REPORT

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MAVUZI II HYDRO POWER PROJECT – PROJECT IDENTIFICATION STUDY

FINAL REPORT

20 DECEMBER 2013

SWECO International

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Summary

The main objective of the Project Identification Study is to identify the Mavuzi II Hydroelectric Power Project development possibilities and options to a reconnaissance level. The proposed power plant location is directly downstream of the existing Mavuzi Hydroelectric Power Plant (HEP) in the Revué River. The existing power plant, along with the available concession area results in a very limited number of options regarding the location of Mavuzi II dam, power house and appurtenant infrastructure.

The proposed Mavuzi II hydroelectric facility consists of a 220 m long concrete dam with a short waterway consisting of a canal and a penstock leading the water to the above ground powerhouse located at the left (northern) bank of the river bend some 2 km downstream of existing Mavuzi HEP. The Mavuzi II powerhouse has a preliminary installed capacity of 37.4 MW, which exceeds the existing design discharge at Mavuzi I HEP, which is 40,8 m^3/s. The resulting capacity of Mavuzi II, which is exceeded 10% of the time, is about 76,4 m^3/s and can also take care of the water that are spilled at Mavuzi Dam. The resulting production of an estimated 100 GWh annually could be further enhanced by expanding the regulation capacity of the Chicamba reservoir by improving the suboptimal local water supply intake.

Due to the exiting large Chicamba reservoir upstream, the project risks regarding hydrology and sediment are considered to be small. Furthermore, some knowledge of the local geology can be gathered from the previous development of Mavuzi HEP, reducing this risk somewhat.

Finally, the available infrastructure and transmission lines substantially reduce the costs of developing the project. There are also considerable economies of scale and synergies in co-locating the operational staff for Mavuzi I and II Power Plants.

The economic analysis shows a robust project economy with a positive net present value for an offtake price of 8 US cents per kWh.

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Table of contents

1 INTRODUCTION

In September 2013, Electricidade de Mozambique (EdM) contracted Sweco International to perform a Project Identification Study for the Mavuzi II Hydro Power Plant. The main objective of the study is to identify the project development possibilities and options to a reconnaissance level. The proposed power plant location is directly downstream of the existing Mavuzi Hydro Power Plant in the Revué River.

The project was first identified in the mid 1950-ies by the Portuguese colonial administration as a part of the development of the Revué River. It has, however, not been developed further since then.

The Mavuzi II HEP site can be accessed by car from Chimoio town that has a domestic airport. The distance is about 60 km on good standard gravel road and the driving time is about one hour.

2 ACKNOWLEDGEMENTS

The Sweco team would like to acknowledge the important support and assistance from the Client, EdM, during the documentation collection and during the site visit.

Firstly, we would like to thank Mr. Sérgio Sacama, Director Generation Directorate, Chimoio for his full support and interest in the study. Secondly, we would like to thank Mr. Abraao Rafael, Project Manager, Maputo for his enthusiasm and valuable assistance, especially during the information acquisition and the site visit. Further, we would like to thank the Plant Manager for Mavuzi Hydro Power Plant, Eng. Antonio Januario and Eng. Bainha Arnaldo for their very helpful assistance during the site visit. Finally, we want to thank the local guides for their assistance during the site visit.

3 SITE VISIT

The site visit to Mavuzi II Hydro Power site was performed 22 and 23 October 2013. The weather condition was good and the water level in the Revué River was low.

The visit started at the existing Mavuzi Dam and bridge over the Revué River. The upstream water level gauge at the headrace tunnel intake was studied and operators interviewed. The water level is read manually twice a day. Through the use of conversion tables, the water levels are converted into discharges by the gauge readers and written into their log book.

The visit then continued to Mavuzi HEP to view the downstream side of the plant, which will be directly upstream of Mavuzi II HEP. It was informed that during rainy season, the water level could be significantly higher than observed on the day of the visit. During this period, spilling of water from the dam to the dry stretch of the river bed would be frequent. It is apparent that the crest level and the design of the dam for Mavuzi II HEP must take into consideration the flooding risk of the existing Mavuzi HEP during high flow events.

The site visit continued with an about 700 meters walk down from the right hand side of the river to the river bed at the location of the proposed dam axis location. The Mavuzi II dam axis will tentatively be located about 1000 meters downstream of Mavuzi HEP.

Lastly, the downstream area of the proposed Mavuzi II HEP was visited on the right hand side of the river. The area can be quite easily assessed by 4WD car and an about 700 meters walk over an open and sparsely vegetated sand bank. The proposed location of the Mavuzi II HEP power house is located about 2,3 km downstream Mavuzi HEP. The left hand side of the river could, however, not be assessed considered the available time and because it was not possible to cross the river. It was mentioned that during high flow periods, the area could be flooded due to constrictions downstream in the Revué River close to the junction to the Buzi River. The risk for downstream flooding should be considered in the future layout of the power house.

4 DOCUMENTATION

The following information and documentation were collected:

1. Development of the Buzi River Monograph and Joint IWRM Strategy. SWECO 2011-13.
2. Joint Integrated Water Resources Management Strategy.
3. Monograph Report, Main Report and Annex 2 Water Resources. Enhanced Knowledge and Information System.
4. Rehabilitation Project for the Chicamba and Mavuzi Hydroelectric Power Stations.
5. Environmental Impact Study. Impacto 2008.
6. Generation Master Plan for the Mozambican Power Sector. Final Report, Vol I Main Report. Norconsult 2009.
7. Feasibility Study for the Rehabilitation of the Hydropower Stations Mavuzi and Chicamba. Final Report. Norconsult 2005.
8. Chimoio Water Supply Project. Final Design Report. Adventist Development and Relief Agency. USAID. July 1994.

In addition, material from the report prepared by Laboratorio Nacional de Engenharia Civil (LNEC) in the mid 1950-ies has been studied; “Esquema Geral de Fomento e Ocupação da Bacia d’Revué HP1957 (DEC1395 and DEC 1440)”.

5 HYDROLOGICAL CONDITIONS

A main purpose of the hydrologic study is to provide a preliminary hydrologic basis for the assessment of the suitability of the selected Mavuzi II site for a new hydropower plant and of the potential power production at this site. The study will do a preliminary assessment of the available hydrologic data and specify further measurements, if this is found to be required.

5.1 PREVIOUS STUDIES

Reports of studies relevant to the present one have been reviewed and information from these applied in the present report.

Norconsult (2005) found that the annual inflow to Chicamba reservoir 1960-2003 was 613 Mm^3, and the annual contribution to inflow to Mavuzi reservoir from the catchment between Mavuzi and Chicamba was 686.9 Mm^3. This mean that the total annual inflow to Mavuzi reservoir would be 1300 Mm^3corresponding to an average flow of 41.2 m^3/s. They also state that with the Chicamba reservoir having a storage capacity of 3.5 times the annual flow, energy can be produced literally without reservoir spill, limited only by the installed capacity.

This means that roughly half of the flow to Mavuzi is regulated by the Chicamba Dam, which has the potential of fully regulating its incoming flow.

Norconsult has based their hydrologic analysis on data provided by EdM.

5.2 DESCRIPTION OF THE PROJECT AREA

The studied Mavuzi II site is located on the Revue River; a tributary to Buzi River. The total Revue catchment area is 8,442 km^2 which represents 29% % of the Buzi River catchment area of 28,870 km^2. Figure 5-1 shows the location of the Revue sub-basin in the Buzi River basin. The catchment of the Chicamba Dam (named Upper Revue) has an area of 2,333 km^2, whereas the Middle Revue between Mavuzi Dam and Chicamba Dam has an area of 2,463 km^2. As shown in Figure 5-1, a small part of the Revue basin lies across the border in Zimbabwe; this is also where the rainfall is the highest.

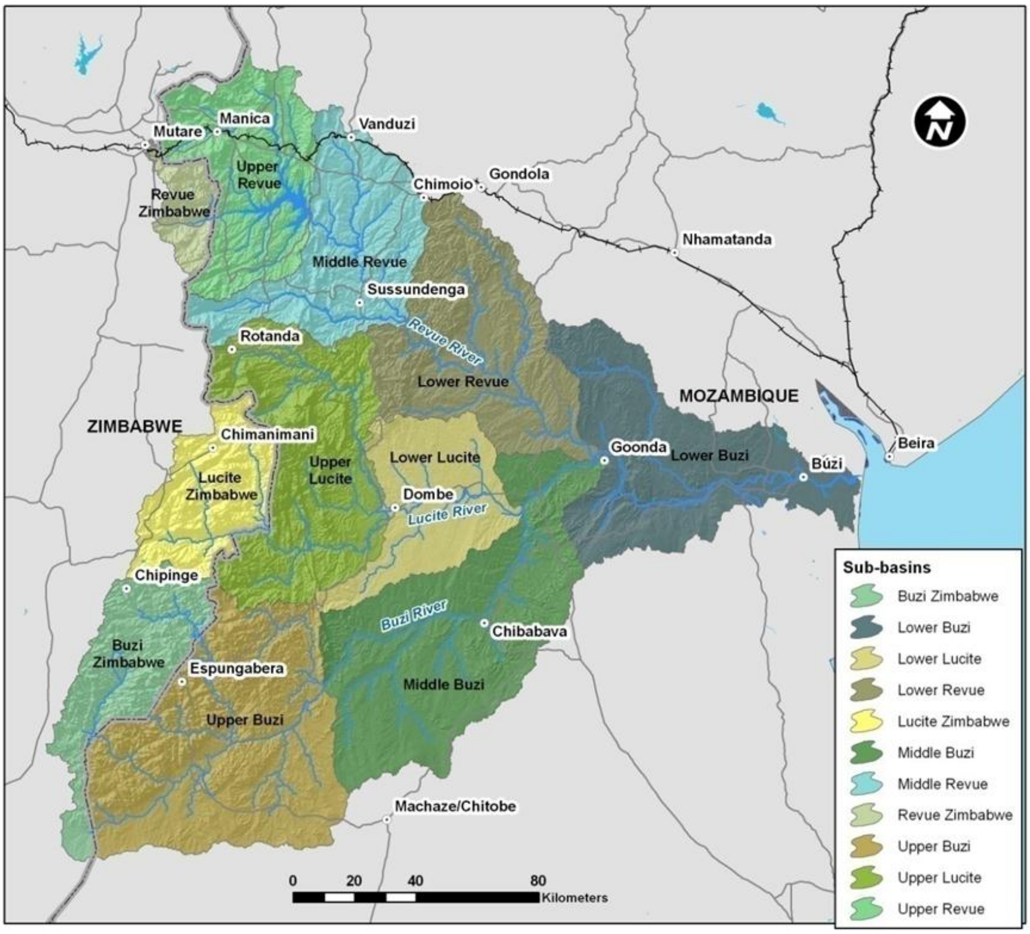

Figure 5-1 ***Main sub-basins of the Buzi River system, showing the location of the Revue sub-basin.***

Table 5-1 Distribution of mean annual rainfall and mean annual evaporation in Revue sub-basins. Based on data from 1955-75.

