

The recent development of low cost high voltage DC transmission technology has now made it feasible to consider the extension of the Namibian power grid from Rundu to Katima Mulilo via Popa Falls, a distance of almost 500km. Thus, an important technical advantage of a hydro power project on the Okavango River would be the ability to connect the Caprivi Region to the Namibian national power grid.

E1.2 AIMS OF THE PRE-FEASIBILITY STUDY

The aim of this pre-feasibility study is to assess and evaluate alternative potential hydro power schemes by considering potentially suitable sites in the proximity of the Popa Falls, from a technical aspect, in order to reach the most economically viable project to achieve maximum power generation for minimum capital and whole life running costs, based on a pre-feasibility level of investigation.

As with any development of this nature, it is essential to take into account the environmental impacts of any potential scheme under consideration, and in order to achieve this, NamPower commissioned a Preliminary Environmental Assessment (**PEA**) which was undertaken in parallel with the technical pre-feasibility study.

The process is necessarily iterative during the early stages of such studies, and although close continuous coordination between the technical and environmental teams was maintained, the environmental study was carried out by independent environmental consultants and the PEA Report is a separate, stand alone document.

E1.3 SCOPE OF THE PRE-FEASIBILITY STUDY

Detailed Terms of Reference were issued by NamPower for both elements of the study. In broad terms, the technical scope included the following tasks:

- Review of previous studies;
- Reassessment of hydrological data using updated records;
- Baseline sediment studies;
- Preliminary site and geological investigations;
- Identification of potentially suitable weir sites;
- Investigation of alternative weir designs;
- Preliminary optimisation of reservoir size, weir and spillway design, and associated mechanical and civil components;
- Preparation of a preliminary electro-mechanical feasibility design for a 5 to 20 kV power generation installation;

- Preparation of pre-feasibility designs and drawings;
- Preparation of cost estimates; and
- Cost benefit analysis to determine the economic and financial implications of a hydro power scheme at the recommended location.

The scope of the PEA is detailed in the PEA Executive Summary. The PEA complies with the Namibian Environmental Assessment Policy (1994) and the provisions contained in the draft Environmental Management Bill.

E1.4 STUDY RESOURCES

The technical team comprised Namibian engineering consultants supported by experienced regional and international firms and individuals who as sub-consultants undertook the specialist aspects of the project related to their expertise. The environmental team comprised national and regional specialists who have had recognised experience of the Okavango River and Okavango Delta systems in order to address the various potential environmental issues.

The Firms and Specialists undertaking the technical aspects comprised:

- Water Transfer Consultants (WTC)**, a joint venture between two Namibian firms, Lund Consulting Engineers and Bicon Namibia, responsible for the civil and electrical engineering components of the study;
- BKS**, Pretoria, sub-consultants specialising in hydrology, geotechnical and dam engineering aspects;
- Fichtner GmbH** of Stuttgart, Germany, specialist sub-consultant responsible for the hydro power components of the study including the economic and financial analyses;
- Professor Albert Rooseboom**, Sigma Beta, Cape Town, specialist sub consultant responsible for sediment transport aspects;
- Peter Townsend**, Flowgate Projects, Johannesburg, responsible for the design of the spillway gates.

The PEA was coordinated and managed by **EcoPlan**, a Namibian based Environmental Consultancy, with support from **WSP Walmsley** from Johannesburg. The specialist sub consultants who undertook the preliminary environmental studies were:

- | | |
|------------------------------|----------------------------------|
| —Chris Hines: | Flora and Birds |
| —Dr John Kinahan: | Archaeologist |
| —Mike Griffin: | Fauna |
| —David Parry: | Public Participation in Botswana |
| —Ms Shirley Bethune: | Aquatic Ecologist |
| —Professor Terence McCarthy: | Sediment Transport |
| —Sven Coles: | Bathymetry Survey |

E 2 THE PROJECT AREA AND METHOD OF APPROACH

E2.1 THE PROJECT AREA: THE OKAVANGO RIVER BASIN

Figure E2-1 shows a map of the Okavango River Basin placing the project location in the regional context. The Project Area is located along the stretch of the Okavango River where it crosses into the Caprivi Strip to downstream of the Popa Falls. This section of the river is below the confluence of the Okavango and Cuito rivers which both rise in the Angolan highlands. **Figure E2-2** outlines the extent of the Project Area on the particular stretch of the Okavango River.

