Chapter 2:
HYDROPOWER POTENTIAL IN THE CUNENE

2.1 GENERAL

2.1.1 Objective

The objective of this chapter is to generally inform about the hydropower potential of the Cunene River basin based on earlier inventories and studies.

2.1.2 Cunene River

General Description

The water resource of the Cunene river is substantial, being a perennial river with a mean annual flow of 50 m$^3$/s at Gove and 160 m$^3$/s at Ruacana. The year to year and annual variation is however considerable, the most serious circumstance being relatively long periods of drought put on record lasting for several years. This has been experienced at the Ruacana Hydroelectric power station, lacking storage for seasonal regulation and thus with a large and unpredictable variation in the electric power generation.

The rainfall over the basin varies over the catchment from 1,300 mm in the upper parts to less than 100 mm per annum in the lower reaches.

Gross open water surface evaporation ranges from 1,700 mm in the upper catchment to 2,300 mm in the lower parts of the river close to the Atlantic Ocean.

The plans for harnessing the Cunene have mainly concerned streamflow regulation, irrigation, water supply and hydroelectric power generation.

Generally the hydropower potential of a river depends on the river gradient and the available stream flow.

The theoretical potential of a river is generally calculated as the integrated stream flow (catchment runoff) times the available head above the sea level.

The technical potential is usually derived from an assessment of the technical possibilities and conditions of a river basin, in which consideration is given to the current capability in technology, for instance geology, dam and equipment technology.

The economic potential further depends not only on the status of technology but also on the cost of hydropower generation in specific locations and in comparison with other compatible sources of energy. As the cost of hydropower and alternative sources of energy varies over time, the economic potential changes with time.
Past Studies

Following the resurrection of the activities in the Cunene River in the mid 1960s, the South West Africa Water and Electricity Corporation (SWAWEK) was created (later renamed NAMPOWER). SWAWEK together with the Water Affairs Branch of the government was appointed to launch studies and investigations of the Lower Cunene from Roçadas to the Atlantic Ocean. These were undertaken by a group of Consultants named the South African Study Group. Simultaneously studies and investigations of the Upper Cunene were embarked upon by the Portuguese authorities, and executed by the Portuguese Study Group concentrating on the upper river from its sources to Roçadas.

The studies by The South African Study Group and the Portuguese Study Group were rather comprehensive, and created the foundation for the negotiations for the implementation of the Gove Dam, the Calueque pumping scheme, and the Ruacana hydropower project.

2.2 HYDROPOWER POTENTIAL

The Upper Cunene

The sources of the Cunene River are situated north of Huambo in Angola at an approximate elevation of 1,800 m, and the contribution to the river flow from the sources upstream of Gove is on the average about 50 m$^3$/s.

The rainfall in these areas is the highest in the river basin (>1,300 mm/Year) and the topography is suitable for building of dams and creation of reservoirs. The reservoirs in the Upper Cunene can give very useful contribution for the regulation of the Cunene and providing other parts of the river with a more uniform flow. A good example is the Gove dam, which will be of great importance for Rucana and future projects in the Lower Cunene.

Gove is built as a regulating reservoir with a maximum water level at +1,590 meters above sea level. Using the head created by the reservoir a hydropower plant could be built in the future for the generation of some 120 GWh per annum.

The river gradient downstream of Gove down to Matala offers several possibilities for hydropower projects along the mainstream. Jamba-Ia Mina and Jamba-Ia Oma are two of the most promising projects that have been studied over the years. Both projects are planned as sizeable reservoir projects with a combined annual generation potential of some 850 GWh.

In the Cunene tributaries a few small hydro alternatives with capacities of about 5 - 15 MW have been identified in the Calai, Cuando and Catapi rivers.

The combined generation from the tributaries would be in the order of 175 GWh/year.