Sub-basin	Area (km^2)	MAP (mm)	MAE (mm)
Revue Zimbabwe	508	1,200	1,100
Upper Revue	2,333	1,100	1,200
Middle Revue	2,463	1,100	1,200
Lower Revue	3,139	1,200	1,300

Table 5-2 Distribution of river runoff (MAR = Median Annual Runoff)

Sub-basin	Area (km^2)	MAR (Mm^3/year)	MAR (mm)	Percentage of total
Revue Zimbabwe	508	173	340	10%
Upper Revue	2,333	498	213	28%
Middle Revue	2,463	449	182	25%
Lower Revue	3,139	659	210	37%
TOTAL	**8,443**	**1,779**		**100%**

Table 5-3 Sub-basin areas and run-off station in the Revue

Basin No.	Sub-basin	Runoff Stn	Local Area [km^2]	Total Area [km^2]
302	Zonwe_ZIM_US_F10	F10	34	
303	Upper_Revue_US_E277	E277	232	
311	Upper_Revue_US_E265	E265	97	
312	Upper_Revue_US_E274	E274	213	
301	Upper_Revue_US_Chicamba	-	2,270	2,846
321	Middle_Revue_US_E263	E263	650	
322	Middle_Revue	-	1,816	5,312
331	Lower_Revue	-	3,130	8,442

The runoff stations listed in *Table 5-2* are also shown in Figure 5-2. Note that of those five, four are upstream of Chicamba Dam and the last one (E263) is on the Muenezi tributary entering Mavuzi reservoir.

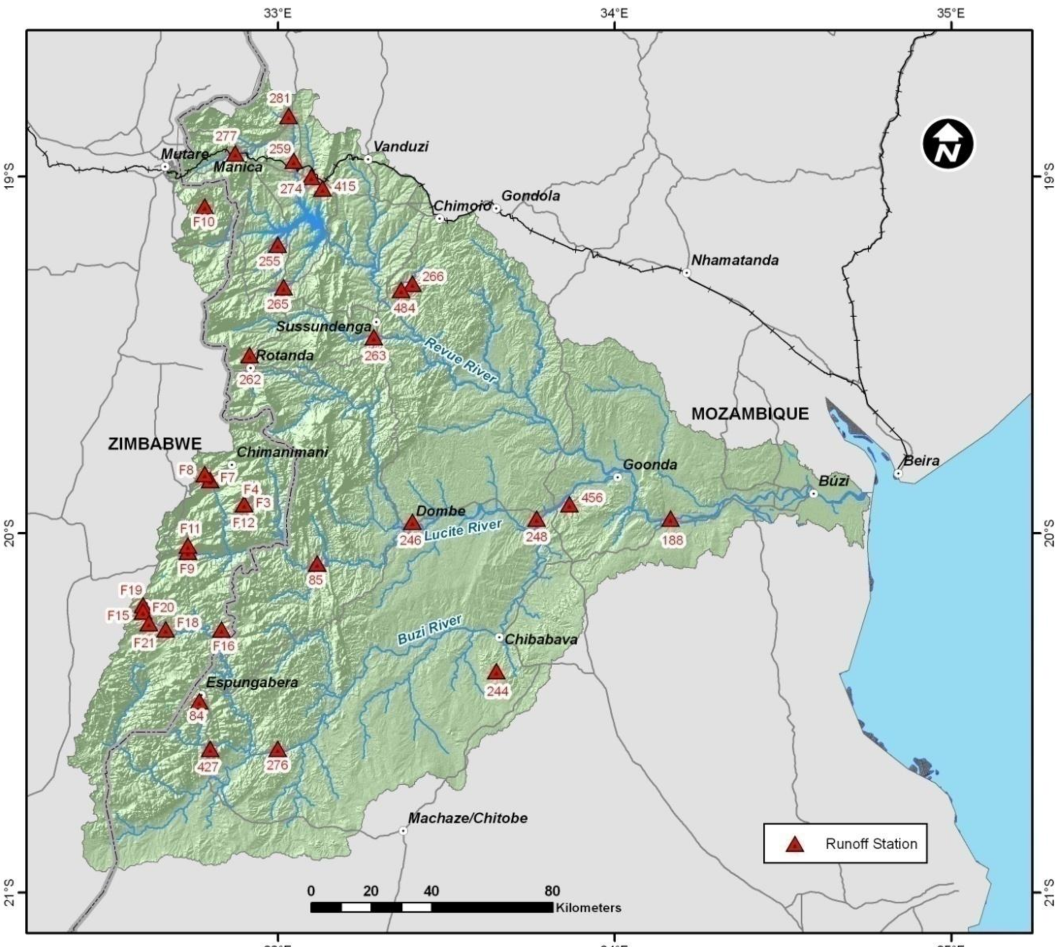

Figure 5-2 ***Runoff measuring stations in the Buzi River system.***

The MAR of the Revue River is 1,778 Mm^3/year, corresponding to 56 m^3/s.

The proposed Mavuzi II site is located approximately 1000 m downstream of the existing Mavuzi HEP power house, and about 5 km downstream of the Mavuzi Dam (measured along the river). The Chicamba dam is located approximately 80 km upstream of the Mavuzi Dam.

Key parameters of the Chicamba Dam and the Mavuzi Dam are shown in *Table 5-4* The Chicamba reservoir is large, corresponding to around 3,5 times the Mean Annual Runoff (MAR). Potentially, this reservoir could provide an almost fully regulated flow for the downstream river and for the Mavuzi HEP. The Mavuzi reservoir is very small and as such unable to regulate the flows.

Table 5-4 : Dams in Revue River Basin.

	Dam Capacity at FSL	Surface Area	FSL	Head	Number of Units	Total power generating capacity
Chicamba Dam	2,020 Mm^3	120 km^2	625 m.a.s.l	52 m	2	48 MW
Mavuzi Dam	1.8 Mm^3	26 km^2	345 m.a.s.l	160 m	5	50 MW

The Revue River sub-basin stretches over two climate types; humid mountainous climate and tropical humid climate. In the west the humid mountainous climate prevails due to the mountain range that is forming the border between Mozambique and Zimbabwe. In this region the mean rainfall can reach above 1,500 mm/year and the temperature is significantly lower than in the surrounding, non-mountainous areas.

Rainfall in the Revue River basin is dominated by the sharp incline between the southern and the northern parts of the basin. The Lower Revue receives about 1,200 mm, while the Middle Revue receives about 1,100 mm. In the Upper Revue the rainfall is about 1,100 mm, but with much more rainfall in the sub-basins in the higher mountain area. In these parts, located in the northern-most part of the Revue basin the annual precipitation is about 1,600 to 1,700 mm.

Moving from upstream to downstream (higher to lower altitudes), temperatures and evaporation rise and rainfall volumes reduce.

5.3 HYDRO-METEOROLOGICAL DATA - PRESENTATION AND ANALYSIS

Hydro-meteorological data relevant for the feasibility of the Mavuzi II feasibility are:

- River discharges
- Water levels
- Rainfall
- Evaporation (alternatively temperatures, humidity and wind speeds for calculation)

In this case, however, with the Revue River regulated by the Chicamba dam, and discharges measured/calculated at the Mavuzi Dam, the data from the two dams have been sufficient for a preliminary assessment.

5.3.1 SIMPLIFIED DESCRIPTION OF THE HYDROLOGIC SYSTEM

The hydrologic system comprises the two dams, inflows and outflows, evaporation/precipitation and abstractions. The system is shown in *Table 5-3*.

