

Figure 7-7 : Longitudinal Section through the Bulb Turbine Powerhouse

(a) Distribution of Bulb Turbines along the Weir

The powerhouse would be constructed as a block type structure on either the left bank or the right bank of the river depending on the flow conditions in the river reach upstream of the weir. If the weir is located immediately downstream of a bend in the river, then the powerhouse would be placed on the outer bank of the river to avoid the entry of sediments into the intake area of the turbines. The **Figure 7-8** below gives a diagrammatic elevation on the weir showing the position of the bulb unit.

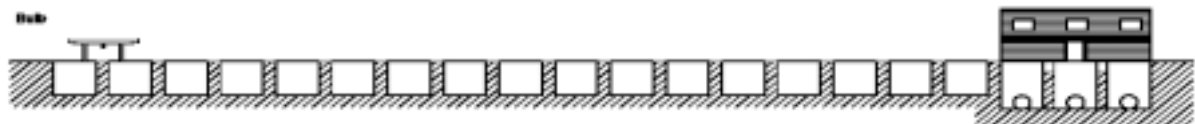


Figure 7-8 : Diagrammatic Elevation on the Weir Showing the Position of the Bulb Unit

It should be pointed out that the placement of the block powerhouse on one side of the river may cause a deposition of sediment entering the reservoir. The deposition of sediment particles, which are in suspension, is expected in areas of low flow velocities. Due to the closed spillway gates and the impoundment during operation of the powerhouse, the flow velocity upstream of the weir is dramatically reduced, which will cause the suspended sediment to settle on the riverbed.

Since the sluicing of sediment during the flood is considered an essential environmental requirement, asymmetric deposits immediately upstream of the barrage may have a negative impact on the efficiency of the sluicing. An increase of deposits could be expected in the centre of the river. During sluicing the main transport of sediments would probably also take place in the centre due to higher flow velocities. Asymmetric deposits upstream of the weir, in the centre of the channel, could be an obstacle to efficient sluicing and may therefore have a negative impact on the effectiveness of sluicing and flushing. Consequently, the bulb

turbine layout with the concentration of flow on one side of the river, over a width of 35 m of a total width of approximately 250 m, or approximately 15% of the available width, cannot be considered as a suitable layout for the sediment sluicing requirements set for the project. However, this matter will need to be investigated by means of physical and numerical modelling to establish the three-dimensional flow pattern for different layouts of the plant.

7.4.3 PIT UNIT WITH CANAL DEVELOPMENT

The Pit unit and canal development was considered at Site 2 for the option where the head over the Falls could be incorporated into the system. This unit is used in project options MB1, MB2 and MB3 above.

7.4.3.1 Pit Turbine Unit

Pit turbines are comparable to bulb turbines in that all mechanical components are located upstream of the runner. The draft tube can therefore be designed to obtain the best hydraulic performance. It is known that for very low heads the kinetic energy of the flow leaving the runner may reach 60% of the total energy available.

A further advantage is that the fitting of a gearwheel between the turbine and the generator provides the possibility of selecting a generator with a higher speed. The size of the generator can be reduced by a considerable amount.

The pit turbine is also double regulated as in the case of the Bulb unit described in **Section 7.4.3**. The turbine can be regulated with the help of the wicket gates as well as the adjustable blades of the runner, and shows a similar performance for reduced discharges as in the case of the bulb unit. A pit unit is therefore considered to be an appropriate solution for the canal developments looked at in options MB1, MB2, and MB3.

7.4.3.2 Electrical Layout with Main Components and Substructures

The electrical system of the plant will be a combination of that of the Hydromatrix and of the bulb turbine power plant.

- (i) **132 kV Switchyard** (refer to **Section 7.4.1.4**)
- (ii) **138/3.3/0.4 kV Step-up Transformers** (refer to **Section 7.4.1.4**)
- (iii) **Pit Turbine Generators**

A total of two pit turbine generator units will be provided. The generators will be designed as synchronous generators with static excitation system. As the two generators work in parallel with the Hydromatrix units they will be connected to the 3.3 kV switchgear via 3.3 kV power cables.

Automatic synchronisation units will be used for parallel switching of each unit to the grid after reaching the synchronous speed.

(iv) Power Plant Substation

A power plant substation will be located on the river bank close to the powerhouse and will incorporate the equipment specified under **Section 7.4.1.4**. Main feeders of the 3.3 kV switchgear are provided for the following:

- Transformers (2 feeders), each including main circuit - breaker, voltage and current transformer,
- Generators, pit turbine type, (2 feeders), each including circuit - breaker, voltage and current transformer,
- Generators, Hydromatrix type, (9 feeders), each including main contactor, main fused load-break switch, voltage and current transformer,
- Regulation resistor (1 feeder), including main contactor, main fused load-break switch, voltage and current transformer,
- Bus coupler, including circuit breaker, busbar VT's, busbar metering,
- Spares (2 feeders, e.g. for compensation equipment, if required), each including main contactor, main circuit breaker, voltage and current transformer.

