Determining the optimum capacities for the Maguga Expansion and the Lower Maguga Hydropower Scheme

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1. Introduction

The Eswatini Electricity Company (EEC) is a state-owned entity and the only electricity utility in the Kingdom of Eswatini. The EEC's internal generation comprises mainly hydropower, with a total installed capacity of 61.1 MW and 2 x 4.5 MW standby diesel generators. The hydro generation is used mainly for peak shaving and the peak load of approximately 231MW is supported through imports from Eskom (RSA), and EDM (Mozambique).

Based on the current EEC load growth, it is anticipated that the maximum demand will be in the region of 350MW within the next 20 years. And with the current power purchase agreement with Eskom lapsing in 2025, coupled with the slow rate of investment in new generation and transmission projects in the region, the Kingdom of Eswatini faces a major risk of not having enough energy for industrial, commercial, and domestic needs to drive economic growth.

The EEC has realigned its strategic objectives to focus on improving business sustainability by increasing internal generation to reduce the ever-increasing cost of electricity imports. Several initiatives are currently being explored in the form of promoting private participation through independent power producers (IPPs), including feasibility studies for hydropower, coal-fired thermal power generation and other renewable energy such as wind and solar. The Lower Maguga Hydro Power Scheme (Lower Maguga HPS) development and the Maguga Hydro Power Station Expansion (Maguga HPS Expansion) form part of the above-mentioned initiative.
Evaluation of the feasibility (technical and economic) of adding extra generation equipment at the current Maguga Power Station was also requested as it has been observed over the years that the Maguga dam spills for extended periods and this can be used to generate more electricity for EEC.

The purpose of this Options Study is to provide a high-level technical, financial, and economic assessment of the various scheme layouts and capacities for the Lower Maguga Hydro Power Scheme and for the expansion of the existing Maguga Hydro Power Station to determine an optimal layout and size based on the available water and associated head for hydropower generation potential. The optimal scheme layout and size will be investigated in more detail during the next phase of the feasibility study.

2. Hydrology

Two sets of hydrological data were obtained from KOBWA and formed the basis for the hydrological and power generation estimates.

- Daily historical dam balance records for Maguga Dam for the period September 2002 to March 2019. The daily record of discharges and reservoir storage levels were converted into average monthly hydrological records for the period October 2002 to September 2018, amounting to 16 years of measured data.
- WRYM modelled monthly outflows and month-end storage levels for Maguga Dam for the period September 1920 to September 2005 (a total of 85 years). This WRYM output is from the recently completed 'Phase II Study to Improve the Operating Rules for the Maguga and Driekoppies Dams' (KOBWA, 2018)

The daily historical flow record reflects an average flow of 13.9 m^3/s and includes 2 dry periods in 2002 to 2003 and 2015 to 2016. The maximum discharge record is 600 m^3/s. The historical MAR of 437 MCM compares well with the MAR for the WRYM timeseries of 456 MCM (4 % difference).

3. Geology and Geotechnical

According to the published 1:250 000 scale geological map of Eswatini the proposed canal route is underlain by medium to coarse-grained basement granite. The general direction of the geological structures, mainly comprising lineations is in a northwest to southeast direction. According to the geological map, no faults are present along the canal or at the remaining parts of the proposed structures.

According to Weinert's climatic N-value the site falls in an area where N is classified as less than 5, which is associated with more humid areas. Chemical weathering is the predominant mode of weathering as opposed to mechanical disintegration, which is associated with arid regions. Deeply weathered granitic soil profiles can produce residual soils with relatively high clay content. These soils often have a high collapse potential with a pinhole voided soil structure. However, on the current site the soil profiles are generally thin due to the steep topography and undulating landscape. Numerous outcrops of granite bedrock are present along the route.

The site is generally covered by topsoil and/or colluvium, which is underlain by residual granite towards bedrock. More detail regarding the test pit profiles is available in the geotechnical report, while the typical soil profile is described below.