The hydropower projects identified and analysed in the 1969 Master Plan are the following:
<table>
<thead>
<tr>
<th>Name</th>
<th>High Water Level/Tailrace level m</th>
<th>Reservoir Capacity, Million Cubic Meter</th>
<th>Potential Capacity MW</th>
<th>Technical Potential, Million Kilowatt-hours, GWh/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gove</td>
<td>1,590/1,545</td>
<td>2,364</td>
<td>25</td>
<td>120</td>
</tr>
<tr>
<td>Jamba-Ia-Oma</td>
<td>1,520/1,478</td>
<td>970</td>
<td>50</td>
<td>224</td>
</tr>
<tr>
<td>Chivondua</td>
<td>1,519/1,487</td>
<td>-</td>
<td>15</td>
<td>70</td>
</tr>
<tr>
<td>Jamba-Ia-Mina</td>
<td>1,420/1,330</td>
<td>517</td>
<td>81.5</td>
<td>622</td>
</tr>
<tr>
<td>Matafa</td>
<td>1,230/1,210</td>
<td>60</td>
<td>45.5</td>
<td>54</td>
</tr>
<tr>
<td>Matunto</td>
<td>1,150/1,122</td>
<td>230</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Chissola</td>
<td>1,597/1,519</td>
<td>360</td>
<td>6.5</td>
<td>30</td>
</tr>
<tr>
<td>Caringo</td>
<td>1,580/1,535</td>
<td>608</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Gungue</td>
<td>1,530/1,485</td>
<td>-</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Lucunde</td>
<td>1,480/1,422</td>
<td>-</td>
<td>6.5</td>
<td>30</td>
</tr>
<tr>
<td>Cambundu</td>
<td>1,460/1,400</td>
<td>404</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Catembulo</td>
<td>1,220/1,195</td>
<td>1,060</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>6,573</td>
<td>309</td>
<td>1,320</td>
</tr>
</tbody>
</table>

In total the potential for hydropower generation in the Upper Cunene would amount to some 1,320 GWh/year.

The Middle Cunene

By definition this stretch of the river starts at Huila and ends at Calueque.

The Middle Cunene, between Matunto and Calueque, offers very limited prospects for hydropower development, the river gradient is low and suitable sites for dams have not been identified.

The Lower Cunene

The Lower Cunene is defined as the river stretch from Calueque to the sea. Studies of the hydropower potential preceded the 1969 Agreement on the Cunene River.

The hydropower projects studied were included in the 1969 Master Plan for the Cunene River. The potential of each project was estimated according to standard criteria and on the basis of prevalent knowledge of hydrology, topography and geology.

The technical potentials presented below have been adjusted according to the present perception of the hydrology. The relation between installed capacity and energy generation potential has been estimated with a plant load factor of 50 % and an overall plant efficiency of 90 %. The average capacity generated at Ruacana has been estimated at 120 MW, corresponding to an average turbine flow at 103 m/s and a specific generation of 1.16 MW per m/s. The technical energy potential of each of the Calueque, Jacavale, Luandege, Ondoruso and Zebra projects, all lacking storage capacity, has been
estimated using the turbine flow at Ruacana and applying an estimated average head on the basis of an assumed minimum drawdown water level of the reservoir.

For the projects from Epupa and downstream, it has been assumed that 90% of the flow would be discharged through the turbines. The large reservoirs would entail a significant, almost complete, reduction of spill, but also increased evaporation. The Epupa reservoir alone gives rise to annual average evaporation losses of some 15 m³/s.

For the estimates of the latter projects the formula \( E=0.9gx(0.9q)xH_{av}\times0.00876 \text{ GWh/year} \) has been applied.

The potentials of the respective projects included in the Master Plan starting upstream would be the following:

<table>
<thead>
<tr>
<th>Name</th>
<th>High Water Level/Tailrace Level m ( (H_{av}) )</th>
<th>Active Reservoir Capacity, Million Cubic Meter</th>
<th>Installed Capacity ( MW ) (Plant Load Factor 0.5)</th>
<th>Generation Potential, Million Kilowatt-hours ( \text{GWh/Year} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calueque</td>
<td>1,092 /1,090 (2)</td>
<td>40</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Jacavale</td>
<td>1,090/1,060 (35)</td>
<td>19</td>
<td>60</td>
<td>270</td>
</tr>
<tr>
<td>Luandege</td>
<td>1,055/900 (155)</td>
<td>4</td>
<td>265</td>
<td>1,230</td>
</tr>
<tr>
<td>Ruacana</td>
<td>900/754 (135)</td>
<td>18</td>
<td>240</td>
<td>1,075</td>
</tr>
<tr>
<td>Ondoruso</td>
<td>754/718 (36)</td>
<td>60</td>
<td>60</td>
<td>280</td>
</tr>
<tr>
<td>Zebra</td>
<td>718/710 (8)</td>
<td>40</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Epupa</td>
<td>710/510 (185)</td>
<td>7,800</td>
<td>470</td>
<td>2,050</td>
</tr>
<tr>
<td>Baynes</td>
<td>510/380 (100)</td>
<td>410</td>
<td>260</td>
<td>1,120</td>
</tr>
<tr>
<td>Marien</td>
<td>380/240 (110)</td>
<td>800</td>
<td>280</td>
<td>1,230</td>
</tr>
<tr>
<td>Hartman</td>
<td>240/170 (70)</td>
<td>225</td>
<td>160</td>
<td>785</td>
</tr>
<tr>
<td>Hombolo</td>
<td>170/70 (100)</td>
<td>200</td>
<td>260</td>
<td>1,120</td>
</tr>
<tr>
<td>Mcha</td>
<td>50/7 (43)</td>
<td>55</td>
<td>110</td>
<td>480</td>
</tr>
</tbody>
</table>
2.3 RANKING OF HYDROPOWER PROJECTS

