.   Future Utilization of Cubango Water Resources

3.1   General

During the 60's a study was carried out aimed at solving the commitment between water availability and needs, through a development programme of this basin's water resources.

Despite eventual limitations of the study and eventual differences between the current post-war situation, concerning the existing environment at the time of the study, the study is a very important document for assessing the potential and include an integrated development of the Cubango Basin in the future, in particular, and throughout Southern Angola, in general.

3.2   Development Scheme

The aim of the proposed scheme is more focussed on gaining global potential rather than determining a short-term development for immediate benefits, given the difficulty in defining in concrete terms the goals to be achieved.

Thus, hydroelectric and hydro-agricultural issues top the concerns of the scheme.

Although the region enjoys great cattle-raising potential, because this activity does not consume a big amounts of water, it would receive lesser attention than other issues. For this reason, the issue was not addressed in this paper.

Navigation, given the fact that the impact of the implementation of the scheme would be the improvement of navigation facilities, because it would have as a direct result the decrease in floods and an increase in the minimum discharges introduced by the regulatory basin.

Taking into consideration the characterization made to the basin, four major spots were identified, and these will guide and condition the implementation of a hydraulic development scheme (Figure 3.1). These spots are as follows:

Area 1

It is comprised of basins of all mouths and from Cubango to the North of parallel 17°. In the face of existing topographic and rainfall conditions it is in this region where the best regulatory development of discharges and power generators will be established. Hydro-agricultural developments to be implemented in this region will be of small-scale nature, and meaningless to the study.

Area 2

This comprises the valley of Cubango main course and has no topographic conditions favourable to the establishment of major storage units, but cover the marginal fields better suitable for watering (36 650 ha). Agricultural development, using regulated discharges upstream would be the predominant feature of this region.

Area 3

This is comprised of Cuito basin's upper course and its mouths, also to the North of parallel 17°. Physiographic conditions are not suitable for establishment of storage units, nor are there fall heights which justify an attempt for hydroelectric production. Hydraulic development of this area should be limited to small pump watering or elementary derivations.

Area 4

This area is similar to Area 2, as it consists of a lower valley of Cuito in which marginal spots of good soils (17 790 ha) call for development by irrigation. However, conditions are not suitable for establishment of storage or derivation dams, and the resort to pumping should be a more advisable solution. Moreover, self-regulation of the Cuito discharges makes of this an easier option.

3.3   Identified Sites for Development

Topographic and geological conditions of the sites played a critical role for the installation of the storage capacity of various developments. Moreover, there was logically concern over adapting the storage system to power generation and irrigation needs.

Overall, both power generation and irrigation require discharges as regulated as possible, being the former subjected to the demands of power consumption and the latter to the periods of increasing demands for agriculture.

Analysing the basin as a whole and necessary care with the considerations made regarding its characterization, it was decided that trickle of water developments be established whenever there were no local conditions for storage in the region, in which observed the existence of a series of natural discharges close to the latitude 14° 30' (Local 3, 10 and 16).

For trickle of water developments, the volume to be provided to the lagoon will be minimum corresponding to daily regulation or, weekly. The upstream of these would have sought to establish drought compensation storage units, or inter-annual, in accordance with the availabilities, in order to make these trickles of water valuable.

To assess the capacity of the storage units, non-dimensional curves of mouth volumes were drawn. For each figure of the relationship discharge/average discharge, the mouth volume and corresponding compensation was determined and divided by the total mouth total volume. These curves allowed to determine, knowing the average or dry mouth annual volume, what volume of compensation is necessary for various levels of discharges for permanent assurance. Thus, it can be concluded that the medium year overall regulation is collected with an equal storage of 0,353 of the volume of the annual average drainage, while to fully regulate the dry year that figure is 0,293.

Therefore, the regulation criterion corresponding to a summery of average year would be to provide a capacity of close to 0,45 of the respective annual drainage, leaving a 0,10 margin of this volume for drought lengthening.

It is obvious that this capacity will be enough for regulation, during the dry year, as the factor for this year is lower as it was indicated in the previous paragraph.

In terms of inter-annual regulation the referred critical period had to be taken into account (average year followed by 4 dry periods) and then the necessary capacity will be 2,7, the annual average volume. In fact, being the dry year drainage close to 43% of the average year (V) onto the average year deficit (0,353 V), the quadruple of the difference between the average and dry year had to be added (4x0,57 V) plus almost 0,10 V to attend to a likely drought lengthening.

This figure is slightly higher than the traditionally considered as being enough for an full regulation, but it derives from the consideration of a critical period intrinsically linked to a very unfavourable natural sequence, which may repeat itself in the future.