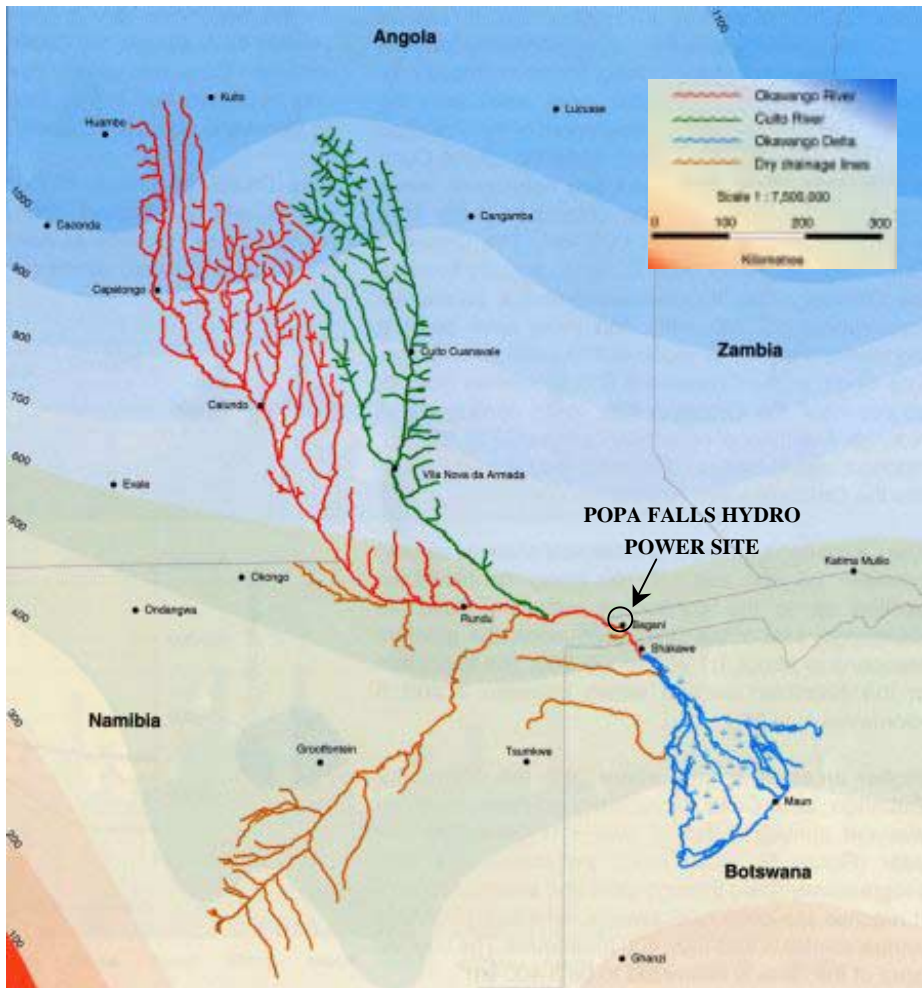


Figure E2-1 The Okavango River Basin



Figure E2-2 : The Project Area

E2.2 OUTLINE METHOD OF APPROACH

At the start of the study, a detailed programme of tasks to be undertaken was drawn up and discussed between the technical and environmental teams in order that the required interchange of information, as it became available, could be communicated to all team members. This ensured, for example, that as new sites and scheme layouts were being considered, and where key environmental issues were identified, these could be taken into consideration as the preliminary outline designs were progressing.