- Topsoil covers the route sporadically and generally comprises loose silty sand with a thickness of between 0,1m and 0,2m.
- Colluvium, which is mostly hillwash, occurs as loose to medium dense gravelly silty sand to silty sand and often contains sub-rounded gravel to cobbles. Along the thicker soil profiles, the colluvium is occasionally a sandy silty clay. The horizon occurs to variable depths of between 0,2m and 1,5m.
- Residual granite occurs below the colluvium and comprises gravelly silty sand to silty sand. The soil has a consistency that varies between medium dense and dense. The layer is generally intact but is occasionally pinhole voided and relict jointed. The thickness of this layer varies between 0,4m to more than 2,8m along the western parts of the route, while the average thickness is 1,5m.
- Granite bedrock was encountered below the residual granite mostly on the eastern and central portions of the canal route. The granite bedrock occurs as highly weathered very soft rock to medium hard rock. Bedrock occurs at various depths between 0,2m and 2,2m. Excavation by hand or TLB could extend beyond the very soft rock until soft rock was reached.

4. Environmental & Social Issues

Knight Piésold (Pty) Ltd also undertook the Environmental Scoping Study for the proposed Lower Maguga HPS and Maguga HPS Expansion. A summary of the scoping study is provided in this chapter and the full report is available for further detail.
The project area is located within the Hhohho Province in the northeast of Eswatini. Three chiefdoms namely Ekuvinjelweni, Nsangwini and Meleti will be affected by the project. The project was categorised as a Category 3 project by the Eswatini Environment Authority (EEA) in terms of the Environmental Management Act of 2002. Therefore, a full Environmental Impact Assessment (EIA) is required and will be undertaken after the Scoping Phase.
A comprehensive public participation process, as well as three baseline specialist studies (Aquatic Ecosystems; Terrestrial Ecology; and Social) were undertaken as part of the Scoping process.

4.1 Terrestrial Ecology

From a terrestrial ecology point of view, five broad habitat units were identified, namely:

- Riparian Woodland (including the Komati River and associated wetland areas)
- Modified (Open) Woodland (including croplands and infrastructure)
- Closed Hillslope Bushveld
- Closed Rocky Hillslope Bushveld
- Rock Outcrops.

Protected species identified in the Riparian Woodland include: *Ansellia africana, Pterocarpus angolensis, Aloe dyeri, Faurea spp., Dombeya rotundifolia var. rotundifolia, Dioscorea dregeana* and *Clematis brachiata.*
One protected floral species, namely *Boophone disticha*, was recorded in low abundance within the Open Modified Woodland habitat unit.
Protected tree species encountered within the Closed Rocky Bushveld habitat unit are *Dombeya rotundifolia var. rotundifolia, Aloe marlothii, A. dyeri, A. arborescens, Pterocarpus angolensis, Hypoxis spp., Dietes irioides, Faurea saligna* and *F. rochetiana.*
Protected floral species associated within Rocky Outcrop habitat unit are *Eulophia petersii, Aloe marlothii, A. dyeri, A. arborescens, Boophone disticha* and *Gladiolus sp.*
During the March 2019 site investigation, five mammals were identified within the project area based on direct and indirect signs. These are: Common Duiker (*Sylvicapra grimmia*), Slender Mongoose (*Herpestes sanguineus*), Water

Mongoose (*Atilax paludinosus*), Thick tailed Bushbaby (*Otolemur crassicaudatus*) and Wahlberg's epauletted fruit bat (*Epomophorus wahlbergi*).

Several herpetofaunal habitats were identified within the project area. These included rocky outcrops (rupicolous), bushveld (terrestrial and arboreal) and riparian woodland habitats (aquatic). These habitats provide foraging and refuge opportunities and the interconnected nature of these habitats provides a network of micro-corridors.

Four amphibians were recorded within the project area during the site investigation. A further three were noted upstream within the Maguga Dam inundation area. Snoring Puddle Frog (*Phrynobatrachus natalensis*) and Guttural Toad (*Sclerophrys pusilla*) were heard calling below the existing weir within the riparian vegetation while Common River Frog (*Amietia angolensis*) was noted in emergent vegetation associated with the middle tributary to the Komati River. The Painted Reed Frog (*Hyperolius marmoratus*) and Guttural Toad (*Sclerophrys gutturalis*) were noted actively calling on the lower portion of the Maguga Dam. These species are largely tolerant to anthropogenic disturbances, readily inhabiting available waterbodies

Seven reptile species were recorded. These are: Water Monitor (*Varanus niloticus*), Rainbow Skink (*Trachylepis margaritifera*), Striped Skink (*Trachylepis striata*); Puff Adder (*Bitis arietans arietans*); Common Giant Plated Lizard (Matobosaurus validus); Southern Tree Agama (Acanthocercus atricollis) and Nile Crocodile (Crocodylus niloticus).