The factor of regulation referred to are linked to the establishment of the useful volume of the lagoons. However, the total volume is also function of the systematic transport which will be deposited and which will allow the setting up of the portion for water intake. In the absence of any records regarding the river's natural systematic transport, and considering the geological structure of the terrains of the Cubango basin, it was opted out for the figure of 100 m3 / Km2 per year, for a 75 year-period of the development.

For purposes of evaporation the of calculation 1000 mm and 2000 mm figures were adopted as annual evaporation for the Northern and Southern of the basin, respectively which, after being applied to the corresponding area to the centre of gravity of the reservoir useful volume, provided the lost drainage. With regard to the trickles of water development activity, there were no losses caused by evaporation.

3.4.3   Electricity

Estimates of intervening factors were considered to determine the power production of the development. Thus, the average power was calculated through the formula $P = 8.Q.H$ kW whereby Q stands for the discharge measured in m3/s and H means the fall measured in metres.

Concerning the fall, the difference between the return portion and the centre of gravity of the useful volume or water intake as it dealt with regulation or trickles of water development activity, respectively. Therefore, the power equivalent, this is, the electricity generated by a cubic metre, falling from 1 m height per second will be as follows:

Ee = 0,00222 k Wh.m-3 m-1 S-1

Global production of the scheme was assessed at two stages. First, the average year production was determined based on the regulated discharge by the lagoons fully developed in the falls of stages downstream added to that, in trickles of water, could be compensated with the existent surplus storage units apart from intrinsic needs of the annual regulation. At a second stage, power generation during dry year was observed and what is the effectively ensured power by the system.

3.4.4   Powers to be established

In establishing the powers to be set up in the various centrals, a top utilization of 4 500 h/year was admitted.

3.4.5   Irrigation

There was shortage of a number of topographic, agronomic, pedologic figures, etc, capable of sustaining thoroughly the dimensioning and characterisation of watering developments.

It was therefore, considered as sufficient to set up a figure for irrigation annual average portion, to select the spots which by its continuity and suitability features are more appropriate to be developed and to assess the compatibility between the available drainage and needs, as an informative figure for assessment in the international segment after Cubango leaving Angola. Apart from this figure, a critical discharge was also established which enables to verify whether the minimum regulated discharges are capable of meeting the needs.

For the watering portion, a 15.000 m3/ha yearly figure was set up and 1,2 1/s.ha for critical discharges. The criteria are similar to those adopted in the Cunene Scheme.

3.5   Proposed Scheme

3.5.1   Overall Considerations

Based on the predicted conception for the development of the Cubango basin water resources, a discussion for each recognised sites took place and the basic criteria of study was put in place, and conditions have been created for the proposal of the development scheme.

Before its specific description is made, a few general issues pertaining essentially to the reasons leading to the abandonment of some recognised sites and specific questions related to the hydro-agricultural development as well as problems concerning the basin's international nature, more particularly aspects related to the segment with which Cubango borders Angola, will be discussed in this document.

The simultaneous observation of the criteria referred to earlier, the annual average drainage in each of the recognised sites and the curves of storing volumes which corresponded to it, led to the conclusion that it was not possible to regulate inter-annually the Cubango discharges. Moreover, the establishment of lagoons which allow a complete inter-annual regulation will usually only be justified when there are privileged sites where benefits are obtained at the expense of carrying out relatively cheap work.

Besides, it appears as if it is confirmed that hydro-power production based on trickle of water development combined with large lagoons of inter-annual regulation will not be a more economically feasible solution. The price by which usually the guarantee is obtained will have to be pondered with alternative solutions of compensation, more adaptable to the progress in the consumption. It is worth pointing out that in a sequence of years, which may be long, where the calculated critical period is not observed, all investment aimed at covering the dry period has become unproductive.

We believe that in the eve of inter-linkage of Angola's networks, considering the length in the establishing thermic central production and the existence of the fluid fuels in the territory are sufficient arguments for support the refusal of the inter-annual regulation unless there advantageous sites for such purpose.

Of all the recognised sites only three (Mumba, Malobas and Mucundi) offered few conditions for major storage. Then followed the criteria of providing to the rest of the sites sufficient capacity to regulate the average year, except pure falls. In those three, capacity was built based on the existing topographic conditions. Additional volumes collected there will operate as partial compensation of the system in dry year, regulating, as much as possible, the discharges downstream. Ensuring an average annual discharge of average year, automatically the dry year average annual discharge will be secured; clearly nothing will be said that, concerning electricity, the average year's discharge will be the long term guarantee.

Having the sites been selected with natural fall, an average year regulation was obtained in the sites upstream and this goal was achieved without making provisions for a dam in all sites. Therefore, sites providing for better conditions were chosen. As mentioned, three of the sites have an excess capability regarding average year's intrinsic needs - Mumba, Malobas

and Mucundi. The first one offer both topographically and geologically good conditions for that purpose and will ensure, by itself, compensation of the trickles of water in Muculungungo.

