

+SECTION 7 : HYDRO POWER UNITS

PROJECT LAYOUTS

Five different sites were initially identified and evaluated and **Section 7** of this report provides an overview and a first assessment of the considered alternative weir sites. The alternatives were subject to a screening process with the aim of eliminating the least attractive alternatives. Based on the results of the screening, Sites 2, 4 and 5 were selected for further detailed analysis.

The following different types for the installation of hydro power units were studied for the aforementioned sites:

- Hydromatrix turbines only,
- Bulb turbines only,
- Combination of Hydromatrix and Bulb turbines,
- Pit turbines with a canal.

Site 2 is close to the Popa Falls and would permit the utilisation of the additional head of the Falls for power generation during high flood periods. Depending on the discharge of the Okavango River, the additional head varies between 3 and 4.5 m. Three different layouts were developed as combined Hydromatrix-Bulb (**MB**) solutions described in more detail below.

The basic concept is to install a number of Hydromatrix modules in the barrage, which would allow for a minimum flow to be maintained over the falls. In the absence of precise environmental requirements, it has been assumed for design purposes from the hydrological records that a minimum flow of approximately $90 \text{ m}^3/\text{s}$ will be required to be maintained over the falls. As can be seen from the flow duration curve given in **Figure 7-1**, a discharge in the range of $100 \text{ m}^3/\text{s}$ corresponds to an availability of approximately 98%. By the installation of three sets of Hydromatrix turbines the minimum flow of $90 \text{ m}^3/\text{s}$ would always be discharged over the Popa Falls. Discharges in excess of a minimum discharge of $100 \text{ m}^3/\text{s}$ would be conveyed via a canal on the left bank of the river and discharge into a headpond from where the water would flow via a penstock to the bulb turbines and powerhouse. The powerhouse would be located downstream of the Popa Falls and the outflow from the turbines would be discharged back into the river via a short tailrace canal.

Three different layout combinations have been investigated for the Hydromatrix-Bulb combinations, which are briefly described below.

- Alternative MB1: Short headrace canal, long penstock, short tailrace canal. The headrace canal would have a length of approximately 1200 m, the penstock a length of approximately 850 and the tailrace canal a length of approximately 70 m.
- Alternative MB2: Long headrace canal (6 000 m), short penstock (200 m), and a short tailrace canal (70 m).

- Alternative MB3: Headrace canal (2 600 m), headpond/penstock (450 m), and powerhouse/tailrace canal (450 m).

These various alternative layouts are shown on **Figure 7-19** in **Section 7.4.3.3**.

The construction of a 3 m high weir with a canal development using the additional head of Popa Falls was also investigated for the sake of completeness. This alternative would not satisfy the criteria of sustaining a minimum flow over the Popa Falls and was therefore discarded at an early stage.

Table 7-1 below shows the different layout options for the different sites that were considered in the framework of the Pre-Feasibility Study:

Table 7-1 : Matrix of Project Alternatives

| Alternative | Site 2 | Site 4 | Site 5 |
|------------------------------------|-------------------|--------|--------|
| Hydromatrix Turbine | X | X | X |
| Bulb Turbine | X | X | X |
| Combined Matrix – Bulb Development | MB1 MB2 MB3 | | |
| Bulb Unit – 3m weir | X | | |

For **Site 2**, three hydro power configurations were investigated in detail. Apart from investigating the Hydromatrix and the Bulb unit layout options, the abovementioned alternative combinations of a Hydromatrix-Pit turbine canal development were also investigated. Due to the inundation upstream of Site 2, the FSL was limited to 1007.5 m.a.m.s.l.

Only Hydromatrix-Bulb configurations were studied for **Site 4** as the additional head of the Falls is too far away to be utilised for power generation. The advantage of Site 4 is that the maximum FSL may be set at a higher elevation. Bearing in mind that the mean riverbed level is 1001.0 m.a.m.s.l. at Site 4, the water depth at the weir can be increased from 7.5 m at Site 2 to 9 m at Site 4 that is to a FSL elevation of 1010.0 m.a.m.s.l. This additional head would improve the installed power capacity and the expected annual energy production of the plant significantly. Moreover, two additional FSLs were studied for this site, namely 1007.5 m.a.m.s.l. and 1012.5 m.a.m.s.l.. This was done in order to assess what effect an increase or decrease of the FSL would have on the installed capacity, the mean annual energy production, as well as the resulting costs.

A closer inspection of the river reach between Site 2 and Site 4 showed that an additional site, **Site 5**, could be considered as appropriate for the development of a weir. This site is located approximately 1 km downstream of Site 4. The conditions are similar to Site 4 except that this site does not have a side channel which could be used for river diversion during construction, but it does have the advantage, when compared to Site 4, that the impoundment depth at the weir would increase by approximately 0,75 m without increasing the inundated area upstream of the weir.

7.2 DESIGN DISCHARGE

For the determination of the design discharge at the Popa Falls HPP the flow duration curve given in **Figure 7-1** on the following page was used to calculate the discharge available for power generation. Based on the flow duration curve, further analyses, related to the sediment sluicing requirements for the Popa Falls HPP, were carried out.

Since it is important that sediment movement is not to be significantly disrupted, since disruption of the movement of sediment may have serious environmental impacts downstream of the weir, and eventually the Delta, regular sluicing, or an alternative sediment bypass system, becomes essential. Experience gained on numerous dam basins world wide has shown that sluicing of sediments that have accumulated in the weir basin, will only be efficient during high flood periods, and if the reservoir capacity of 2% of the MAR is not exceeded. The sluicing volume is a function of the reservoir capacity. For a storage capacity of 2% of the MAR, the sluicing volume amounts to approximately 80% of the MAR.

According to the flow duration curve the sluicing volume of 80% MAR would correspond to a discharge of 210 m³/s. This would lead to an annual operation time of only 3 500 hours. **Figure 7-2** shows the relationship between discharge and the MAR.

