Norconsult

N'hangue Hydropower Development

Supplementary Hydrology Assessment

Interim Report
22 March 2007

Cambambe Dam, River Kwanza, Angola

Water Resource Associates

DOCUMENT CONTROL

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Signed on behalf of Water Resource Associates:

Nick Mandeville
Project Manager

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Contents

1 Introduction

1-1 Project Location and Programme

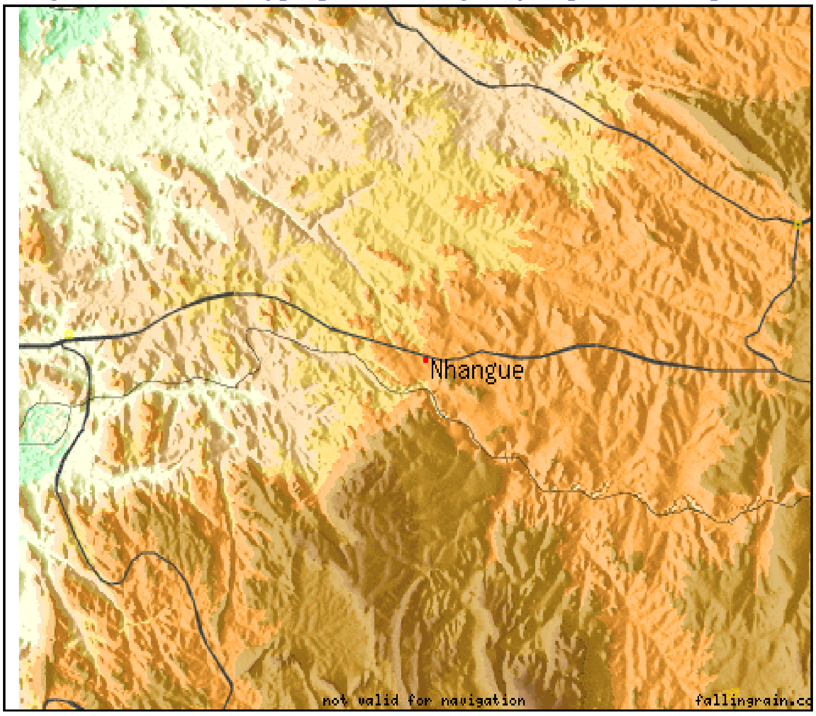
This study has been undertaken following an email from Kjell Mathiesen, Chief Hydropower Engineer of Norconsult, on 05 Jan 2007, and is based on the Scope of Work issued by their own client Norsk Hydro ASA.

The proposed hydropower development is located on the River Kwanza in Angola at Longitude 15 degrees 09' 41" east, Latitude 9 degrees 46' 18" south, at the head of the gorge where the river passes through the escarpment on its way down to the coastal plains (Figure 1-1). A 50m high dam constructed at the site would form a reservoir with surface area of 200 km^2, which would supply a 1600 MW power house.

The hydrology assessment in the Pre-feasibility Report already completed by Norconsult was based on a 12 year long record of River Kwanza flows spanning the period 1963-74.

This Supplementary Hydrology Assessment obtained additional streamflow and/or meteorological records to extend this 12 year flow record to enable improved estimates of firm energy production to be made.

Figure 1-1 Location of proposed N'hangue hydropower development



1-2 Main Objectives

The proposed N'hangue hydropower scheme lies downstream of the existing Capanda dam, such that the high water level of the N'hangue reservoir will form the tail water level of the Capanda dam. The daily river flows used in the Norconsult Pre-feasibility study were formed by amalgamating shorter records from two neighbouring river gauging stations close to the proposed N'hangue dam site. These records were collected prior to the construction of the Capanda dam, and so were unaffected by the latter's daily operation.

Examination of the 12 year record of natural flows indicates that there are two particular years in the 1970s during which the flows were insufficient to fill the reservoir behind the N'Hangue dam, which means the proposed hydro-electric scheme is unable to run at its full potential. The Client wished to know if similar low flow sequences would occur on a regular basis if a much longer flow record was available, and what is their likely frequency of occurrence.

Also of concern is what effect climate change might have in the future on the size of the annual flow volumes in the River Kwanza.

1-3 General approach

In order to estimate a suitable long flow record for analysis, two standard hydrological approaches are possible:

(i) compare the existing short flow record with a long river record drawn from a neighbouring basin with the same hydrological attributes, and then use the correlation to extend the shorter record. This was the approach adopted by Norconsult during their feasibility study of the Epupa Falls hydropower scheme, when the short length of record on the Cunene river at Ruacana was compared to the longer record on the Okavango river at Rundu.

(ii) abstract long periods of rainfall records to prepare a suitable mean basin rainfall series. Use the 1963-74 period of simultaneous rainfall and flow records to calibrate the parameters of a rainfall-runoff model. Then use the long period of basin rainfall with the calibrated model to prepare a long period of simulated flow records.

In the present study the second of these two approaches was adopted. This is because suitable rainfall and natural flow records are available from observations actually taken on the Kwanza basin itself rather than on a neighbouring basin, and it is also easier to examine the consequences of climate change scenarios by using a rainfall-runoff model.

Of the flow records available from rivers in the surrounding region, only one, the Cunene river, behaves in a similar hydrological way, and its observed flows are affected artificially by several reservoirs. Even if these neighbouring rivers do not possess similar monthly flow hydrographs to that of the River Kwanza, their annual sequences of flow volumes will be examined, to see whether there is any pattern in their occurrences of low runoff years similar to those found for the River Kwanza.

It is proposed that the initial stages of this supplementary hydrological assessment should be a short desk study making use of suitable records which are easily available from internet sources or previous investigations and reports. In this way the modelling approach chosen can be tested without incurring substantial costs. This would be a first attempt at learning more about the hydrology of the Kwanza basin, without the need for detailed discussions with the relevant departments of the Angolan government.

Then, if the flow simulations looks promising, further more detailed data, such as records from tributary flow stations in the Kwanza basin or records from rivers in neighbouring countries, could be elicited by visits to government offices in Angola and neighbouring countries, or colonial archives in Lisbon. But such visits would entail considerable time and expense, so it is suggested that they would be more appropriate for a later stage of the investigation or as part of the Feasibility Study itself.

2 Hydrometric records

2-1 Catchment areas

The most important locations in the Kwanza basin for the purpose of this study are shown in Figure 2-1. The proposed N'hangue dam site is shown near the downstream end, with the existing Cambambe dam a further short distance downstream. Just upstream of the N'hangue dam site is the first of the river gauging stations at Quissaquina, with the second gauging station at Mutula a further 55 km upstream. In between these two gauging station lies the existing Capanda dam.

The upper part of the basin was divided into three main sub-basins, which will be delineated as Luando, Upper Kwanza and Cutato. For the convenience of the modelling analysis, these three sub-basins were assumed to converge at a single location, the confluence of the Luando and Kwanza rivers; although not strictly correct, it is not thought this will introduce any substantial error, since the total of the three sub-basin areas was maintained.

To determine the individual catchment areas, the various sub-basins were initially abstracted from a 1:3 000 000 topographic map contained in the *Atlas Geografico* published by the Angolan Ministry of Education in 1982, in conjunction with the Swedish Esselte Map Service. Some difficulties were encountered in matching up the meridians of latitude and longitude on this map with other map projections; it is not certain how accurate this map is, so further checks will be necessary in due course.

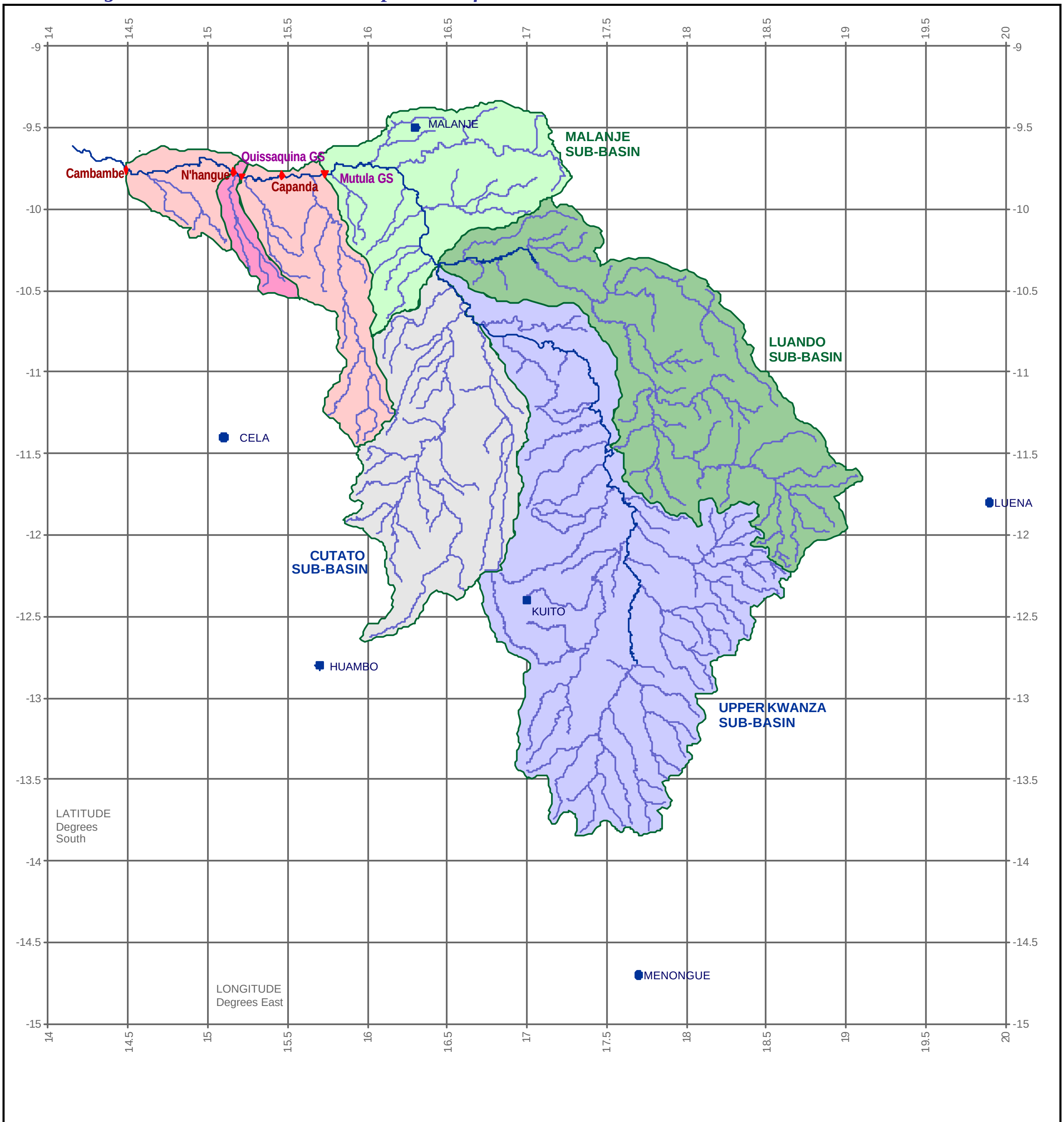
During the preparation of *The Rapid Water Resources and Water Use Assessment of Angola* in March 2005, Sweco Groener had spent considerable time in improving the accuracy of sub-basin areas. There were many such areas listed for the Kwanza basin, but the only two which coincided with locations shown in Figure 2-1 were Quissaquina gauging station with area 111 279 km^2 and Cambambe gauging station, just downstream of Cambambe dam, with area 115 658 km^2. To ensure consistency, it was decided to take this area for Quissaquina gauging station as the base value, and slightly adjust all the other estimated areas to match in with it.

Since the areas for Mutula and Quissaquina gauging stations were critical in comparison with the N'hangue dam site, it was decided to abstract their intervening areas from a more detailed map to ensure their accuracy. The Operational Navigation Chart N-3 Sheet at a scale of 1:1 000 000, published by the National Imagery and Mapping Agency of the USA, was employed to determine the three sub-basin areas lying between Mutula gauging station and Cambambe dam site.

The recommended final values of the areas to be used in the study are shown in Table 2-1. The areas given for Mutula, Quissaquina, N'hangue and Cambambe are considered accurate. For example, the cumulative value for Cambambe shown in the table is 115 896 km^2, which differs by only 0.2% from the value 115 658 km^2 given by Sweco Groener. During the present study the two values for Mutula and N'hangue were mainly used. It will be seen that the area upstream of Mutula is 91.0% of the area upstream of the proposed N'hangue dam site.

In further stages of the study in future, the areas of the four sub-basins upstream of Mutula may be used. The partition into individual areas is considered less accurate, although the sum of their areas is considered accurate. It may be necessary to use the 1:1 000 000 ONC maps N-3 and N-4 to improve their delineation.