The second includes the more favourable sites of the scheme in which the natural discharge to the storage in an impressive fashion, and finally in Mucundi where, in terms of storage volume, the conditions offered are better, it will all depend on the excessive capacity provided to cope with the floods, which will later benefit, considerably agricultural development of the valley downstream.

With regards to soils suitable for watering and those to be developed for such a purpose, located along the international segment, there are plans for one dam, the Mbambi, whose final purpose will be, apart from a additional regulation and coping with floods, a major production centre of power for watering. This development could be subject to a joint study, between Portugal and South Africa, firstly because its direct junction is at that territory and secondly, because like the Angolan territory, there are also irrigation spots, which could benefit from these works.

Concerning watering of suitable soils, the scheme will necessarily elevation, through a dam, of regulated discharges with power generated from the upstream development and the launching into canals that dominate watering perimeters.

In fact, through recon that was carried out, only in Mbambi could it be implemented under good conditions, to establish a dam capable of predominating, by gravity, of those soils. But the spot with enough continuity is located so far away that the construction of a dead pipeline canal would be highly expensive. Even if all suitable soils were to be developed in future, it was preferable for specific purposes of the present scheme to consider only the blocs which possess sufficient continuity and which should start in sites where the highest margin is close to the lower waterbed, making pumping easier. Therefore, four blocs in Cubango and one in Cuito were selected.

Therefore, the proposed scheme consists of ten hydro-power development (three trickle of water and seven storage) and five hydro-agricultural (Figure 3.2)

Six sites were set off. In Cutato, Chimue site, by its unfavourable topographic and geologic conditions, and because desired regulation was successful downstream. Similar reasons topped the elimination of Catangua, Dala, Camué and Masseu sites at Cuchi and Cacuchi. Regarding Chumbua, at Cuelei, topography and geology were also unfavourable, although profitable discharge is estimated at 30 metres, available drainage was still small and, in terms of power generation, had no dimension, compared with others pertaining to the scheme.

Finally, Capango, at Cuatir, was not considered as of any interest due to unfavourable geologic conditions of the foundations, to non-existence of natural discharge, which would offer appreciative power generation, and due to the fact that it contributed too little to Cubango drainage.

Figure 3.1 : General Layout of Development Schemes in the Cubango River Basin

3.6   Individual Description of each Development

3.6.1   Development of Cuvango (No. 1)

Development of Cuvango is the first one considered along the main course of the Cubango, and it is aimed at regulating the discharges to be affected by the turbines in the falls close to Cavango, together with Chazenga, which is more downstream (Development of Mangonga).

The site's geographical situation and its geologic features led to the adoption of a structure and gravity profile of bitumen with an integrated hydraulic circuit, leading to a standing power unit.

Th draining basin has a site of 2 452 Sq. Km which is equivalent to an average annual drainage of 870 hm3.

The Figure 3.3 shows the feature of the development which are summarized as follows:

Maximum height	26 m
Coronation Portion	1 553 m
NPA Portion	1 550 m
Completion of Coronation	700 m
NPA Flooded Surface	51 Sq. Km
Useful Volume	393 hm3
Average bruto Fall	16 m

The hydraulic circuit is located on the right side of the dam's area. With 7 MW capacity, the plant restores 1 537 m of discharges to the portion. The average annual power output is 29,8 GWh.

Flooding discharges will be discharged over the dam through an uncontrolled exhaust attached to a waste basin on the base.

Figure 3.2 : Cavango Scheme

3.6.2   Development Chazenga (No. 2)

The development of Chazenga is the following stage of Cubango and as it has been stated, it is aimed at regulating the drainage which are not dominated by the Cavango.

The site's geographical situation and its geologic features led to the adoption of a bitumen structure of gravity profile.

The overall draining basin of the section consists of 6 508 Sq. Km and the partial one up to the Cavango section is 4 056 Sq. Km. The average annual drainage which correspond to them are 1 848 hm3 and 978 hm3, respectively.

Figure 3.4 shows development features which are summarised as follows:

Maximum height   21 m
Coronation portion   1 501 m
NPA portion   1 498 m
Completion of coronation 500 m
NPA flooded surface   65 Sq. Km
Useful Volume   440 hm3
Average bruto fall   17 m

The planned hydraulic circuit corresponds to the intake upon direct encounter and the low pressure pipeline leading to the central unit located close to 1,4 km downstream after an expressed curve of the river. It is likely that later in the study it should be recognised that, economically, it will not be advisable to carry out such a long circuit to win some more metres of discharge and, under such circumstance, the solution will rest on the standing dam central unit similar to that of Cavango.

The central unit, with a total of 15 MW capacity, restores 1 475 m to the portion. The average annual power output, considering the already regulated discharges upstream is 67,4 Gwh.

The flooding discharges will be discharged over the dam through an uncontrolled exhaust attached to a waste basin on the base.