Eighty-four avifauna species were identified including three avifaunal species of conservation concern. The species of conservation concern recorded are: Lanner Falcon (*Falco biarmicus*); African Finfoot (*Podica senegalensis);* and Half-collared Kingfisher (*Alcedo semitorquata*)

4.2 Aquatic Ecology

Water samples were taken at all four monitoring sites and analysed. The results show exceedances of the DWS Ecosystem guidelines, at all four monitoring points, for the parameters: Nitrite; Ammonia, Copper; and Aluminium. Sodium concentrations exceeded the SANS 241 drinking water guidelines at all four sites. No exceedances were observed for any parameters when compared to the Eswatini guidelines. Two sites showed elevated levels of E. coli, an indication of faecal contamination by warm-blooded organisms (most likely livestock or wild game).

In terms of Aquatic Ecology, the Macroinvertebrate Response Assessment Index (MIRAI) was used to provide a habitat-based cause and effect foundation to interpret the deviation of the aquatic community from the reference condition. The results from MIRAI categorise the Ecological category of the Komati River as a Category E) Seriously Modified.

Fish sampling was done by electroshocking which was limited to the side of the embankments as the water flow and levels were elevated during the survey. Only one point was sampled comprehensively. The fish assemblage index categorised the site as Category E (Seriously Modified). The Fish Response Assessment Index (FRAI) results categorised the river reach in Category D (Largely Modified).

4.3 Social Issues

The project-affected area communities at Ekuvinjelweni, Nsangwini and Meleti have a total population of approximately 7 000, as per the table below.

Based on the preliminary layout of infrastructure, there are approximately 91 homesteads in the potentially affected area with an estimated 300 inhabitants who may be indirectly affected. Approximately 12 households may be directly impacted.

4.4 Archaeology

The Nsangwini area is home to historic rock art, which is not within close proximity of the project footprint. No evidence was found of communal graveyards in the project area, although two homesteads directly affected by the project have family graves.

5. Existing Maguga Power Station

Maguga Hydropower Station was completed in November 2006 and is downstream of Maguga Dam. It includes two 9.9 MW Alstom horizontal Francis turbines with two 11.3 MVA Alstom synchronous generators. Maguga substation has two transformers which step up the voltage from 11kV to 66kV for transmission to the grid. Each of the turbine's rated capacity is 9.9 MW for a flow rate of 12.09m^3/s at a head of 90m. It is generally used as a peaking station operating during peak power demand times and only produces base power when Maguga Dam spills. The historical analyses indicate that the turbines on average operate for 9.5hrs per day resulting in a plant capacity factor of 0.4. The historical analyses indicate that on average the turbines operate for only 7hrs per day during the period of high demand (June, July, August) and during the wet months when the dam is more likely to spill from

January to April, the turbines operate on average for 12.3hrs per day. Hydropower generation is secondary to downstream water requirements and water is only released from the dam to meet the downstream requirements.

Figure 1. Maguga Dam Spillway and Hydropower Scheme

6. Maguga Hydro Power Station Expansion

To expand the capacity of the existing Power Station, there is insufficient space in the existing powerhouse to add an additional turbine, therefore it will be necessary to construct a new powerhouse at the toe of the dam. The arrangement envisaged is to extend the existing pipework from the sleeve valve house to the new powerhouse. This would require a new sleeve valve house to be relocated.

Three options were investigated for the Maguga expansion, a 0%, a 25% and a 50% increase in power.