(v) Mode of Operation of the Pit Turbine Power Plant

Refer to **Section 7.4.1.4**

Concluding Statement on Operational Behaviour of the Pit Turbine Units System

In conclusion it can be stated, that with the combination of pit turbine generators and Hydromatrix units the voltage and load control capabilities of the power plant will be in line with common technical hydro power generation features. Supply of reactive power by the pit turbine generators is possible within their stability limits. Full contribution to power frequency and voltage control in the interconnected grid will be available.

An unrestricted island mode of operation will be possible. However, there will be limitations for direct-on-line starting of large motors of several MW's (5 MW as discussed with NamPower), depending on the spinning reserve of the generating system. However, for this alternative, the available generation capacity can only contribute towards voltage and frequency control to a level of two thirds of the bulb turbines alternative.

7.4.3.3 Concept and Layout of Pit Turbine Units: Site 2**(a) Turbine Size and Number of Units**

The basic concept for all canal development alternatives studied at Site 2 is a combination of Hydromatrix turbines and Pit turbine units. Due to environmental reasons and as a requirement to maintain the aesthetic value of the Popa Falls area, it is essential that flow over the Popa Falls should not be interrupted at any time. . This implies that the discharge may not be less than the minimum recorded flow, which is approximately 80 m³/s. The flow duration curve given in **Figure 7-1** of **Section 7.1** shows a flat curve between the Q_{100%} and

the $Q_{90\%}$, which lie between $80 \text{ m}^3/\text{s}$ and $120 \text{ m}^3/\text{s}$ respectively. Although minimum flow requirements have not been defined, a minimum discharge of approximately $80 \text{ m}^3/\text{s}$ has been assumed for design purposes. The application of Hydromatrix units would give a high flexibility for the hydro power production, guaranteeing that the reservoir outflow would be the same as the inflow, hence maintaining natural discharge conditions downstream of the weir. The general characteristics of the three sets of Hydromatrix modules are identical to the one mentioned in **Section 7.3.1**.

The Hydromatrix turbine installation is best suited for ensuring that the minimum flow is maintained, whereas the pit turbine units can utilise discharges higher than the flow. For the Hydromatrix installation, three Modules should be used, each with 3 TG-Units with a discharge capacity of approximately $12 \text{ m}^3/\text{s}$ each, which will result in a total discharge capacity of $108 \text{ m}^3/\text{s}$.

The difference between the design discharge and the minimum discharge is the rated flow for the pit type turbine alternative within the canal development. A rated flow of $170 \text{ m}^3/\text{s}$ and an operating net head of 10.8 m for the full water supply level of 1007.5 m.a.m.s.l. are the basic criteria for an installation of 16.2 MW and a generating unit size of two units each 8.1 MW. The turbines are within the range of the pit-turbine type that suit an application for large discharge and high-power output at relatively low head. Based on the design discharge, a powerhouse with two units is the best technical and economical canal development solution for the project using a pit turbine type. The key turbine data is listed below in **Table 7-7** and a sketch of the powerhouse is given in **Figure 7-9** below.

Table 7-7 : Key Turbine Data for the Pit Turbine Alternative

| Parameter | | Bulb Unit at Barrage |
|---------------------------|-----------------------|-----------------------------------|
| Headpond Level | m.a.m.s.l. | 1007.5 |
| Tailwater Level | m.a.m.s.l. | depends on tailwater rating curve |
| Rated flow | m^3/s | 85 |
| Number of Units | No. | 2 |
| Turbine rated efficiency | % | 0.92 |
| Turbine setting elevation | m.a.m.s.l. | 992.8 |
| Runner Diameter | m | 3.65 |
| Number of Blades | No. | 4 |
| Nominal Speed | rpm | 150 |
| Generator Speed | rpm | 600 |
| Suction Head H_s | m | -3.50 |