Field visits took place at the start of the study in order to reconsider those sites identified in the 1969 study, and to identify new alternative sites that warranted consideration. Very rough outlines were produced as a starting point for an environmental overview, and to form the background for Public Participation meetings to enable interested and affected parties to become aware of the project as early as possible.

Public participation meetings were held in Windhoek, Maun in Botswana, Divundu and Rundu within the first two months of the study period. The outcome of these are detailed in the PEA reports.

The hydrology of the river provides the basis for any hydro power scheme, and therefore the first task of the study was to update the existing hydrological analyses to verify long term stream flow records, assess low flow events, and determine flood frequencies. Based on these results, full supply levels and peak flood lines for each site considered were drawn up on recent mapping provided by NamPower.

The geological conditions at each potential site were assessed, and sources for construction materials were located.

Reports on existing sediment transport studies within the Okavango Delta and experience from rivers elsewhere in Southern Africa, both drawn from specialists within the team, showed that sediment transport would be a key issue for the design of this scheme. It was therefore recognised that measurements of sediment transport would need to be undertaken in the proximity of the project site as an additional task during this stage of the study.

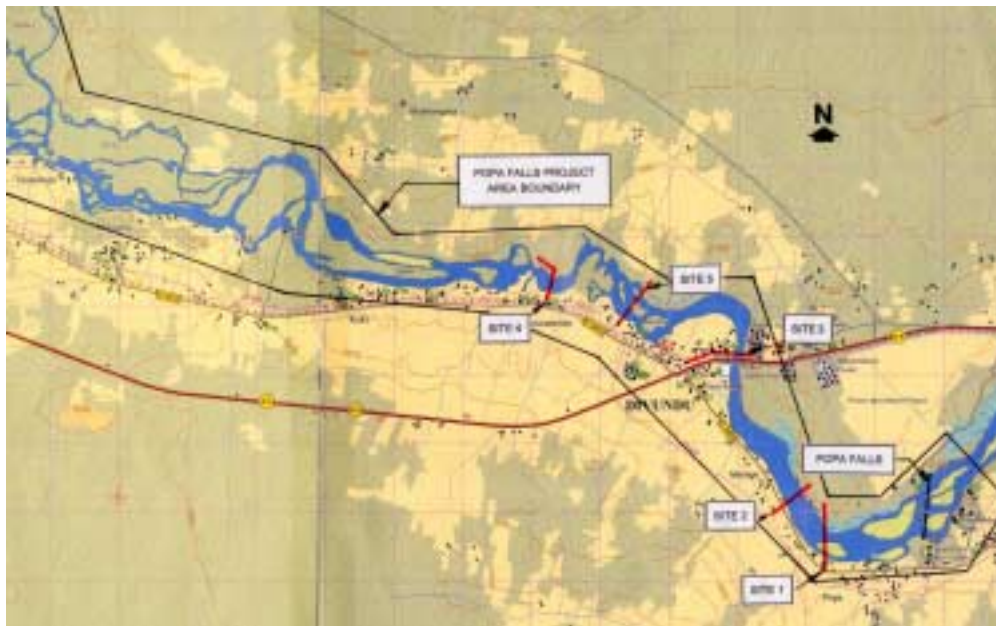
Based on the initial conceptual scheme layouts, an environmental overview was undertaken which covered the following aspects:

- Land ownership and tenure;
- Climate;
- Geology, topography and soils;
- Water quality;
- Fauna;
- Flora;
- Archaeology; and

- Socio-economic structure.

Based on knowledge of the area and preliminary surveys by the specialists, potential impacts were identified. Further quantification of these impacts will be required in the full EIA for the project during the next phase.

Potential sites were then identified which seemed feasible on inspection from an engineering point of view and that would produce sufficient power, as well as taking into account the initial environmental impacts. Alternative layouts at five different sites were drawn up and analysed, capital and operating costs were derived, and optimised schemes were compared. Three of these sites were favourable and these were compared in more detail. **Figure E2.3** shows the location of the three sites that were evaluated in detail.