Option 1: Do nothing and keep existing scheme as a 20MW ($Q = 25m^3/s$)
Option 2: Add an additional 5MW unit ($Q_{incremental}$ +7.5m^3/s; $Q_{total} = 32.5m^3/s$)
Option 3: Add an additional 10MW unit ($Q_{incremental}$ +15m^3/s; $Q_{total} = 40m^3/s$)

Options for a flow greater than 40m^3/s or (20m^3/s per penstock) were not investigated as the maximum allowable velocity through the butterfly valves should not exceed 7.5m/s. The average release during June, July and August is 8m^3/s. Assuming five hours of peak time during the day, the maximum flow available for the peak is 38m^3/s.

Figure 2. Maguga Dam Hydropower Scheme Expansion

7. Lower Maguga Hydro Power Scheme

Downstream of the Maguga Dam and the existing regulation weir the river has a steep gradient. The full supply level at the regulation weir is 518.5masl with the river invert level some 7km downstream at approximately 436masl resulting in a total static head of over 82.5m. Combined with the releases from the upstream Maguga Dam and existing Hydropower Station, this provides a good opportunity to build a new hydropower scheme downstream. The scheme would compromise of an intake, canal, two siphons, a head pond, two penstocks, a powerhouse and a new regulation weir. Four options were investigated.

Option 1: New 14MW Powerhouse (Q = 25m^3/s)
Option 2: New 17.5MW Powerhouse (Q = 32.5m^3/s)
Option 3: New 21MW Powerhouse (Q = 40m^3/s)
Option 4: New 25.5MW Powerhouse (Q = 47.5m^3/s)

8. Lower Maguga regulation Weir Mini Hydro

There is an option to add Kaplan turbines to generate power from both the releases from the regulating dam and from spillages. A single turbine will be added to make use of the constant release in the order of 10m^3/s and additional units will be added to make use of the spillages. Three options were investigated.

Option 1: New 0.67MW Powerhouse (Q = 10m^3/s)
Option 2: New 1.34MW Powerhouse (Q = 20m^3/s)
Option 3: New 2.0MW Powerhouse (Q = 30m^3/s)