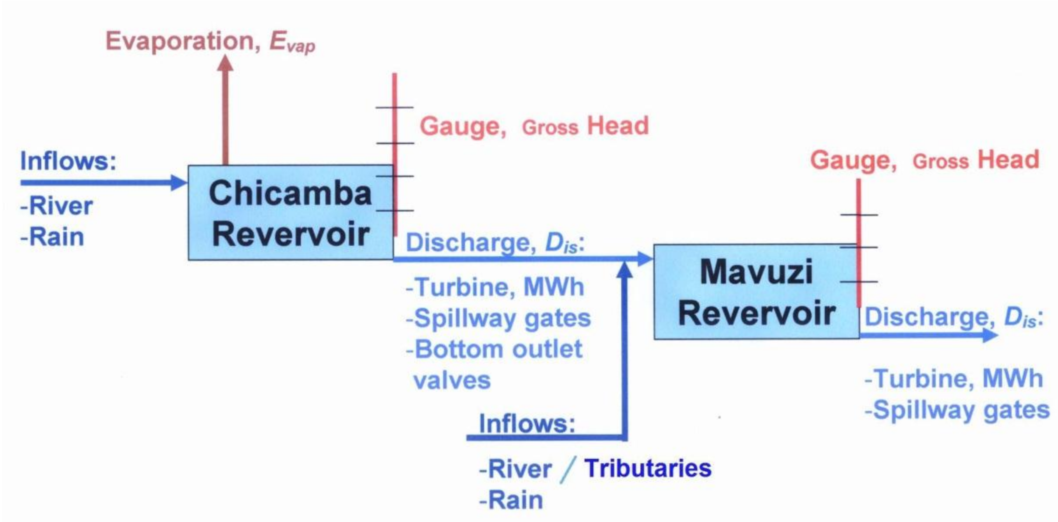

Figure 5-3 Schematic representation of the hydrologic system

The Mavuzi reservoir is very small and it is assumed that evaporation/precipitation contributions from its surface is negligible. Likewise, its ability to temporarily store the inflow is assumed to be negligible. The total balance of the system may then be expressed as follows:

$$Q_{M,out} = Q_{C,in} – E + Q_{C\text{-}M,in} – Q_A – dV/dt$$

where:

$Q_{M,out}$: total outflow from Mavuzi Dam
$Q_{C,in}$: inflow to Chicamba Dam
$Q_{C\text{-}M,in}$: inflows to the Revue between Chicamba and Mavuzi dams
Q_A: Abstractions at Chicamba Dam
E: Evaporation (corrected for rainfall) at Chicamba Dam
dV/dt: The rate of storage at Chicamba Dam (V=storage volume)

All have the unit of a discharge, for instance m^3/s.

The data obtained from EdM comprise the following:

$Q_{C,in}$ – E: 1953-2003 and 2010-2011
$Q_{M,in}$: 1960-2003 and 2010-2011
$Q_{C\text{-}M,in}$: 1960-2003
$Q_{M,out}$: 2008-2013

Water levels at Chicamba Dam are only available for 2010-11, but the volume curve (storage volume vs level) is not available. Therefore, the storage (dV/dt) cannot be calculated. Also the abstraction volumes from Chicamba Dam are unknown (but likely to be small and therefore less important at this stage).

Thus, it is not possible without further data to calculate the outflow past Mavuzi Dam for the long period (1960-2003). However, since we have the flow past Mavuzi Dam for the 5-year period 2008-2013, this data series can be used, after some comparisons that are useful in the understanding of the system and to assess the representativeness of the short data series.

5.3.2 DISCHARGES FROM THE DAMS

The inflows to a future Mavuzi II HEP are to a large extent controlled by the flows released by the Chicamba Dam. The distance from Chicamba Dam to Mavuzi Dam is 80 km, and inflows from tributaries will contribute considerably. Optimised hydropower production from Chicamba HEP, a future Tsate HEP, Mavuzi I and Mavuzi II HEPs will be obtained through coordinated operation of the Chicamba Dam (and Tsate Dam, if applicable), taking into account the need for water supply abstraction. Flows are determined at the existing Mavuzi Dam, from here the distance to Mavuzi II is only around 5 km, measured along the river.

Ideally, >30 years of daily flow records would be available. In this case, the following records are available:

a) Long series of monthly inflow data: Chicamba Dam; monthly inflow discharges 1953/54 to 2003/4 and Mavuzi Dam; monthly inflow discharges 1960/61 to 2003/4 (from catchment between Chicamba and Mavuzi Dams)
b) Short series of daily inflow data: Chicamba and Mavuzi Dams, 2010 to 2011(for Mavuzi, inflow from catchment between Chicamba and Mavuzi Dams)
c) Daily discharge data from Mavuzi Dam: Daily discharges 2008-2013 (June)

The following displays some main characteristics of the three data series.

Series a:

The 50 years of data offers a good opportunity to assess the variation in flow from year to year and the spatial variation in generated runoff. Figure 5-4 shows the mean annual (unregulated) discharge into Chicamba Dam (less evaporation loss). Note that this calculated “discharge” is actually negative some years. This is when the inflow has not been sufficient to balance the evaporation from the Chicamba reservoir. What these situations indicate is that during certain periods, the runoff past the dam would be zero, while the reservoir water level is reducing.

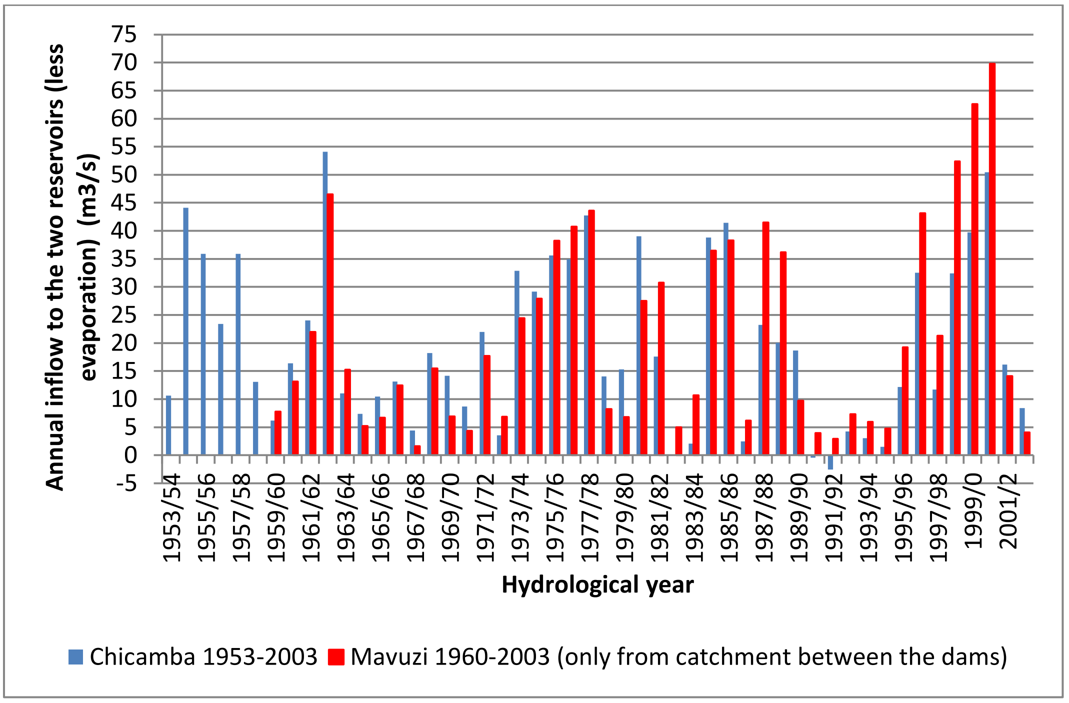

Figure 5-4 Annual inflow discharge to Chicamba Dam 1953-2003 and to Mavuzi Dam 1960-2003 (for Mavuzi, the contribution from Chicamba Dam is not included)

On average, the inflow to Chicamba Dam (after evaporation) was 19.18 m^3/s and the inflow to Mavuzi Dam was 21.56 m^3/s in the period 1960-2003. The data series clearly shows the following characteristics:

- The variation from year to year in annual runoff in the Upper and Middle Revue River is large. There are no clear cycles, but there are distinct wet and dry periods lasting up to 5-6 years.
- The generated runoff in Upper and Middle Revue are quite well correlated, ie the spatial variation is not dominant. It is remarkable, however, that the Middle Revue was significantly wetter than Upper Revue 1995-2000 (approximately).

Average monthly inflow discharges to Chicamba and to Mavuzi (from catchment between the two dams) are shown in Figure 5-5 and Figure 5-6.

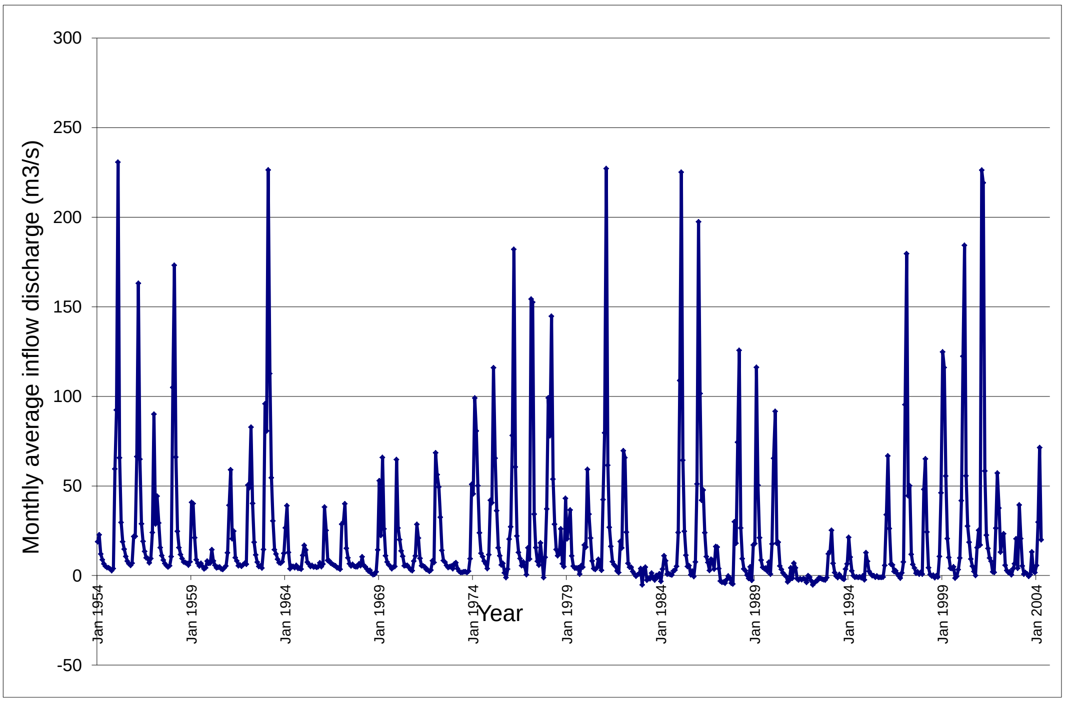

Figure 5-5 Monthly average inflow discharge to Chicamba Dam 1954 to 2004 (minus evaporation)