The recommendation at this pre-feasibility level was derived from this evaluation by identifying the scheme that would produce maximum power for the least whole life cost at the same time minimising environmental impacts identified at this stage.

E3. HYDROLOGY

E3.1 HYDROLOGICAL ANALYSES

Analysis of the hydrology of the river is fundamental to the design of a hydro power scheme. The key components are:

- Derivation of flow duration relationships;
- Estimation of flood peaks, and
- The computation of water surface profiles.

The flow duration relationships provide information on the percentage of time that any flow is equalled or exceeded. This information is required for the sizing and optimisation of hydro power generation. Determination of a design flood peak is required in order to size and design the outlets and spillways at each of the identified weir sites. The water surface profiles are calculated to identify the full supply water levels and flood levels that will occur for any particular weir design. These also have an influence on the positioning and optimum design of the turbines.

There are only two flow gauging stations on the river reach above the stretch that passes through the Caprivi Strip both providing daily river flows upstream of the proposed sites. These are at Rundu and Mukwe. Mukwe is located approximately 120 km downstream of the confluence of the Okavango River with the Cuito River and is close to the proposed site. Over fifty years of records were used for the analysis.

E3.2 FLOW DURATION CURVES

Flow duration relationships were developed for Mukwe following careful screening and elimination of inconsistencies. The results of the flow duration relationships show that there is a significant variation in flow for the different months and that this will have a definite influence on the availability of flow to generate power throughout the year.

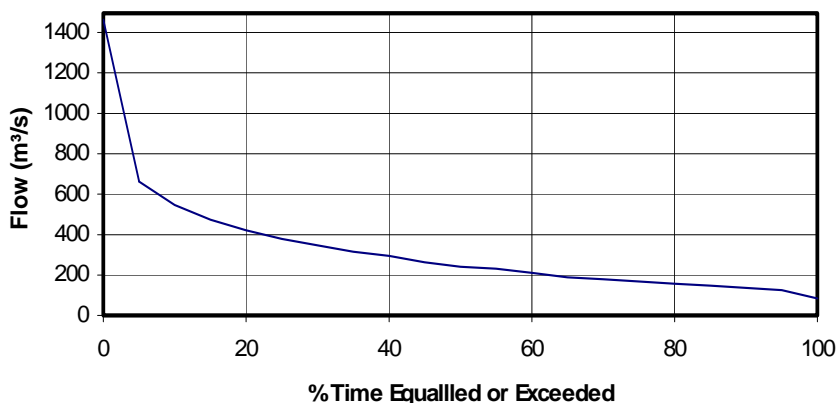


Figure E3-1 : Flow Duration Curve : Annual

It can be seen from this figure that a flow of 180 m³/sec can be expected for over 80% of the time.

E3.3 FLOOD PEAKS

Recorded flood peaks were plotted in chronological order which indicated a trend of slightly decreasing flood levels since 1985. Three methods were used to assess flood peaks, namely a statistical method, an empirical analysis, and a comparison with the Cunene River flood peaks. The statistical analysis using the Log Pearson Type 3 distribution was selected because it is the most commonly used method in hydrological analyses in Southern Africa, and it fits most sets of hydrological data.

The Probable Maximum Flood (**PMF**) was derived by taking the flood value that lies at the upper confidence limit that would statistically occur every 1,000 years, which coincides with the value that could occur every 10,000 years using the lower confidence limit. This flood peak value is 3 000 m³/sec.

The analysis showed that the floods in the Okavango River have long durations with up to 20 days either side of the peak still yielding approximately 50% to 70% of the peak flow. Since the storage capacity of a low weir in the river is minimal, the weir will provide no flood attenuation and the discharge capacities were based on peak flows.

E3.4 WATER SURFACE PROFILES

Water surface profiles were calculated for each of the weir sites considered using the HEC-RAS River Analysis System, which was developed by the US Army Corps of Engineers. The longitudinal section and cross sections of the Okavango River were extracted from the recent laser survey data provided by NamPower. The computer model was calibrated using the flow data from Mukwe gauging station and the actual river water levels observed at the time that the survey was undertaken.