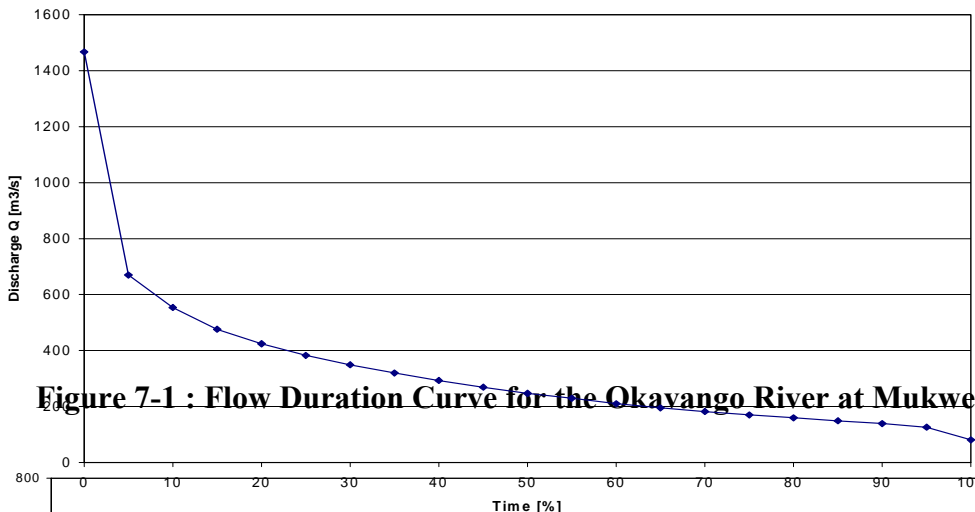


Figure 7-1 : Flow Duration Curve for the Okavango River at Mukwe

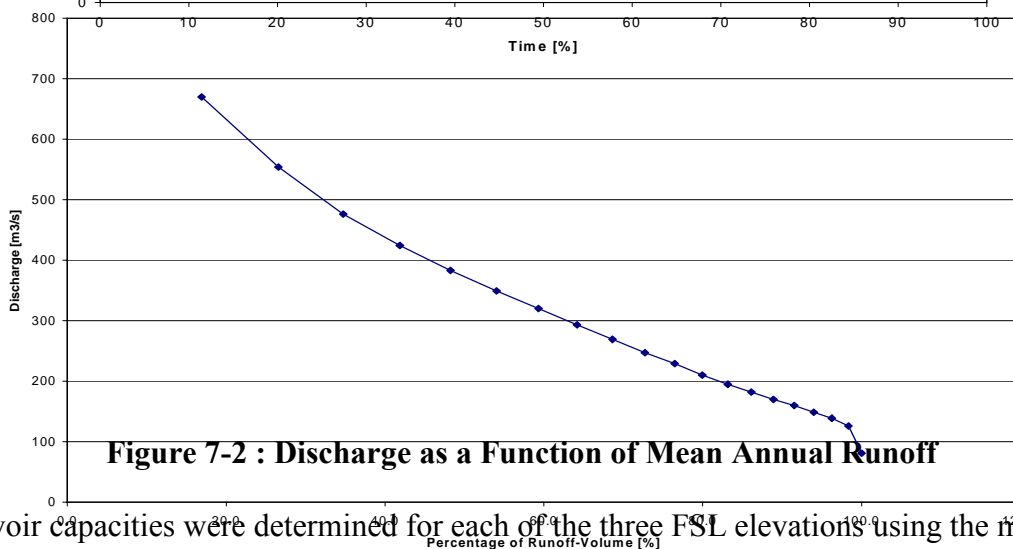


Figure 7-2 : Discharge as a Function of Mean Annual Runoff

Reservoir capacities were determined for each of the three FSL elevations using the mapping prepared from the airborne laser surveys. The reservoir capacities for the three sites in terms of a percentage of the MAR, vary between 0.18% for Site 4, 0.23% for Site 2, and 0.26% for Site 5. The sluicing and flushing volume of 80% of the MAR for a reservoir capacity of 2% of the MAR can therefore be reduced considerably to allow for the actual reservoir capacity.

Actual sluicing volumes will, however, need to be determined in model tests to be carried out in the next stage of the study.

The initial assumption used for the present Pre-Feasibility Study was that a period of one month per year would be required for sluicing. This value was established in co-operation with the sedimentologist on the team. Sluicing would ideally straddle the peak of the flood. In this way, the annual operating time of the power plant would amount to approximately 8 000 hours per year. In order to assess the effect of sluicing on power production and project benefits, the duration of sediment sluicing was increased from four weeks to six weeks, and further to eight weeks. The results of this analysis are presented and discussed in **Section 7.3** of this report.

The determination of the optimum design discharge was based on the sluicing requirements as well as taking into consideration the investment costs, expected revenues, and the annual operation time of 8 000 hours per year.

This analysis was carried out using an iterative approach in which the investment costs were compared to the expected benefits to determine the optimum cost-benefit ratio. Calculations were carried out for different design discharges to determine the relationship between the cost-benefit ratio and the design discharge. The following methodology was followed.

(i) Investment Costs

Initially only rough cost estimates were prepared for the civil works based on local and international prices. The costs for the hydro-mechanical components and the electrical equipment were based on quotations obtained from international turbine manufacturers. Total investment costs were thus determined.

(ii) Benefits

The installed capacity as well as the annual energy production were calculated based on the selected design discharge. The time required for sluicing was determined for the annual generated energy. Operating periods between 3500 hours and 8000 hours were analysed.

The expected annual revenues were calculated using a mean energy price of US\$ 0.03/kWh. This value is based on the Long Run Marginal Cost (**LRMC**) for the next few years, which was provided by NamPower. The present worth of revenues was determined, based on an interest rate of 9% p.a. and a lifetime of approx. 25 years.

The calculation carried out for an annual operation time of 3500 hours, as required for maximum sluicing requirements, did not produce an economically feasible project.. The comparison of investment costs to expected revenues showed that the project would not be economically viable in this case, as power would only be generated between $80 \text{ m}^3/\text{s} < Q < 210 \text{ m}^3/\text{s}$ during a limited period of the year. For all analysed discharges the investment costs would be higher than revenues, with the result that the cost-benefit ratio would always be below unity, as can be seen in the **Figure 7-3**.

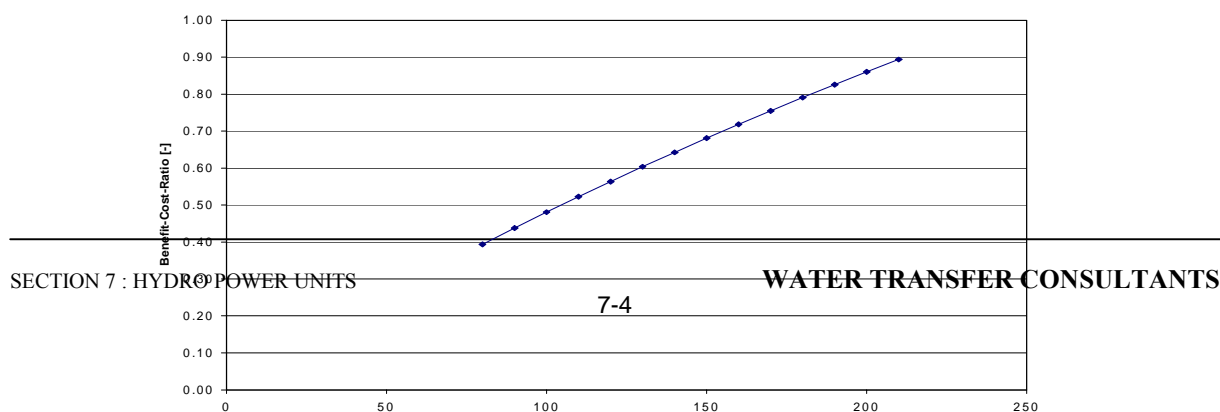


Figure 7-3 : Cost-Benefit Ratio for an Operating Time of 3500 Hours

The annual operation time can be considered as one of the most important parameters in the economics of a hydro power scheme. Since the existing capacity of the reservoir is only in the range of 0.2% of the MAR, the flushing volume may be decreased considerably from 80% to a value of between 20% and 30%. The reduction of the flushing period will increase the annual operation time of the hydro power scheme. In further analyses during the optimisation procedure, the annual operation time was increased in increments of 500 hours annually.