In the study by the South African Group, the ranking of projects in the Lower Cunene was done according to a comparative unit cost of power, and on the basis of a predicted growth of power demand in the region. Ruacana was awarded the highest ranking followed by Luandege, Epupa, Hombolo and Baynes. Corresponding comparative ranking for the Upper Cunene has not been possible to identify.

2.4 DESCRIPTION OF SCHEME ALTERNATIVES EXAMINED IN FORMULATION REPORT

According to the Terms of Reference the Epupa development should be contained within the river reach between elevations 710 and 510 m above sea level.

The public concern, as expressed at public hearings and in the local and international media about the potential environmental impacts related to hydropower development at Epupa, encouraged PJTC and NAMANG to expand the study with alternative project sites along the Lower Cunene. Sites that, if possible, would reduce the negative environmental and social impacts, but maintaining an acceptable power generation potential.

In the beginning of the Feasibility Study seven different sites, including the A, B and C sites at Epupa (described in the Pre-Feasibility Study), Baynes and Marienfluss were considered and screened from both technical and environmental perspectives on a relative scale.

It was later decided by PJTC that the alternatives to be included in the Project Formulation Report would be (see Figures 2.1 & 2.2):

- Epupa site A upstream of Epupa Falls in combination with site C downstream of Epupa Falls
- Epupa site B downstream Epupa Falls
- The Baynes project

Technical characteristics of these three schemes are as described in sections 2.4.1 through 2.4.4.

2.4.1 Description of Epupa Scheme A

Epupa Scheme A develops the portion of the river from El 710 to 572 m.a.s.l. In order to provide a more equal comparison to Epupa Scheme B (which develops the river from El 710 to 510 m.a.s.l.), Scheme C develops the river potential from El 572 to 510 m.a.s.l. Epupa Scheme A is only evaluated in combination with Epupa Scheme C.

The dam is located 4 km upstream of the falls in the position that gave the smallest dam volume and where visual impact is acceptable.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir High Water Level</td>
<td>710 m.a.s.l.</td>
</tr>
<tr>
<td>Reservoir Low Water Level</td>
<td>680 m.a.s.l.</td>
</tr>
<tr>
<td>Tailwater Level</td>
<td>572 m.a.s.l.</td>
</tr>
<tr>
<td>Maximum Gross Head</td>
<td>135 m</td>
</tr>
<tr>
<td>Active Storage</td>
<td>7027 Mm$^3$</td>
</tr>
<tr>
<td>Inundated Area Max. Reservoir Level</td>
<td>352 km$^2$</td>
</tr>
<tr>
<td>Inundated Area Min. Reservoir Level</td>
<td>142 km$^2$</td>
</tr>
<tr>
<td>Average Flow</td>
<td>160 m$^3$/s</td>
</tr>
<tr>
<td>Dam Height</td>
<td>97 m</td>
</tr>
<tr>
<td>Headrace Tunnel, unlined 85 m$^2$</td>
<td>0.2 km</td>
</tr>
<tr>
<td>Tailrace Tunnel, unlined 85 m$^2$</td>
<td>3.9 km</td>
</tr>
</tbody>
</table>
Figure 2.1 General Location
Figure 2.2 Location of Dam Sites Studied During the Formulation Report
2.4.2 **Description of Epupa Scheme C**

Epupa Scheme C is the companion scheme to A that allows a more equal basis for comparison with Epupa Scheme B. It is located 13 km downstream of Epupa Falls with a powerhouse which is integral to the dam. There are minimal headrace and tailrace tunnels and essentially no storage capability.