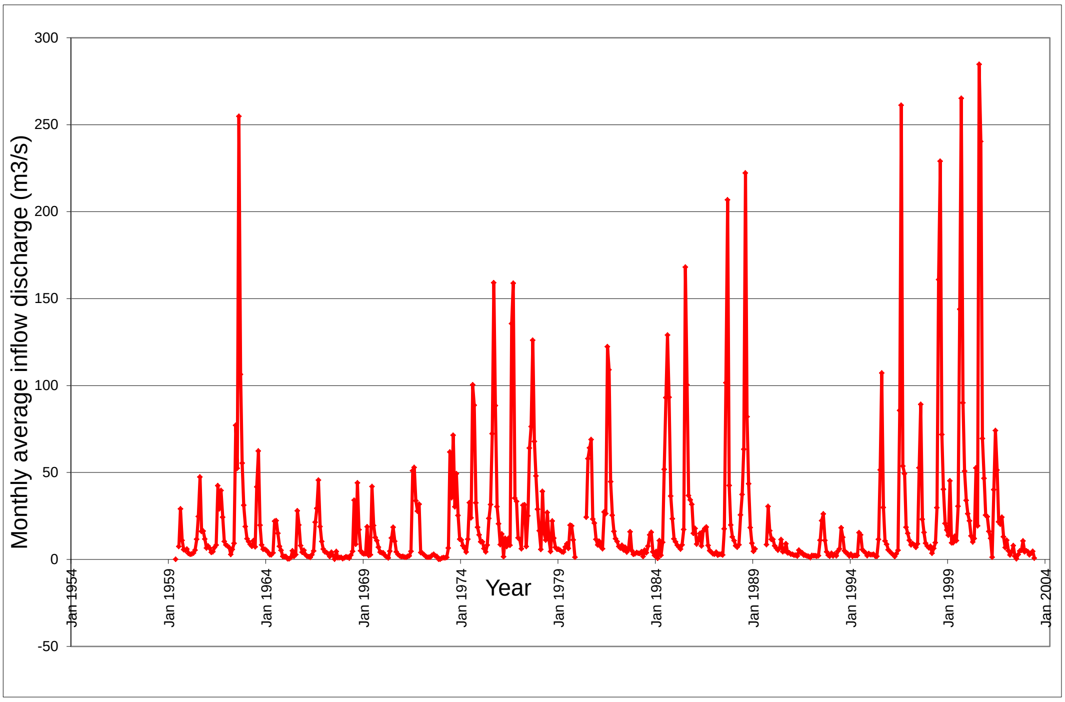

Figure 5-6 Monthly average inflow discharge to Mavuzi Dam 1960 to 2004, from catchment between Chicamba and Mavuzi Dam.

Series b:

There are two years with daily inflow discharges both to Chicamba and to Mavuzi Dam. The time series are shown in Figure 5-7.

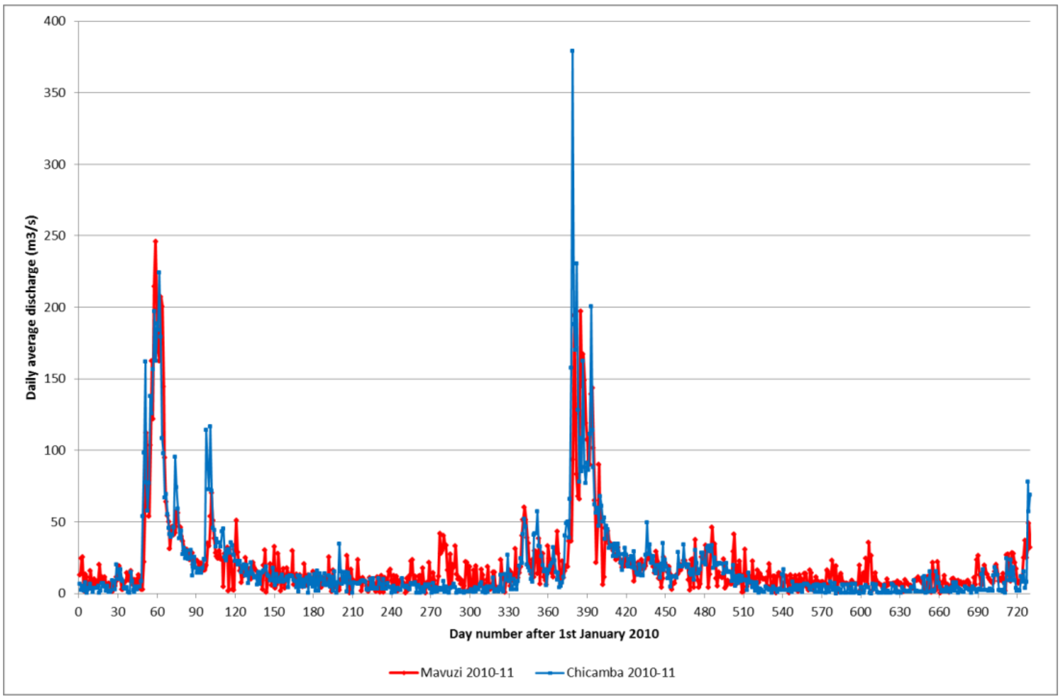

Figure 5-7 Discharge time series from Mavuzi and Chicamba Dams 2010-11.

Figure 5-7 illustrates how the runoff from Middle Revue (between Chicamba and Mavuzi Dams) follows the same pattern. A marked difference is the higher daily variability in the Middle Revue compared to the Upper Revue.

Series c:

The 5-year series of daily discharges from Mavuzi Dam is shown in Figure 5-8 below.

The 5-year series displays a large variation, between years and within each year. It shows that a large flood was experienced in 2008, whereas in 2012 there was hardly any flood.

The monthly flows for an average year for the two series, 1960-2003 and 2008-2013, are compared in Figure 5-9.

It is remarkable that this 5-year series of discharge data from Mavuzi Dam has a mean value of only 20.4 m^3/s, whereas the corresponding total inflow to Mavuzi Dam for the period 1960 to 2003 is 41.2 m^3/s. The latter is the sum of the inflow to Chicamba Dam (minus evaporation) and inflow to Mavuzi Dam from the catchment between the two dams. With only minor storage at Mavuzi Dam it is assumed that outflow is equal to inflow.

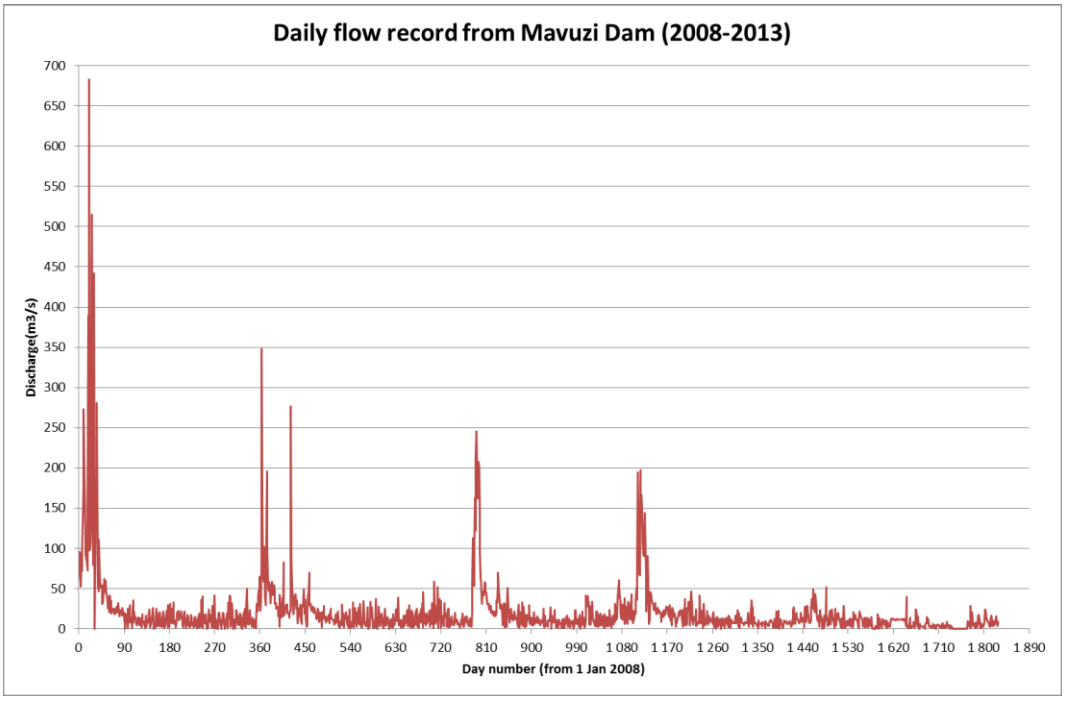

Figure 5-8 Five-year time series of daily discharges from Mavuzi Dam 2008-2013.

Considering the huge variability in the annual runoff in the Revue River, as illustrated in Figure 5-4, it is not unlikely that a data sequence of 5 years can have a mean value of less than half of the mean value of a longer 43 years data series. However, this needs to be investigated further in coming study phases.