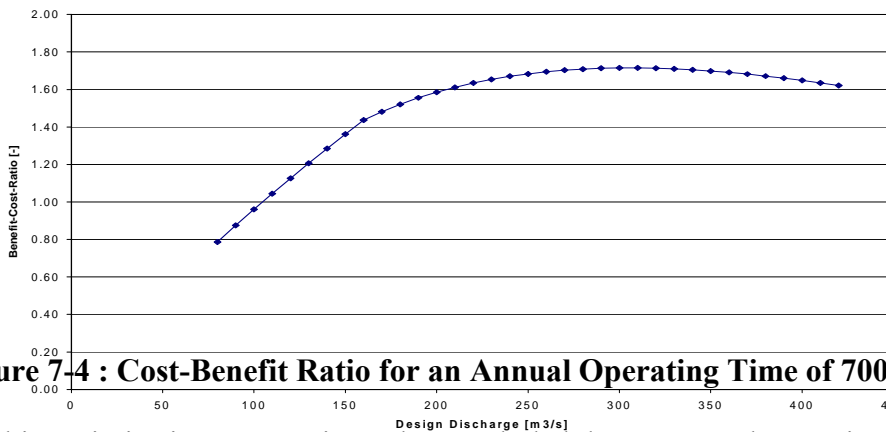


Figure 7-4 : Cost-Benefit Ratio for an Annual Operating Time of 7000 Hours

Based on this optimisation process it can be concluded that an annual operation time of at least approximately 7 000 hours should be considered to ensure the economic viability of the proposed hydro power project at Popa Falls. **Figure 7.4**, above, shows the cost-benefit ratio as function of the design discharge. The figure shows that the optimum ratio is reached with a design discharge between 280 – 320 m³/s. From 80 m³/s the graph is steadily increasing up to the optimum of approximately 300 m³/s where the curve is flat. The design discharge is also a function of costs, sluicing requirements etc., with the result that it can be concluded that a design discharge of between 280 m³/s and 320 m³/s can be considered to be the range for optimum discharge for the scheme. The relatively wide range of design discharge is selected on account of the Hydromatrix arrangement in which one Hydromatrix unit requires a design discharge of approximately 10 to 12 m³/s. Three Hydromatrix turbine units will be built into one Module so that the addition of one single module will increase discharge capacity by approximately 30-40 m³/s.

Consequently, based on environmental and sediment movement considerations as well as economics, an operating period of 8000 hours/a was assumed, which provides for a sluicing period of 4 weeks per annum. The energy calculations, evaluated in **Section 7.5** of this report, have therefore been based on this operation time.

The conditions at **Site 5** are similar to Site 4 with the exception that it does not have a side channel which could be used for river diversion during construction, but has the advantage that the impoundment depth at the weir would increase by approximately 0,75 m, when compared to Site 4.

The different units are described in more detail in the following sections and the installed capacity and mean annual energy production at each weir site is discussed in **section 8.3**.

7.3 PROJECT LAYOUTS

7.3.1 HYDROMATRIX UNITS

7.3.1.1 Hydromatrix Module

(a) Definitions

A "Unit", or "TG-Unit" as it is better known, is a turbine-generator set, with the generator directly connected to the turbine runner. It is proposed that the Plant consists of twenty seven "TG-Units", which can be put in operation individually.

One Hydromatrix[®] module ("Module") consists of one base-frame, containing three TG-Units, and three draft tubes with gates. The Plant consists of nine Modules.

"Auxiliaries" or the "Auxiliary Equipment" is the equipment necessary to operate the Hydromatrix Turbines.

(b) Module Steel Structure

Each Module consists of a rigid steel fabricated structure, which supports the three TG-Units.

The Module includes the steel fabricated draft tubes. The draft tube shape and length is optimised to achieve high turbine efficiencies. The three draft tubes mounted within the Module assembly contribute to providing a highly rigid and robust structure.

The main parts of the Module structure are the following:

- Support wall for the TG-Units.
- Draft tubes with draft tube gates.
- Guide blocks on both sides, to use the guiding rails mounted on the pier nose.
- Dogging system (manually operating locking device) for Module to fix the Module in the maintenance and operating position.
- Rubber seals are provided at the bottom and top of the Module as well as along the Module sides to minimize bypass leakage.
- Module trash rack.

(c) Turbine Generator Units

Each TG-Unit is mounted in the Module, thereby permitting easy removal of the Unit for maintenance purposes.

The two TG-Units on either side of the central unit are mounted at an angle of 11° off the Module centreline such that the inlet faces towards the central Module, thereby improving the inflow characteristics into the turbines. Each TG-Unit consists of the following components:

Refer to **Figure B7-1.** of **Appendix B** of **Volume 2** of this report for details of the Hydromatrix Module installation.

(i) Generator

The generators are of the synchronous type with permanent magnet poles and are directly connected to the turbine runner. The stator forms a watertight steel housing and is mounted to the stay ring. Two bearings situated within the bulb, support the generator rotor, shaft and runner rotating assembly. The downstream bearing will be a combined guide and thrust bearing and is mounted on the bearing support ring mounted to the generator stator housing. The downstream bearing will have suitable axial thrust bearing capability. Both of them will be roller type bearings.

(ii) Stay Ring

The stay ring, a water passage cone with fixed stay vanes and throat ring, forms an integral part of the generator housing at its downstream end. This stay ring serves to streamline the flow to the turbine propeller type runner, and to mount the TG-Unit to the draft tube assembly. The stay ring is either a cast or a fabricated steel unit.

(iii) Runner

The turbine fixed blade propeller type runner is integrally cast of aluminium-bronze. To ensure high turbine performance and efficiencies, the runner blade contours are based on a hydraulic model design, tested and optimised at the manufacturer’s laboratory facilities.

(iv) Shaft Seal

The shaft seal is located within the generating housing (stay ring). The seal is a radial type mechanical face seal. A mechanical seal is generally maintenance-free.

(v) Monitoring Devices

Included in each TG-Unit are the following devices:

- three generator winding and two bearing temperature detectors ("RTD's"),
- two water detector and,
- one speed sensor.

(vi) Maintenance of Module

A suggested Minimum Maintenance Schedule for maintaining the Hydromatrix® Power Plant is given in **Table 7-2** The actual and definitive Maintenance Schedule for the Plant will be included in the Operation and Maintenance Manual submitted prior to Commissioning. All actions and observations shall be listed in a logbook.

Table 7-2 : Maintenance Schedule for Hydromatrix Turbine

| Interval | Action |
|----------|--------|
|----------|--------|

| Interval | Action |
|-------------------------|---|
| As required | Lift Modules Lower Modules Crane inspection |
| Req. Manpower | 2, (20 min to lift Module) |
| One (1) Week | Acoustic and visual check of all Modules during operation as far as possible, watch for possible vibrations, damages, etc. |
| Req. Manpower | 2, (one day total) |
| One (1) Month | Check transformers silica gel air dryer Start emergency generator set and run for ten minutes, check fuel tank |
| Req. Manpower | 1, (two days) |
| Six (6) Months | Check transformers for leakage Charge Batteries if necessary |
| Req. Manpower | 1, (one day) |
| 8000 hours or two years | Service all crane lubrication systems Service of TG-Unit, renewal of lubricants for bearings and sealing Inspect all lubrication of auxiliary equipment Inspect all exposed electric cables Cleaning of switch gears and control cubicles with vacuum cleaner Check of electrical connections (bus bars, cables) |
| Req. Manpower | 10, (4 h each Module) |
| Five (5) Years | Inspection of painted surfaces, apply touch up paint as far as necessary Check all insulation resistances |
| Req. Manpower | 4, (6 h each Module) |
| Ten (10) Years | Dismantle TG-Units to maintain the main shaft seals and bearings (replacement) Inspection of rubber seals on Modules and replacement if necessary Check all PCs and Monitors of the control system Check Contactors and Circuit Breakers Check all Capacitors |
| Req. Manpower | 4, (40 h each Module) |

It is recommended that the TG-Units be brought into a workshop for replacement of bearings and seals after 10 years of operation.

7.3.1.2 Crane Facility

It is proposed that an electric powered Double Girder Gantry Crane, supplied with power from a 400 V bus bar by a 400 V bus bar system, will be provided.

(a) Operation

- The crane can be operated from floor level with the aid of a pendant controller,

- a travelling speed of 10 to 40 m/min,
- a trolley driving speed of 8 to 25 m/min,
- a hook hoisting speed of 3 to 0,5 m/min,
- The construction and design of the crane allows operation over the full weir length, to lift and lower the Hydromatrix Modules as well as the stoplogs,
- The crane will service the area around the substation building, transformers and equipment,
- The crane is also required for placing the maintenance platform adjacent to the corresponding Hydromatrix Module.