Figure 3.3 : Chanzenga Scheme

3.6.3   Development of Mangonga (No. 3)

Mangonga scale is the first trickle of water planned in Cubango, after the regulating lagoons upstream. As it has already been mentioned, there is a small scale hydro-power development at the site, which structures will have to be abandoned when decision in the construction of Mangonga's plant has been made, as the fall and discharges are substantially higher. This is the reason why, although the design is the similar, the present development is located at a more adequate position.

The scheme is comprised of a drifter dam, a canal that leads to a compensation camera, starting point of the forced pipeline which ends at the centre of the left margin of the river.

The overall draining basin of the section consists of 7 065 Sq. Km and the non-dominated is composed of 557 Sq. Km. The corresponding average annual drainage is 1 935 hm3 and 87 hm3, respectively.

Figure 3.5 shows features of development which summarised as follows:

Maximum height	8 m
Coronation portion	1 463 m
NPA portion	1 460 m
Completion of coronation	200 m
Average bruto Fall	30 m

The hydraulic circuit progresses at the left margin. The canal will consist of about 2 000 m length, being 300 m of forced pipeline.

Having the plant 26 MW, the plant restores 1 430 m to the portion. The average annual power output is 124.2 GWh, if we consider that the regulated discharge is the same as in Chazenga section.

The flooding discharges will be discharged over the dam through an uncontrolled exhaust attached to an elementary waste at the base, in face of the rocky nature of the foundation.

Figure 3.4 : Mangonga Scheme

3.6.4 Development of Mumba (No. 4)

After the Cutato junction, the neck of Mumba provides favourable conditions for the establishment of a big regulated dam. Its features led to opt out for an arco-gravity bitumen structure.

The overall draining basin is 12 495 Sq. Km and the non-dominated is 2 606 Sq. km. The corresponding average annual drainage is respectively 2 899 hm3 and 195hm3.

Figure 3.6 shows the development features which are summarised as follows:

Maximum height	30 m
Coronation portion	1 400 m
NPA portion	1 397 m
Completion of coronation	200 m
NPA flooded surface	66 Sq. Km
Useful Volume	656 hm3
Average bruto Fall	30 m

The planned hydraulic circuit is located on underground gallery, and close 800 m length are developed along the left margin.

With a 40 MW capacity, the plant restores 1 360 m to the portion. The average annual power output, considering the regulations of other scales upstream and the development itself will be 183.5 GWh. When included in the set of Scheme scale, the lagoon allows a compensation volume of 568 hm3.

The flooding discharges will discharge on a free fall coronation for a standing waste basin of the dam.

Figure 3.5 : Mumba Scheme

3.6.5   Development of Muculungungo (No. 5)

Existence of one of the natural discharges in the Cubango after the Cuchi River junction, although it is a small-scale one included the development of Muculungungo in the Scheme.

The site's geographical situation and geological features led to the adoption of trickle of water development consisting of a jumping bitumen dam. A side doorway shall be closed by a bitumen wall at the right margin or by a thoroughly impermeable hydraulic dike.

The draining basin at the site is 38 148 Sq. km and the partial one, until the regulated development upstream, is 16 879 km.

The average annual drainage corresponding to it are 5 653 hm3 and 1 004 hm3, respectively.

Figure 3.7 shows the development features which are summarised as follows:

Maximum height   15 m
Coronation portion   1 173 m
NPA portion   1 170 m
Completion of coronation   400 m (plus 100 m at the doorway lock)
Average bruto Fall   20 m

The planned hydraulic circuit develops itself at the left margin and it consists of a 700 m canal leading to a charge chamber, start of the 300 m forced pipeline and ends with the localised plant at the margin, the falls downstream.

The plant, with 54 MW capacity could have a year average of 241.5 GWh power output. Based on the trickle of water development, apart from the regulated discharges from upstream, compensation of the development Mumba, which could introduce to the drainage of the intermediate basin, was taken into account.

The flooding discharges will be discharged at the dam by means of an uncontrolled exhaust.

Figure 3.6 : Muculungungo Scheme

3.6.6 Development of Mucundi (No. 6)

Somehow, upstream Cueio junction there is a narrowing which could serve as storage through the construction of a dam, the Scheme's biggest.

Its correct geographic situation and the geological features led to the adoption of a land work. The dam's capacity is such that, besides the regulation in average year it has 1 66 hm3 available for compensation of the dry year, which could help value substantially all development activity at the valley downstream.

The overall draining basin at the section consists of an area of 50 024 Sq. Km and the non-dominated is 11 876 Sq. Km to which correspond the average annual drainage of 6 400 hm3 and 1 752 hm3, respectively.