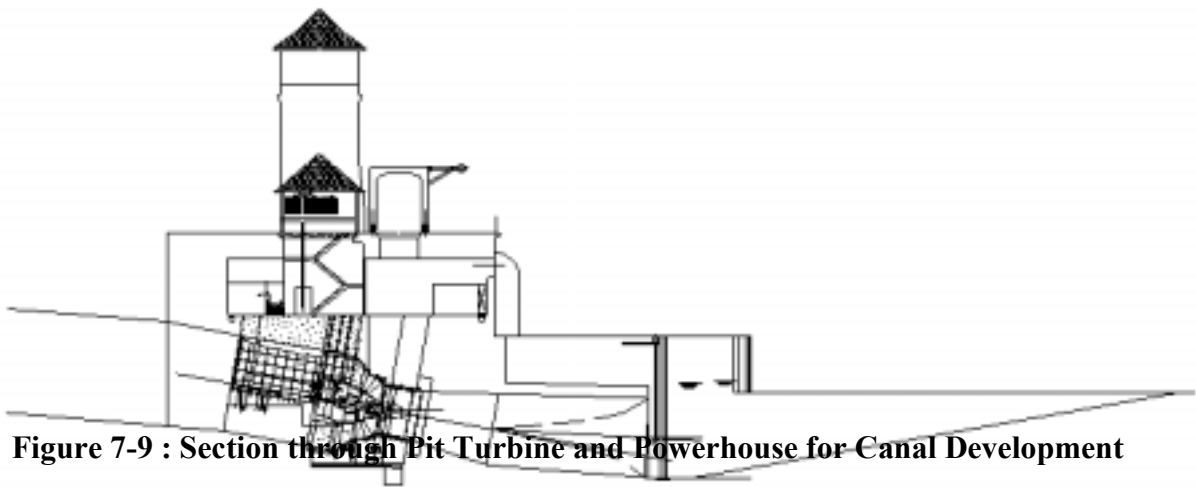


Figure 7-9 : Section through Pit Turbine and Powerhouse for Canal Development

(b) Description of Waterway

Discharges in excess of $108 \text{ m}^3/\text{s}$ being discharged by the Hydromatrix turbine Units, enter the pit turbines through a lateral intake to a headrace channel, which will be located on the left bank of the river. The headrace channel conveys the water to a headpond where it enters the penstock. The outlet structure of the headpond will incorporate a trash rack, trash rack cleaning equipment and stoplogs for maintenance purposes of the penstock. For environmental reasons the penstock will be underground over its total length to the powerhouse. The powerhouse will be a surface structure located on the left bank of the river downstream of the Popa Falls. The outflow from the turbines is conveyed back to the river via a tailrace channel.

The powerhouse is anticipated to be approximately 24 m wide, 41 m long and 22 m high. A typical section through the powerhouse is given in **Figure 7-9** above. Costs for the powerhouse are expected to be high when compared with the Hydromatrix installations. However, the pit turbine type option has the advantage over the conventional bulb unit option, that the powerhouse dimensions are smaller and therefore less costly.

(c) Description of Canal Development Alternatives

As already mentioned in **Section 7.2**, three different waterways were investigated for the canal developments. The difference in the waterways is the location of the headpond and the powerhouse. Consequently, the length of the headrace channel, the penstock, as well as the tailrace channel, differ for the various alternatives. The main dimensions of the principal civil structures are, however, the same.

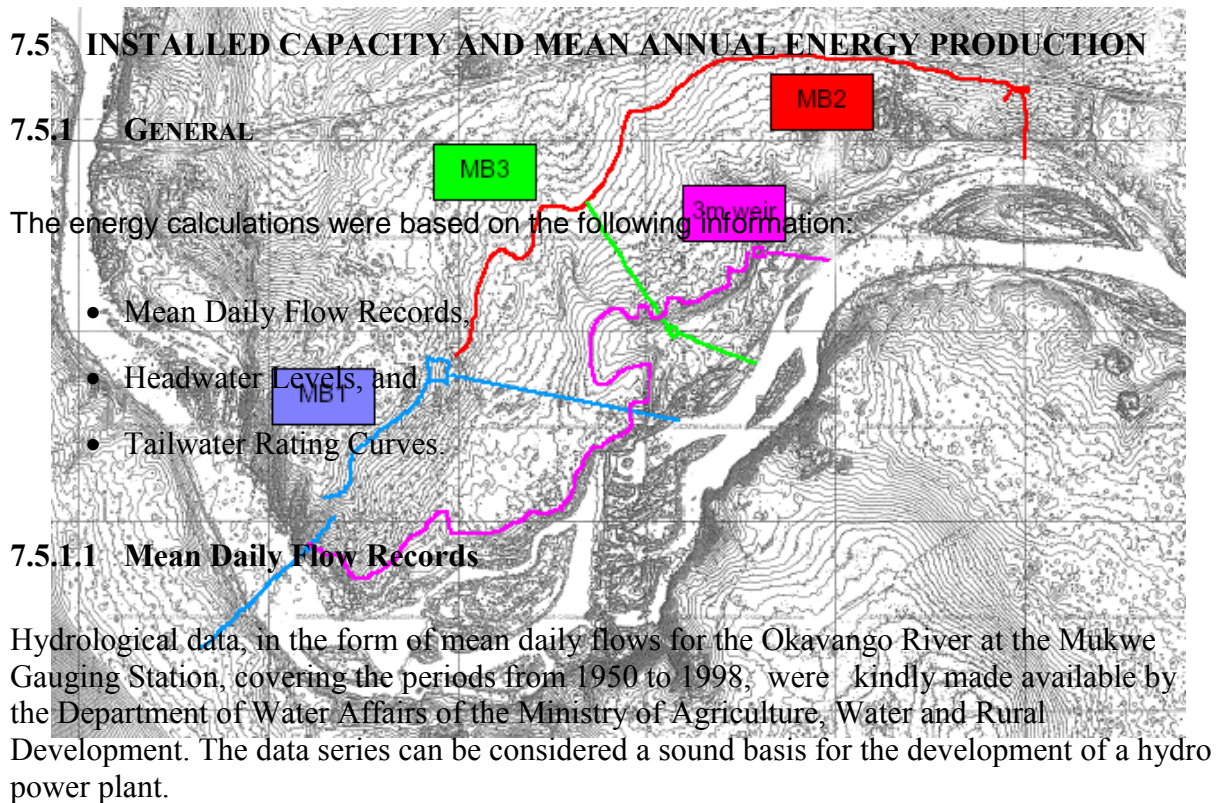
The **Figure 7.10** below shows the principal layout of the waterways. For the alternatives MB1, MB2 and MB3, the headwater level is 1007.5 m.a.m.s.l., while the tailwater was determined in a first approximation from the tailwater rating curve of the Popa Falls. Additional to the combination of Hydromatrix / Bulb Turbine options, the option of constructing a 3 m high weir upstream of the Falls was investigated.