(b) Maintenance

Table 7-3 below shows a suggested Minimum Maintenance Schedule for the crane. All actions and observations shall be listed in the crane logbook

Table 7-3 : Maintenance Schedule for Crane

| Interval | Action |
|--------------------------------|--|
| One (1) Month Req. Manpower | Check crane for proper function of all drives 1, (half day) |
| One (1) Year Req. Manpower | Service all crane lubrication systems Grease crane cables Check of electrical connections (bus bars, cables) 1, (one day) |

7.3.1.3 Trash Rack and Raking Equipment

(a) Operation

Each Module is equipped with a trash rack mounted directly on the Module. Conventional hydraulically operated raking equipment will be provided for each Module. The debris collected during the upward movement of the rake will be deposited back into the river on the downstream side of the Hydromatrix Module. The operation of the raking equipment must be carried by the operation personnel. However, the operation personnel’s attention will be called by an alarm based on the difference between the actual unit output and the target output for the actual head. The setting level for that difference (power loss due to trash rack blockage) is programmable.

(b) Maintenance

It is proposed that the Maintenance Schedule given in **Table 7-4** below be applied once the plant is in operation. All actions and observations shall be listed in the plant logbook.

Table 7-4 : Maintenance Schedule for Raking Machine

| Interval | Action |
|--|---|
| As required (once a week) Req. Manpower | Check hydraulic hoses 1, (15 min) |
| One (1) Year Req. Manpower | Lubrication of bearings and axles Check of electrical connections (bus bars, cables) 1, (one day total) |

7.3.1.4 Electrical Layout with Main Components and Substructures

A general single line diagram of the Hydromatrix turbine plant and the interface to the 132 kV public grid is shown in **Figure B7-2** of **Appendix B** of **Volume 2**

Two 100% step-up transformers, each 24 MVA, will connect the power plant to the 132 kV outdoor switchyard. Power transmission to the Namibia grid will be established via a new 132 kV over-head line connection of about 200 km length up to an existing 132 kV switchyard at Rundu. For power transmission system design features refer to **Section 10**.

The electrical system of the plant will mainly consist of:

(i) 132 kV Switchyard

The 132 kV outdoor switchyard will be located close to the substation of the Popa Falls power plant. It will include:

- two transformer feeders from the power plant, each including circuit-breaker, isolators, earthing switches, surge arresters, voltage and current transformers,
- overhead line feeders to Rundu, equipped as before (at present only one line considered),
- bus bar voltage metering, and,
- two step-up transformers.

Control, protection and supervision of the complete switchyard will be included in the power plant substation.

(ii) 138/3.3/0.4 kV Step-up Transformers

Two 24 MVA, 138/3,3/0,4 kV, oil-immersed step-up transformers, including on-load tap-changer, will be provided. Each transformer will be designed to transmit 100% of the power

generated. In case of maintenance of one transformer or any transformer fault, the other transformer will allow for continuous plant operation. In addition, both transformers operating in parallel (each about 50% of full load), will reduce the transformer losses.

Tertiary windings of the transformers (0,4 kV) will feed the 400 V power plant auxiliary switchgear. For short high voltage connections, both step-up transformers will be located outdoors within the 132 kV switchyard based on concrete foundations provided with oil-collecting and oil-separation pit.

(iii) **Hydromatrix Modules**

A total of 27 TG-Units assembled in 9 Modules of three units each with a common control board and synchronous generators with permanent magnet rotor poles and fixed power factor close to 1,0 will be provided. The generators will be designed to attain rated generator voltage of 3,3 kV at full load operation. An outstanding feature for this type of generator is, that due to the rotor design with permanent poles there is no provision of reactive power possible, neither in parallel operation with the grid nor for isolated operation.

Each generator will be connected via 3,3 kV power cable to the power plant 3,3 kV switchgear.

A universal frequency transducer will be used for switching on each unit to the grid after reaching the synchronous speed. Each generator unit will be equipped with the following:

- Required protection relay systems combined with measuring instruments and providing a display for setting and monitoring,
- Control hard and software handling analogue and digital signals,
- Generator temperature monitoring.

(iv) **Power Plant Substation**

A power plant substation will be located on the river bank close to the weir and will comprise the following:

- Main indoor metal-clad 3.3 kV switchgear,
- 400 V switchgear and D.C. systems,
- Emergency diesel set,
- Panels and operator VDUs for the digital control, protection and supervision systems (**DCS**) for the power plant and 132 kV switchyard,
- Communication systems,
- Individual rooms for:

- Electrical switchgears 3,3 kV, 400 V, D.C.,
- Emergency diesel set,
- Power plant and switchyard control room (DCS),
- Operator rooms, rest rooms,

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 (27 feeders), each including main contactor, main fused load-break switch, voltage and current transformer,
- Bus coupler, including circuit breaker, bus bar VT's, bus bar metering,
- Regulation resistor (1 feeder), including main contactor, main fused load-break switch, voltage and current transformer, and
- Spares (2 feeders, e.g. for compensation equipment, if required), each including main contactor, main circuit breaker, voltage and current transformer.

A 3,3 kV load resistor (water resistor) with rated power equal to one generator unit will allow for continuous active load adjustment of the power plant within a range of approx. 900 kW. River water fed into a separate tank fitted with electrodes, will be used to cool the resistors.

Main auxiliary systems of the power plant will comprise the following:

- 400 V switchgear, (normally fed from the tertiary windings of both step-up transformers),
- D.C. systems (fed by 400 V switchgear) and batteries,
- Emergency diesel generator set (feeding the 400 V switchgear),
- All power cabling (MV = 3,3 kV, LV = 400 V and D.C.) as well as communication and control cables with armouring against vermin,
- Earthing installations for potential gradient control and earthing of all equipment and facilities in the power plant, at outdoor transformers and 132 kV switchyard,
- Indoor and outdoor lighting systems (normal and emergency) and socket systems.

In the case of a power failure or black-start, the emergency diesel generator will supply power to the power plant and the 400 V switchgear. The generator will be designed for unrestricted

parallel operation with the electrical network (required for regularly testing purposes) and for isolated operation. A brushless rotating diode exciter will be provided.

(v) Digital Control , Protection and Supervision Systems (DCS)

The Hydromatrix turbine modules will be equipped with a state-of-the-art digital automation system.

It is proposed to provide a modern control concept to take full advantage of the currently available integrated control system technology to maximise plant performance and availability as well as to achieve a cost effective installation. To achieve this, the control protective and supervisory functions required for the central operation of all the plant facilities shall be implemented in a Distributed Control System (DCS).

Functional de-centralisation of the “hydroelectric power station process” means division of the process into sub-processes, which are required to be as independent of each other as possible. The structure of these sub-processes is reflected in the design of the process control technology, which is divided into autonomous function areas such as each generation Module, 3,3 kV switchgear, 132 kV switchyard and power plant control centre,

Because of the functional de-centralisation, a failure of the local area control network will have no effect on the safe operation of the plant,

(vi) Communication Systems

A telephone and portable radio system will be provided as a communication system for the power plant.

(vi) Mode of Operation of Hydromatrix Power Plant

The following modes of operation shall be considered.

Generation Mode (Interconnected with Namibia Grid)

(a) Normal Operation

The main mode of operation shall be to supply electrical energy into the Namibia grid as required. The main part of the power generated by the Hydromatrix turbine generators is fed into the public utility grid, while a smaller part is needed for the auxiliary demand of the plant. The Hydromatrix generators running in parallel with the grid will be able to supply continuously a fixed amount of active power, but no reactive power.