Figure 3.8 shows the features on the development summarised as follows:

Maximum height   35 m
Coronation portion   1 153 m
NPA portion   1 150 m
Completion of coronation   750 m
NPA flooded surface   161 Sq. Km
Useful Volume   2 541 hm3
Average bruto Fall   25 m

The hydraulic circuit develops along the gallery at the left margin with about 500 m of length.

With 74 MN, the plant restores 1 115 m to the portion and it may generate during average year a power bloc of 330,8 GWh, if we consider the regulations that have been introduced by development activity downstream.

Floods discharger, also on gallery, will be parallel to the hydraulic system.

Figure 3.7 : Mucundi Scheme

3.6.7 Development of Mbambi (No. 6)

The development of Mbambi should be seen as being different from the rest for the conditions which are inherent to them, as a result of its location at the international segment. Its implementation shall obviously be subject to agreement with Namibia and, based on the certainty that the Republic of South Africa, which preceded it from the beginning has shown interest in studying the potential of the site, it was decided to wait for the delivery of the outcome of this study, of which, to date the Angolan counterpart has no knowledge, to include in this scheme at the same footing of the rest.

These considerations, however, do not mean that a summarised contextual analysis and prediction of the features should not be made.

The dam site is located at about 10 km downstream of the Chissombo tributary, at the right margin. Given the good watering soil spots of the Angolan territory only have 14 km downstream, there is a need to ponder whether it is economical that the development will be a derivation of the water for irrigation.

Therefore, it seems that the function will basically be regularisation and possible power generation , making use of the fall caused by the dam per se.

Due to the conditions of the transverse lines and in the attempt to obtain a major dam, the NPA will be limited to the portion of the restoration of the Mucumbi plant which, with regard to the level of reference to Namibia, will be 1 120 m. Under these conditions, an on-land dam could be he alternative, with a maximum height of 29 m and a coronation length of 1 650 m, to the portion 1 123 m. The hydraulic circuit and flooding discharger could be located at the left margin, on gallery, by a similar system to that of Mucumbi, providing a 20 m fall.

Given the uncertainty, no estimates are given on the capacity power nor regarding power output.

Moreover, there is too limited interest under the framework of the Scheme, as the Development of Mucundi with the same purpose appears to be much more interesting. Furthermore, it is considered that as far as purely national interest is concerned and considering the remaining planned scales upstream, the Development of Mbambi should not be included.

Figure 3.8 : Mbambi Scheme

3.6.8   Development of Calemba (No. 9)

In the adopted numerical sequence, Calemba is the first development of the Cubango tributaries, specifically at Cutato.

Cutato falls do not allow the establishment of a regulating dam in its surroundings, and as such, power output will only be valued once construction of a storage upstream has taken place.

This is the purpose of the Development of Calemba, which geographic localization and geological features allow the construction of a gravity type bitumen dam.

The draining basin of the section has an area of 3 381 Sq. km representing an average annual volume of 856 hm3.

Figure 3. 10 shows the features of development summarised as follows:

Maximum height	22 m
Coronation portion	1 507 m
NPA portion	1 504 m
Completion of coronation	550 m
NPA flooded surface	52 Sq. Km
Useful Volume	385 hm3
Average bruto Fall	13 m

The hydraulic circuit will be included in the body of the dam, progressing to the plant's base, at the right margin.

The power inbuilt capacity will be 53 MW and an average year power outcome in a bloc will be 23,8 GWh.

The flooding discharger will be over the dam in a free layer.

Figure 3.9 : Calemba Scheme

3.6.9   Development of Cutato (No. 10)

The regulated discharges in the development of Calemba are used downstream to generate power during great discharges of the whole of the basin, such as that of Cutato.

As mentioned earlier in this paper, the development of these falls was already studied. The design of the works proposed herein is basically the same, this is, development of the trickle of water through a derivational dam, a canal, as well as a forced pipeline.

From the geographic situation and geological features of the site, resulted a prediction of a bitumen shift dam.

The overall draining basin of the segment is 3 683 Sq. Km. and Cutato itself to Calemba is only 302 Sq. Km. Average annual drainage is 933 hm3 and 77 hm3, respectively.

Figure 3.11 shows the features of the development summarised as follows:

Maximum height   10 m
Coronation portion   1 483 m
NPA portion   1 480 m
Completion of coronation   250 m
Average crude Fall   80 m

The hydraulic circuit expands on the left margin and it is formed by a canal strip of about 900 m, followed by a charging chamber, beginning of the forced pipeline, with 700 m which ends at the canal close to the margin. The restoration of the portion will be 1 400 m.

The power inbuilt capacity will 32,5 MW, and in average year it will generate power at the amount 159.7 GWh with the regulated discharge upstream.

The flooding discharge will done over the dam.

Figure 3.10 : Cutato Scheme

3.6.10   Development of Malobas (No. 13)

Situated at Cuchi river, nearby Cuchi village, the development of Malobas allows to meet good storage conditions as well as the regulation of an appreciable natural fall.