The different lengths of the waterways is as follows:

- **Option MB1:** Headrace channel (1200 m), headpond, penstock, (850 m), powerhouse and tailrace channel (70 m).

- **Option MB2:** Headrace channel (6000 m), headpond, penstock (200 m), powerhouse, and tailrace channel (70 m).
- **Option MB3:** Headrace channel (2600 m), headpond, penstock (450 m), powerhouse, and tailrace channel (450 m)
- **3m high Weir Option:** Headrace channel (4300 m), headpond, penstock (50 m), powerhouse, and tailrace channel (300 m)

Figure 7-10 : Canal Development Alternatives



7.5.1.2 Headwater Levels

The headwater level mainly depends on the selected full supply level of the site, to which must be added the maximum overflow depth defined by the Tops spillway gates, which at present has been set to a maximum of 300 mm. (See section ...) In the feasibility phase of the study, a more detailed reservoir operation guideline will need to be established in co-operation with experts for turbines, control equipment, and gate operation. For this purpose it is important to install a river gauging station near the border with Angola.

7.5.1.3 Tailwater Levels

The backwater analysis, was based on airborne laser survey mapping from which the tail water levels were derived, and the results were used for the energy calculations. The determination of the river channel profile, and the depth of flow on the date of the airborne survey, was carried out using an iterative modelling process and was based on the flow recorded on the date of the survey. Actual water levels were not recorded during this pre-feasibility study with the result that present power and energy calculations should be considered as preliminary since they have been based on estimated tailwater levels only. During the next phase of the project, tailwater rating curves based on field surveys at specific locations should be used for accurate energy calculations. The values determined in the present study can, however, be considered as conservative.

7.5.2 INSTALLED CAPACITY AND ENERGY PRODUCTION AT SITE 2

Due to environmental considerations the maximum full supply level at Site 2 has been limited to 1007.5 m.a.m.s.l. **Tables 7-8 to 7-12** below and on the following pages, give the results of the hydraulic parameters, the installed capacity and the energy production for the Hydromatrix turbine, Bulb unit and Pit unit with canal development.

7.5.2.1 Hydromatrix Turbines

Table 7-8 : Results of Hydromatrix Turbine Energy Calculations

| Parameter | Unit | Value |
|---------------------------|-------------------|-------|
| Maximum Gross Head | m | 6.72 |
| Design Discharge per Unit | m ³ /s | 11.5 |
| Number of Turbines | No. | 27 |
| Maximum Turbine Output | MW | 0.628 |
| Maximum Turbine Output | MW | 16.9 |
| Generator Efficiency | % | 94.5 |
| Generator Output | MW | 0.594 |
| Total Generator Output | MW | 16.0 |
| Annual Energy Production | GWh | 83.4 |

7.5.2.2 Bulb Unit at Weir

Table 7-9 : Results of the Bulb Unit Energy Calculations

| Parameter | Unit | Value |
|---------------------------|-------------------|-------|
| Maximum Gross Head | m | 6.72 |
| Design Discharge per Unit | m ³ /s | 93.33 |
| Number of Turbines | No. | 3 |
| Maximum Turbine Output | MW | 5.475 |
| Maximum Turbine Output | MW | 16.4 |
| Generator Efficiency | % | 95.0 |
| Generator Output | MW | 5.200 |
| Total Generator Output | MW | 15.6 |
| Annual Energy Production | GWh | 88.7 |

7.5.2.3 Pit Unit with Canal Development

Power and energy calculations were carried out for Site 2 for the combined Hydromatrix-Bulb-Canal Development alternative for a FSL of 1007.50 m.a.m.s.l. **Tables 7-10, 7-11 and 7-12** below and on the following page, list the technical details and power output for the Hydromatrix turbines and the Pit Unit.