As pointed out in section 5.3.1, the present identification study did not collect sufficient data describing the function of the Chicamba Dam to regulate the flow downstream. The 5-year time series of daily discharges from the Mavuzi Dam does not show the presence of a constant regulated flow from Chicamba Dam. It is therefore doubtful if the Chicamba Dam is being utilized to its full potential for regulating the flow of the Revue.

In order to combine the average discharge value determined over several decades (1960-2003) with the information about the detailed variation in daily flows obtained in the 5-year discharge series 2008-13, the latter has been scaled to provide the same average value as the former. The average monthly discharges of the two series are shown in Figure 5-9. The considerable differences between the annual flow variations in the two data sets needs to be investigated further.

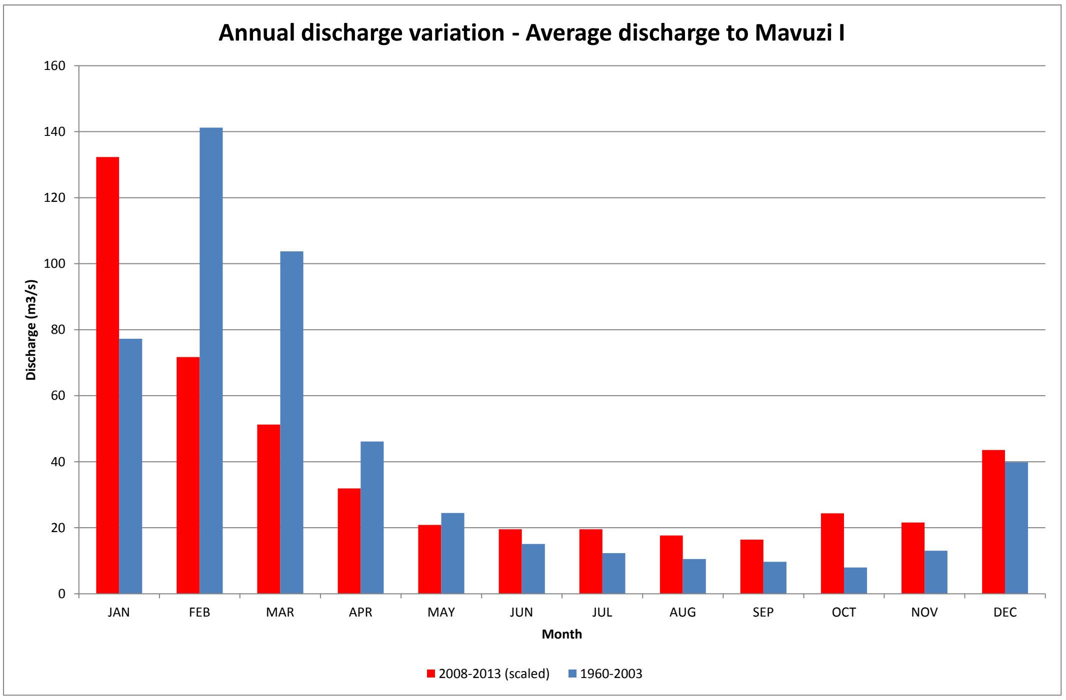

Figure 5-9 Annual discharge variation for average year at Mavuzi Dam for two periods, 2008-13 (scaled) and 1960-2003.

5.4 FLOW DURATION CURVE AT MAVUZI II HEP

A flow duration curve provides the necessary hydrologic information for the assessment of the power production potential.

The long monthly data series provides reliable assessments of the mean annual discharges and of the annual variation of the discharge. It does not, however, provide sufficient information about the short-term variability of the discharge.

The short series of daily discharges provides the short-term variability of discharges for the period of measurements, but is too short for generalization.

It is of interest to distinguish between the flow to Mavuzi Dam provided by the Chicamba Dam and the flow generated as run-off from the catchment between the two dams. The reason is that the flow from Chicamba Dam is a regulated flow, while the run-off generated between the two dams is unregulated.

Chicamba Dam has a large reservoir with the potential to regulate the flow entirely for the majority of the time. This potential to regulate, however, appears not to be fully utilized (see for instance the 1960-2003 data series in Figure 5-9, showing average flows below 20 m^3/s for half of the year). The reason for low regulation in the Chicamba dam may be due to the fact that the reservoir supplies domestic water to the town of Chimoio (and

possibly others) and this results in regulation restrictions of the Chicamba reservoir and possible design limitations. It is clear that the flow releases from the Chicamba are very important to the power generation potential at Mavuzi HEP, and also at a future Mavuzi II HEP. The operation of Chicamba Dam and requirements for domestic water supply has, however, not been studied further.

The average annual discharge from Mavuzi HEP has been calculated for the two data sets:

1960-2003 (monthly values only, and with missing months filled in with median values): 19.2+21.6 = **40.8** m^3/s

2008-2013 (daily values): **20.44** m^3/s

It was not possible during the site visit to get a clear impression of the spilling from the Mavuzi Dam. The Mavuzi reservoir has a High Regulated Water Level (HRWL) of +345.6 m. We were informed that normally the gates will be operated once the water level reaches +345.65 m.

The duration curve has been produced based on the 2008-2013 (up-scaled by approx. a factor 2) daily average discharges, for the total flow past Mavuzi Dam, see Figure 5-10 below.

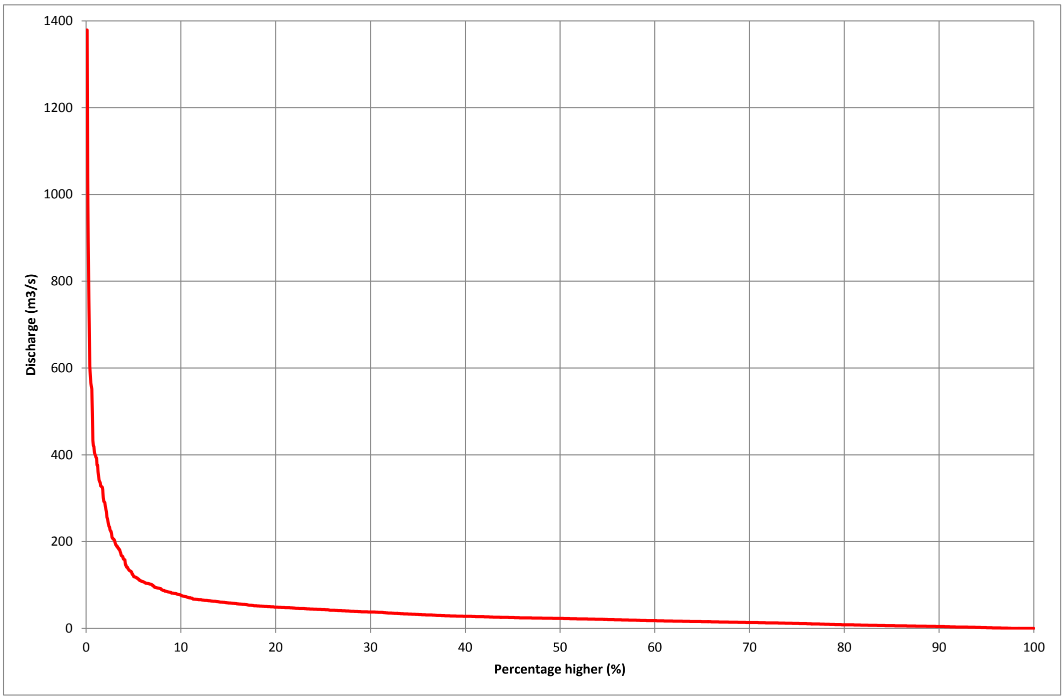

Figure 5-10 Flow duration curve at Mavuzi Dam based on daily discharge record 2008-2013

Percentage higher (%)	Flow (m^3/s)
5	121.8
10	76.4
20	49
30	37.8
40	27.8
50	22.9
60	17.7
70	13.5
80	8.3
90	4.4
95	1.7

Table 5-5 Tabulated summary of duration curve.

5.5 DESIGN FLOOD

The Mavuzi II dam will not be a large dam, and the consequences of a failure are presently assessed to be limited. This means there is no reason to apply the very large RMF (Regional Maximum Flood) value.

SWECO (2012) used **2½ times the 100-year flood** as a preliminary design discharge for dams in the Buzi River basin. At the confluence with the Buzi River the 100-year flood was estimated to 2,550 m^3/s, which then gives 6,375 m^3/s for the design flood. The corresponding value at Mavuzi II would be considerably lower.

It should be noted that the available discharge records are not suitable for estimation of the design flood. Not only because it is too short, but also because of the regulation of the river flow. An estimate based on statistical flow data should assume that the reservoirs are full, to obtain a sufficiently conservative value.

5.6 SEDIMENT

Based on information received during the site visit, it is assumed that the risks posed by sedimentation and sediment content in the water will be small. The Mavuzi reservoir has no significant sediment issues today due to the upstream Chicamba dam, which probably collects most of the existing sediment in the Revué River. The frequent opening of bottom gates and emptying of the Mavuzi I reservoir has a favourable effect, which needs to be replicated for the Mavuzi II pondage.