(b) Disturbed Operation (Variations in Grid Frequency / Voltage)

The following cases are considered for frequency and voltage response behaviour:

(ii) With Falling Frequency

(iii)

A fast response within seconds is possible by using the load resistor, however maximum contribution to system stabilization will be in the range of one generator unit output only which means approx. 800 kW. The activation of further power to be released will last at least one minute until the mechanical and electrical auxiliaries of the individual Hydromatrix generators are ready for parallel switching to the grid.

Therefore primary frequency response of the Hydromatrix system is poor. Further activation of power in discrete steps for participation in secondary frequency response can be made available only in the range of minutes.

With Rising Frequency

An immediate primary frequency response is possible by fast switching-off of Hydromatrix modules following the rate-of-change of rising frequency.

Falling or Rising Voltage

The synchronous generators used will not be able to contribute to the reactive power needs of the grid system connected during voltage excursions and thus can not participate on grid voltage control.

Any reactive power compensation can only be handled by stepping up and down with the on-load tap-changers of the Popa Falls step-up transformers.

During later design stages the needs of further compensation / voltage control equipment at Popa Falls will have to be assessed for all relevant cases like low load/high load scenarios, loss of load cases, inductive power needs for motor starting, etc.

Normal Start-up Mode

For start-up of the power units, it will be necessary to import power from the grid via the tertiary winding of the step-up transformers, which energises the 400 V switchgear. Then consecutive start of Hydromatrix generators will be possible.

Island Operation Mode

In an island operation mode there is no interconnection to the Namibia grid either at the 132 kV switchyards at Popa Falls or at Rundu substation. In the case of a sudden disconnection from the grid, the Hydromatrix modules will be switched off selectively in such a number, that a load rejection to the remaining system load will take place in order establish a stable island operation. After grid voltage recovery, a quick re-synchronisation of the power plant

unit is possible via the 132 kV circuit breaker.

A fine adjustment of the active load in the power island is possible by means of the load resistor, coarse adjustments may be made by switching on and off further Hydromatrix generators. Adjustments of reactive loads in the power island can be made only via the on-load tap changers of the step-up transformers.

Starting large motors in island operation mode with a motor load exceeding the control range of the load resistor, will be only possible by use of motor “soft” starting technologies.

In the detailed feasibility study stage of the project, and in particular for the case of island operation such load flow/ voltage profile/ motor starting calculations have to be undertaken using modern power system analysis software programs such as “DigsiLent”.

Blackout Mode of Operation

A total “Blackout” occurs when there is an unexpected power cut on the public utility grid and there is also no electrical power output from the generators at the plant. Under such conditions, the critical loads like the DC consumers, computers and I & C auxiliaries will continue to receive their uninterrupted power supply from the DC batteries and inverters. The in-plant emergency diesel generator set will start automatically to its relevant load to maintain the necessary essential services within approx. 30 seconds. The emergency power supply program will be switched in automatically by the DCS and power feed to the rectifiers, batteries, the inverters and all other essential loads will be restored. The emergency diesel generator shall be adequately rated to start up at least one Hydromatrix generator in order to restore power supply to the Popa Falls power system.

Conclusions on The Operational Behaviour of the Hydromatrix System

- To summarise, it can be stated, that the Hydromatrix system will allow the simple production of active power, provided that a permanent interconnection to the Namibia utility grid will be maintained,
- Supply of reactive power by the Hydromatrix generators is not possible,
- Any contribution to power frequency and voltage control in an interconnected grid will be very restricted,
- An island mode of operation implies particular problems with any load changes exceeding the relatively small control range available, limited to the power rating of one Hydromatrix generator.

7.3.1.5 Concept and Layout of Hydromatrix Turbine for Popa Falls HPP

(a) Turbine Size and Number of Modules

The special advantage of the Hydromatrix concept is the possibility of being able to lower the complete Hydromatrix Module in to the weir with the aid of Module guides similar to the guides used for stoplogs. The hydraulic design sizing and setting is based on bulb turbine technology. The generator is based on a standard motor with improved design for generation, efficiency and harmonics, which can be operated as a synchronous machine.

(i) Sizing of Turbines

The size of the turbine (runner diameter) has to be optimised between technical parameters and economic aspects. The aim is to obtain the largest runner diameter which will result in the least number of turbines per Module. A limitation of the maximum runner diameter is based on a standard given by the required submergence of the draft tube exit in relation to the river bed level immediately downstream of the weir. The ratio of intake width per turbine to runner diameter should not be less than 1,6.

The draft tube exit area should be large enough to minimise the draft tube exit losses, which have a large influence on the economics, due to the low head. Taking all these parameters into account, three turbines per gate-opening, each with a runner diameter of 1.32 m, was found to be the optimum solution.

The available gross heads for the turbine operation, is the typical range of a four-bladed turbine runner. The big advantage of a four bladed runner is the high efficiency level at high discharge.

(ii) Setting of Turbines

Due to the small gross heads, the criteria for the setting of the turbine is not cavitation but the required submergence of intake and draft tube exit, which is dictated by the weir structure.

(iii) Turbine Speed

The turbine speed of 378.75 rpm is based on the range of available heads, selected runner diameter of 1.32 m and the 4 bladed runner performance.

(iv) Number of Modules

The number of Modules has been optimised according to the calculations carried out for the determination of the design discharge. By considering the available discharge of 90 m³/sec to approximately 400 – 500 m³/s (depending on sediment sluicing requirements) an optimum number of 9 Modules (27 units) is chosen from a technical and economic point of view.

(v) Technical Data of Selected TG-set

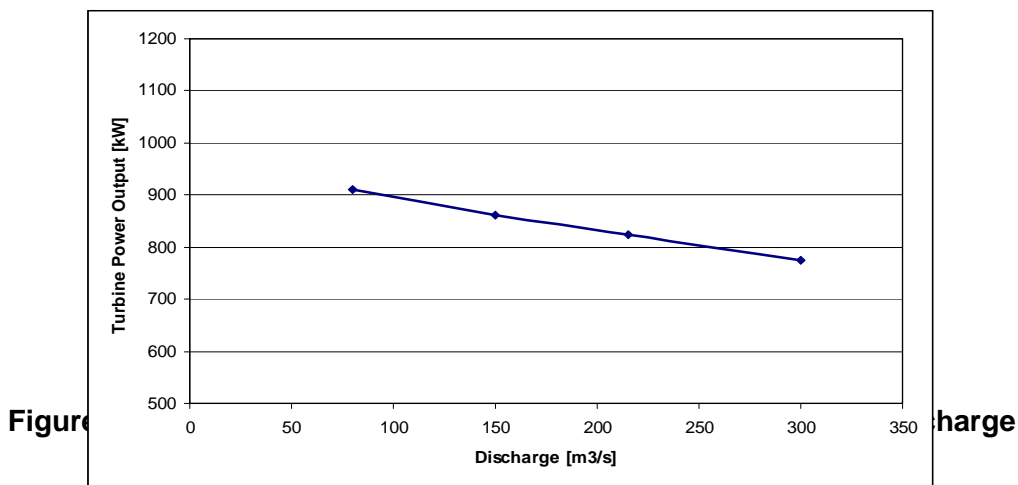
The selection of the number of modules and determination of the best turbine size was carried out in parallel. As a result of the turbine-optimisation, the data given in **Table 7-5** was determined for the maximum gross head for one TG-Unit:

Figure 7-5 shows the power output performance of one Hydromatrix turbine unit in relation to river discharge. With increasing discharges, the tailwater level rises and thereby the gross head is reduced. As a consequence the discharge through the turbine will also be reduced. For example, at Site 5, the gross head reduces from 9,1 m at 80 m³/s to 8,0 m at 300 m³/s. The discharge through the turbines is therefore also slightly reduced from 12,3 m³/s to 11,95 m³/s. As can be seen in **Figure 7-5**, the turbine output at full load decreases slightly to 772,2 kW. The following maximum power output and energy production was used for the present study:

Max. Plant Output [MW]: 14,3 – 26,1 (depending on site and weir height)
 Annual Energy [GWh]: 66,5 – 141,8 (depending on site and weir height)

Table 7-5 : Technical Data of Selected TG-Unit

| Parameter | Unit | Value |
|--|-------------------|--------------|
| Maximum Gross Head (for Site 5) | m | 9.1 |
| Design Discharge per Unit (depends on river flow and net head) | m ³ /s | 11.95 – 12.3 |
| Runner Diameter | m | 1.32 |
| No. of Blades | No. | 4 |
| No. of Turbines | No. | 27 |
| Maximum Turbine Output | MW | 0.912 |
| Total Turbine Output | MW | 24.624 |
| Generator Efficiency | % | 94.5 |
| Generator Output | MW | 0.861 |
| Total Generator Output | MW | 23.244 |
| Frequency | Hz | 50 |
| Generator Voltage | V | 690 |
| Rated Speed | rpm | 378.75 |



(B) DISTRIBUTION OF HYDROMATRIX TURBINES ALONG THE WEIR

The modular concept of the Hydromatrix turbines, makes it possible to determine the position of individual Modules in the weir to cater for environmental requirements in respect of uniform stream flow across the width of the river. As already pointed out in **Section 5** of this report, it is of utmost importance that sediments should not be allowed to accumulate in the weir basin and need to be removed either by bypass pumping or by annual sluicing during the peak flow period (see **Section 9**). The flow conditions during sluicing, should be as close as possible to the natural condition which will be achieved by lifting the spillway gates to a level that water can pass through the weir without any restrictions, other than the relatively minor restriction imposed by the weir piers. If sluicing is considered it will be necessary to arrange

the Hydromatrix Modules along the weir in such a manner that the outflow during sluicing will be as natural as possible.

(i) Module Distribution

An equal distribution of the Hydromatrix Modules, interspersed with spillway gates across the barrage would result in a uniform distribution of the flow downstream of the weir. Sediment, floating debris and trash would thus not be concentrated on one side of the weir where Hydromatrix turbine Modules would otherwise be located, but would be distributed evenly across the width of the river. The only minor disadvantage would be that longer cables would be required to connect the turbine units to the switchgear containers. On the other hand, a wider spread of the Modules permits easier handling of Modules during maintenance, and an upstream view on the weir would be more harmonic.

(ii) Modules on One Side of the Weir

A concentration of turbine Modules on either the left or right end of the weir would direct the flow from the turbines to one side of the river only, where flow velocities will be high compared to those elsewhere in the river. Floating debris and trash would also be concentrated to the side of the weir where the turbine Modules are located. Flow under the spillway gates would only occur during peak flow periods. The only minor advantage is that shorter cables would be required to connect to the turbine units.

It is therefore recommended that the Hydromatrix turbine Modules be distributed as evenly as possible across the length of the weir. Since sediments are expected to be transported through the central section of the river, it is proposed that the Hydromatrix turbine Modules be distributed as shown in **Figure 7-6**.

Figure 7-6 : Diagrammatic Layout of Hydromatrix Turbine Modules and Spillway Gates

7.3.2 BULB TURBINE UNITS IN THE WEIR

7.3.2.1 Bulb Unit

The bulb unit is a horizontal axial turbine with a direct coupling of the generator, which is widely used for large power plants. The stator is part of the water passage and the inlet hub is often used as a heat exchange for cooling the stator and bearings.

In most cases today, the generator is bolted to the stay column embedded in concrete. The generator and turbine have separate access hatchways to permit maintenance and inspection. A water tight access manhole is also required over the water passage, which is required for lowering parts of the generator during assembly. This access has to be closed by a pressure-tight cover.



For projects with a low head, bulb turbines provide higher full-load efficiency and higher flow capacities over conventional vertical Kaplan turbines. This results in higher annual

energy production and lower relative construction costs. The advantage of the Bulb unit against conventional Kaplan turbines is the double regulation of the turbine.

The turbine can be regulated with the help of the wicket gates as well as the adjustable blades of the runner. Thereby the turbine can be operated to approximately 25% of the design discharge. This means, that the turbine can be operated for all available flow variations between the minimum flow and the rated flow of approximately 280 m³/s.

7.3.2.2 Electrical Layout with Main Components and Substructures

Two 100% step-up transformers, each 24 MVA, will connect the power plant to the 132 kV outdoor switchyard. Power transmission to the Namibia grid will be established via a new 132 kV over-head line connection of about 200 km length up to an existing 132 kV switchyard at Rundu. For power transmission system design features refer to **Section 10**.

The electrical system of the plant will be similar to that of the Hydromatrix power plant, except the generation units, therefore only differences in design and operational behaviour will be dealt with below.

(I) 132 kV Switchyard

For a description of the switchyard refer to **Section 7.3.1.4**.

(II) 138/6.6/0.4kV Step-up Transformer

For a description of the step-up transformers refer to **Section 7.3.1.4**

(III) Bulb Turbine Generators

A total of three bulb turbine generator units will be provided. The generators will be designed as synchronous generators with static excitation system. An economic generator voltage of 6,6 kV is proposed. Each generator will be connected via 6,6 kV power cable to the power plant 6,3 kV switchgear. An automatic synchronisation unit 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 weir and will comprise the following:

- Main indoor metal-clad 6,6 kV switchgear,
- 400 V switchgear and D.C. systems,
- Emergency diesel set,
- Panels and operator VDUs for the digital control, protection and supervision systems (DCS) for the power plant and 132 kV switchyard,
- Communication systems,

- Individual rooms for:
 - Electrical Switchgears 6,6 kV, 400 V, D.C.,
 - Emergency diesel set,
 - Power plant and switchyard control room (DCS),
 - Operator rooms, rest rooms,

Main feeders of the 6.6 kV switchgear are provided for the following:

- Transformers (2 feeders), each including main circuit - breaker, voltage and current transformer,
- Generators (3 feeders), each 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.

Main auxiliary systems of the power plant are described in **Section 7.4.1.4**

(V) Digital Control , Protection and Supervision Systems (DCS)

The bulb turbines will be equipped with a state-of-the-art digital automation system. The proposed DCS system is described in **Section 7.4.1.4**

(vi) **Communication Systems**

A telephone and portable radio system will be provided as a communication system for the power plant.

(vii) **Mode of Operation of the Bulb Turbine Power Plant**

The following modes of operation shall be considered.

Generation Mode (Interconnected with Namibia Grid)

(a) **Normal Operation**

The main mode of operation shall be to supply electrical energy into the Namibia grid as required. The main part of the power generated by the bulb turbine generators is fed into the public utility grid, while a smaller part is needed for the auxiliary demand of the plant. The generators running in parallel with the grid will be able to continuously supply active power and reactive power into the grid.

(b) **Disturbed Operation (Variations in Grid Frequency/Voltage)**

The following cases need to be considered for frequency and voltage response behaviour:

(I) With Falling Frequency

A fast response within seconds is possible by changing the power output of the bulb turbine by adjusting the wicket gates and/ or the runner blades. (a typical load change from 20 to 100% will be possible within 5 seconds). Therefore the contribution of the bulb turbine generators to primary and secondary frequency response is on a similar level as hydro generators.

(II) With Rising Frequency

An immediate response to rising frequencies is possible as described above.

(III) Falling or Rising Voltage

The synchronous generators used will be able to contribute to the reactive power needs of the grid system within the limits of the generator power chart and can participate in grid voltage control.