Figure 2-1 Kwanza river basin upstream of Cambambe dam



Key:

- River Flow Stations: Quissaquina, Mutula
- Dam Sites: Cambambe, N'hangue, Capanda
- Sub-Basin Boundaries
- Main Rivers

Table 2-1 Individual and cumulative areas at various locations within the Kwanza basin

Location	Individual sub-basin area	Proportion of area upstream of N'hangue dam site	Cumulative area	Proportion of area upstream of N'hangue dam site
	km^2	%	km^2	%
Outlet of Luando sub-basin	28 686	25.4		
Outlet of Upper Kwanza sub-basin	40 787	36.2		
Outlet of Cutato sub-basin	19 477	17.3		
Outlet of combined 3 upstream sub-basins			88 950	78.9
Mutula gauging station	13 661	12.1	102 611	91.0
Quissaquina gauging station	8 668	7.7	111 279	98.7
N'hangue proposed dam site	1 422	1.3	112 701	100.0
Cambambe dam site	3 195	2.8	115 896	102.8

2-2 River flow records

The Client provided two observed daily river flow records on the Kwanza river, which had been used previously during the pre-feasibility study of the N'hangue hydropower scheme. The details are summarized in Table 2-2. The catchment areas have been adjusted to follow the discussion in Section 2-1. The start and finish dates have been taken as the ends of the continuous usable records, although there are other isolated months of data before Jun 1966 for the Quissaquina station.

Table 2-2 Observed river flow records available on Kwanza river

Station No	601 936	601 955
River name	Kwanza	Kwanza
Station name	Mutula	Quissaquina
Latitude	9 degrees 43' 0" S	9 degrees 48' 0" S
Longitude	15 degrees 43' 0" E	15 degrees 13' 0" E
Altitude	940 m	780 m
Catchment Area	102 611 km^2	111 279 km^2
Start date of complete months data	Jan 1963	Jun 1966
End date of complete months data	Mar 1975	Sep 1975

Both daily flow records were present for the period 01 Oct 1966 – 31 Mar 1975, and comparison plots are shown in Figures 2-2 and 2-3. Because the catchment area for the Quissaquina station exceeds that for the Mutula station by 8.4 %, it would be expected that the daily flows at Quissaquina would slightly exceed those recorded at Mutula. Both plots show that this is the case. However the consistency between the two stations is remarkably good for two observed daily flow records, and, if the records are truly independently measured, show that the quality of collecting flow records must have been extremely high during those years. This gives confidence that the subsequent fitting of rainfall-runoff models should at least not fail because of poor quality flow records.

Table 2-3 compares some monthly values for the two stations. The values of annual runoff depth are obtained by dividing the mean annual flow by the corresponding catchment area. This removes the differences arising from the 8.4% difference in area, so the values of annual flow expressd in these units should be consistent between the stations. Here again the table shows they are very consistent, with the greatest discrepancy in any one year being 4.4%. For the mean of the annual runoff values taken over the common 8 years of records, the Mutula runoff is 98.6% of that recorded at the Quissaquina station, although both maximum and minimum values slightly exceed 100%.

Because it is possible to abstract 12 years of continuous monthly flows from the Mutula record, compared to 8 years for the Quissaquina record, it was decided to calibrate the rainfall-runoff model on the former record.

Figure 2-2 Two observed flow records at Mutula and Quissaquina plotted against time

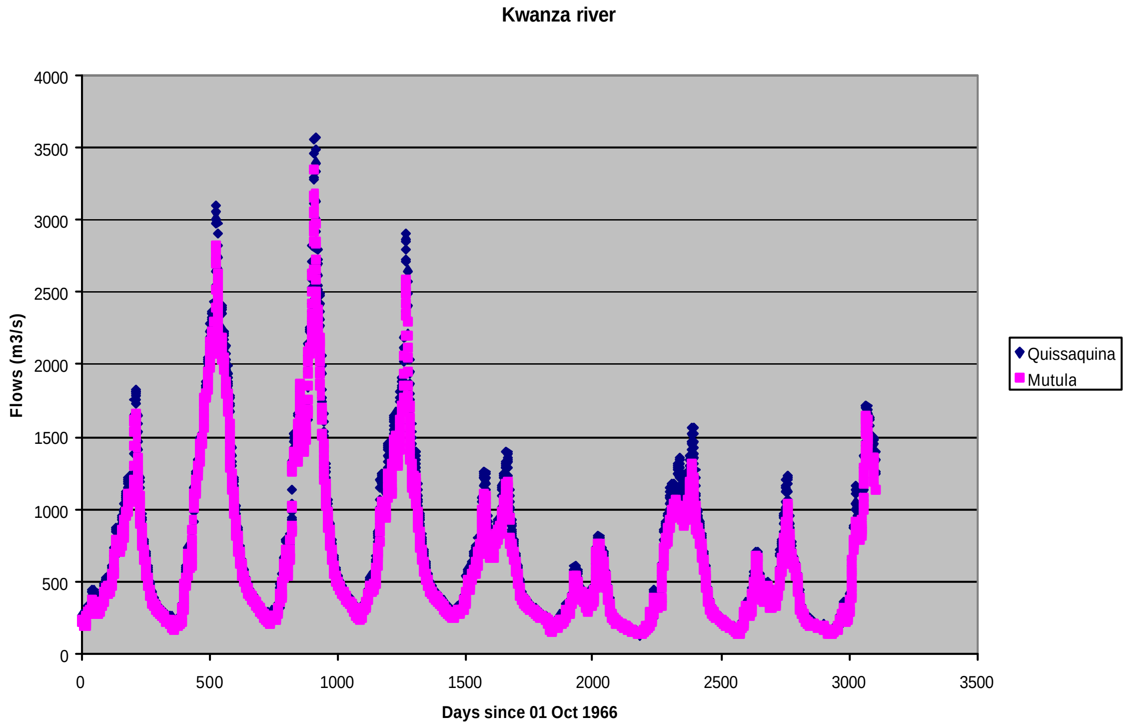


Figure 2-3 Comparison of daily flow records at Mutula and Quissaquina stations

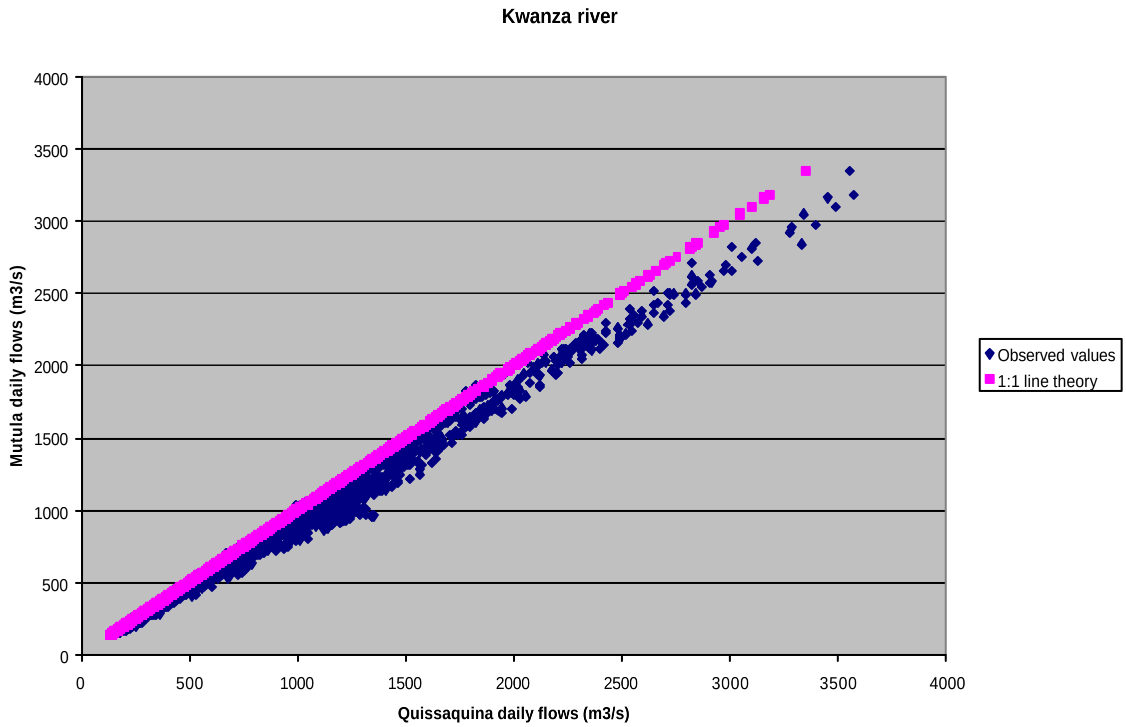


Table 2-3 Comparison of flow records from two gauging stations on Kwanza river

Water year Oct-Sep	Quissaquina gauging station		Mutula gauging station		
	Mean annual flow	Annual runoff	Mean annual flow	Annual runoff	Ratio Mutula runoff /Quissaquina runoff
	m^3/s	mm	m^3/s	mm	
1963/64			616	189	
1964/65			579	178	
1965/66			773	238	
1966/67	600	170	541	166	0.976
1967/68	1092	310	1022	314	1.012
1968/69	1031	292	952	293	1.003
1969/70	930	264	825	254	0.962
1970/71	626	177	559	172	0.972
1971/72	333	95	312	96	1.011
1972/73	639	181	563	173	0.956
1973/74	413	117	374	115	0.983
1974/75	641	182			
Mean 1966-73	708	200.6	643.5	197.8	0.986
Max 1966-73	1092	310	1022	314	1.013
Min 1966-73	333	95	312	96	1.011

2-3 Precipitation

Various sources of observed monthly precipitation records for Angola were considered, with the main categories being from a) colonial archives in Lisbon b) internet web sites.

2-3.1 Colonial archives in Lisbon

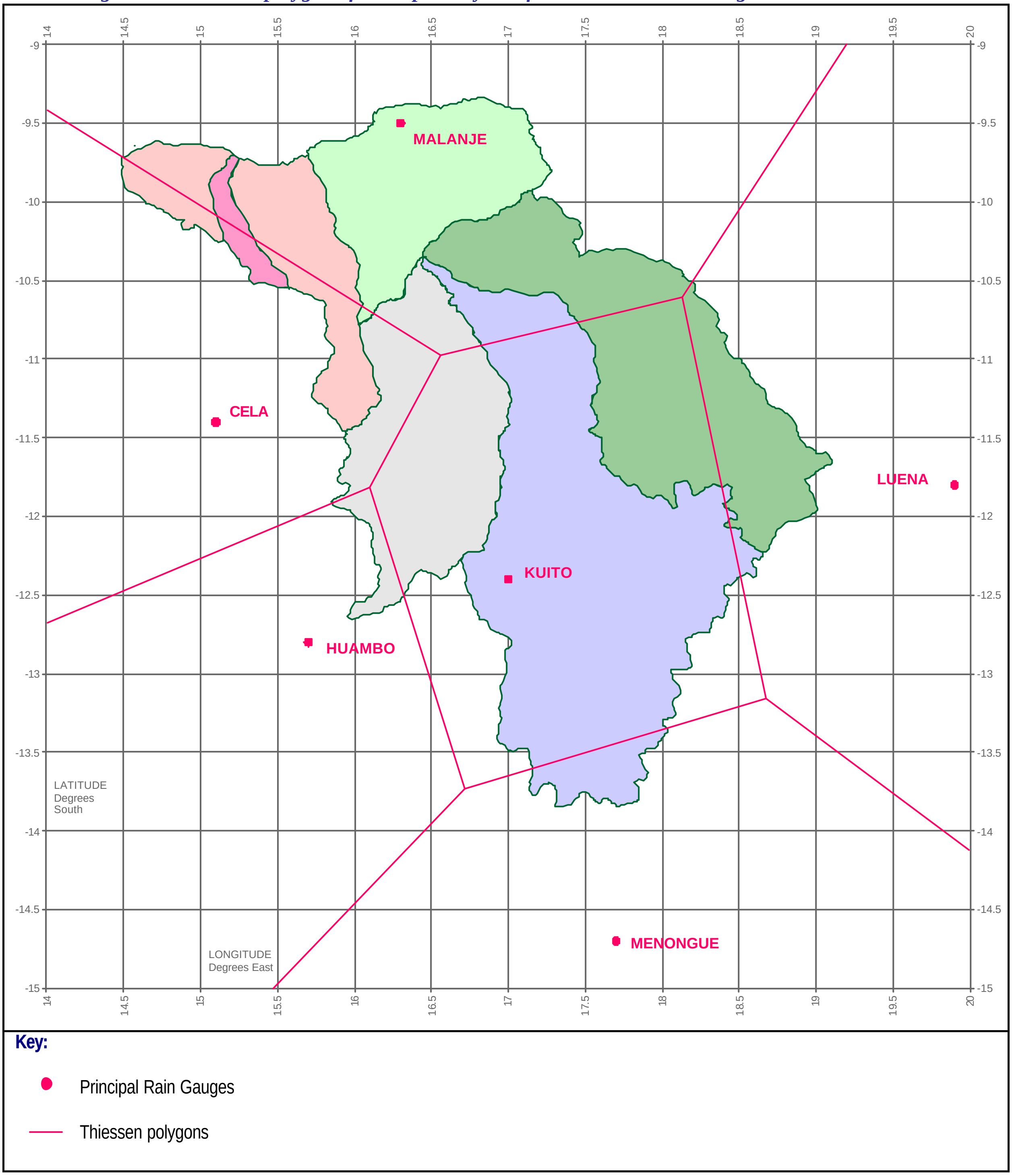
During a study of the Okavango Wetland by one of the Water Resource Associates principals several years ago, the colonial archives in Lisbon were searched for long rainfall records which lay in or surrounding the Cubango and Cuito river basins. These are the two rivers flowing down from the Angolan plateau in a south-easterly direction which form the main inflow to the Okavango Wetland. Appendix A shows the length of the records found, which broadly spanned the period 1929-1974. The table indicates that the records are drawn from 5 historical publications.