Table 7-10 : Technical Data and Installed Capacity for the Hydromatrix Turbines

| Parameter | Unit | Value |
|---------------------------|-------------------|-------|
| Maximum Gross Head | m | 6.72 |
| Design Discharge per Unit | m ³ /s | 11.5 |
| Number of Turbines | No. | 9 |
| Maximum Turbine Output | MW | 0.628 |
| Total Turbine Output | MW | 5.65 |
| Generator Efficiency | % | 94.5 |
| Generator Output | MW | 0.594 |
| Total Generator Output | MW | 5.34 |

Table 7-11 : Technical Data and Installed Capacity for the Pit Unit

| Parameter | Unit | Value |
|---------------------------|-------------------|-------|
| Maximum Gross Head | m | 12.3 |
| Design Discharge per Unit | m ³ /s | 85 |
| Number of Turbines | No. | 2 |
| Maximum Turbine Output | MW | 8.285 |
| Total Turbine Output | MW | 16.57 |
| Generator Efficiency | % | 95.0 |
| Generator Output | MW | 7.870 |

| | | |
|------------------------|----|-------|
| Total Generator Output | MW | 15.74 |
|------------------------|----|-------|

Table 7-12 : Installed Capacity and Mean Annual Energy Production for Hydromatrix/Bulb Alternative

| MB 1 | | MB2 | | MB3 | |
|------------|--------------|------------|--------------|------------|--------------|
| Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] |
| 21.1 | 113.7 | 21.0 | 111.2 | 20.9 | 109.5 |

Table 7-12 above shows that alternatives MB2 and MB3 have slightly higher energy losses with the result that the energy production would be slightly lower than in the case of alternative MB1.

7.5.2.4 3 m Weir

In the case of the 3 m weir alternative, the maximum installed capacity is only 7.5 MW with an annual energy production of 40.8 GWh. It is therefore obvious that this option does not comply with NamPower’s requirements for the Popa Falls Hydro Power Project.

7.5.3 INSTALLED CAPACITY AND ENERGY PRODUCTION AT SITE 4

The maximum FSL at Site 4 would be at 1010.0 m.a.m.s.l. due to environmental considerations. However, within the framework of the present study, the FSL of 1007.5 m.a.m.s.l. as well as 1012.5 m.a.m.s.l. were studied in terms of installed capacity and mean annual energy production to demonstrate the impact of the FSL on the project’s financial and economic feasibility. Only two alternatives would be technically feasible at Site 4, namely the installation of Hydromatrix turbines or the installation of the Bulb units at the weir. Details of these alternatives are given in the following Sections:

7.5.3.1 Hydromatrix Turbine

The technical data, power output, and annual energy production figures for the Hydromatrix turbine alternative for various FSLs are given in **Table 7-13**.

Table 7-13 : Installed Capacity and Mean Annual Energy Production for the Hydromatrix Unit at Site 4 for Various FSLs

| Parameter | Unit | FSL | FSL | FSL |
|--------------------------|-------------------|------------------------|------------------------|------------------------|
| | | 1007.5 [m.a.m.s.l.] | 1010.0 [m.a.m.s.l.] | 1012.5 [m.a.m.s.l.] |
| Max. gross head | m | 5.6 | 8.1 | 10.6 |
| Design discharge | m ³ /s | 11.38 | 12.22 | 13.05 |
| Number of turbines | No. | 27 | 27 | 27 |
| Max. turbine output | MW | 0.495 | 0.803 | 1.075 |
| Max. Turbine output | MW | 13.4 | 21.6 | 29.0 |
| Generator efficiency | % | 94.5 | 94.5 | 94.5 |
| Generator output | MW | 0.468 | 0.759 | 1.016 |
| Total Generator Output | MW | 12.6 | 20.5 | 27.4 |
| Annual Energy Production | GWh | 61.8 | 102.2 | 144.1 |

7.5.3.2 Bulb Unit at Weir

The Bulb unit proposed for Site 4 is able to operate between the abovementioned gross heads of 5.6 m and 10.1 m. Details of the power output and energy production for the various FSLs are given on **Table 7-14** below:

Table 7.14: Installed Capacity and Mean Annual Energy Production for the Bulb Unit at Site 4 for Various Full Supply Levels

| FSL 1007.5 [m.a.m.s.l.] | | FSL 1010.0 [m.a.m.s.l.] | | FSL 1012.5 [m.a.m.s.l.] | |
|----------------------------|--------------|----------------------------|--------------|----------------------------|--------------|
| Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] |
| 13.2 | 67.4 | 19.4 | 105.3 | 25.5 | 143.3 |

7.5.4 INSTALLED CAPACITY AND ENERGY PRODUCTION AT SITE 5

The maximum FSL for Site 5 would also be at 1010.0 m.a.m.s.l. but the total head at the weir is 9.75 m as opposed to 9.0 m at Site 4. Power and energy calculations were carried out for this alternative. Additional to this, calculations were also carried out for a FSL of 1011.0

m.a.m.s.l. for the purpose of demonstrating the impact of the FSL on the energy production as well as on the installed capacity.