The geographic situation and geologic features of the site have led to the adoption of a double-curve arch bitumen dam.

The draining basin is located at section of 8 774 Sq. Km. which corresponds to an average annual drainage of 1 749 .

Figure 3.12 shows the development features summarised as follows:

Maximum height   47 m
Coronation portion   1 420 m
NPA portion   1 417 m
Completion of coronation   120 m
NPA flooded surface   120 Sq. Km
Useful Volume   1634 hm3
Average crude Fall   58 m

The existence of small doorway at the left margin demands the construction of a closing dike with about 100 m of length.

The hydraulic circuit on gallery will be developed at the left margin and the restoration to the portion will be 1 350 m downstream of the rapids. Inbuilt power will be 84 MW and the average annual power supply output will be 215,5 GWh.

The flooding discharge will be made over the coronation in free stream falling into the exhaust dam of the dam base.

Figure 3.11 : Malobas Scheme

3.6.11   Development of Cuangar (No. 18)

Based on data available and from the criteria adopted along the Low Cubango valley, the first spot of suitable soils, which have enough continuity and closer to the low bedsteads, is located about 14 Km downstream of the Development of Mbambi, and was considered as being the first irrigation bloc.

Figure 3.13 provides an idea of the form and dimensions. The area concerned has 3000 ha consisting entirely of small-river borders, with an expansion of about 25 km and a maximum width of 2 km. Cuangar village is located about the centre of the bloc.

It is admitted that the work scheme will consist of a pumping unit to a canal que dominates the indicated area or, alternatively, a serious of plot pumping.

According to indicated criteria, the annual consumption will be 45 hm3, will a peak consumption of 4 m3/s.

3.6.12   Development of Tondoro (No. 19)

Situated 10 km downstream far side of the anterior bloc, the irrigated perimeter of Tondoro (Figure 3.14) has features which are slightly different from these.

With a length of about 20 km, it includes an overall of 4 000 ha of which only 2 350 ha correspond to very suitable lands. The remaining 1 650 ha refer to the lands with conditional aptitude (low lands), which development could take place easily when the regulation of the river becomes a reality.

The work scheme will also b similar to that of Cuangar. The annual volume needed for irrigation is 60 hm3, and the discharge is estimated at 5 m3/s

3.6.13   Development Sâmbio (No. 20)

Under the criteria used to choose priority watering blocs it is established that there is a continuously vast spot of highly suitable soils, about 20 km downstream of the Village of Calai. It was decided therefore to locate here the development of Samio. (Figure 3.15).

This bloc has about 50 km of length with a maximum varying width of 3 km. The area to be explored is 8 120, of 2 250 ha, corresponding to conditionally suitable lands.

The work scheme will be similar to those of other blocs. The annual volume needed for irrigation is 122 hm3, and the peak discharge is estimated at 10 m3/s.

3.6.14   Development of Mucusso (No. 21)

Following the junction with Cuito and about 30 km from it, it is located the last continuous spot of good soils which was designated as Development of Mucusso (Figure 3.16).

Progressing for about 40 km with maximum widths reaching 3 km, this bloc has a total area of 6 970 ha of which 6 020 ha correspond to highly suitable lands.

The annual volume needed for watering will be 105 hm3, and the peak discharge is estimated at, 5 m3/s.

3.6.15   Development of Xamavera (No. 22)

Despite the overall unfavourable features mentioned for marginal lands of Cuito, it was possible to identify a uniformed bloc of suitable lands near Xamavera, which starting point is located sufficiently close to the lower riverbed. This appears to have provide good perspectives for development.

This bloc has an area of 3 740 suitable lands extended through about 35 km.

The annual volume needed for watering would be 56 hm3, which represents a peak discharge of 5 m3/s.

3.7   Electricity Aspects of the Scheme

3.7.1   General

In this chapter it will estimate, in view of the basic criteria, as described under 3.2, the Scheme's electrical potential.

Therefore, this problem will be discussed in two different aspects:

(1)   power output per average year;
(2)   power output per dry year and critical period, and
(3)   more productive scales.

The first item will be based on the hypothesis of the executing all developments from the each of the electrical equivalents, as defined earlier.

The second will attempt to verify to which extent the power output per average year is guaranteed during dry year and, if not, how much will be secured under such circumstances. At the end, a systematic critical analysis will be made on what is to take place.

Finally, it will be helpful, through a study of the possibilities of each scale per se,
to assess the scale or scales that appear to be more interesting in the field of power generation.

For a better coverage of the scales, Table 3.7.1 summarises the underlying features of each of them.

3.7.2   Power Output

Power output per average year is obtained by determining which are power equivalents of each development based on their own fall (Table 3.7.1).