The natural flow levels at Mukwe and immediately downstream of the Popa Falls were calculated. From this, the water surface level for different flows and floods under natural conditions were calculated for the entire reach of the Okavango River under consideration. The water levels created upstream of placing a weir in the river at the proposed sites was then determined.

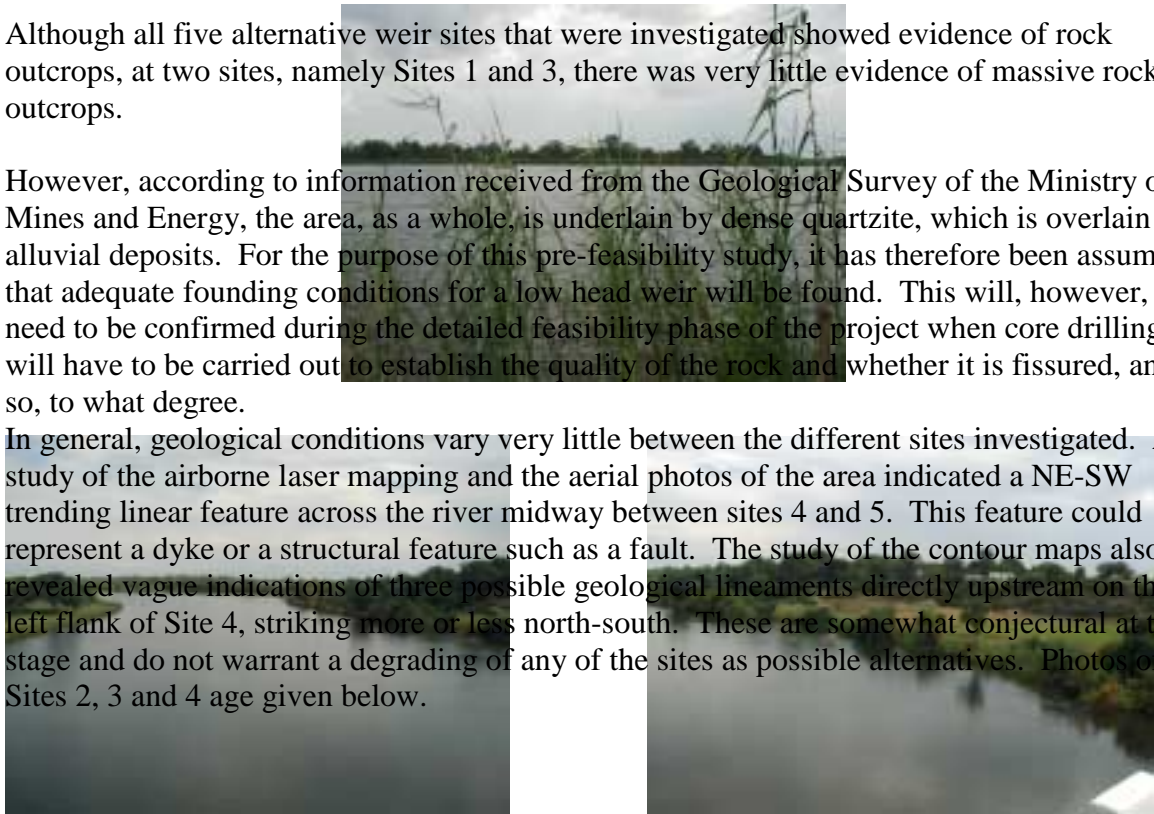
E4. ENGINEERING GEOLOGY

The entire project area is covered by Tertiary to Quaternary deposits of the Kalahari Group, consisting of sand, calcrete and gravel. Calcrete terraces and red, partially consolidated dune deposits of the Namib Desert are also present. Geological maps show no geological features/structures of any description, except the covering of Tertiary deposits and a quartzitic sandstone rock outcrop at the Falls. Below these partially consolidated Tertiary deposits, which are visible in the riverbed, is the quartzite (or quartzitic sandstone) of the Nosib Group of the Damara Sequence (Damara Supergroup).