7.5.4.1 Hydromatrix Turbine

The results of the power and energy calculations for the Hydromatrix turbines alternative are given in **Table 7-15** below:

Table 7-15 : Installed Capacity and Mean Annual Energy Production for the Hydromatrix Unit at Site 5 for Various FSLs

| Parameter | Unit | FSL | FSL | FSL |
|--------------------------|-------------------|------------------------|------------------------|------------------------|
| | | 1007.5 [m.a.m.s.l.] | 1010.0 [m.a.m.s.l.] | 1011.0 [m.a.m.s.l.] |
| Max. Gross Head | m | 6.6 | 9.1 | 10.1 |
| Design Discharge | m ³ /s | 11.48 | 12.3 | 12.65 |
| Number of Turbines | No. | 27 | 27 | 27 |
| Max. Turbine Output | MW | 0.601 | 0.912 | 1.056 |
| Max. Turbine Output | MW | 16.2 | 24.6 | 28.5 |
| Generator Efficiency | % | 94.5 | 94.5 | 94.5 |
| Generator Output | MW | 0.568 | 0.861 | 0.998 |
| Total Generator Output | MW | 15.3 | 23.2 | 26.9 |
| Annual Energy Production | GWh | 77.3 | 118.2 | 133.8 |

7.5.4.2 Bulb Unit at Weir

Various full supply levels were investigated similar to the Hydromatrix turbine alternative, the results of which are presented in **Table 7-16** below.

Table 7.16 : Installed Capacity and Mean Annual Energy Production for the Bulb Unit at Site 5 for various FSLs

| FSL 1007.51010.0 [m.a.m.s.l.] | | FSL 1010.0 [m.a.m.s.l.] | | FSL 1011.0 [m.a.m.s.l.] | |
|----------------------------------|--------------|----------------------------|--------------|----------------------------|--------------|
| Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] | Power [MW] | Energy [GWh] |
| 16.1 | 82.6 | 22.2 | 120.5 | 24.7 | 135.7 |

7.6 SITE EVALUATION

7.6.1 METHODOLOGY

The objective of the site evaluation is to identify the most economic layout alternatives for the present project. The project screening for the present project has been developed in a step-by-step approach, which is described below.

Firstly, all possible sites located between the Popa Falls and the Frans Dimbare Youth Centre were identified. Sites further upstream were excluded as these would result in inundation of the Andara Mission Station. For a detailed description of the alternative sites originally identified and the selection of Sites 2, 4 and 5 for further detailed analysis, refer to **Section 6** of this report. Site 2, Site 4 and Site 5 are briefly summarised below.

Site 2:

The height of the weir at this site is limited to 7,5 m in order to minimise the impoundment area and hence the extent of relocation required. An increase of the weir height would also require the raising of the Trunk Road TR8/4 to the Caprivi Region.

Site 4:

The weir height at this site is limited to 9 m (1010.0 m.a.m.s.l.) constrained by environmental reasons and prevention of inundation of the Frans Dimbare Youth Centre which would occur at higher weir levels. This site has the advantage that a higher head is available for power generation compared to Site 2. The FSL would result in an inundation of approximately 29% (1,36 km²) of the islands located upstream of the site.

Site 5:

This site will allow a weir to be constructed to a height of 9,75 m (1010.0 m.a.m.s.l.) which would increase the available head and consequently the power generation potential compared to Site 4. The area of islands that would be submerged at FSL would only increase marginally to 30% of the islands located upstream of the site.

Secondly, all possible layouts (turbine types) for each site as well as different full supply levels were considered. A total of 18 project alternatives were considered during the site evaluation, which are given in **Table 7-19**:

Table 7-19 : Matrix of Project Alternative

| Site | Alternative | FSL [m.a.m.s.l.] | | | | |
|------|-----------------------|------------------|--------|--------|--------|--------|
| | | 1003.0 | 1007.5 | 1010.0 | 1011.0 | 1012.5 |
| 2 | Hydromatrix Turbine | | X | | | |
| | Bulb Unit at Weir | | X | | | |
| | Canal Development MB1 | | X | | | |
| | Canal Development MB2 | | X | | | |
| | Canal Development MB3 | X | X | | | |
| | 3m Weir | X | | | | |
| 4 | Hydromatrix Turbine | | X | X | | X |
| | Bulb Unit at Weir | | X | X | | X |
| 5 | Hydromatrix Turbine | | X | X | X | |
| | Bulb Unit at Weir | | X | X | X | |

The alternatives were evaluated in terms of construction costs for installed capacity as well as construction costs per annual energy production. The ratio between the construction costs and the installed capacity is called the unit cost per MW. The ratio between the construction costs per average annual energy production is the unit cost per kilowatt hour without consideration of interest rates. Both provide a first indication of which alternatives would be the most economical and which need to be investigated further with a detailed cost estimate and a preliminary bill of quantities.