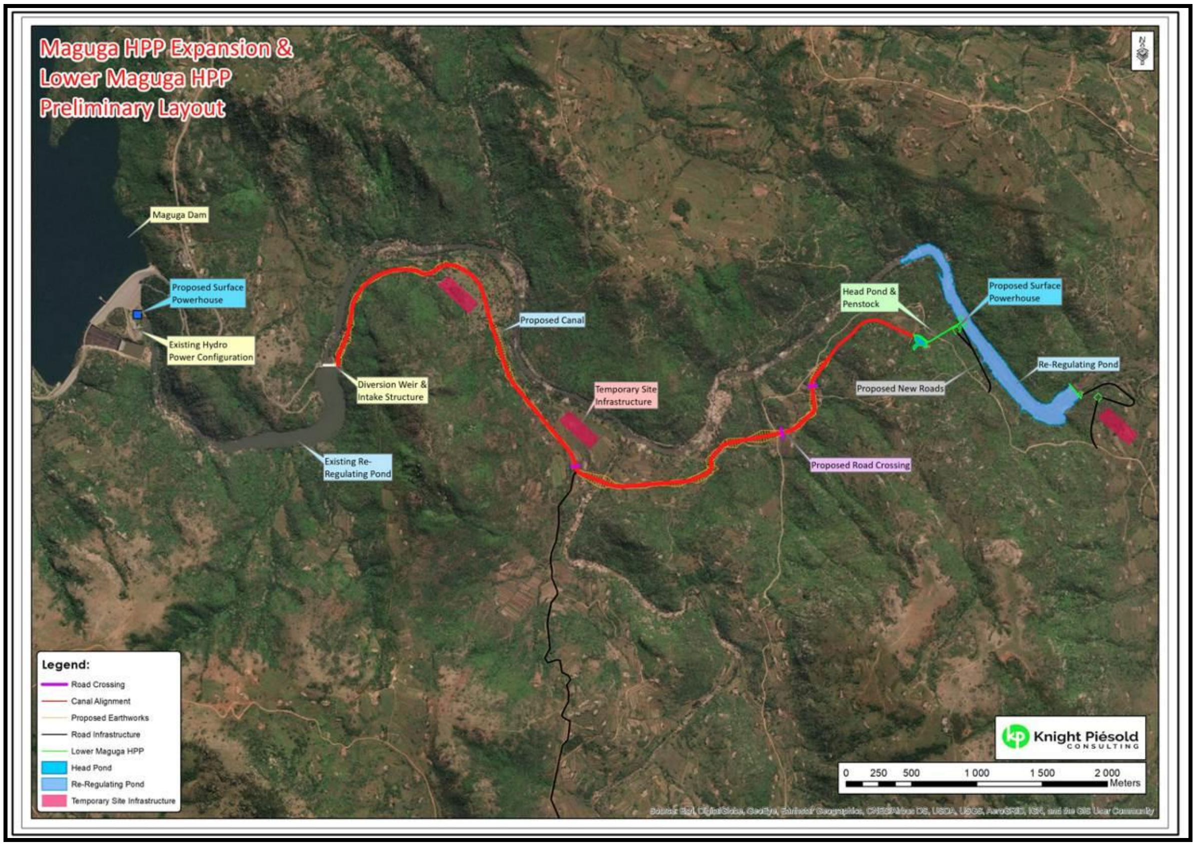

Figure 3. Maguga Expansion and Lower Maguga Hydropower Scheme

9. Energy Production

Energy simulations for the proposed Maguga HPS Expansion, Lower Maguga HPS and Lower Maguga Regulation Weir Mini Hydro were undertaken using the historical and modelled flow records at Maguga Dam. The simulations were compared with the historical record and found to correspond well.

The system was modelled so that energy is generated according to the demand pattern where Peak Energy demands are met before Standard Energy demands and what is remaining will service the Off-Peak Energy demands. Increasing the capacity of the existing Maguga Power Station resulted in only a marginal increase in energy produced, however, there was a significant increase in the amount of peak power which may be generated.

A) MAGUGA DAM EXPANSION HPP - AVERAGE YEAR (2002 to 2017) - VARIABLE HEAD					
OPTION	**AAEP (GWh)**	**PEAK (GWh)**	**STANDARD (GWh)**	**OFF-PEAK (GWh)**	**Δ ENERGY (%)**
OPTION 1	68.9	25.9	42.9	0.0	
OPTION 2	71.3	32.8	38.5	0.0	3.5%
OPTION 3	72.5	39.2	33.3	0.0	5.3%
B) LOWER MAGUGA HPP - AVERAGE YEAR (2007 to 2017)					
OPTION 1	47.5	17.2	29.5	0.8	
OPTION 2	50.8	22.5	28.3	0.0	6.9%
OPTION 3	53.6	28.0	25.7	0.0	12.8%
OPTION 4	55.6	33.1	22.5	0.0	17.0%

C)LOWER MAGUGA NEW REGULATING WEIR HPP - AVERAGE YEAR (2007 to 2017)					
OPTION 1	5.0	0.9	2.2	1.9	
OPTION 2	6.4	1.8	4.0	0.6	27.0%
OPTION 3	7.0	2.7	4.3	0.0	40.0%

AAEP = Average annual energy produced

Table 1. Energy Production Estimates: Determined with Historical Record

10. Cost Estimates & Financial Analyses

Civil, mechanical, electrical and transmission costs were determined for each option by preparing a high-level design and measuring the quantities. The NPV, IRR and levelized cost of energy was calculated for each option.

11. Options Analyses

Options analyses was undertaken by comparing the NPVs, Levelised cost of energy and IRRs. A summary of the options analyses is provided in the table below. The table presents relative values. The NPV and IRR are relative to the lowest NPV and IRR of the schemes analysed. The levelized cost of energy is relative to the highest cost of energy. Financial values are presented as relative values as the actual values are confidential as the project will soon go to tender.

Scheme	Option	Difference to the lowest NPV (△E Millions)	Difference to the highest Levelised Cost (△E/kWH)	Difference to the lowest IRR (△%)
A.) Maguga HPS Expansion	2	0	0	0.0%
	3	**196**	**-1.28**	**19.0%**
B.) Lower Maguga HPS	1	0	-0.28	0.0%
	2	41	-0.22	0.6%
	3	**51**	**-0.13**	**0.6%**
	4	28	0	0.1%
C.) Lower Maguga Regulation Weir HPS	**1**	**35**	**-1.06**	**6.0%**
	2	28	-0.61	3.3%
	3	0	0	0.0%

Table 2. Relative comparison of options

12. Conclusions and Recommendations

To augment the hydropower potential at the site, three new potential hydropower stations have been investigated at Maguga Dam and downstream of Maguga Dam.