Inspection showed that these records had more missing data than the same stations listed on the internet sites, and were in a less usable format. Since this phase of the hydrology study was meant to be a desk study, it was decided that visits to the colonial archives to follow up some of the queries on the data were not feasible at present, so this source was not pursued. However Appendix A did prove useful in identifying stations with long records which could be downloaded from the internet websites: for example Ganda, Rio Chipia and Cuima.

2-3.2 GPCC webite

The German Meteorological office GPCC maintains a website of precipitation stations throughout the world at a one degree grid spacing. There were 6 stations of interest to this study which surround the Kwanza basin, as shown in Figure 2-4. These stations are the primary climate stations in the region, according to the *Atlas Geografico* published by the Angolan Ministry of Education in 1982. The records were at a monthly time interval and spanned the period Jan 1951-Dec 2004. Because the value for Jan 1951 was set to zero for many of the stations, the year 1951 was excluded from subsequent analysis.

Figure 2-4 Thiessen polygons for the primary rainfall stations surrounding the Kwanza basin



Of more concern was the quality of the records from 1975 onwards. The rainfall was summed in period of consecutive 5 years, and the total for each of the 6 gauges are listed in Table 2-4. It is immediately obvious that for the 4 gauges Cela, Nova Lisboa, Serpa Pinto and Silva Porta the rainfall decreases to about half of that recorded prior to 1975. The decrease for the Luena gauge is not so marked, but still reduces to about two thirds of the prior rainfall. For the Malanje station, the totals decrease immediately after 1975, but subsequently increase to values much higher than those prior to 1975. It was decided to curtail the period of records used as input to the rainfall-runoff modelling to the reliable period Jan 1952-Dec 1974, which gave 23 years in total.

Table 2-4 Reduction in quality after 1975 for the GPCC records at primary rainfall stations

Total rainfall (mm) for 5 year periods

	Menongue	Huambo	Luena	Kuito	Cela	Malanje	Mean	Thiessen
Total 1951-55	5630	5959	6106	6152	4500	5168	5586	5697
Total 1956-60	4380	6322	6281	5987	4928	5215	5519	5642
Total 1961-65	5215	7543	6840	7144	5548	5334	6271	6361
Total 1966-70	5509	6527	6778	6677	5223	5584	6050	6193
Total 1971-75	4651	5494	5665	5817	4340	5442	5235	5540
Total 1976-80	3897	3530	5250	4344	3061	4685	4128	4427
Total 1981-85	3422	3943	4705	4503	3149	4077	3966	4250
Total 1986-90	2220	1873	5447	1959	3969	8548	4002	4561
Total 1991-95	2595	1524	4704	1686	2116	6493	3186	3579
Total 1996-2000	2536	2126	4773	2537	3663	6522	3693	4107

Figure 2-4 shows the Thiessen polygon distribution for these six raingauges. The areas within each polygon were planimetered and the corresponding Thiessen weightings to be applied to each individual rainfall record are listed in Table 2-5. The weights for Silva Porta and Malanje dominate, with rather minor contributions arising from the other 4 gauges. Comparisons between the mean rainfall values found from the Thiessen weighting and the alternative of giving equal weight to each of the 6 gauges showed there was not much difference. So the Thiessen weighting was not carried forward into the rainfall-runoff modelling.

Table 2-5 Thiessen weights for each of 6 primary rainfall stations surrounding Kwanza basin

Rainfall station	Thiessen weighting
Serpa Pinto/Menongue	0.0325
Nove Lisboa/Huambo	0.0108
Luso/Luena	0.0896
Silva Porta/Kuito	0.4740
Cela	0.0672
Malanje	0.3259
TOTAL	1.0000

2-3.3 CRU website

The Climatic Research Unit (CRU) of the UK University of East Anglia runs a website containing climate data from around the world. One of its products is a monthly series of rainfall spanning the period Jan 1901-Dec 2000 representing the whole of Angola.

This countrywide series looked very promising initially, as it possessed 100 years of data. But analysis showed that the mean annual rainfall over the period Jan 1952-Dec 1970 was 1037 mm, which is considerably lower than the 1166 mm found for the same period for the mean of the 6 GPCC stations. This necessitated multiplying the CRU monthly record by a factor 1.1244 prior to its use in the rainfall-runoff model. This discrepancy is probably due to incorporating a number of stations along the coastal strip and the drier parts of the southern region of Angola in this countrywide CRU rainfall series. As such it would not be representative of the plateau area to which the Kwanza basin is confined.

It is also not clear how a record as long as 100 years was obtained. Before 1935 there only appear to be rainfall records available from a handful of gauges such as Cabinda, Luanda, Andulo, Lobito, Silva Porta, Cangamba, Mupa, and Pereira d'Eca.. Subsequent to 1974 there appear to be very few reliable gauges without breaks in the data. Perhaps comparison was made of long rainfall records located in countries neighbouring Angola.

2-3.4 NOAA website

The most promising source of easily available historical rainfall records was the web-site belonging to the National Climatic Data Center, which is part of the United States government organisation NOAA. This contains monthly observations for a total of 104 individual stations located within Angola.

From these, 28 stations were selected for use in this study. The majority of these were located on the same plateau region where the Kwanza basin is located (Figure 2-5). The records for one of the stations, Cacuso, were subsequently found to be of too poor quality and excluded, but all the others were satisfactory. The gauge at Sa da Bandeira/Lubango was included, even though it is far away from the Kwanza basin, because along with the station at Ganda, it had records stretching back to Jan 1937; no other stations had records earlier than Jan 1940. The gauge at Serpa Pinto/Menongue was included because it is a primary climate station, even though it also lay a little way away from the basin boundary. The stations at Mupa and Pereira d'Eca have records commencing Jan 1937 and Apr 1932 respectively, but they were not included in the final group because they were not situated on the plateau but in the drier region at lower altitude in the south of the country.

There were some longer records available from a handful of stations located in the coastal strip. However it is considered that the weather systems affecting these coastal stations are different to those occurring over the plateau, and the coastal stations should not therefore be used to extend the records for the plateau stations.

Six stations possessed some records in the period Jan 1975-Dec 1989, and consideration was given to trying to extend the records past Dec 1974. However there were two gaps, July-Dec 1975 and Jan-May 1982, for which no records at any of the 27 stations were available. So it was decided for the time being to confine the subsequent analysis to the 38 year period Jan 1937-Dec 1974, and revisit this task later, if desirable.

A module in the HYSIMM software package was applied to the incomplete monthly records from the 27 stations, and by correlation between neighbouring records, it was possible to fill the missing gaps and extend all the individual records, to obtain continuous records spanning the 38 years for all 27 stations.

Three different methods of obtaining the mean rainfall for the Kwanza basin were then applied to these 27 infilled records:

a) 6 primary rainfall stations;
b) 13 rainfall stations lying within or close to boundary of Kwanza basin;
c) 22 rainfall stations lying both within and surrounding the boundary of the Kwanza basin;

No Thiessen weights were used, and the equal weighting was given to each record in the subgroup. Table 2-6 shows which stations were used in each group.

Because these 22 infilled rainfall stations were spread reasonably widely over the Kwanza basin, it was possible to estimate mean rainfall over the 5 sub-basins shown in Figure 2-1. This arrangement allows between 5 or 6 individual rainfall stations to be allocated to each sub-basin, with some stations allocated to more than one sub-basin. Using the 22 infilled rainfall records, the areal monthly rainfall for each sub-basin has already been determined for the period Jan 1937-Dec 1974. However these rainfall records have not yet been used as an input to a rainfall-runoff model based on splitting the basin up into 5 sub-basins.

Figure 2-5 Rainfall stations from the NOAA website used for the Kwanza basin

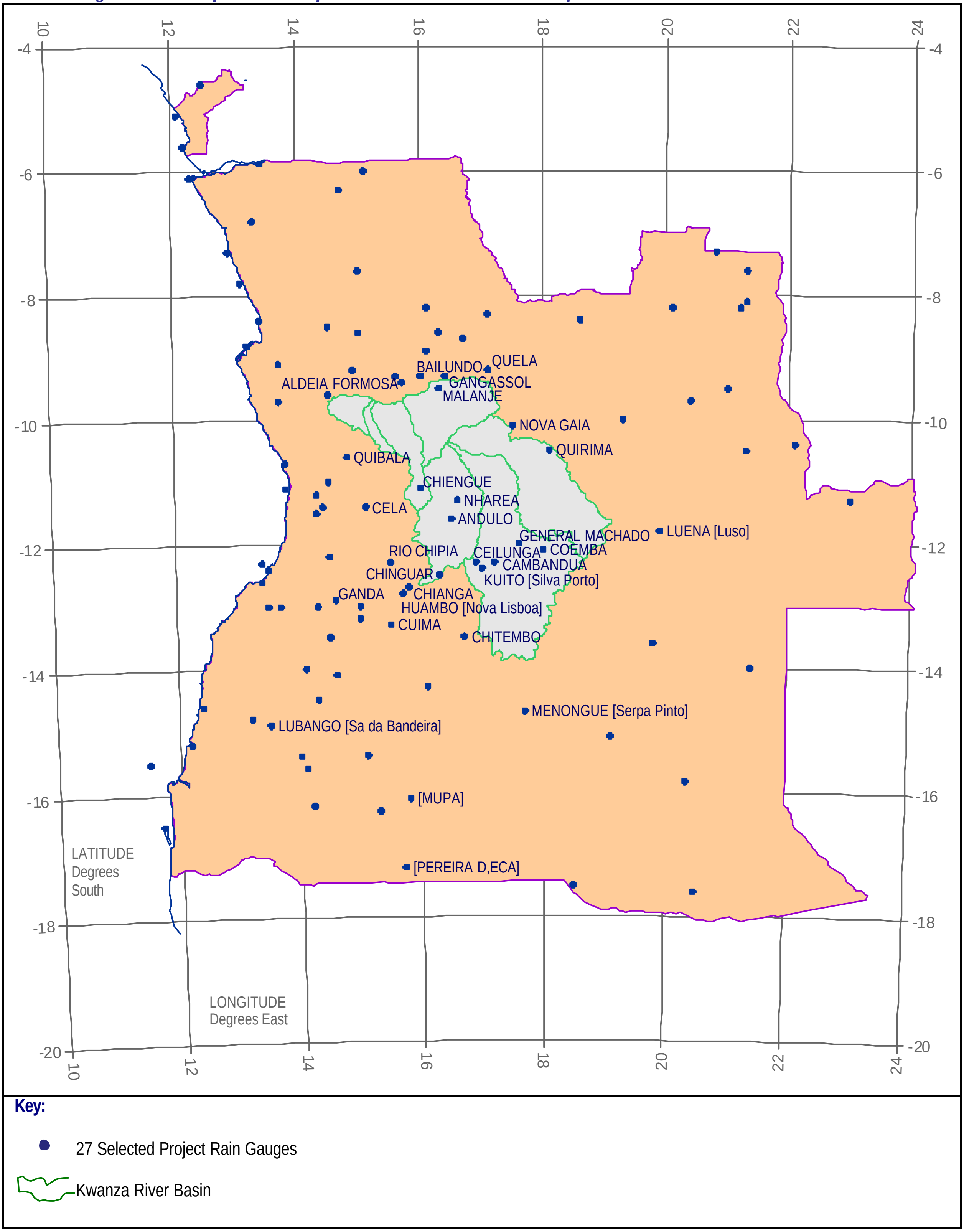


Table 2-6 Monthly rainfall stations located within or close to the River Kwanza basin

Station		GPCC	CRU	NOAA			
Original name	**New name**	**6 primary stations**	**Countrywide single record**	**Stations used for infilling of records**	**6 primary stations**	**13 internal stations**	**22 internal and external stations**
Countrywide value			X				
Malanje	Malanje	X		X	X	X	X
Cela		X		X	X		X
Chiengue	Gabela			X		X	X
Luso	Luena	X		X	X		X
Nova Lisboa	Huambo	X		X	X		X
Cuima				X			
Ganda				X			
Rio Chipia				X			
Silva Porta	Kuito	X		X	X	X	X
Ceilunga				X		X	X
Chitembo				X			X
Coemba				X		X	X
Andulo	Andulo			X		X	X
Sa da Bandeira	Lubango			X			
Serpa Pinto	Menongue	X		X	X		X
Gangassol				X		X	X
Quirima				X		X	X
Nova Gaia				X		X	X
General Machado				X		X	X
Cambandua				X		X	X
N'harea				X		X	X
Chinguar				X		X	X
Chianga				X			
Quela				X			X
Bailundo				X			X
Quibala				X			X
Aldeia Formosa				X			X

2-4 Potential evapotranpiration (PET)

Besides the record of basin rainfall, the other series required as input to the rainfall-runoff model is that of potential evapotranspiration (PET). This variable can be estimated from separate series of four different standard climatic variables: temperature, humidity, solar radiation and wind speed.