The construction costs were calculated on the basis of preliminary unit prices for civil works, and on computed prices for hydraulic machinery, hydraulic steel structures, electrical equipment and environmental mitigation costs, and these were used for the comparison of the economics at each site. For each major cost item, physical contingencies of 10% were assumed. In addition, costs for various sundry items such as engineering design, and construction supervision, model testing, professional fees and miscellaneous costs, etc., were included.

The installed capacity and the annual energy production figures for each site and for various full supply levels were taken from the calculations carried out and described in **Section 7.5**.

7.6.2 RESULTS

The costs per installed capacity were calculated for all nineteen project alternatives mentioned in **Section 7.6.1**. The results of the calculations are given in the **Table 7-20** and **Table 7-21**.below. The results for alternatives selected for further investigation based on technical and environmental criteria are indicated in bold type. The results show that costs per installed Kilowatt vary from 2 000 US\$/kW to 5 250 US\$/kW and unit costs per year vary from 0.31 US\$/kWh a to 0.96 US\$/kWh a.

Table 7-20 : Summary of Investment Costs per Installed Megawatt

| Installation Type | Sub-Alternative | Weir height [m.a.m.s.l.] | Site 2 [US\$/kW] | Site 4 [US\$/kW] | Site 5 [US\$/kW] |
|-------------------------------------|-----------------|-----------------------------|---------------------|---------------------|---------------------|
| Alt. 1 : Hydromatrix Turbine | | 1007.5 | 2499 | 3204 | 2764 |
| Bulb Turbines | | 1007.5 | 2562 | 3065 | 2804 |
| Alt 2 : Hydromatrix Turbine | | 1010.0 | - | 2023 | 1959 |
| Bulb Turbines | | 1010.0 | - | 2125 | 2009 |
| Alt 3 : Hydromatrix Turbine | | 1012.5 / 1011 | - | 1935 | 2122 |
| Bulb Turbines | | 1012.5 / 1011 | - | 1870 | 2259 |
| Alt. 4 : Canal Developments | MB1 | 1007.5 | 2333 | | |
| | MB2 | 1007.5 | 2343 | | |
| | MB3 | 1007.5 | 2463 | | |
| Alt. 5 : 3m High Weir Option | | 1003.0 | 5235 | | |

Table 7-21 : Summary of Unit Costs per Year of the Project Alternatives

| Installation Type | Sub-Alternative | Weir height [m.a.m.s.l.] | Site 2 [US\$/kWh a] | Site 4 [US\$/kWh a] | Site 5 [US\$/kWh a] |
|-------------------------------------|-----------------|-----------------------------|------------------------|------------------------|------------------------|
| Alt. 1 : Hydromatrix Turbine | | 1007.5 | 0.4075 | 0.5547 | 0.4863 |
| Bulb Turbines | | 1007.5 | 0.4506 | 0.6002 | 0.5296 |
| Alt 2 : Hydromatrix Turbine | | 1010.0 | - | 0.3444 | 0.3266 |
| Bulb Turbines | | 1010.0 | - | 0.3912 | 0.3702 |
| Alt 3 : Hydromatrix Turbine | | 1012.5 / 1011 | | 0.3129 | 0.3604 |
| Bulb Turbines | | 1012.5 / 1011 | | 0.3328 | 0.4112 |
| Alt. 4 : Canal Developments | MB1 | 1007.5 | 0.4327 | | |
| | MB2 | 1007.5 | 0.4423 | | |
| | MB3 | 1007.5 | 0.4698 | | |
| Alt. 5 : 3m High Weir Option | | 1003.0 | 0.9624 | | |

For Site 2 the maximum full supply level would be limited to 1007.5 m.a.m.s.l. All alternatives, either Hydromatrix turbine, bulb turbine at weir or pit turbine with canal development, are restricted to this FSL due to environmental considerations. Whilst the investment costs for both the Hydromatrix turbine and the bulb unit alternatives, are in the range of US\$ 2500/kW, the investment costs for the canal developments lie between US\$ 2300/kW and US\$ 2459/kW. This shows that, whilst the investment costs per installed capacity would be lower for the canal developments, the investment costs per kilowatt hour exceed US\$ 0.43/kWh a. The reason for this is the high costs for the civil works of the canal developments, which include costs for the canal, penstock and powerhouse, whereas the additional energy generated during the flood season would be relatively small.

At Site 4 the full supply levels of 1007.5, 1010.0 and 1012.5 m.a.m.s.l. were investigated. The costs per installed capacity vary between US\$ 1900/kW and US\$ 3200/kW. The costs per installed capacity are the highest for the full supply level of 1007.5 m.a.m.s.l. and decrease with the increase of FSL. Specific investment costs therefore also decrease with higher FSLs. The reason for this is the considerably higher installed capacities with limited additional costs to achieve 2.5 m or even 5 m additional head. The major cost items would be the weir itself including the civil structures. The depths for the foundations of the weir are almost independent of the height of the weir in the range of weir heights considered. The impact of the height of the weir would therefore not be of great significance in the total costs of the hydro power project. Consequently, the investment per energy generated annually will decrease with increasing head. The investment costs decrease from US\$ 0.60/KWha at a FSL of 1007.5 m.a.m.s.l. to US\$ 0.32/KWha at a FSL of 1012.5 m.a.m.s.l.