Although all five alternative weir sites that were investigated showed evidence of rock outcrops, at two sites, namely Sites 1 and 3, there was very little evidence of massive rock outcrops.

However, according to information received from the Geological Survey of the Ministry of Mines and Energy, the area, as a whole, is underlain by dense quartzite, which is overlain by alluvial deposits. For the purpose of this pre-feasibility study, it has therefore been assumed that adequate founding conditions for a low head weir will be found. This will, however, need to be confirmed during the detailed feasibility phase of the project when core drilling will have to be carried out to establish the quality of the rock and whether it is fissured, and if so, to what degree.

In general, geological conditions vary very little between the different sites investigated. A study of the airborne laser mapping and the aerial photos of the area indicated a NE-SW trending linear feature across the river midway between sites 4 and 5. This feature could represent a dyke or a structural feature such as a fault. The study of the contour maps also revealed vague indications of three possible geological lineaments directly upstream on the left flank of Site 4, striking more or less north-south. These are somewhat conjectural at this stage and do not warrant a degrading of any of the sites as possible alternatives. Photos of Sites 2, 3 and 4 are given below.



View of Site 2 from the right bank towards the left bank

View looking upstream from the Divundu bridge towards Site 3 : Left photo shows both river banks and the right photo is a view on to the steep left bank



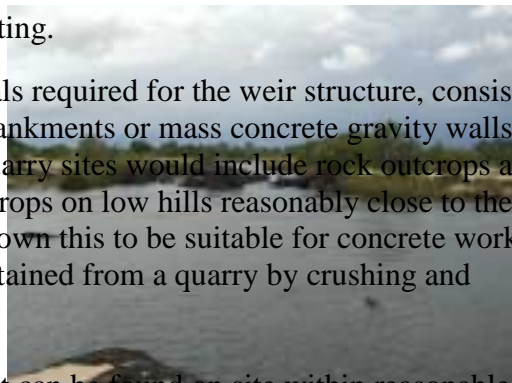
Views looking upstream from Site 4 showing rock outcrops

Site 5 was not visited during the field inspections as this site was only identified at a later stager during the study.

Further investigations that will need to be carried out during the detailed feasibility study phase will include the following:

- Geophysical surveys such as seismic refraction surveys to determine the depth and quality of bedrock, electromagnetic, magnetic and/or resistivity surveys to determine the type, orientation and conditions of the linear features.
- Rotary core drilling and Lugeon Testing.
- The excavation of deep test pits.
- Sampling of materials and laboratory testing.

It is possible that most of the construction materials required for the weir structure, consisting of a central concrete section and either earth embankments or mass concrete gravity walls on the flanks, can be found near the site. Suitable quarry sites would include rock outcrops along the riverbanks (located below FSL) and rock outcrops on low hills reasonably close to the river. Tests carried out on the river sand, have shown this to be suitable for concrete works. Rock for filter and rip-rap layers could also be obtained from a quarry by crushing and screening to the required sizes.



Fill material for the outer shell of the embankment can be found on site within reasonable distance from any of identified weir sites. However, in the case of the impervious core, no suitable source of clay material was identified during the field inspections. This material may

have to be imported from as far away as Omuramba Omatako, a distance of 120 km from the site.

Visible linear geological features, the origins of which are unknown, seem to indicate that the project area is located in a seismically active zone. However, according to a published map by Fernandez and Guzman (1979) (Preliminary map of natural seismic hazard (100 years)), the site lies in an area where there is a 90 per cent probability of a seismic intensity of 6,2 (modified Mercalli scale) not being exceeded during a period of 100 years, and a 90 per cent probability of a seismic intensity of 7,0 not being exceeded during a period of 500 years. This would indicate that a weir would not be in a high risk area and due to the low height of the wall it is anticipated that no special earthquake design requirements will be necessary. This aspect will, however, need to be investigated more closely during the detailed feasibility study phase.