Two sources of potential evapotranspiration (PET) data were examined. Initially use was made of a previous study of evaporation in Malawi (Mandeville & Batchelor, 1990), a country which has similar ranges of altitude, latitude and annual rainfall totals to those occurring in Angola. This study collected monthly values of temperature, humidity, sunshine hours and wind run over the period 1970-78 for 20 climatic stations spread throughout the country. From these basic data, monthly values of potential evapotranspiration (PET) were estimated by the Penman formula, and the average monthly values tabulated for each station.

The average monthly values of Penman short grass potential evapotranspiration were abstracted for a climate station at Thyolo (Table 2-7), and these values were then replicated for each of the successive years between 1937 and 1974 to provide a 38 year long record suitable for use over the Kwanza basin. The mean annual value of PET for Thyolo is 1427 mm. This Thyolo station lies in the tea-growing area of southern Malawi, with a mean annual rainfall of 1229 mm, and a moist climate for 10 out of the 12 months of the year (Table 2-7); in this respect it is considered to possess a local climate similar to that of Huambo on the Angolan plateau. However one major difference is that of altitude, with Huambo situated at 1701 m, while Thyolo is much lower at 820 m. This would mean that Huambo would possess lower temperatures than Thyolo, and consequently slightly lower values of PET.

Table 2-7 Monthly variation of rainfall and PET at Thyolo station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Annual
Rainfall (mm)	215	190	218	93	27	33	30	11	7	42	127	234		1229
PET (mm)	136	119	121	100	91	71	78	110	139	170	155	136		1427

Selection of the Thyolo record ensured that the modelling procedures could start without delay. Later during the study, a potential evapotranspiration record was estimated, using only Angolan sourced data, for the climate station at Bie, located at 12.38 degrees South 16.95 degrees East, in the headwaters of the Kwanza basin. Alternative names for this place are Kuito (currently) or Silva Porta (historically) (Figure 2-6).

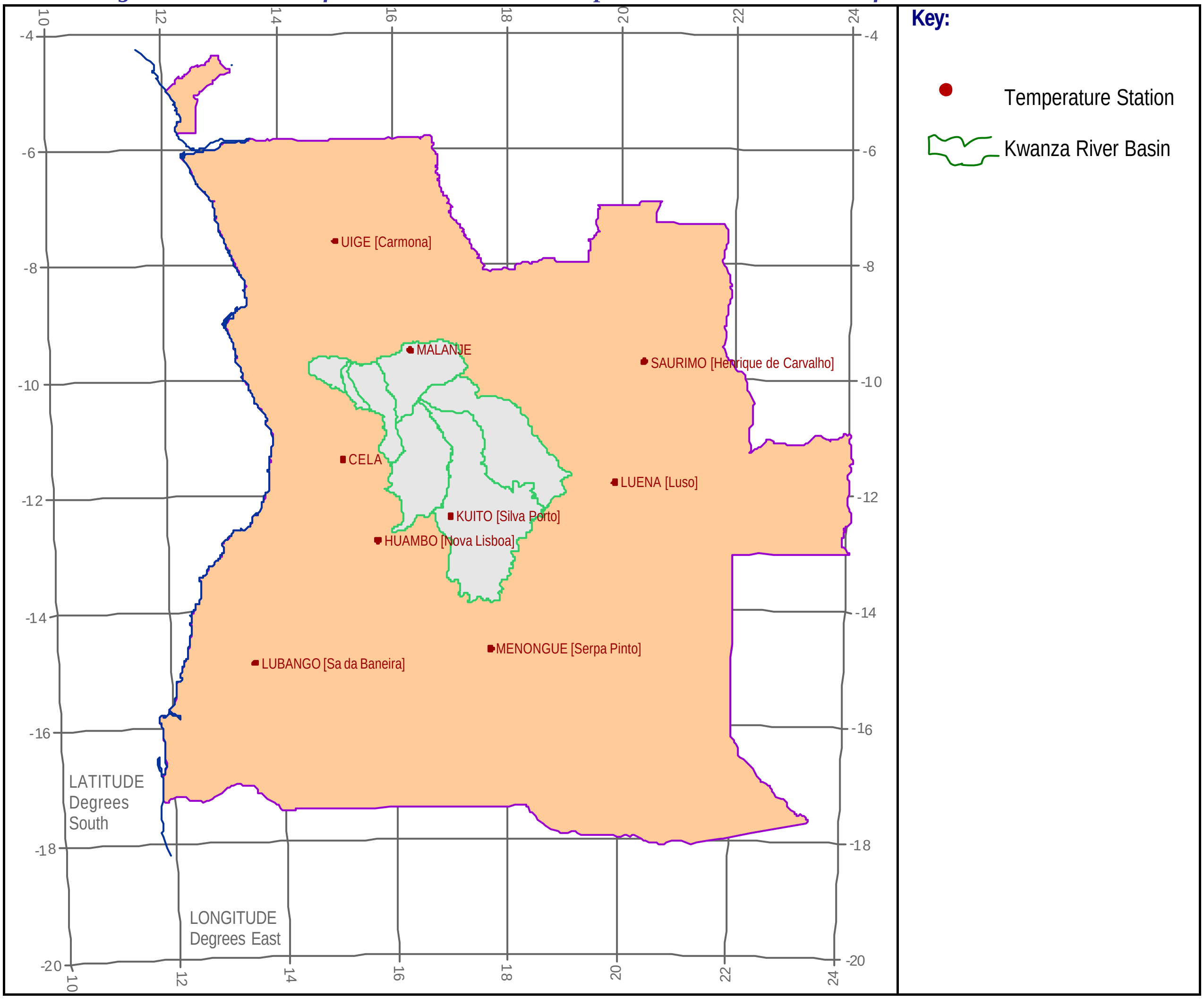
The Climate Research Unit of the University of East Anglia in the United Kingdom maintains a database of climatic variables. Long term averages over standard normal periods, for example, for 1931-60, 1961-90 are retained. Among the variables are temperature, humidity, solar radiation, and windspeed, which are suitable for estimating monthly values of PET for grid squares of 0.5 by 0.5 degree size. Mean monthly values of humidity, solar radiation and windspeed were downloaded for the square containing the Bie location.

The mean monthly values of these three variables were then combined with a long monthly record of temperature spanning the period 1941-1985 to provide a basin wide PET estimate. The same NOAA website from which the rainfall were downloaded was inspected, and several climate station surrounding the Kwanza basin identified (Figure 2-6), which also had monthly temperature records available. The temperature record for Bie was downloaded, and then infilled by comparison with the other records listed in Table 2-8, to provide a continuous 45 year long record. Finally the Penman formula was applied to these temperature, humidity, sunshine hours and wind run records to estimate a long record of monthly PET. The mean annual value was found to be 1512 mm.

Table 2-8 Temperature records available from the NOAA website

Station	Year				
	1940 to 9	1950 to 9	1960 to 9	1970 to 9	1980 to 9
BIE (KUITO)	....	.xXxXXxXXx	xXXXXXXXXx	....	....
CELA	....	xXXXXXXXXx	XXxXXXXXXx	....	....
HUAMBO	.XXXXXXXXX	XXXXXXXXXX	XXXXXXXXXX	XXXXx.XXXX	....
LOBITO	X	XXXXXXXXXX	XXXXXXXXXX	.xxx......	....
LUENA (LUSO)	.xXxXxxxXX	XXXXXXXXXX	XXXXXXXXXX	XXXXx.....	....
MENONGUE	x	xxxXXXXXXX	XXXXXXXXXX	XXXXx.xxxx	....

Figure 2-6 Location of climate stations with temperature records available from NOAA website



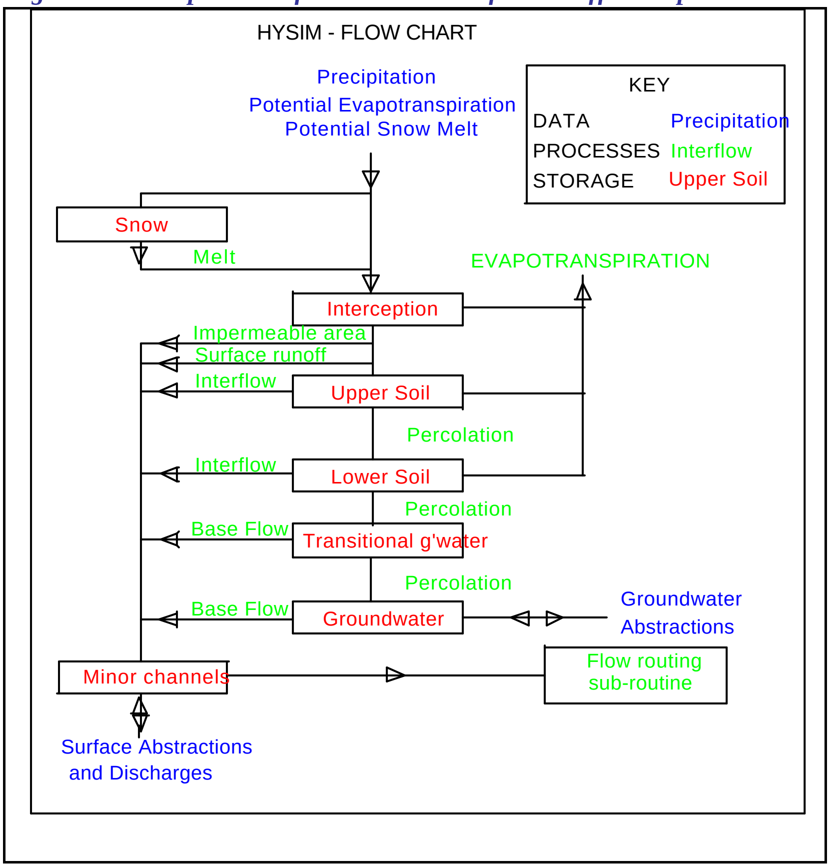
3 Methodology

3-1 Rainfall-runoff modelling

Once the long series of monthly catchment rainfall and potential evapotranspiration have been prepared, the rainfall-runoff model can be applied. Initially the model was calibrated by applying it to the years 1963-74, by adjusting the parameters to ensure the simulated flows are as similar as possible to the observed monthly flow record. Once no further improvement was possible, the long series of monthly records of catchment rainfall and potential evapotranspiration for 1937-1974 were applied to the calibrated model to simulate a 38 year long record of monthly flows.

The HYSIM model was developed in the United Kingdom 25 years ago, and has been extensively improved since then (Figure 3-1). It is capable of being applied using either a daily or monthly time step; the simplified monthly version is termed the HYSIMM model. It has been used in many parts of the world on previous studies, in both humid and semi-arid regions.

Figure 3-1 Components of the HYSIM rainfall-runoff conceptual model



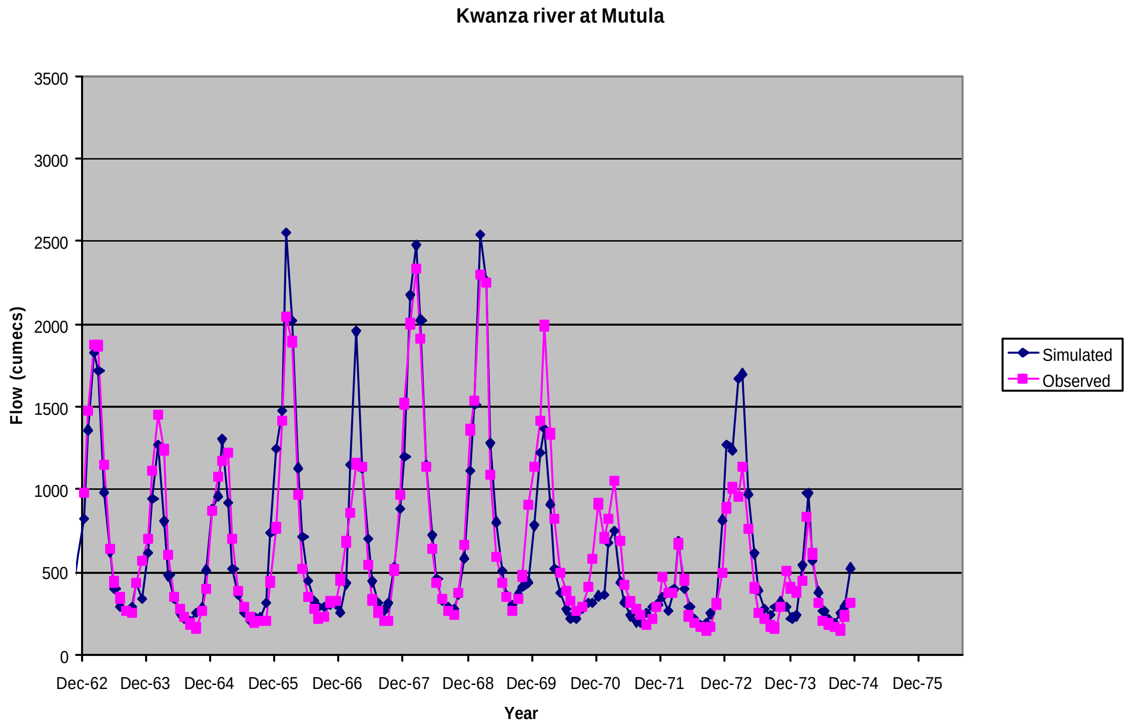
The flow sequence used for calibration was that observed at Mutula gauging station, spanning the years Jan 1963-Dec 1974. The potential evapotranspiration sequence used was that from the Thyolo climate station located in Malawi, with each year's 12 monthly values a repetition of the previous year. A number of different model runs were made, with each one a gradual improvement to those before. The main factor influencing each run was the use of a different rainfall sequence, as listed in Table 3-1.