5.7 FURTHER MEASUREMENTS

Even though the established monitoring stations upstream of Mavuzi II are not useful (they are upstream of Chicamba Dam or on the Muenezi, a Revue tributary), there is no need to establish new measuring stations for the Mavuzi II preparation. Regarding measurements the following is recommended:

1. Measure water levels downstream of the Mavuzi HEP. This will assist in setting the pond level for Mavuzi II HEP.
2. Check in detail the calculations of the discharges both at Mavuzi Dam and Chicamba Dam.
3. Investigate if daily discharges and water levels can be found for the period 1953-2003 for Chicamba Dam and for 1960-2003 for Mavuzi Dam
4. Obtain the reservoir curves (volume and area) for Chicamba Dam

5.8 CONCLUSIONS ON HYDROLOGY

- The latest series of discharge records from Mavuzi Dam are only half as large (average) as the corresponding monthly values for the period 1960-2003. The reason for this difference needs to be investigated in further studies.
- Both Mavuzi I and Mavuzi II should be able to benefit from an almost fully regulated flow from Chicamba Dam. At present Chicamba Dam does not seem to regulate the Revue River flows to its full potential regulation capability. A possible reason for this may be related to the water intake at Chicamba Dam. Several sources cite that the intake, supplying Chimoio town and other population centres, has been placed at a too high level, thereby limiting the Chicamba reservoir in its flow regulating capacity. This needs to be further investigated, as it is important for the power production in the Revue River that the regulation capacity of the Chicamba reservoir is utilised.
- The annual variation in flows is considerable. Even the inter-annual variation is large.
- The flow duration curve for Mavuzi has been produced based on daily records of flows at Mavuzi Dam, which produces an average flow which is 5% lower than the average for the much longer and more representative monthly series 1960-2003.
- With long series of water level data from Chicamba Dam and reservoir curves it will be possible to calculate the flow series at Mavuzi for the longer period 1960-2003. For increased accuracy, also the abstraction at Chicamba Dam should be provided.
- With no clear information on spilling at Mavuzi Dam available, spilling has not been assessed. In the future spilling may be of insignificant importance, since it

can be avoided almost entirely if the regulating capacity of the Chicamba Dam is utilized.

- It was not found necessary to propose new measuring stations for the Mavuzi II project, but to check in detail the existing measurements and to measure water levels downstream the Mavuzi HEP.

SWECO

6 GEOLOGICAL CONDITIONS

Mavuzi HEP's is located in a complex geological area, with rock formations mostly hailing from the Proterozoic era.

Figure 1 Hydrogeological mapping of the area, UNESCO 1989.

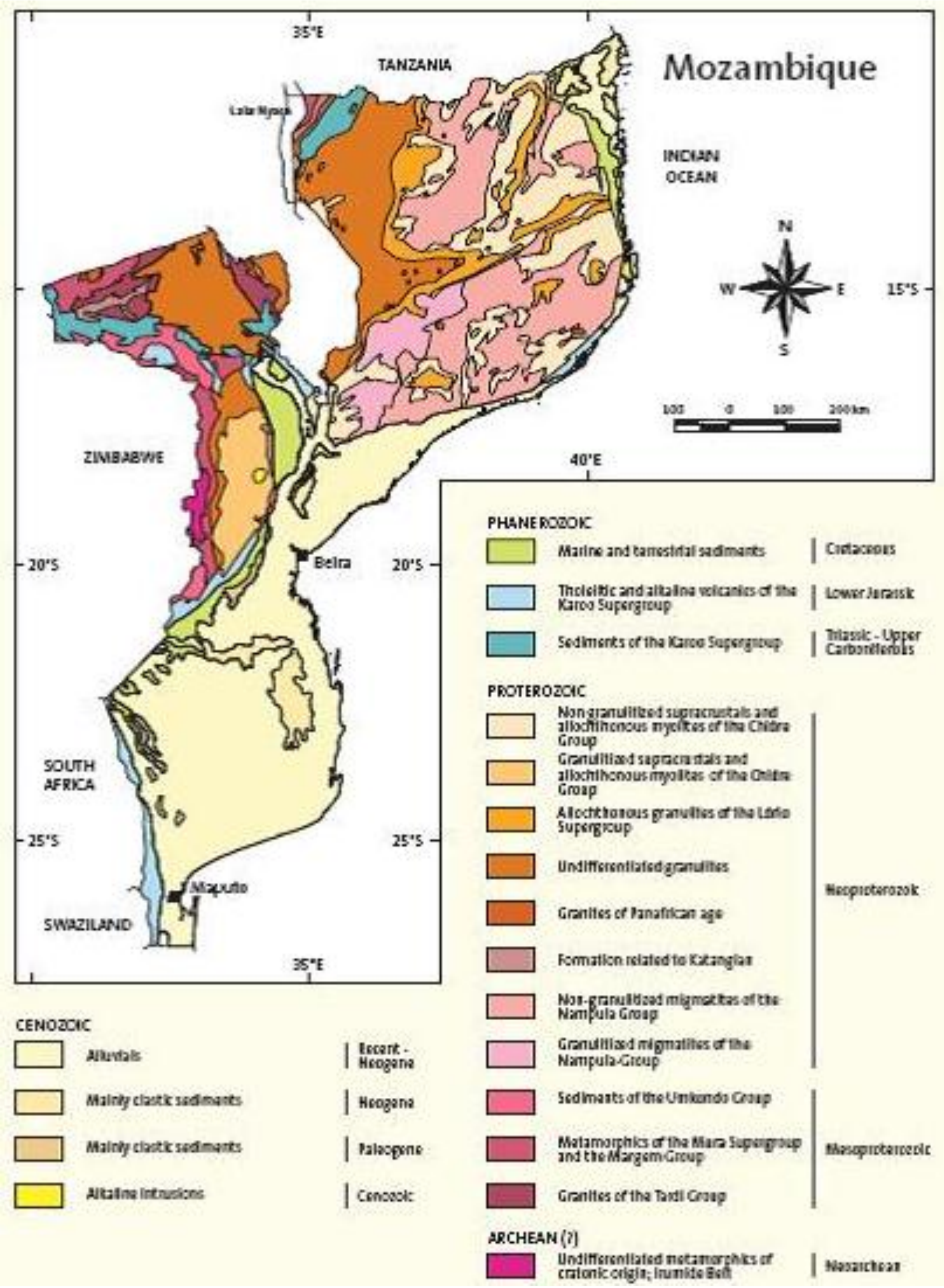

Figure 6-1 Geological mapping of Mozambique based on a 1987 survey.

6.1 FOUNDATION

An ocular inspection of the foundation at the top of the falls leads to the conclusion that the exposed bedrock seems to have good characteristics for strength and permeability. The bedrock has main strikes perpendicular to the stream with a dip some 30 degrees (estimate) towards the east. Mechanical weathering is apparent with cracking patterns in both the transverse and longitudinal direction (north-south and east-west).

Figure 6-2 Bedrock at the falls. This specific section shows cracking in the north-south direction (along the river bed).

The waterway and power house areas were not inspected due to limited access at the time of the site visit and possible risk for presence of mines in the area.

6.2 CONSTRUCTION MATERIALS

Some two kilometres downstream of the proposed dam site and closer to the proposed power station site, there is a substantial sand deposit at an old river bend. This material has been used for Mavuzi HEP but should be tested for alkali reactiveness.

Figure 6-3 Sand deposits in river bend downstream of proposed location of Mavuzi II.

Coarser aggregate material for drainage applications and concrete will have to be crushed on site or sourced from a suitable quarry nearby.

7 TOPOGRAPHY

The available topographical data of the project area is somewhat limited, but adequate for overview planning. Figure 7-1 below presents the suggested impounded area superimposed on a Google Map image with 5m equidistance Shuttle Radar Topography Mission (SRTM) data.

Figure 7-1 SRTM Topographical map with 5 m equidistance over the project area overlaid on a Google earth image. A feasible plant layout is included with the reservoir in light blue, the access road in red and waterway in blue.

A detailed power plant layout will need supplemental cartography with higher resolution, so it is proposed that a more detailed topographical survey is done in the next phase on the Mavuzi II HEP project development. The option of including the project area in the mapping that is deemed to be included in the coming feasibility study for Tsate HEP (anticipated to be done by LIDAR (LIght Detection And Ranging) scanning or equivalent) should be considered, as the additional cost will be negligible compared to a completely new topographic survey.

8 PLANT LAYOUT OPTIONS

Several options are available but all are bounded by the tail water level of the existing Mavuzi HEP on elevation +156.5 m, with the maximum allowable water level at +157.5 m. This elevation should be the maximum head water elevation for Mavuzi II HEP. The end of EDMs concession area is at elevation +100 m downstream that should be the minimum tail water elevation for Mavuzi II HEP.

One feasible design has been presented in Figure 7-1 above, but more detailed studies should be able to optimize locations with respect to geology, topography, cost of construction etc.

8.1 DAM AXIS AND TENTATIVE PLANT LAYOUT

Figure 8-1 View from top of penstock leading to Mavuzi HEP. The head water of the proposed intake dam of Mavuzi II HEP reaches almost to the tail water of Mavuzi HEP.

Figure 8-2 Proposed dam location at top of falls. Waterway to powerhouse in a canal along the left bank.