After these figures are known, by adding the scales located downstream, the power equivalents of each one of the regulating developments is obtained (Table 3.7.2)

From observing these two tables it can be concluded that the scale with greater own power equivalent is No. 10 (Cutato), since that has a greater fall. On the other hand, the scale with greater total power equivalent is No. 9 (Calemba), also influenced by No 10, since scales 1, 2 and 3 put together have a lower equivalent than No 10.

If the system is fully concluded, its productivity may be obtained in global terms, by reducing all regulating scales to one only, and the same will occur with trickles of water.

Concerning the first ones, Table 3.7.3 shows the results. Relevant volumes tributary to the basins themselves which supply power outputs were considered. After these are obtained through the described criteria, and the compensation volumes needed for the relevant tributaries, by difference of volumes stored, the volume available for compensation and, subsequently, the respective power can be obtained. After this, it was established that the total power output by regulating development per average year will be 1 299,4 GWh, however some 422,3 GWh compensation power will still be available.

The system contains three trickle of water developments, such as Mangonga, Cutato and Muculungungo. As far as the first is concerned, its relative proximity to the upstream regulating, could to admit that the basins themselves have trivial drainage, therefore their electricity is included in previous calculations. The opposite is true with Muculungungo where the relevant drainage tributary of the basin itself is 1 223 hm3, which is likely to generate 54,3 GWh at the existing 20 m fall.

Subsequently, the system would generate 1 353 GWh of which only 54,3 GWh will not be permanent. The partial or total return of power is likely, since admitting the Figure 2.19 curve as being valid, the power total return would be 3 x 54,3 = 162,9 GWh lower than the available power for return. It is obvious, therefore, that in terms of average year, power output will not exceed that of the tributary.

3.7.3   Power Output during Dry Year and Critical Period

It was already mentioned that, at first, the drainage of dry year could be considered close to 0,43 of the average year. If no strictness is sought, which criterion is permissible in a study of this nature, it can be stated that power tributary to the development sites will be 0,43 x 1 299,4 = 558,7 GWh and to the main trickle of water will be 0,43 x 54,3 - 23,3 GWh, leading to a total of 582.0 GWh bearing in mind that there exist at the dams power available for return of 422,3 GWh lower than the average year.

The previous hypothesis would presuppose that the occurrence of a humid year as a result of the dry year considered in order to restore the reserves. In admitting the critical period, considered as being of four dry years and dividing equally the reserves for these years, the guarantee would be 687,6 GWh.

3.7.4 More productive scales

In the previous chapters, assessment was made on the power output productivity of the globe system, this is, starting from the principle that all scales would be constructed and interlinked.

From the practical viewpoint, however, schematisation made has immediate interest under the framework of any scale in a global and mediate planning to estimate the value of the basin concerning power.

It is important to identify the development activity made which, on their own, will only have greater possibility, and therefore they will be in a position to meet the important demands that might occur.

Of the description made for each one of the scales under 3.5 it can be observed that, over 200 GWh annually during the average year, there are three which, in chronological order, are Mucundi (330, 8 GWh), Muculungungo (241,5 GWh) and Malobas (215,5 GWh).

However, each of them has a different nature. Therefore, Muculungungo is a pure trickle of water, and consequently, the 241,5 GWh,are not permanent. For this reason, power will be limited by the minimum river discharge. On the other hand, Mucundi has such a storage capacity that it only allows estival regulation. Dry year production, close to half of the average year (165,4 GWh) is, thus, effectively guaranteed, although permanently. Regarding the development of Malobas, with 1.8 regulation ratio, will allow, apart from regulating within the average year, to still predict the average year return. This return power will cost 113,4 GWh which leads to almost 135,8 GWh, based on the criteria that headed the power assessment guaranteed during the critical period.

Table 3.7.4 shows more clearly the results of the previous reasoning, supplying the power output and guaranteed of each of the considered scales. Trickles of water figures were obtained approximately based on the dimensional curves mentioned earlier.

The result is that, in terms of guaranteed power, the development efforts of more interesting features are Mucundi and Malobas. What is at steak is not defining which of them will have priority of implementation, because in such a decision very important factors not taken into consideration in this study, some of which will only be thoroughly examined when the chance and need comes for the launch of the enterprise (namely, distance to the consumer centre, type of energy required, multiple purpose of the enterprise, development status of the power network, etc.).

3.8   Irrigation Aspects of the Scheme

3.8.1   Aspects of Flow Regularisation

In this Chapter, a few considerations will be made concerning the problem of regulation of the discharges as a result of the implementation of various scales of the scheme.

The regulation of the discharges can assume two distinct aspects: *(1) increase in the minimum discharges, and (2) decrease in the high floods*. The first aims at basically meet the irrigation needs and regulate the power output, while the second could substantially benefit the development of Cubango's low-land marshy lands. The chapter that discussed Cubango's navigation problem, there appears that clarifications were made on the various conditions which are at steak which attach this river usage a secondary role.