Further reactive power compensation can be handled by stepping up or down with the on-load tap-changers of the Popa Falls step-up transformers.

However, during the detailed feasibility phase of the project, the need for further compensation/voltage control equipment at Popa Falls will have to be assessed for all relevant cases such as low load/high load scenarios, loss of load cases, inductive power requirements for motor starting, etc.

Normal Start-up Mode

For the start-up of the power units, it will be necessary to import power from the grid via the tertiary winding of the step-up transformers, which energises the 400 V switchgear. Consecutive start of turbine generators will then be possible.

Island Operation Mode

In the Island Operation Mode there is no interconnection to the Namibia grid at the 132 kV switchyards at Popa Falls nor at the Rundu substation.

In the case of a sudden disconnection from the grid, a load rejection to the remaining system load will take place in order to establish a stable island operation. After grid voltage recovery, a quick re-synchronisation of the power plant unit is possible via the 132 kV circuit breaker. Fine adjustment of the active load in the power island is possible by means of the turbine controller, by adjusting the wicket gates and/ or the runner blades. Fine adjustment of reactive load in the power island can be made only via the generator excitation system. For coarse adjustments, the on-load tap changers of the step-up transformers will be activated. Large motor starting at island operation with a motor load in the MW range will depend on how many turbine generators are in operation at the time.

However, in the detailed feasibility phase of the project, and in particular for the case of

island operation, such load flow/voltage profile/motor starting calculations have to be made using modern power system analysis software programs like Digsilent”.

Blackout Mode of Operation

A total “Blackout” occurs when there is an unexpected power cut on the public utility grid and there is also no electrical power output from the generators at the plant. Under such conditions, the critical loads such as the DC consumers, computers and I & C auxiliaries will continue to receive their uninterrupted power supply from the DC batteries and inverters. The in-plant emergency diesel generator set will start automatically to maintain the necessary essential services within approx. 30 seconds.

The emergency power supply program will be switched in automatically by the DCS and power feed to the rectifiers, batteries, the inverters and all other essential loads will be restored. The emergency diesel generator shall be sufficiently rated to start up at least one bulb turbine generator in order to restore power supply to the Popa Falls power system.

Concluding Statement on Operational Behaviour of the Bulb Turbine Unit System

In summary it can be stated, that with the bulb turbine generators applied Voltage and load control capabilities will be in line with common technical hydro power generation features. Supply of reactive power by the bulb turbine generators is possible within their stability limits.

Full contribution to power frequency and voltage control in an 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, depending on spinning reserve of the generating system.

7.4.2.3 Concept and Layout of Bulb Unit for Popa Falls Project

(a) Turbine Size and Number of Units

A rated flow in the range of 280 m³/s and an operating head of between 7.0 m and 11.5 m, for the different FSLs and tailwater levels under consideration at the various sites, implies that a powerplant of between 15.7 and 28.8 MW is required and a possible generating unit size of between 5.8 and 8.5 MW. This range suits the type of bulb turbine that operates under conditions of high discharge and high-power output at relatively low heads.

The bulb unit planned as a block powerhouse arrangement incorporated in a weir can be considered as a standard solution which could be applied to the Popa Falls project. Based on the design discharge, a powerhouse with three units would be the best technical and economical bulb turbine type solution for the project. The key turbine data is listed below in the **Table 7-6**. A sketch of the powerhouse is given in **Figure 7-7** on the following page.

Table 7-6 : Key Turbine Data for the Alternative for the Bulb Unit in the Weir

| Parameter | Unit | Value |
|-----------------------------|-------------------|--------------------------------|
| Headpond Level | m.a.m.s.l. | 1007.5 – 1012.5 |
| Tailwater Level | m.a.m.s.l. | dep. on tailwater rating curve |
| Rated flow | m ³ /s | 280 |
| Number of Units | No. | 3 |
| Turbine rated efficiency | % | 0.92 |
| Turbine setting elevation | m.a.m.s.l. | 996.2 |
| Runner Diameter | m | 3.60 |
| Number of Blades | No. | 4 |
| Runner Hub Diameter | m | 1.44 |
| Nominal Speed | rpm | 150 |
| Suction Head H _s | m | 4.00 |
| Draft Tube Exit | m | -2.86 |

The width of the powerhouse is approximately 35 m, its length approximately 45 m, and the height approximately 30 m. A typical section through the powerhouse is given in **Figure 7-7**. As can be seen from this Figure, the Bulb unit requires a deep foundation. Construction costs for this type of turbine are therefore relatively high compared to the founding depth required for the Hydromatrix turbines, which is described in detail in the **Section 7.4.1**.

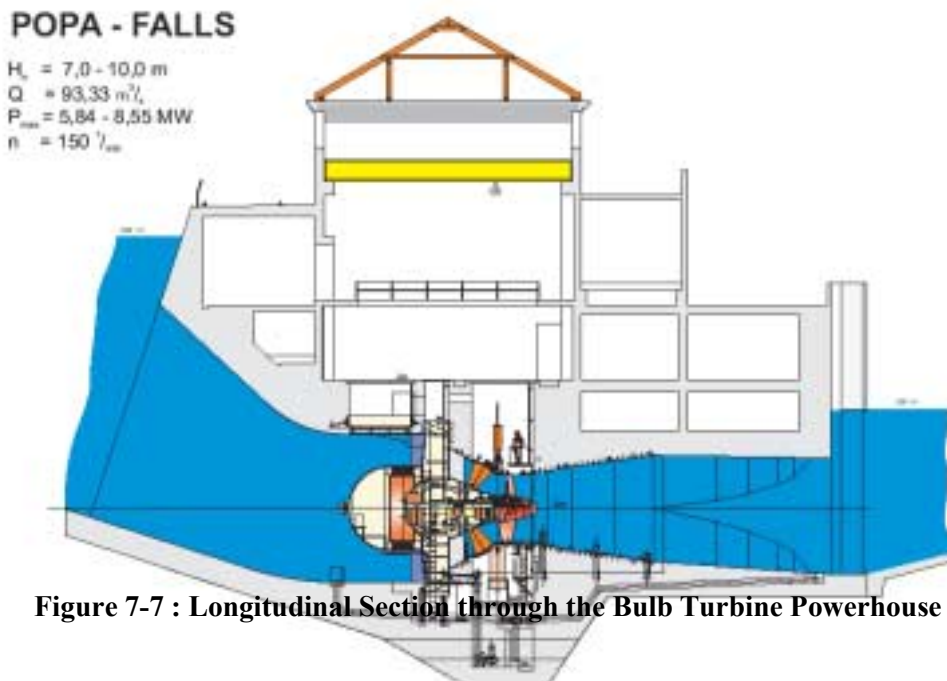


Figure 7-7 : Longitudinal Section through the Bulb Turbine Powerhouse

(b) 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.