8.2 SPILLWAY CAPACITY

It is assumed that the concrete dam will be able to spill along its entire length of about 220 metres is recommended as a minimum. To avoid backwater build-up during evacuation of large floods an additional spillway might be constructed to improve discharge capacity. A preliminary estimate shown in Figure 8-3 serves to show the link between discharge capacity and backwater effect without any additional spillway capacity,

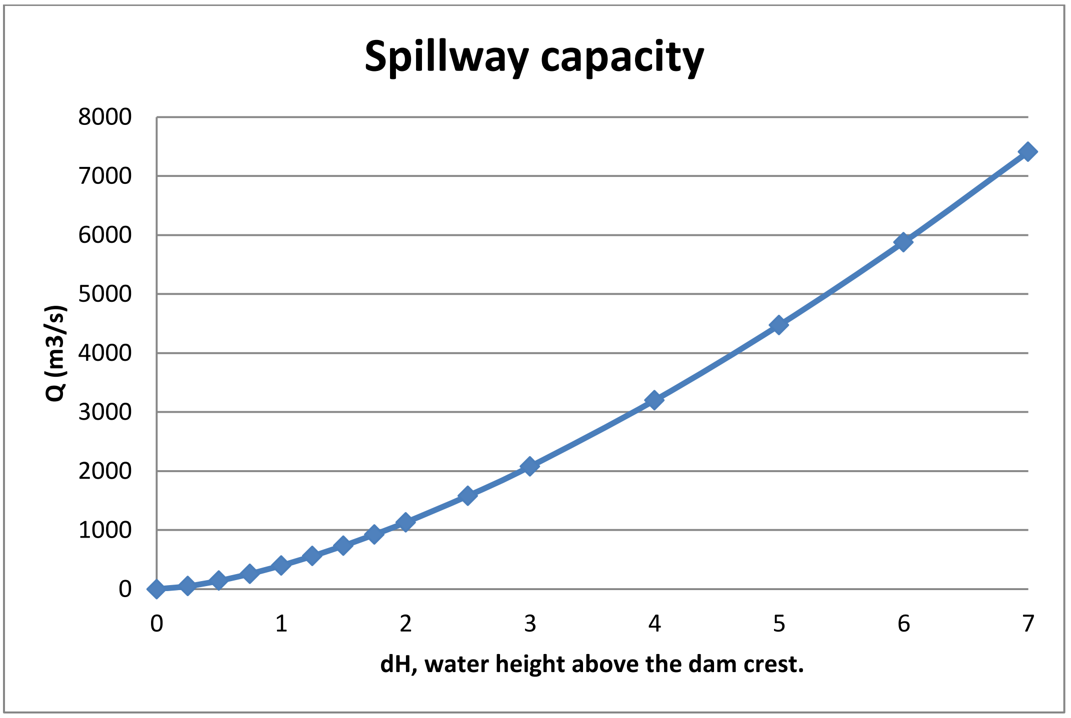

Figure 8-3 Theoretical spillway capacity of a 220 m ogee shaped crest.

If needed the spillway capacity can easily be increased by increasing the crest length, either along the dam or on the banks. This will be decided in a techno-economic optimisation at a later stage in the project.

8.3 POWER EVACUATION

As there is an existing substation and transmission lines for the Mavuzi HEP the spare capacity of these can appropriately be allocated to Mavuzi II HEP. A tentative study of the existing transmission lines indicates that there is sufficient available capacity for the evacuation of power from Mavuzi II HEP. A short transmission line from Mavuzi II HEP, approx. 2 km, to the Mavuzi HEP substation along with an extension of the same substation will be sufficient to ensure power evacuation.

9 PLANT CAPACITY AND GENERATION

The main factors in deciding plant capacity and therefore generation are; available head and design discharge.

9.1 AVAILABLE HEAD

Upstream the head is contained by the tail water level of Mavuzi HEP at elevation +157.5 m while downstream the tail water level for Mavuzi II HEP can stretch down to about elevation +100 m where the EDM concession ends resulting in a maximum available geodetic head for the Mavuzi II HEP of 57.5 m.

Considering that the full available theoretical geodetic head cannot be utilized, the gross head available at the chosen power plant configuration is chosen to H_g = 53.5 m.

Out of this height, 3.5 meters have been estimated for head losses in the waterway.

9.2 DESIGN DISCHARGE

As outlined in the hydrology section above, the design discharge of Mavuzi II HEP consists of two factors;

1. Outflow from Chicamba
2. Inflow from the river basin between Chicamba and the Mavuzi reservoirs

These two will behave differently from a hydrological viewpoint, and a hydrological model will have to be established to ensure a correct value.

Aproveitamentos	Produções 10^6 kWh		Energia marginal 10^6 kWh		Custo do aproveitamento Contos	Custo marginal do kWh		Custo marginal do kWh corrigido (a)	
	1947-56	1947-54	1947-56	1947-54		1947-56	1947-54	1947-56	1947-54
Mavúzi I + barragem da Chicamba (1.ª fase)	172	172	-	-	-	-	-	-	-
Barragem da Chicamba (2.ª fase)	221	221	49	49	-	-	-	-	-
Mavúzi II	271	271	50	50	40.000	0$08,0	0$08,0	0$08,8	0$08,8
Mavúzi III + central na Chicamba	455	377	184	106	202.500	0$11,0	0$19,1	0$12,1	0$21,0
Muenézi	640	537	185	160	241.000	0$13,0	0$15,1	0$14,3	0$16,6
Tsate	937	780	297	243	542.000	0$18,2	0$22,3	0$20,0	0$24,5
Munhinga + Toa	955	797	18	17	93.000	0$51,7	0$54,7	0$56,9	0$60,1

Table 9-1 Hydrological data from the initial screening study performed by LNEC, showing that the basin contribution to annual flow between Chicamba and Mavuzi reservoirs is as observed in the hydrology section above

In order to assess an economical design discharge, a preliminary level of 10% discharge exceeding the capacity is used as basis, referring to Table 5-5 above. In this case this confers to a rough estimate of 76.4 m^3/s for Mavuzi II.

Based on these factors the potential installed capacity can be estimated as follows;

Available head = 53.5 - 3.5 (head losses in waterway w/o production losses)

Installed capacity = 50 m x 9.81 m/s^2 x 76.4 m^3/s = 37.4 MW.

For this scheme, no environmental flow in the dry stretch of the Revué River between the Mavuzi II pondage and the HEP directly downstream has been included. In a further study, environmental impacts will have to be investigated, but it should be factored in that there is significant precedence in that there are no downstream flows for the longer dry stretch between the Mavuzi Dam and the existing power plant.

9.3 ELECTRICITY GENERATION

The possible electricity generation from the Mavuzi II HEP is estimated from the flow duration curve, the available head and plant efficiency.

With the plant design discharge set to 76.4 m^3/s and the net head to about 50 m, the generated electricity has been estimated. The calculations of this is done by integrating the area under the flow duration curve and multiply the result with the head, water density, acceleration of gravity and plant efficiency. For simplicity the plant efficiency factor has been set to 85 % over the whole operation range.

Using these parameters, the generation is estimated to about 100 GWh. This scenario includes a spillage in the dam at discharges above the design capacity of 76.4 m^3/s, which will be the case about 10 % of the time. If, however, a more optimized regulation of the river at the Chicamba Dam is made possible the generation can be increased substantially due to reduced spillage during high flood season. If spillage could be reduced, the annual average discharge of 40.8 m^3/s will result in a possible generation of an additional 20-25% in Mavuzi II HEP. Optimised regulation from the Chicamba reservoir would even benefit power production at Chicamba itself, along with Mavuzi I HEP and the planned Tsate HEP.

10 COST ESTIMATE

For Africa a cost range of 3000-4000 USD/kW is typically indicated for budget purposes for smaller and medium hydropower facilities, reflecting a higher than average development cost. The Mavuzi II project already has infrastructure largely available, social and environmental costs are low and overall project risks small. Typical main risk areas are geology and hydrology. Geological risks appear to be low and the hydrological risks are very low as the Revué River is a (potentially) regulated river. This indicates that an initial budget assessment should be in the lower range.

Based on the budget range and the factors above, an upper estimate of 3000 USD/kW seems to be indicative. Thus, a development of Mavuzi II HEP can be preliminary budgeted at an approximate 100 MUSD.

11 ECONOMIC EVALUATION

The investment in a new hydropower facility at Mavuzi II can be evaluated in three ways:

1. Cost-Benefit based on current electricity tariffs
2. Cost-benefit based on alternative sources of energy
3. Corporate/governmental investment threshold

11.1 COST BENEFIT - TARIFF BASED

A fixed tariff is difficult to ascertain due to the complex pricing structure of EdM, with a range of tariffs available spread between 4 and over 12 US cents per kWh based on end user classification.

With an annual production of 100 GWh this gives a range of benefits between 4 and 13 MUSD annually.

Costs mainly depend on cost of capital (loans) and operational costs, both of which are unknown. However, if one makes a few assumptions (aggregate commercial rate 7%, inflation 5%, operational costs 150.000 USD/year and factors in a maintenance fund, one can make a cash flow analysis such as the one presented in Figure 11-1 below.

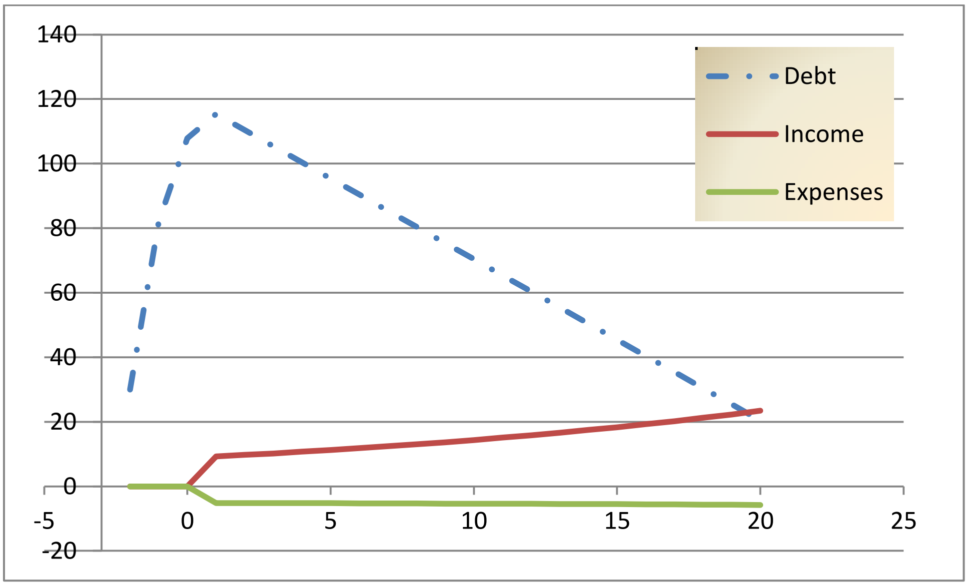

Figure 11-1 Preliminary cash flow analysis based on power price 0,08 USD, three loan tranches, three year construction time and a 20 year flat loan repayment.