E5. SEDIMENT TRANSPORT

E5.1 BACKGROUND

It became evident early in the study that sediment transport would be a key issue for this project. The fear that sediment movement along the river would be disrupted by the construction of a weir, and the potential consequences downstream of the site and for the Okavango Delta clearly need to be comprehensively addressed and an acceptable means found to ensure that sediments would not be trapped in the basin.

Out of a large number of publications dealing with sediment transport in rivers and reservoirs, the most widely used in the South African context include those written by Basson and Rooseboom (1997 and 1999) and Rooseboom and le Grange (2000). These papers outline the tools used for mathematical modelling and the design of reservoir outlets used to limit sediment build-up in South African rivers and reservoirs.

Turbulent transport would be the dominant sediment transport mode in this case. The turbulent sediment is divided into two components, bedload and suspended load. Bedload refers to sediment particles that are carried along the bed and which are not carried in suspension over long distances. Suspended load refers to that load which is generally carried above the bed. In sand bed rivers it is often difficult to distinguish the interface between suspended load and bedload.

The amount of sediment transported increases exponentially with flow velocity. Therefore a large proportion of total sediment load is transported during floods when velocities are high. When velocities are low, for example when entering the still waters of an impounded area, the suspended load precipitates out and the bedload transport slows, creating a build up of sediment at the head of the impoundment. Under normal river flows, the water leaving the impoundment will contain little sediment, and will be erosive downstream of a weir until a new dynamic equilibrium of sediment load has been achieved.

Numerous studies have been undertaken by the Department of Geology of the University of the Witwatersrand under the guidance of Professor T McCarthy since 1986 to examine the

sedimentation dynamics of the major fluvial channel of the Okavango Delta. Many measurements of bedload transport and suspended sediment movement were taken in the Delta, and a relationship was derived between bedload discharge and flow velocity. Suspended sediments were found to be low in these studies. Caution should be exercised when applying results from one area to other reaches of a river because basic factors will be different, such as velocities and channel gradient and profile. However, these long term studies found that sediment transported to the Delta plays a pivotal role in maintaining the biological diversity of the Okavango Delta.

The upper catchment of the Okavango river is underlain by quartzitic Kalahari sands producing a river sediment load that is primarily fine sand, with little clay or silt in suspension, such that the river has clear water with a low suspended sediment load for most of the year. Most of the sediment is therefore transported as bedload. The majority of the sediment is transported during the peak flow period and during floods. In most other Southern African rivers, the catchments comprise more complex geology and more diverse land uses and the rivers tend to carry a more varied range of particle size from coarse rocks down to fine colloidal particles.

The sediment load and particularly the sand in the Okavango River system is vital to the ecological functioning and life of the Okavango Delta. The design of the weir for the hydro power project has therefore to be certain not to interrupt the transport of sediment over time.

E5.2 SEDIMENT SAMPLING

In view of the importance of sediment for both the design of the hydro power project and for the functioning of the ecosystem downstream, it was recommended that more accurate measurements of sediment being transported as bedload and in suspension should be undertaken at the proposed project site during this stage of the study. Sediment surveys were therefore carried out in April and June 2003 at Divundu as follows:

- Bedload sampling using the Helley-Smith sampler
- Side-scan sonar and high-resolution bathymetric technique to quantify bedload movement
- Suspended sediment sampling using a tube sampler

The extensive bedload sampling previously undertaken in the Delta by Professor T McCarthy was carried out using a Helley Smith sampler, a device designed by the United States Geological Survey comprising a rectangular funnel fitted with a catch bag. The device is placed on the river bed and the quantity of sediment measured over a specified time. Since the bedload varies across the channel width and because many readings are required, the results showed a wide variation of sediment concentrations. However, a relationship was established between bedload transported and velocity.