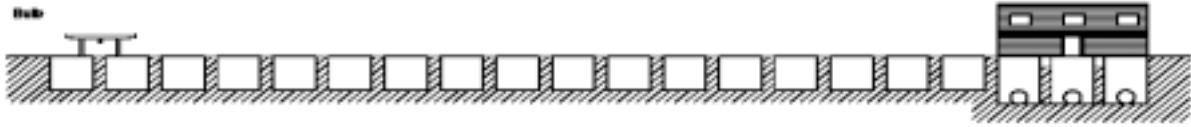


Figure 7-8 : Diagrammatic Elevation on the Weir Showing the Position of the Bulb Unit

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 m³/s and 120 m³/s respectively. Although minimum flow requirements have not been defined, a minimum discharge of approximately 80 m³/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 m³/s each, which will result in a total discharge capacity of 108 m³/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 m³/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 Hs | m | -3.50 |

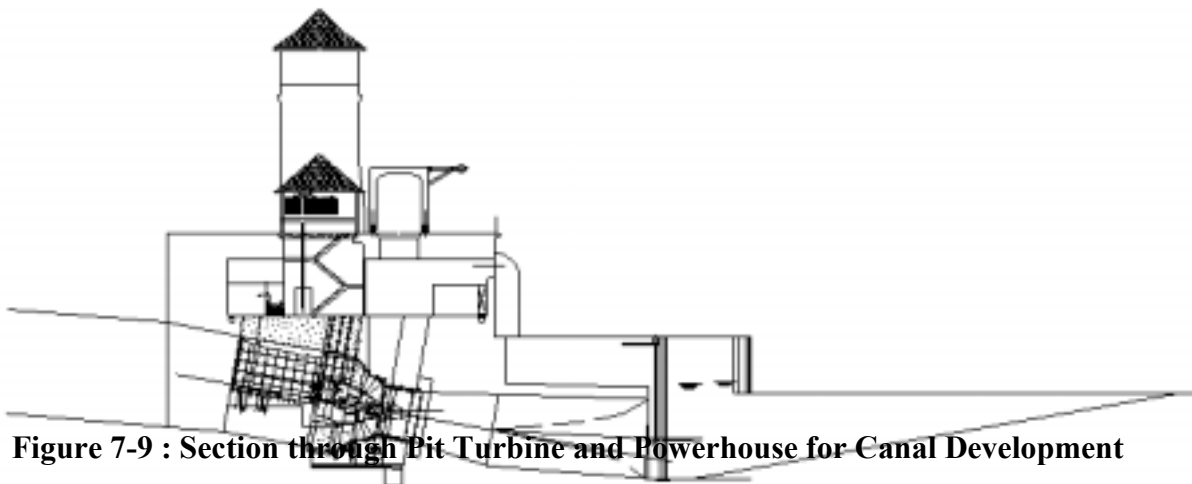


Figure 7-9 : Section through Pit Turbine and Powerhouse for Canal Development

(b) Description of Waterway

Discharges in excess of 108 m³/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 pumphouse 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).

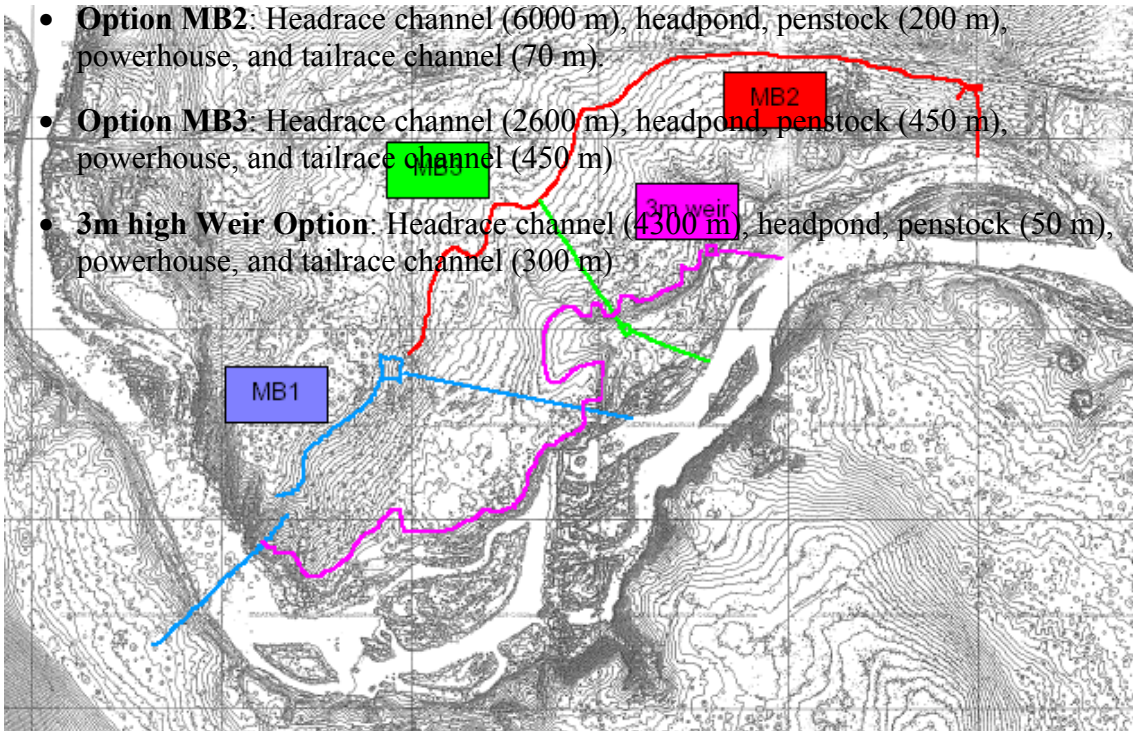


Figure 7-10 : Canal Development Alternatives

7.5 INSTALLED CAPACITY AND MEAN ANNUAL ENERGY PRODUCTION

7.5.1 GENERAL

The energy calculations were based on the following information:

- Mean Daily Flow Records,
- Headwater Levels, and
- Tailwater Rating Curves.

7.5.1.1 Mean Daily Flow Records

Hydrological data, in the form of mean daily flows for the Okavango River at the Mukwe Gauging Station, covering the periods from 1950 to 1998, were kindly made available by the Department of Water Affairs of the Ministry of Agriculture, Water and Rural Development. The data series can be considered a sound basis for the development of a hydro power plant.

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 1007.5 [m.a.m.s.l.] | FSL 1010.0 [m.a.m.s.l.] | FSL 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 7-17**:

Table 7-17 : 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 7-18** and **Table 7-19**. 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 7-18 : Summary of Investment Costs per Installed Kilowatt

| 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 7-19 : 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 | | |

The apparent anomaly of increasing investment costs per installed kilowatt, when comparing these for Sites 4 and 5 in **Table E7-18**, is due to the fact that the costs of Site 4 are for a FSL 1012.5 m.a.m.s.l. whilst those for Site 5 are only for a FSL of 1011.0 m.a.m.s.l. which consequently also has a lower installed kilowatt capacity than Site 4. The same applies to the values given in **Table E7.19** below. Further detailed optimisation will be carried out in the full feasibility study for both Sites 4 and 5 to determine the optimum weir height from a technical and financial point of view.

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.m.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 7-18** and **Table 7-19** 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\$ 0.40KWh 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 7 alternatives listed in **Table 7-20** below:

Table 7-20 : Alternatives Selected for further Analysis

| Location | Turbine Type | FSL (m.a.m.s.l.) |
|----------|--------------|------------------|
| Site 2 | Hydromatrix | 1007.5 |
| Site 4 | Hydromatrix | 1007.5 |
| | Hydromatrix | 1010.0 |
| | Hydromatrix | 1012.5 |
| Site 5 | Hydromatrix | 1007.5 |
| | Hydromatrix | 1010.0 |
| | Hydromatrix | 1011.0 |

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.

Whist this analysis has shown that Hydromatrix option results in the financial and economical most viable project alternative, further detailed investigations need to be carried out in the detailed feasibility phase to establish if the Hydromatrix turbines are capable of operating efficiently in an Island Mode configuration. In the event that this is not the case then the bulb option will be investigated further. An evaluation of various hydro power unit options is given in **Table 7-21** below.

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 7-21 : Evaluation of Various Hydro Power Unit Options

| Criteria | Hydromatrix | Hydromatrix | Bulb Units | Pit Units |
|----------|-------------|-------------|------------|-----------|
|----------|-------------|-------------|------------|-----------|

| | Units Distributed across River | Units on One Side of Weir | in the Weir | 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 |