Table 3-1 Different rainfall sequences used in HYSIMM model

Run No	Source of data	Description of which records used to prepare mean rainfall value	Start month	End month	Record length (years)
1	GPCC	Observed records from 6 primary stations	Jan 1952	Dec 1974	23
2	CRU	Single countrywide record for Angola	Jan 1901	Dec 2000	100
3	NOAA	Infilled records from 6 primary stations	Jan 1937	Dec 1974	38
4	NOAA	Infilled records from 13 stations lying within the basin	Jan 1937	Dec 1974	38
5	NOAA	Infilled records from 22 stations lying both within and surrounding the basin	Jan 1937	Dec 1974	38

Initially the simulated hydrographs prepared gave reasonable estimates of peaks and minimum flow, but were in general too spiky. If the N'hangue hydropower scheme was a run-of-river type, this would be no problem, because the flow duration curve showing frequency of low and medium flow would be of most importance. But because the N'hangue scheme is designed with a large reservoir to sustain the flows to the power house, it is important the simulated flow volumes are as close as possible to those in the observed record. By adjusting the parameters controlling the proportion of flow going to each groundwater store in the model, and also adjusting the two recession parameters, it was possible to match up the simulated and observed flows over the period 1963-1974 (Figure 3-2)

Figure 3-2 Comparison of simulated and observed flows from HYSIMM model run No 5



The model parameter values used in this calibration are shown in Table 3-2. The statistics of fit are shown in Table 3-3. During the course of the successive model runs, the simulated standard deviation had been reduced from 600.0 to 550.9 m^3/s.

Figure 3-3 shows the simulated monthly flows for Kwanza river at Mutula for the 38 year period Jan 1937-Dec 1974. These flows are retained in the computer file Angola HEP\Modelling 22 external 1937-74\Comparison of flows 1937-74.xls. One aspect that may need further improvement is that the lowest flows during the earliest years 1937-1940 are a little too low.

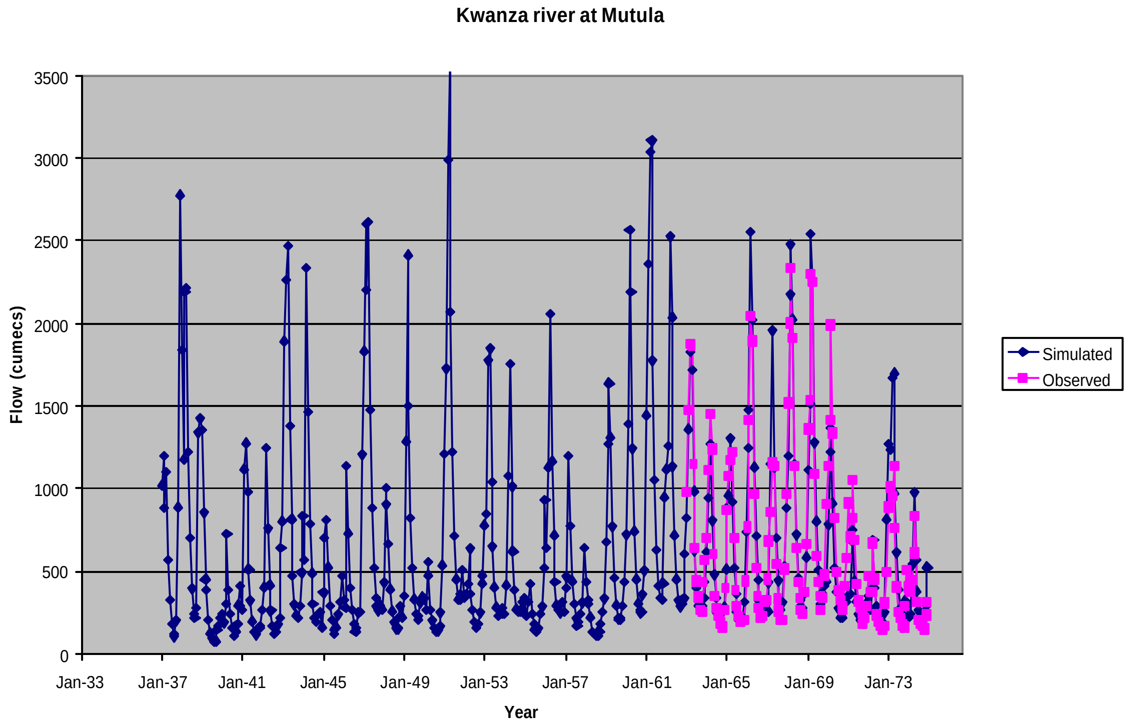
Table 3-2 Final parameter values found for model run No 5

River name	Kwanza
Measuring site	Mutula
Catchment area (km²)	102 611
Proportion impermeable	0.020
Soil storage (mm)	160
Precipitation factor	1.035
PET factor	1.000
Proportion groundwater 1	0.80
Recession groundwater 1	0.55
Proportion groundwater 2	0.25
Recession groundwater 2	0.99
Initial baseflow	700

Table 3-3 Statistics of fit obtained from model calibration run No 5

Statistic	Kwanza river at Mutula
	m³/s
Recorded mean 1963-1974	660.6
Simulated mean 1963-1974	661.5
Recorded standard deviation 1963-1974	525.6
Simulated standard deviation 1963-1974	550.9
Simulated mean 1937-1974	648.1
Simulated standard deviation 1937-74	621.2

Figure 3-3 Simulated flows over period Jan 1937-Dec 1974 from model run No 5



To obtain the corresponding series for the proposed dam site at N'hangue, which is further downstream, the same parameters (Table 3-2) and inflow sequences (basin mean rainfall and PET) were used for the HYSIMM model, but the catchment area value was increased from 102 611 km^2 to 111 000 km^2, equivalent to multiplying the Mutula flows by a factor 1.082. This new area is a little less than the actual catchment area of 112 701 km^2 found previously for N'hangue (Table 2-1); this reduction is to reflect the fact that the average rainfall in the part of the basin lying between Mutula and N'hangue is 1193 mm, which is less than the basin average of 1248 mm, so leading to a reduced runoff contribution. The statistics of the N'hangue dam site series of simulated flows is given in Table 3-4. The simulated monthly flows are retained in the computer file Angola HEP\N'hangue simulation 1937-74\N'hangue-sim.csv.

Table 3-4 Statistics for simulated flow sequence at N'hangue dam site

Statistic	Kwanza river at proposed N'hangue dam site
	m^3/s
Simulated mean 1937-1974	700.8
Simulated standard deviation 1937-74	671.8

3-2 Comparison with other regional rivers

There are a number of other rivers in the region which possess long flow records (Table 3-5), although for a number of reasons their hydrological behaviour is not closely matched to that of the River Kwanza. Some of these records proved difficult to obtain, for example for the Zaire and Ogoone rivers; they are contained on the database operated by the Global Rivers Data Centre, but their use is restricted to research purposes only.

The sequence of low values of monthly runoff in the Kwanza river simulated flow will now be examined and compared with sequences from other rivers in the region to see if they follow a similar pattern. Plots for the Kwanza river were compared with those for the Cunene and Zambezi rivers.

Table 3-5 Records available from other rivers in surrounding region

River	Location	Advantages	Disadvantages
Cunene	South west Angola	Medium length record of 45 years; Headwaters from same plateau as River Kwanza; Similar steepness and size to River Kwanza;	Several large reservoirs in main channel and tributaries; Lower half of basin has much drier climate than Kwanza basin upstream of N'hangue;
Cuito	South East Angola	Long flow series available simulated from rainfall records in Angola; Headwaters from same plateau as R. Kwanza;	Much less steep than Kwanza river;
Zambezi	Western Zambia; North east Namibia;	Medium length records 1949-1993; Headwaters from same plateau as R. Kwanza;	Large basin; Much less steep than River Kwanza;
Zaire	Kinshasa, DRC Congo	Long record 1905-1983.	Extremely large basin; Much less steep than River Kwanza basin; Bi-modal rainfall distribution;
Ogoone	Lambarene, Gabon	Medium length record 1930-1949, 1954-1975	Much less steep than River Kwanza basin; Bi-modal rainfall distribution;
Luangwa	Eastern Zambia	Medium length record 1949-1992;	Much less steep than river Kwanza; Far away from Kwanza basin;
Lake Malawi freewater inflows	Malawi	Long record estimated for 1900-2000. Same latitude at R Kwanza basin. Sensitive barometer of dry and wet year sequences.	Other side of Africa to Angola.

3-2.1 Kwanza river at Mutula

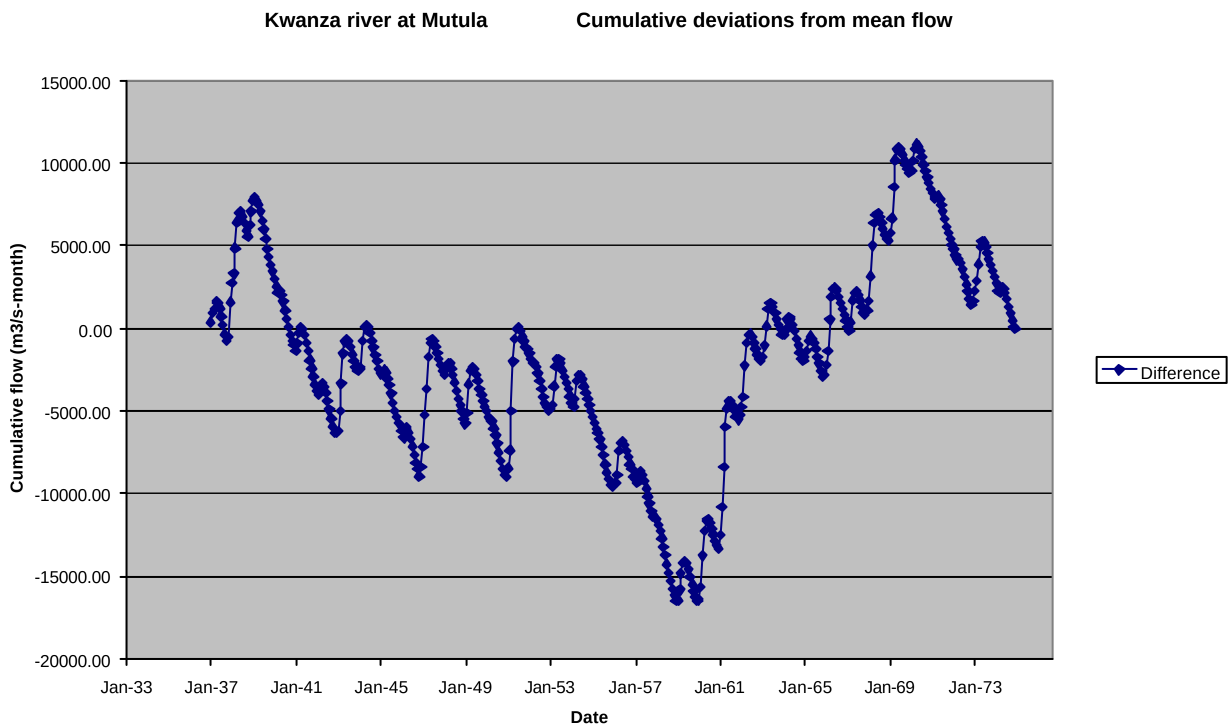
The 38 year long record of simulated flows at Mutula, found in Section 3-1, were now examined in more detail. If the hydropower system was proposed as just a run-of-river scheme it would be sufficient to examine the flow duration curve of these monthly flows to ascertain the reliability of the lowest flows.

But it is proposed that a reservoir would be constructed at the site to ensure that the fluctuations in monthly flows are smoothed out as far as possible, and reliable flows would still supply the hydropower scheme during years of lower than normal flow. The best way to determine the reliability of such flows would be to use the 38 year long record as input to a hydropower simulation production program, and examine different possible configurations of reservoir capacity and turbine flows to determine their optimum sizes.

To obtain an initial idea of which sequences of years will contain the most critical low flows, the following analysis is suggested. First, the mean monthly discharge for the complete period, Jan 1937-Dec 1974, of simulated flow is calculated. Then the cumulative monthly values of simulated flows are compared with the corresponding cumulative monthly values of a series with each month set to the mean monthly flow. The difference between these two series will fluctuate according to whether the simulated flows are in general higher or lower than average at that time, but at the end of the 38 year period the fluctuations will automatically reduce back to a value of zero.

Such a graph is presented for the Kwanza river at Mutula in Figure 3-4. Since the basin area at this location forms 91.0 % of the total basin area down to the N'hangue dam site, it will present a very similar picture to the fluctuations at the proposed dam site.

Figure 3-4 Cumulative deviations from mean flow Jan 1937-Dec 1974 for Kwanza river at Mutula



If the plot is either oscillating about the horizontal or increasing, this shows there is adequate inflow to the proposed reservoir. For example, the virtually unbroken 12 year long period from Jan 1959-Dec 1970 of average or above average inflows is well highlighted.