The determination of the regulating minimum discharge could follow a methodology parallel to that which was adopted for the power issue. With the help of values obtained at the previous paragraph, it could be concluded that, at average year, the minimum discharge is equal to the average, this is 179 m3/s downstream of the Development programme of Mucundi. This value should be kept until such a time that junction with Cuito is made, upon which 100 m3/s could be added. During dry year or preferably during the critical period this figure, due to return from the surplus storage, will be down to almost 117 m3/s at Cubango before the junction with Cuito added to the referred 100 m3/s, after that point.

Decrease of the high floods will only be obtained by major regulating dams or by means of an appropriate exploration of smaller reserves. In the case of the proposed scheme, the only development effort which have features that are capable of producing the an striking effect in the reduction of the floods is that of Mucundi with its 3 541 hm3 of relevant capacity. Downstream Mbambi, could play a similar role, because even if it has no gained its storage capacity, everything indicates that it is very near to that of Mucundi. It is believed that in the future, when the development programme is implemented with major dams, Cubango Low-land could largely benefit with the decrease of the floods and subsequent development of its lands.

3.8.2   Meeting Irrigation Needs

Based on the aforementioned Agronomic Study it is inferred that in the segment entailing Cubango Low-land up until the confluence with Cuito, there are 53 350 ha of suitable or conditionally suitable land.

The annual consumption towards watering these lands would be 8 000 hm3 corresponding to a high discharge of 64 m3/s.

So, as it can be observed from previous paragraphs, downstream Mucundi, the relevant average annual drainage it is close to 5 641 hm3 with a guaranteed discharge during average year of 179 m3/s which, as it can be established, although meeting the key needs, would not guarantee the needs in terms of annual volumes. Worst still would be the situation in terms of dry year or critical period.

After concluding that it was not possible to irrigate all soils suitable for watering, it was opted out for the exclusion of soils with conditioned suitability and only consider more suitable lands which cover an area of 29 800 ha, with needs amounting to 4 470 hm3, a theoretically affordable figure. Consideration would also be given to suitability for irrigation of the lands located at the right margin of the river in Namibian territory, regarding which an agreement should be reached on the fair share of water resources.

In Cuito river, agricultural areas reach 21 663 ha with annual needs of 3250 hm3 and a high consumption of 26 m3/s. From the point of view of available discharges no impediment is in view, including lands with conditioned suitability.

After the junction of Cuito there are 11 310 ha of irrigating lands corresponding to the needs of 1 700 hm3 per year and 13,6 m3/s. Equally, consideration would also be taken into for watering suitability of existing good lands at the right margin, for which consumption an agreement should be reached regarding a fair share of the resources.

The following table summarises the watering suitable areas, as well as the conditioned suitability and the corresponding needs of water for that purpose.

	Suitable Areas (ha)	Water Require-ments (hm3/a)	Areas suitable after improvement (ha)	Water Require-ments (hm3/a)	Total Areas (ha)	Water Require-ments (hm3/a)
Cubango upstream of the confluence	29 800	4 470	23 550	3 873	53 350	8 000
Cuito	17 790	2 670	3 873	580	21 663	3 250
Cubango downstream of the confluence	6 850	1 030	4 460	670	11 310	1 700
Totals	54 440	8 170	31 883	4 780	86 323	12 950

3.9   Navigability

For many years, the flowing navigation has always constituted the one and only most efficient option to solve communication difficulties in the Cubango low-land regions which, during rain season, are deprived of communication on land.

There are a number of projects, some have already been materialized and other are still to be implemented for support of fluvial navigation.

Since 1960, when the Services of Fluvial Convoys in Cubango were enforced, there were regular fluvial transport convoys. That is why any integrated exploration project of the basin should consider the navigating demands.

3.10   Cubango River and Water Supply to Cuvelai River Delta

Between Cunene and Cubango Rivers there is a region limited by basins of two rivers to West and to East and, by the border with Namibia to the South, with an almost triangular shape, known as the *Cuvelai River Delta*. (See Figure 3.9.1).

This region is characterized by a peculiar natural drainage network. In its upper side towards North of parallel 17°, the water lines present well-defined waterbeds in spite these being very large; towards the South of that parallel, namely at the Western half, bedsteads are very unclear and difficult to identify, in such a way that drainage, during rain time, are processed in a very little defined way and erratic to the South in expanded zones of low in-depth.

During drought, all water lines dry up and, except some lagoons at the proximity of Cubango, only resort to underground water, in most of the cases, can quench the thirst of humans and animals.

A poor water distribution between the rain season with surplus of water as well as the drought with a total shortage and the absence of geological and topographical conditions in order for storage to be build, has led to the fact that over 30 years before the question of derivational works of water for the region, either by the Cunene River like Cubango River.

4.   Recommendations

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Bibliography

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