At Site 5 the focus was on the full supply levels of 1007.5 m.a.m.s.l., 1010.0 m.a.m.s.l. and 1011.0 m.a.m.s.l. The specific costs range from US\$ 2000/kW to US\$ 2250/kW for the supply levels of 1010.0 and 1011.0 m.a.s.l.. The investment per power generation annually for both alternatives lies between US\$ 0.32/KWha and US\$ 0.41/KWha, which makes this the most economical solution. For the full supply level of 1007.5 m.a.m.s.l. the costs per installed capacity and per annual power generation are the highest for this site.

Based on the results of the calculations in **Table 7-20** and **Table 7-21** it can be concluded that project alternatives with investment costs less than US\$ 2200/kW are of interest for further study and development. Regarding the costs per annual energy production it can be stated,

that alternatives below US\$ 0.40KWha are also considered to be of interest for a more detailed analysis in the framework of the present project. Moreover, the analysis showed, that the Hydromatrix Turbine alternatives have lower investment costs / generation costs than the alternative with a bulb unit at the weir. The 18 alternatives investigated were further screened thereby reducing the number selected for further investigation to the following 7 alternatives:

| | | |
|----------------|---------------------|---|
| Site 2: | Hydromatrix Turbine | FSL 1007.5 m.a.m.s.l. |
| Site 4: | Hydromatrix Turbine | FSL 1007.5 m.a.m.s.l. FSL 1010.0 m.a.m.s.l. FSL 1012.5 m.a.m.s.l. |
| Site 5: | Hydromatrix Turbine | FSL 1007.5 m.a.m.s.l. |
| | Hydromatrix Turbine | FSL 1010.0 m.a.m.s.l. |
| | Hydromatrix Turbine | FSL 1011.0 m.a.m.s.l. |

For Site 2 the maximum permissible FSL was limited to 1007.5 m.a.m.s.l. due to environmental considerations. The FSLs of Site 4 and Site 5 of 1010.0 m.a.m.s.l. is also considered the most feasible for environmental reasons. However, in order to demonstrate the impact of lower / higher heads, the full supply levels of 1007.5 m.a.m.s.l. and 1012.5 m.a.m.s.l. were also evaluated for Site 4 and full supply levels of 1007.5 m.a.m.s.l. and 1011.0 m.a.m.s.l. were also evaluated for Site 5.

Detailed cost estimates were prepared for the above mentioned project alternatives. These are discussed and presented in depth in **Section 13** of this report. The cost estimates for above mentioned project alternatives are also considered for the financial and economic analysis of the project presented in **Section 14** of this report.

Table 8-18 : Evaluation of Various Hydro Power Unit Options

| Criteria | Hydromatrix Units Distributed across River | Hydromatrix Units on One Side of Weir | Bulb Units in the Weir | Pit Units with Canal |
|----------|--|---------------------------------------|------------------------|----------------------|
|----------|--|---------------------------------------|------------------------|----------------------|

| | | | | |
|---|-----------|-----------|-----------|-----------|
| <u>TECHNICAL</u> | | | | |
| ● Minimum maintenance | 2 | 1 | 2 | 2 |
| ● Contribution to power frequency and – voltage control | 2 | 2 | 3 | 2 |
| ● Ability to supply reactive power | 3 | 3 | 3 | 3 |
| ● Sluicing ability | 3 | 2 | 1 | 2 |
| ● Maximum power output (MW) | 3 | 3 | 3 | 2 |
| ● Maximum annual energy production (GWh) | 3 | 3 | 3 | 2 |
| ● Island mode operation | | | | |
| Sub-Total Technical | 16 | 14 | 15 | 13 |
| <u>FINANCIAL</u> | | | | |
| ● Cost of Unit (capex) | 3 | 3 | 2 | 1 |
| ● Operating costs | 3 | 3 | 2 | 1 |
| Sub-Total Financial | 6 | 6 | 4 | 2 |
| <u>ENVIRONMENTAL</u> | | | | |
| ● Non interruption of normal flow | 3 | 3 | 1 | 1 |
| ● Ability to move sediments | 3 | 1 | 1 | 2 |
| ● Impact on River downstream of weir | 3 | 3 | 1 | 1 |
| ● Evenly distributed discharge | 3 | 1 | 1 | 1 |
| ● Area of disturbance | 3 | 3 | 2 | 2 |
| Sub-Total Environmental | 15 | 11 | 6 | 7 |
| <u>SOCIAL</u> | | | | |
| ● Visual Impacts | 2 | 2 | 2 | 2 |
| ● Noise impacts | 2 | 2 | 2 | 2 |
| Sub-Total Social | 4 | 4 | 4 | 4 |
| TOTAL | 41 | 35 | 29 | 26 |