Dry spells with inadequate inflows to the proposed reservoir are highlighted by a steady decline in the plotted line lasting two or more years. The following longer periods stand out, although there are other individual years when flows are inadequate

Dec 1939-Dec 1942
Dec 1944-Dec 1946
Dec 1956-Dec 1958
Dec 1970-Dec 1972

During their prefeasibility studies using the 12 year observed flow records for Jan 1963-Dec 1974 on the Kwanza river, Norconsult had already identified the same period Dec 1970-Dec 1972 as being one of the critical periods with low inflow to the reservoir. One of their main concerns was whether other similar low flow periods occurred outside the 12 year period. It may be concluded that in a simulated record of monthly flows just over three times as long as the observed record, there are four sustained periods of inadequate flows, though none lasted more than three years long.

The other pertinent point is that, of the 12 years of observed flows used in the prefeasibility study, eight of them fell within the period of sustained flows Jan 1959-Dec 1970 identified in the plot.

3-2.2 Cunene river at Ruacana

There is only one hydrologically similar large neighbouring basin, the Cunene River, which has its headwaters on the same high plateau as the River Kwanza, and then drops steeply down to the Atlantic Ocean. The basin area upstream of Iacavala gauging station in Angola is 91 052 km^2, which is of a similar size to the 110 000 km^2 upstream of the N'hangue dam in the Kwanza basin. There is also a station on the River Cunene in Namibia at Ruacana with basin area of 91 815 km^2. However a noticeable difference to the River Kwanza basin upstream of N'hangue is that the lower half of this River Cunene basin upstream of Iacavala has a much drier climate.

Although the natural streams in the headwaters of the River Cunene are considered to behave hydrologically in a similar way to those of the River Kwanza, the flows will be materially altered by a number of reservoirs within the basin. These include the large Gove scheme near Huambo, the Matala scheme further downstream, and also new dams constructed in recent years on the River Caculuvar tributary.

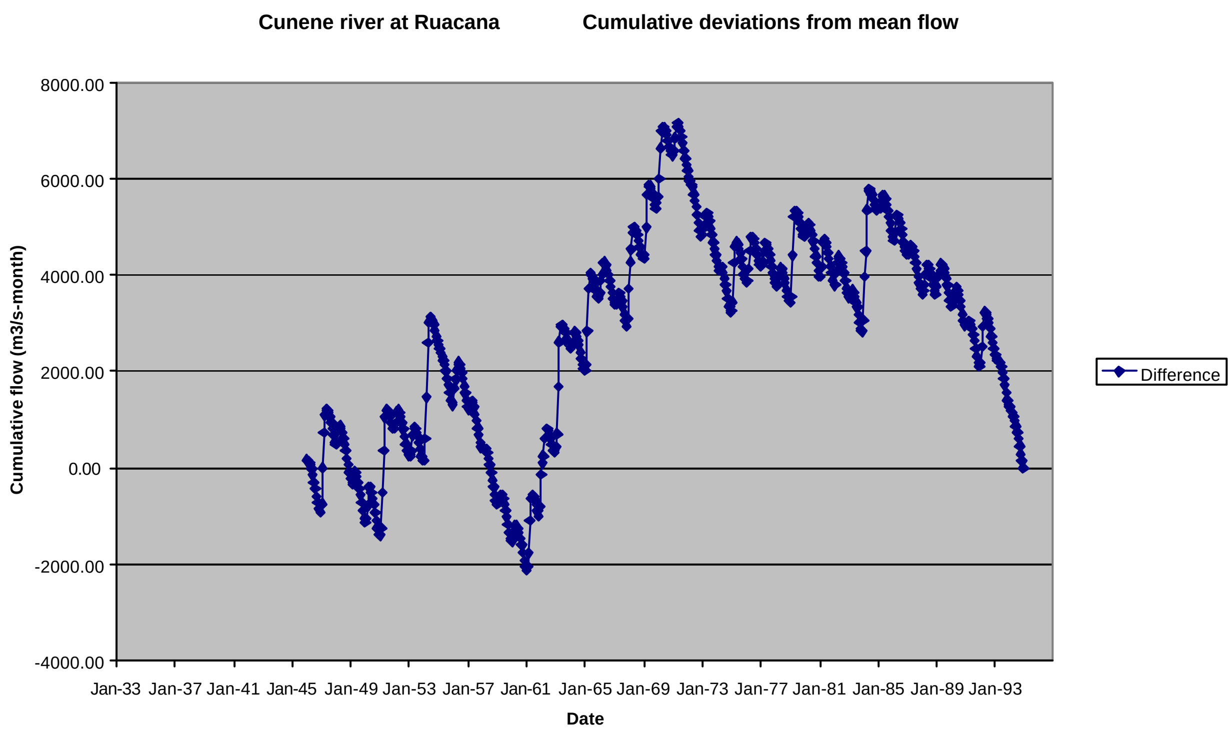
During the Feasibility Study of the hydropower scheme at the Epupa Falls on the Cunene river, undertaken by Norconsult in 1995-96, a 50 year record of natural monthly flows were estimated for the period Oct 1945-Sep 1995. This was done by correlating a short length (Oct 1961-Sep 1973) of reliable flows, observed on the Cunene river at Ruacana, with a much longer period of observed flows on the Okavango river at Rundu. The 50 years of observed flows on the Okavango river were used together with the correlation to extend the Cunene flow record.

The Okavango river rises on the plateau in central Angola, where it is formed of two main tributaries named the Cubango and Cuito rivers. The headwaters of the Cubango tributary lie just to the east of the headwaters of the Cunene river, and it is likely that this is the reason there is found to be such a good correlation between the annual flows from these two rivers.

The headwaters of the Kwanza basin lie just to the north of the headwaters of the Cubango and Cuito rivers, although flowing directly north-west, rather than south-east for the latter rivers.

Therefore there should be some relation between the fluctuations of flows in the Rundu and Kwanza rivers, even it is not as strong as the relation between the Rundu and Cunene rivers. For this reason the 50 year record of estimated flows on the Cunene was subjected to the same analysis as that already done for the Kwanza simulated flows, and the plot of differences in cumulative flows is shown in Figure 3-5

Figure 3-5 Cumulative deviations from mean flow Oct 1945-Sep1995 for Cunene river at Ruacana



One immediately noticeable feature of the plot is the sustained rising portion between Jan 1961 and Dec 1971. This indicates years when the inflow to the reservoir is either adequate or more than adequate. Although the start and finish months do not exactly coincide with those found for the Kwanza river plot (Jan 1959-Dec 1970), the absence of any intervening low flow sequences in this 11 year long period is remarkable.

Inspection of the plot reveals the following periods when the plot is noticeably deceasing, which indicates that inflows to a reservoir located on this river would not be adequate:

Dec 1954-Dec 1955
Dec 1956-Dec 1958

Dec 1971-Dec 1972
Dec 1973-Dec 1974

Dec 1982-Dec 1983

Dec 1986-Dec 1987

Dec 1990-Dec 1991
Dec 1992-Dec 1994

The periods in the 1950s and 1970s are similar, though not identical, to such periods already found for the simulated flows for the Kwanza river, and tend to confirm the problems of inadequate inflows on the Kwanza during those times. However the steep drop in the early 1990s on the Cunene river plot was not recorded on the Kwanza river plot because the latter ended on Dec 1974. It can be surmised that almost certainly the Kwanza river would have insufficient inflows in the 1990s. This means that in the 60 year period from 1940-2000, there were, in general, four periods of insufficient flows, namely in the 1940s, 1950s, 1970s and 1990s.

3-2.3 Zambezi river at Senanga

The upper reaches of the Zambezi river drain the eastern region of Angola and the western region of Zambia. Its tributaries in Angola adjoin the headwaters of the Kwanza river, so there should be some relationship between the two basins regarding the sequence of wet and dry years, although it may not be too strong.

There were two river gauging stations available with monthly flow records (Table 3-6). The catchment of the Zambezi basin at the Lukulu gauging station is about twice that of the Kwanza basin at Mutula, and that of the Senanga station is about three times as large.

Table 3-6 Observed river flow records available on the Zambezi river

Station No	60370030	60370001
River name	Zambezi	Zambezi
Station name	Lukulu	Senanga
Latitude	14 degrees 23' 0" S	16 degrees 07' 0" S
Longitude	23 degrees 14' 0" E	23 degrees 15' 0" E
Altitude	-	-
Catchment Area	212 450 km^2	290 572 km^2
Start date of months data	Oct 1950	Mar 1950
End date of months data	Sep 1987	Aug 1992

Because the Senanga record appeared to be the more complete of the two, it was selected. However on closer inspection doubts were raised about the period from Oct 1978 onwards, so these were excluded from subsequent analysis. Consequently the period Oct 1950-Sep 1978 was subjected to the same cumulative runoff analysis (Figure 3-6) as had been applied previously to the simulated Kwanza river record and the estimated Cunene river flow record.

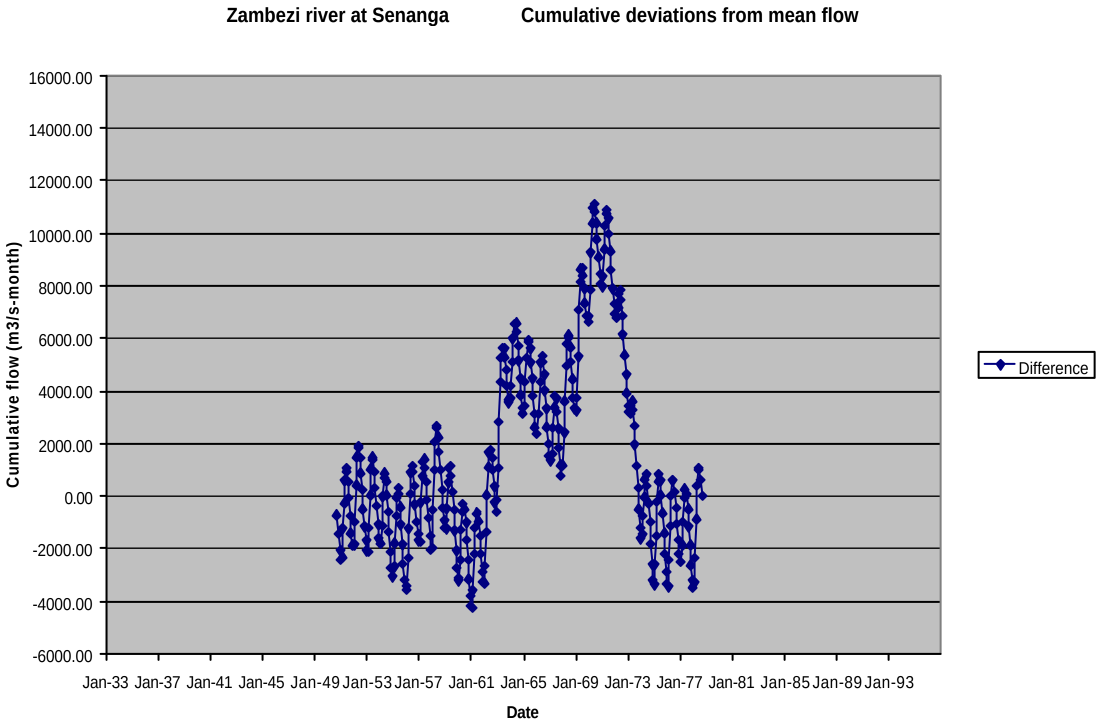
The plotted line is generally oscillating about the horizontal or increasing between the dates Feb 1961 to Jun 1971, which shows there is adequate inflow during this period. There are two periods of three years each in which the plot is increasing rapidly: Feb 1961-Jul 1963 and Dec 1967-Jun 1971. In this respect the plot is very similar to that found for the Cunene river at Ruacana (Figure 3-5).

During the period Jun 1971 to Jan 1975 the plotted line is generally decreasing, with a steep drop between Dec 1971 and Dec 1973. The same low flow period identified on both the Kwanza and Cunene river plots also occurs for the Zambezi river, though the dates do not match up exactly.

The low flow period from Dec 1956-Dec 1958 that was identified on both the Kwanza and Cunene river plots does not appear to occur for the Zambezi river at Senanga.

It is recommended that some further work could be done to compare cumulative runoff plots from the two Zambezi stations, with a view to extending the plot from Oct 1978 onwards and checking the quality of their corresponding data during this particular period.