- Reservoir High Water Level 572 m.a.s.l.
- Reservoir Low Water Level 572 m.a.s.l.
- Tailwater Level 510 m.a.s.l.
- Maximum Gross Head 65 m
- Active Storage ~0 Mm$^3$
- Inundated Area Max. Reservoir Level ~3 km$^2$
- Average Flow 160 m$^3$/s
- Dam Height 76 m

2.4.3 **Description of Schemes Epupa A+C**

As Epupa Dam Sites A & C are considered as a single entity for evaluation, much of the generation and present value information is described for the combined projects.

- Installed Capacity 297 MW
- Firm Scheme Production 1919 GWh

2.4.4 **Description of Epupa Scheme B**

Epupa Dam Site B is located 7 km downstream of Epupa Falls and utilises the head between elevation 710 and 510 with a single dam and power station. The entire Epupa Falls would be inundated with this scheme.

- Reservoir High Water Level 710 m.a.s.l.
- Reservoir Low Water Level 680 m.a.s.l.
- Tailwater Level 510 m.a.s.l.
- Maximum Gross Head 200 m
- Active Storage 7809 Mm$^3$
- Surface Area Max. Reservoir Level 382 km$^2$
- Surface Area Min. Reservoir Level 164 km$^2$
- Average Flow 160 m$^3$/s
- Dam Height 161 m
- Installed Capacity 300 MW
- Headrace Tunnel, unlined 85 m$^2$ 0.3 km
- Tailrace Tunnel, unlined 85 m$^2$ 6.4 km
2.4.5 Description of Baynes

Baynes was chosen as an alternative to the Epupa Falls area. It is located approximately 40 km downstream of the Falls and utilises the head between elevation 580 and 380.

- Reservoir High Water Level: 580 m.a.s.l.
- Reservoir Low Water Level: 520 m.a.s.l.
- Tailwater Level: 380 m.a.s.l.
- Maximum Gross Head: 200 m
- Active Storage: 1744 Mm³
- Surface Area Max. Reservoir Level: 49 km²
- Surface Area Min. Reservoir Level: 15
- Average Flow: 160 m³/s
- Dam Height: 203 m
- Installed Capacity: 300 MW
- Headrace Tunnel, unlined 85 m²: 0.4 m
- Tailrace Tunnel, unlined 85 m²: 1.9 km
- Firm Scheme Production: 1768 GWh

2.5 CONCLUSIONS FROM FORMULATION REPORT

The main conclusions were that the three schemes, Epupa A+C, Epupa B and Baynes, were technically feasible and none of them could be excluded purely on environmental scientific grounds. The economic viability was somewhat in disfavour of Epupa Scheme A+C and as this scheme was almost equal to Epupa Scheme B with regard to environmental acceptability it was abandoned.

When comparing Epupa Schemes B and Baynes the economic viability was found to be slightly in favour of Epupa Scheme B with Gove regulation, without Gove regulation the economic comparison was further in favour of Epupa Scheme B. Baynes has superior comparative environmental features.

It was decided to complete a full feasibility study and environmental assessment report for both Epupa Scheme B and Baynes in order provide a complete picture of the advantages and disadvantages of both schemes.

Epupa Scheme B will be hereafter be referred to as Epupa in the feasibility report.

2.6 FUTURE HYDROPOWER DEVELOPMENT IN THE LOWER CUNENE

The total power potential of the Lower Cunene exists regardless of which alternative would be selected as the first hydropower project to be developed on the Lower Cunene. It appears from the studies and field reconnaissance that it is technically feasible to utilise the total head of the river along the stretch considered, however the order of development is relevant for the economic viability of the alternatives.
From an economic viewpoint, the main reservoir should generally be as far upstream as possible and should be incorporated into the first scheme. Subsequent downstream projects will then get the advantage of regulated water and can thereby produce firm power. New schemes downstream of the reservoir increase the energy potential of the reservoir as additional head becomes available downstream.

If Epupa is developed first, the next scheme could be either Baynes with reduced head (HWL 510 and TWL 380) or Marien. Total technical development potential of the Lower Cunene with Epupa developed first is shown on Figure 2.3.

If Baynes is the first alternative, the next scheme could be Marien with HWL 380 and TWL 240 and/or Epupa Scheme A with HWL 710 and TWL 580 or possibly Epupa Scheme A with a reduced head (HWL 625) and without a reservoir. Total technical development potential of the Lower Cunene with Baynes developed first is shown on Figure 2.4.
Figure 2.3 Long Term Development Potential with Epupa Developed First
Figure 2.4 Long Term Development Potential with Baynes Developed First