A cash flow analysis as the one here will give a rough estimate of the financial viability of the project. Given this configuration, the NPV of this project will be above 130 MUSD, adjusted for inflation from start of construction. The calculation becomes overly conservative as one assumes that the power plant is worth zero at the end of the 20 year period (i.e. that the cost of rehabilitation balances the financial value of the asset – which is unlikely).

11.2 COST BENEFIT – INVESTMENT THRESHOLD

Finally, we will discuss the third option available at this stage – the investment threshold. Based on alternative investment analysis, governments and corporations have investment thresholds that can be transferred to USD/kWh. This factors market expectations as well as cost of capital. For EdM and Mozambique, such a figure is not readily available but typically investment analysis in mature markets the threshold lies around 8 US cents/kWh. For Mozambique, this figure could be expected to be higher – especially if one factors in future price development. Indeed, off-take prices in the region are already approaching or exceeding 8 US cents/kWh. (with Rwanda at 7.9 US cents/kWh and other, confidential, projects at above 10 US cents/kWh.)

11.3 FINANCIAL VIABILITY

Regardless of financial model, the project economy seems to be robust –given reasonable energy pricing. The NPV is positive for all scenarios above, but an improved calculation should be performed once the offtake price can be fixed.

Other factors such as the implementation of a tax shield or inclusion of remaining value of assets after 20 years of operation will improve the overall economy. On the negative impacts, increased operational costs or higher rehabilitation costs can be mentioned, both which will decrease the economic performance.

Market considerations such as global energy prices of petroleum products, possible gas extraction or supply/demand shifts in the SAPP can affect the scheme in many ways and should be reviewed in detail with detailed design and risk management.

12 TENTATIVE TIME SCHEDULE

Following this identification study, the following steps are typically followed in hydropower planning, design and construction.

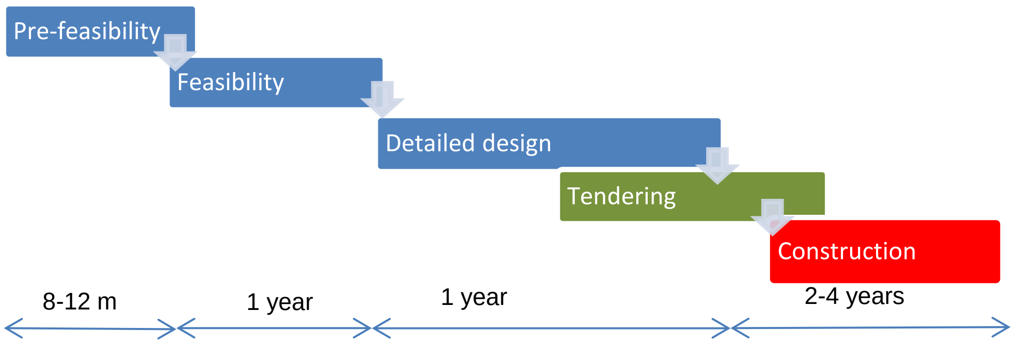

Figure 12-1 Hydropower from concept to construction

The staged approach described above is suited to devolve risks and narrow the technical choices until a design has crystallized and been negotiated with contractors and suppliers. By overlapping the design and tendering process somewhat, the time schedule can be compressed somewhat. Further compaction of the processes will probably incur increased overall costs due to higher risk-taking in the design process.

EdM will have to have staff dedicated to following the project implementation in parallel with the processes above, preferably involving an external Owners Engineer.

13 FURTHER STUDIES

The next step would be to assess the technical and economic feasibility of the development of Mavuzi II HEP and associated power evacuation. The study should

include a preliminary engineering design and layout for the main structures of the power plant and a preliminary Environmental and Social Impact Assessment (ESIA). The study would appropriately be done in two phases. First phase should be to conduct a Pre-Feasibility Study to establish that the project is economic and technical viable before a Full Feasibility Study is conducted in the second phase, as illustrated above. The main purpose in this set-up is to optimize the scope in the Feasibility Study, especially with respect to geotechnical investigations. The main objective of this study would be bring further competence into the project to further study and document challenges and risks as well as to elaborate the plant layout alternatives in details and lay out risk mitigation measures. The full ESIA can be conducted either as an integrated part of the Full Feasibility Study or as an independent study. Prior to the execution of the Pre-Feasibility Study, the area on the left bank of Revué River must be cleared and secured from land mines. The minimum area to be cleared is shown in the satellite image below (red). Further, a more detailed topographical survey should be performed within the area shown below (blue) – preferable as a LIDAR scanning.

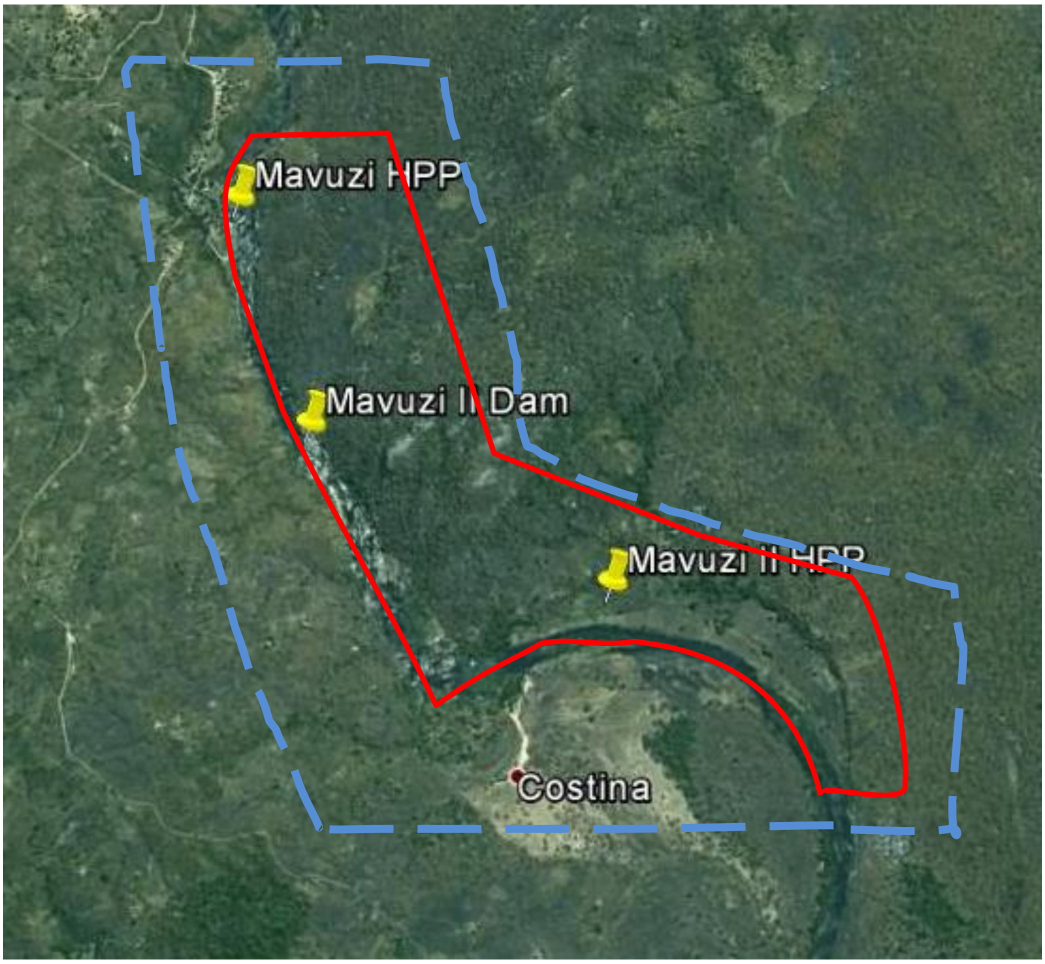

Figure 13-1 Map over areas suggested mine-clearing (red) and topographical survey (blue).

The first phase of the Feasibility Study should preferably also include a more detailed study of improved regulation of the Chicamba reservoir and requirements for the local water supply to enable a more optimized water management and higher socioeconomic performance overall. Alternatively, the possible improved regulation of the Chicamba reservoir could be investigated as a separate study, but prior to the Feasibility Study.

14 CONCLUSIONS

Based on the study and analysis made above it can be concluded that the development of a hydropower facility downstream Mavuzi I, i.e. Mavuzi II, is techno-economically desirable. The main conclusions are;

- A power plant with an approximately installed capacity of 37.4 MW and an annual generation of 100 GWh is feasible.
- The project risks regarding geology, hydrology and sediment are considered to be low.
- A tentative economic evaluation of the project concludes that the project economy is robust.
- The available infrastructure and transmission lines substantially reduce the costs and economic risks of developing this project.
- The layout of a possible power plant is rather straight forward with a limited number of layout options.
- The Mavuzi II HEP will be run synchronous with Mavuzi I HEP with focus on base load generation –secured by the Chicamba reservoir. Additionally, it will be able to utilize the spilled water from Mavuzi Dam.
- There are considerable economies of scale and synergies in co-locating the operational staff for Mavuzi I and II HEPs.

Parallel to the Mavuzi II HEP studies, the present regulation of the Chicamba reservoir and thereby the Revué River should be reviewed and improvement considered. The economic benefits of optimizing the local water supply intake at the Chicamba reservoir and adapting regulation strategies appear to be obvious.