Figure 3-6 Cumulative deviations from mean flow Oct 1950-Sep1978 for Zambezi river at Senanga



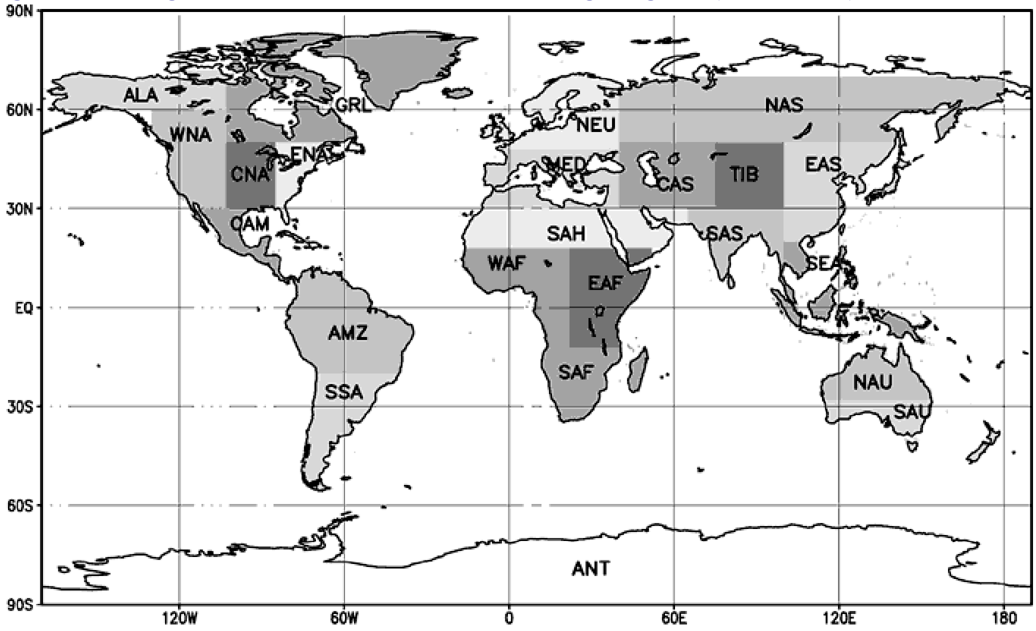
4 Future changes in runoff in Kwanza basin

4-1 *Climate change*

The possibility of climate change has created growing concern both among scientists, business people and politicians. The consequences of climate change may be serious, and in particular water resources are highly vulnerable to such changes.

The best source of information about climate change can be found in the reports prepared by the Intergovernmental Panel on Climate Change (IPCC). One of their major works was *Climate Change 2002 Impacts, Adaptions and Vulnerability (IPCC, 2001)*. The analysis undertaken in the *IPCC Report* is divided into 23 regions (Figure 4-1*)*. This map shows that the Kwanza basin falls on the border between the West Africa and Southern Africa regions.

Figure 4-1 Intergovernmental Panel on Climate Change Regions (IPCC, 2001)



ALA	Alaska	NEU	Northern Europe	NAS	Northern Asia
WNA	Western North America	MED	Mediterranean	TIB	Tibet
CNA	Central North America	CAS	Central Asia	EAS	Eastern Asia
ENA	Eastern North America	SAH	Sahara	SAS	Southern Asia
GRL	Greenland	WAF	West Africa	SEA	South East Asia
CAM	Central America	EAF	East Africa	NAU	Northern Australia
AMZ	Amazonia	SAF	Southern Africa	SAU	Southern Australia
SSA	Southern South America	ANT	Antarctic		

A review was undertaken of a number of climate change papers which are relevant to the study area, as listed below. From these the aim was to determine whether the rainfall is likely to increase or decrease over the Kwanza basin in the longer term.

i) Hulme (1996)

In this study the baseline period was assumed to be 1961-1990, and the forecast moment in the future as 2050 AD. The general conclusion is that rainfall will decrease for those regions located from the 12 degree latitude meridian southwards. Remaining areas will experience increases in rainfall. The Kwanza basin is split in two by the 12 degree latitude grid line. This forecast is based on the HadCM1 general circulation model.

ii) Rageb and Prudhomme (2000)

This report examined the Southern African region, one of the 23 regions of the world demarcated by the Intergovernmental Panel on Climate Change (IPCC), as shown in Figure 4-1. The forecast moment in time was 2050 AD. The report states that in the northern part of this region, where the Kwanza basin is located, the rainfall will decrease in future by 5-10%. This forecast was based on the HadCM2 general circulation model. The report also mentioned that the temperature will increase in this particular region by 2.5-3.0 degrees C during the same period.

iii) Hulme et al (2001)

This report, and any relevant more up-to-date reports, have been requested from Professor Mike Hulme of the Climate Research Unit at the University of East Anglia, but at the time of writing have not yet been received. They will be reviewed in due course.

iv) CSAG (2002)

This report includes a small map which shows that the Kwanza basin lies in an area where there is a predicted drop in precipitation of up to 10% in the last quarter of the 21st century, compared with the baseline period 1978-1998. However the basin lies close to the boundary line which separates the two areas which are demarcated as -10% and +10% change in future precipitation.

It is difficult to draw firm conclusions from these four sources regarding future changes to the rainfall regime over the Kwanza basin. This is because the basin lies close to the line which separates those regions with increasing rainfall in future and those with decreasing rainfall. On balance, it appears more likely that the rainfall over the Kwanza will decrease, rather than increase. But to place a specific percentage difference on this change is even more difficult, and at present it is only possible to say that the decrease lies in the range 0 % – 10%.

It is recommended that an expert on climate change in southern Africa is engaged to assist with this assessment, during the next phase of the hydrology studies. This is because even a small percentage decrease in rainfall will lead to a much larger decrease in river flow (Section 4-2). However the calibrated HYSIMM rainfall-runoff model does allow this change in rainfall to be converted to the corresponding change in flows in the Kwanza river. It should be possible to rerun the rainfall-runoff model used earlier with the long series of input rainfall adjusted by a suitable factor for climate change, to obtain a long series of modified simulated flows. These could be applied to the hydropower simulation program to see what difference arise.

4-2 Relation between annual rainfall and runoff

The results of the long term simulation of the Kwanza basin at N'hangue for the period Jan 1937 – Dec 1974, described in Section 3-1, were examined, and the values for the most important variables abstracted (Table 4-1).

The mean annual value of the simulated discharge was found to be 648.1 m^3/s, which is equivalent to a mean annual runoff of 199 mm for a basin area of 102,611 km^2. In this simulation the rainfall is determined as the average of the individual records from 22 raingauges, which have been extended by correlation to the full period 38 year period. The mean annual rainfall was found to be 1248 mm, which, together with a value of 1.035 for the Precipitation Correction Factor parameter, suggests the rainfall actually falling over the complete basin was of the order of 1292 mm. The actual evapotranspiration value of 1093 mm is found as the difference between these two individual rainfall and runoff values. Its value forms 76.6 % of the potential evapotranpiration value of 1427 mm.

Table 4-1 Mean values of the main variables for simulations over period 1937-1974

Variable	Mean annual value (mm)
Runoff	199
Rainfall	1292
Actual evapotranspiration	1093
Potential evapotranspiration	1427

In order to determine what changes will occur in annual runoff due to small increases or decreases in long term annual rainfall, a countrywide relationship is needed between these two variables for Angola. *The Rapid Water Resources and Water Use Assessment of Angola* conducted by Sweco Groener in 2005 collected rainfall and runoff data for 93 sub-basins, but used the data to draw up a map of the variation of runoff coefficient throughout the country, and this was applied to the mean annual rainfall in that part of the country.

In the absence of such a relation for Angola, use will be made of a relation obtained for Malawi. Because these catchments in Malawi possess the same ranges in altitude, latitude, annual rainfall and landcover, as the tributaries in the River Kwanza basin in Angola, it is felt reasonable to assume that this relation can also be applied there. Hill and Kidd (1980) examined the values for 47 catchments, and determined that annual runoff AAY is broadly related to annual rainfall AAR by the relation

$$AAY = 0.71\ AAR - 490$$

with correlation coefficient R = 0.93 and standard error of estimate s.e.e.= 90 mm.

Retaining the same coefficient 0.71 but modifying the constant to a value of 718.3, it is suggested a first estimate for the similar relation for Angola could be

$$AAY = 0.71\ AAR - 718.3$$

If the rainfall over the Kwanza basin is allowed to vary in the range -10% to +10% of its mean annual value of 1292 mm, this relation can be used to estimate the corresponding changes in the runoff (Table 4-2)

Table 4-2 Variations in runoff due to changes in rainfall for Kwanza basin

Variable					Mean value				
% change in rainfall	-10	-7.5	-5.0	-2.5	0.0	+2.5	+5.0	+7.5	+10.0
Rainfall (mm)	1162.8	1195.1	1227.4	1259.7	1292.0	1324.3	1356.6	1388.9	1421.2
Runoff (mm)	107.3	130.2	153.2	176.1	199.0	222.0	244.9	267.8	290.8
% change in runoff	-46.1	-34.6	-23.0	-11.5	0.0	+11.6	+23.1	+34.6	+46.1
Ratio between % changes in runoff and rainfall	4.61	4.61	4.60	4.60		4.64	4.62	4.61	4.61

It will be seen from the table that there constant ratio between the percentage change in the runoff compared with the percentage change in the rainfall, of the order of 4.6. The exact value of this ratio is less important than its magnitude. It shows that even small variations in long term rainfall will cause much larger changes in runoff values. This is the reason that climate change is so important to water resources assessment in this part of Africa, though it can be shown it is even more important in the drier parts of the region in places such as Botswana and western South Africa, where values of mean annual rainfall and runoff are much less than those in Angola.

This ratio 4.61 is determined from the formula

(Coefficient in countrywide relation) x (Mean annual rainfall)/(Mean annual runoff)

= 0.71 x 1292 / 199 = 4.61

The values of mean annual rainfall 1292 mm and mean annual runoff 199 mm for the Kwanza basin are essentially fixed, so the ratio depends on the estimate of the coefficient 0.71 deduced from the Malawi relationship. While this coefficient might actually lie in the range 0.6 – 0.8, it can be seen that the same principle applies whatever the value, and runoff values, expressed as percentages, will vary much more that the rainfall variations, also expressed as percentages.

In future it may be possible to draw up a more precise rainfall-runoff relation for Angola, by making use of the data collected for the 93 sub-basins during *A Rapid Water Resources and Water Use Assessment of Angola*. If these data are presented in one of the appendices of that report, it should be possible to plot their values against each other, and fit a linear relation through them, in the same way as was done for those from Malawi.

5 Conclusions

i) Preliminary checks indicated that, in general, the flow data available for this study were of a good standard. Two short periods of continuous flow records on the Kwanza river at two separate locations at Quissaquina (Jun 1966-Sep 1975) and Mutula (Dec 1962-Mar 1975) were provided by the Client. Comparison of the overlapping period of eight years indicated very close agreement between their monthly hydrographs.

ii) Historical monthly rainfall records for Angola were available for downloading from three websites. From the German GPCC site long monthly records were available for 7 primary rainfall stations for the period Jan 1951 – Dec 2004. However tests revealed that the quality deteriorated severely after 1975, and use was made of only the records for Jan 1952-Dec 1974 in initial model simulations.

The CRU website provided a single 100 year monthly rainfall record for the whole of Angola, spanning the period Jan 1901-Dec 2000. Analysis showed that the mean annual value of this record was more than 11% lower than that from the GPCC mean record, so was not representative of the rainfall falling over the plateau region where the Kwanza basin is located.

From the American NOAA website, monthly records from 104 rainfall stations in Angola were available. Of these, 28 stations of interest to this study were downloaded, of which 11 lay within the Kwanza basin itself. Tests revealed that records from 1975 onwards were patchy, so these years were excluded from further analysis, but it was also possible to find 5 stations with virtually continuous records stretching back from 1974 to 1940, with 2 stations starting in Jan 1937. Only one out of the 28 stations needed to be excluded because of obvious poor quality of data. For the remaining 27 stations the missing periods of data were infilled successfully by correlation with the records from the most suitable neighbouring stations, and all their records extended to the full 38 year period, using the special module included within the HYSIMM rainfall-runoff model package for this purpose.

iii) Two sources of potential evapotranspiration data were examined. Initially use was made of a previous study of evaporation in Malawi, a country which has similar ranges of altitude, latitude and annual rainfall totals to those occurring in Angola. The monthly mean values of Penman short grass potential evapotranspiration were abstracted for a climate station at Thyolo, and these were replicated for each of the years between 1937 and 1974 to provide a suitable 38 year long record suitable for use over the Kwanza basin. This Thyolo station lies in the tea-growing area of southern Malawi, with a mean annual rainfall of 1229 mm, and a moist climate for 10 out of the 12 months of the year; in this respect it is considered to possess a local climate similar to that of Huambo on the Angolan plateau.

Selection of the Thyolo record ensured that the modelling procedures could start without delay. Later during the study, a potential evapotranspiration record was estimated for the climate station at Bie (Kuito) using only Angolan-sourced climate data. Mean monthly values of humidity, sunshine hours and windspeed were obtained from the CRU website, while long series of individual months of temperature data were downloaded from the NOAA website. Gaps in this temperature record were infilled from similar NOAA temperature records for the neighbouring climate stations of Cela, Lobito, Huambo, Luena and Menongue.

iv) The quality of the rainfall, flow and potential evapotranspiration monthly records were sufficiently good to allow the calibration of the HYSIMM rainfall-runoff model on the observed flows at Mutula gauging station over the period Jan 1963-Dec 1974. A basin-wide version of the model was employed, with areal rainfall determined as the mean of 22 individual infilled rainfall records. The longer rainfall records available were then used as input to this calibrated model to produce a 38 year long record of simulated flows at the proposed N'hangue dam site, after a suitable 8.2 % adjustment for the difference in relevant basin areas.

v) The hydropower simulations at N'hangue dam site undertaken by the Client during their prefeasibility study were based on the observed flow record 1963-74 on the Kwanza river. They had noted that for certain years in the early 1970s the inflows to the proposed N'hangue reservoir were lower than normal, and insufficient to produce the required power output and replenish the reservoir levels. One of the main questions for this present study was to see whether similar low flow periods existed outside the period 1963-74.

The simulated flow record Jan 1937-Dec 1974, produced by the HYSIMM rainfall-runoff model during the current study, confirmed that similar low flow periods occurred both in the 1940s and separately in the 1950s.