- Maguga Hydropower Station Expansion,
- Lower Maguga Hydropower Scheme and
- Lower Maguga Regulation Weir Hydropower Scheme

Options	Rated Flow	Rate Head	Number of Turbines	Turbine Type	Per Turbine	Per Generator	Total Power	Total Energy	Capacity Factor
	m^3/s	m	No.		MW	MVA	MW	GWh	GWh
Existing	**24.18**	**92.6**	**2**	**H. Francis**	**9.9**	**11.3**	**19.8**	**68.864**	**0.40**

Table 3. Details of the existing Maguga Hydropower Scheme

Options	Rated Flow	Rate Head	Number of Turbines	Turbine Type	Per Turbine	Per Generator	Total Power	Total Energy	Capacity Factor
	m^3/s	m	No.		MW	MVA	MW	GWh	
Option 1	-	-	-	-	-	-	-	68.864	
Option 2	7.25	90	1	H. Francis	5	5.9	5	71.303	0.33
Option 3	**15**	**87**	**1**	**H. Francis**	**10**	**11.8**	**10**	**72.534**	**0.28**

Table 4. Details of the Maguga Hydropower Scheme Expansion

Options	Rated Flow	Rate Head	Number of Turbines	Turbine Type	Per Turbine	Per Generator	Total Power	Total Energy	Capacity Factor
	m^3/s	m	No.		MW	MVA	MW	GWh	
Option 1	25	61.7	2	H. Francis	7	8.2	14	47.522	0.39
Option 2	32.5	62	2	H. Francis	8.75	10.3	17.5	50.814	0.33
Option 3	**40**	**62.5**	**2**	**H. Francis**	**10.5**	**12.4**	**21**	**53.635**	**0.29**
Option 4	47.5	62.5	2	H. Francis	12.75	15.0	25.5	55.615	0.25

Table 5. Details of the Lower Maguga Hydropower Scheme

Options	Rated Flow	Rate Head	Number of Turbines	Turbine Type	Per Turbine	Per Generator	Total Power	Total Energy	Capacity Factor
	m^3/s	m	No.		MW	MVA	MW	GWh	
Option 1	10	8	1	Kaplan	0.67	0.8	0.67	5.009	0.85
Option 2	**20**	**8**	**2**	**Kaplan**	**0.67**	**0.8**	**1.34**	**6.349**	**0.54**
Option 3	30	8	3	Kaplan	0.67	0.8	2.01	6.998	0.40

Table 6. Details of the Lower Maguga Weir Mini Hydropower Scheme

For each potential scheme a range of plant capacities was investigated. The higher the capacity of each potential scheme the greater the proportion of peak power the scheme can produce and the lower the capacity factor of the plant.

The NPV, IRR and levelized cost of energy were calculated for each option. This analysis indicated that;

- Maguga HPS Expansion, the best return on investment was for a 10MW expansion. This is the maximum possible expansion size without major alterations to the Maguga Dam Outlet Works. This would require increasing the release capacity from $25m^3/s$ to $40m^3/s$.
- Lower Maguga HPS, the optimum scheme size was a 21MW plant with a rated flow of $40m^3/s$ which gave the best return on investment. However, the returns on both the smaller and larger plants were not too different indicating that Lower Maguga Plant size is not as sensitive to capacity change as Maguga expansion.
- Lower Maguga Regulating Weir Mini Hydro be further investigated.

The levelized cost of energy is high from all of the schemes as a result of them being peaking stations with low-capacity factors.

It is recommended that the feasibility study focuses on a 10MW expansion at Maguga Power Station with a rated flow of $40m^3/s$ and a 21MW plant at Lower Maguga with a design flow of $40m^3/s$. Although the best option for the mini hydro at the Lower Maguga Regulating Weir is a single 0.67MW unit, it is recommended that two turbines be installed for flexibility of operation and ease of maintenance.

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