Comparison with other simulated and observed flow records in the region confirmed that similar low flow periods occurred in the 1950s and 1970s, with further periods in the 1990s. A noticeable feature of all the records was that higher than average flows occurred for a sustained period of about ten years during the 1960s.

vi) Using a countrywide relationship between mean annual rainfall and runoff for Malawi, and modifying it for Angolan conditions, showed that the percentage change in runoff depended directly on the percentage change in rainfall, if there was any long term change in rainfall due to climate change. For the Kwanza basin, where the mean annual rainfall is about 1292 mm, and mean annual runoff 199 mm, it can be shown that the relevant multiplying factor is of the order of 4.6.

This means that if the long term rainfall over the Kwanza basin declines by 3 %, the corresponding decline in long term runoff will be approximately 13.8 %. A 5 % increase in long term rainfall would result in approximately a 23 % increase in runoff. This emphasises the point that slight changes in rainfall regime in the future are very critical to the potential power output of the proposed N'hangue hydropower scheme.

vii) There is not much scope for extending the plateau rainfall records backwards before Jan 1937. There is one station in the far south of the country at Pereira d'Eca with continuous records starting in Apr 1932, but this is not located on the plateau and is in a much drier area, so would only give a tenuous correlation with the plateau rainfall records. There are also some stations along the coastal strip with records extending back before 1900, such as Luanda (starting in Jan 1894), but it is considered that these stations possess a quite different climate to that of the plateau, so cannot be used to extend the records of the latter stations.

Attempting to extend the historical rainfall records forward from Jan 1975 may be worth revisiting. Six primary stations out of the 27 considered have records for at least part of this period, with three ending in Dec 1989. This gives the possibility of adding a further 15 years of monthly rainfall values to the 38 years considered in this initial study. But there are two separate periods of 5-6 months during which none of the 6 stations possess records, so some way round this problem would need to be sort.

6 Recommendations

i) During this preliminary study the calibration of the HYSIMM rainfall-runoff model was applied as a single basin-wide version to the Kwanza river at Mutula. The areal rainfall for the basin was determined as just the mean of the 22 individual rainfall records that covered the basin. This initial simple approach gave promising results, and suggests that further improvements would be worthwhile.

The coverage of these 22 rainfall stations is sufficiently dense and complete over the Kwanza basin, particularly in the runoff-producing headwaters, to allow the possibility of breaking up the main basin into a limited number of sub-basins. However a balance needs to be struck, as selection of too many sub-basins would render the areal rainfall estimate over each one too imprecise. It does appear that the mean annual rainfall is higher in the south-west and north-east of the basin, with a strip with slightly lower rainfall running from south to north between them. Rainfall in the downstream part of the basin between Mutula and N'hangue also appears lower.

Bearing in mind the layout of the main tributary streams in the basin, a possible arrangement of suitable sub-basins is shown in Figure 2-1. The areas of each sub-basin are given in Table 6-1.

Table 6-1 Possible division of Kwanza basin into 5 sub-basins

Sub-basin name	Sub-basin area	Cumulative basin area	Mean annual rainfall for each sub-basin Jan 1937 - Dec 1974
	km^2	km^2	mm
Luando	28 686	-	1298
Upper Kwanza	40 787	-	1199
Cutato	19 477	88 950	1305
Malanje	13 661	102 611	1239
N'hangue	10 090	112 701	1193

This arrangement allows between 5 or 6 individual rainfall stations to be allocated to each sub-basin, with some stations allocated to more than one sub-basin. Using the 22 infilled rainfall station records, the areal monthly rainfall for each sub-basin has already been determined for the period Jan 1937-Dec 1974, with the mean values shown in Table 6-1.

Previous experience with using the HYSIMM model has shown that determining the flows at the basin outlet by summing the simulated flows from several sub-basins is usually more effective than applying a single basin-wide model over the same time period. This is because the sub-basins take account of the areal variations of rainfall occurring over different parts of the basin.

The HYSIMM model allows a configuration in which up to 3 separate upstream sub-basins flow into a single downstream sub-basin. For the Kwanza basin the downstream sub-basin could be taken as that of Malanje, with the upstream sub-basins taken as Luando, Upper Kwanza and Cutato (Figure 2-1). A common set of parameters could be adopted for all 4 sub-basins, with just the catchment area differing. This would first allow a calibration of the recorded flows at Mutula. A second version of the model could then be adopted with the N'hangue sub-basin as the downstream sub-basin, and the upstream sub-basin represented by the flows at Mutula. This would allow simulation of the flows at N'hangue dam site. Sufficient data is currently available to undertake this type of analysis.

If further information is available about the behaviour of individual sub-basins, then even further improvements to the overall calibration are possible. *A Rapid Water Resources and Water Use Assessment of Angola*, conducted by Sweco Groener in March 2005, mentions short periods of usable flow records being currently available at 93 flow stations in Angola. Of these, there are a selection which are located in the Kwanza basin, with sufficiently large catchment areas to be of interest during the next stage of investigations (Table 6-2). Efforts could be made to obtain monthly flow records for these stations, particularly for the 5 stations at N'harea, Cauisso, Cangandala, Lucunga and Cutato Andulo, which are mainly located near the outlets of the individual sub-basins or combinations of them. It is possible that these records might be available in the appendices of *A Rapid Water Resources and Water Use Assessment of Angola*, otherwise the Angolan authorities would need to be approached.

Table 6-2 Stations for which monthly flow records should be obtained in future

Station No	River	Station Name	Catchment area
			Km2
601 930	Kwanza	Lucala KM34	22 619
601 942	Kwanza	N'harea	35 679
601 906	Kwanza	Cauisso	61 175
601 944	Kwanza	Cangandala	93 169
601 908	Kwanza	Cambambe	115 658
601 958	Jombo	Rimba Luquembo	5 573
601 935	Luando	Lucunga	27 776
601 917	Cutato	Cutato Andulo	7 936
601 929	Gango	Gango	2 737
601 946	Cuije	Ponte de Cuije	3 777

ii) The main text of *A Rapid Water Resources and Water Use Assessment of Angola* (2005) mentioned that average values of rainfall and runoff had been collected for 93 sub-catchments throughout the country. These values had been used to determine the runoff coefficient for each of these sub-catchments. However the same values could be used to prepare a plot of mean annual runoff against mean annual rainfall, from which the provisional relation used in Section 4-2 of this study, based on a comparison with the same relation in Malawi, could be considerably improved.

It is recommended that the appendix volumes of that report are searched for this information.

iii) During the Feasibility Study of the hydropower scheme at the Epupa falls on the Cunene river, a 50 year record of natural monthly flows was estimated for the period Oct 1945-Sep 1995. This was done by correlating a short length of observed flow on the Cunene river at Ruacana with observed flows on the Okavango river at Rundu. The 50 years observed flows on the Okavango river was then used with the correlation to extend the Cunene flow record.

The Okavango river rises on the plateau in central Angola, where it is formed of two main tributaries named the Cubango and Cuito rivers. The headwaters of the Cubango tributary lie just to the east of the headwaters of the Cunene river, and it is likely that this is the reason there is found to be such a good correlation between the annual flows from these two rivers.

The headwaters of the Kwanza basin lie just to the north of the headwaters of the Cubango and Cuito rivers, although flowing directly north-west, rather than south-east for the latter rivers. For this reason it is suggested that, during the next stage of this study, the possible correlation between the short lengths of mutual flow records on the Kwanza river at Mutula and Okavango river at Rundu should be examined. It is not anticipated that the relation will be as strong as that between the Cunene and Rundu, but it might be sufficient to consider extending the Mutula record to the same number of years as those recorded on the Rundu.

The Okavango river at Rundu is operated by the Department of Water Affairs in Namibia, and they could be approached to assist with provision of records. If the original flow record for Oct 1945-Sep 1995 is still available in Norconsult's office, then it would be sufficient to obtain an updated record Oct 1995 to at least Dec 2006. This might allow a long flow record Oct 1945-Dec 2006 to be estimated for Mutula. This would allow an additional period Jan 1975-Dec 2006 to be found for the simulated flows at N'hangue, extending the complete flow record there from 38 years to 70 years.

One slight disadvantage of this approach, compared to the rainfall-runoff model adopted in this initial study, is that it is more difficult to integrate the effects of possible future changes to rainfall arising from climate change, and their consequent effects on runoff.

iv) The delineation of the catchment areas for the 4 sub-basins upstream of Mutula gauging station could be improved by abstracting their areas from the Operational Navigation Charts published by NIMA in the USA at a scale of 1:1 000 000. Charts ONC N-3 and N-4 are already available to do this work. However these sub-basins were not actually used during the present study.

v) Some further work is needed to process and tidy up the potential evapotranspiration estimates that are based on data from Angola. When this is complete, this PET series should be used in the rainfall-runoff modelling instead of the series based on the Thyolo climate station in Malawi.

vi) It is recommended that an expert on climate change in southern Africa is engaged for the next phase of the hydrology studies, to determine as precisely as possible the percentage change in future rainfall over the Kwanza basin. The calibrated rainfall-runoff model will then allow this rainfall change to be converted to a corresponding change in river flows at the N'hangue dam site.

vii) It is recommended that some further work could be done to compare cumulative runoff plots from the two Zambezi river flow stations, with a view to extending the plot from Oct 1978 onwards.

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Appendix A Monthly rainfall records from colonial archives in Lisbon held by Water Resource Associates

Rainfall data: at stations in or close to the
Kubango River basin, Angola

No data: -
Monthly mean, mm: *** in Anuario Climatologico de Portugal
AAA in Elementos Meteorologicos e Climatologicos, Luanda, Angola.
BBB in Boletim Oficial da Colonia de Angola.
CCC in Anais Meteorologicos das Colonias
DDD in Observações Meteorológicas de Superfície em Angola.

Name	Lati-tude S	Longi-tude E	Filename	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
Luanda	08º48	13º13	iucn01.wr1	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	-
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Nana Candundo	11º31	23º01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Luacano	11º32	22º02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lovua	11º32	23º55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Andulo	11º40	16º32	iucn01.wr1	-	-	BBB	CCC	CCC	BBB	-	-	-	-	-	AAA	-	AAA	AAA	CCC	AAA	AAA	AAA	-	-	-	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Vila Luso	11º47	19º55	iucn01.wr1	-	-	-	-	-	-	-	AAA	AAA	-	AAA	CCC	CCC	CCC	CCC	CCC	CCC	CCC	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	-
Cazombo	11º53	22º54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vila General Machado	12º02	17º25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ganda	12º05	14º32	iucn01.wr1	-	-	-	-	-	-	BBB	BBB	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Coemba	12º06	17º42	iucn01.wr1	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Calunda	12º07	23º28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vila Teixeira da Silva	12º10	15º50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Munhango, CFB	12º10	18º47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lobito	12º19	13º35	iucn01.wr1	-	-	BBB	BBB	BBB	BBB	BBB	BBB	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	-
Silva Porto	12º21	16º54	iucn01.wr1	BBB	CCC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Ceilunga	12º22	16º54	iucn01.wr1	-	-	-	-	-	-	-	-	-	-	AAA	-	-	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Bela Vista	12º34	16º17		-	-	-	-	-	-	-	-	-	-	-	-	CCC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macondo	12º34	23º46	iucn01.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	DDD	DDD	DDD	-	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-	-	-
Lumbala	12º39	22º34	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-
Rio Chipia	12º45	15º35	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	AAA	CCC	CCC	CCC	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-
Nova Lisboa(Huambo)	12º46	15º44	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	CCC	CCC	CCC	CCC	CCC	CCC	CCC	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
T'Chenga (Chenga)	12º54	15º12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	CCC	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cuima	13º15	15º41	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	AAA	CCC	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Chitembo	13º31	16º45	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	AAA	CCC	CCC	-	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Cangamba	13º41	19º52	iucn02.wr1	CCC	CCC	-	BBB	-	-	-	-	-	-	-	-	-	-	-	-	-	CCC	***	***	***	***	***	***	***	DDD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caconda	13º44	15º05	-	-	-	-	-	-	-	-	-	-	-	-	CCC	CCC	-	-	-	AAA	AAA	-	-	-	-	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gago Coutinho	14º06	21º26	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Artur de Paiva	14º32	16º23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Serpa Pinto	14º40	17º42	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	AAA	CCC	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	-
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Chibia	15º10	15º33	-	-	-	-	-	-	-	-	-	-	-	-	CCC	CCC	-	-	-	AAA	AAA	AAA	-	AAA	-	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cuito-Cuanavale	15º10	19º13	iucn02.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-
Mavinga	15º50	20º21	iucn03.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	-
Mupa	16º07	15º55	iucn03.wr1	-	-	BBB	CCC	CCC	BBB	BBB	BBB	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Cafu	16º19	15º18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	CCC	AAA	CCC	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cuando, Missao Catolica	16º31	22º05	iucn03.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Roçadas	16º45	14º58	iucn03.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	***	***	***	***	***	***	***	***	***	***	***	***	-
Vila Pereira d'Eça	17º04	15º44	iucn03.wr1	-	-	-	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	CCC	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-
Cuangar	17º37	18º38	iucn03.wr1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AAA	AAA	AAA	AAA	AAA	AAA	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	DDD	-	-	-	-	-	-	-