This method was therefore used for sampling at Divundu to see whether some correlation existed. 134 samples were taken and the volumes of bedload varied from 1 cm³ to 1005cm³, equivalent to a total bedload transport of 197 m³/day.

A portion of the river was also investigated using side-scan sonar and high-resolution bathymetric techniques. This geophysical survey was conducted by the Marine Geoscience Unit (MGU) of the Council for Geoscience (CGS) in order to assess bedload sediment transport rates within the river. A location 300 m downstream of the Divundu road bridge was selected in which the channel width was reasonably uniform and the width relatively constant. Sediment transport rates appeared to vary widely within the section of river surveyed and indicate both sediment accretion and erosion. A preliminary estimate of the total bedload over the full river width equated to 113 m³/day.

Suspended sampling was carried out using a pump sampler pumping into 100 litre containers. Samples were taken at various depths and at different points across the river. The results of this sampling exercise showed that concentrations of suspended sediments were highest closer to the riverbed, and least near the water surface. The values of suspended load measured ranged from 0.85 m³/day 500 mm below the surface to 16.84 m³/day at a point 200 mm above the river bed.

The results of the sampling tests showed that the methods used produce different results. Bedload sediment transport varied between 114 m³/day and 194 m³/day. Using the mathematical relationship developed by McCarthy from the samples taken in the Delta yields a value of 310 m³/day.

The small number of samples taken was insufficient to extrapolate values of sediment transport over time, for example over a year. It is important to establish the total sediment that is transported, whether by bedload movement or in suspension.

It is therefore recommended that additional sediment sampling is undertaken during the next stage of the project over a period of twelve months. A suitable site should be selected where no rock outcrops occur, and where the river has a uniform cross section. Bedload sampling should be done using the side-scan sonar method at the same time as sampling suspended sediment load. The programme should allow for sampling every three months, but to include additional sampling during the period when the river is at or close to its peak flow.

E6. PROJECT OVERVIEW

E6.1 ENGINEERING DESIGN REQUIREMENTS

The project is required to evaluate the feasibility of constructing a low to medium head run-of-the-river hydro power plant at a suitable location upstream of the Popa Falls. A run-of-the-river hydro power plant operates at a constant head for most of the year and is designed to operate continuously at maximum power output. During low flow periods the head, and as a consequence, the power generated, would drop. The design of the hydro power plant is required to maximise power output, which should ideally lie between 20 and 25 MW, for a given weir height.

Due to the ecological and environmental sensitivity of the Okavango Swamps and islands in the Okavango River with unique and rare habitat, it was essential that weir heights, and hence impoundments be minimised whilst at the same time striving to maximise power output. A

further essential restriction placed on the project was that sediment transport may not be disrupted as this could result in severe channel scouring and removal of sediments downstream of the weir.

In this study two main types of turbines were investigated, namely the conventional Bulb Turbines and the Hydromatrix Turbines. Bulb Turbines are generally mounted horizontally but can also be mounted vertically, in which case they are called Pit Turbines.

Hydromatrix turbines are a relatively new concept of hydraulic energy generation which combine the advantages of proven technology and low cost installation. The Hydromatrix design utilises a factory assembled module of small propeller turbine-generator units (± 0.75 MW each) which are easily installed into existing gates incorporated into the spillway structure of a weir.

The weir heights considered for the Popa Falls study range from 6,5 m to 9.75 m in order to limit impacts resulting from the impoundment. Weir heights up to 11.5m were also investigated to assess the sensitivity of weir height on the economic viability of the project.

To ensure that the hydro power plant can operate at maximum power output for as long a period as the river flow allows, it was essential that spillway gates be provided that would automatically open gradually as the discharge over the weir increases beyond a certain pre-defined overflow depth, to prevent flooding upstream of the weir. The gates chosen have been patented in South Africa by Flowgate Projects, and these would also close automatically as the flood recedes thereby ensuring that the turbines operate continuously at maximum power output.

E6.2 ENVIRONMENTAL REQUIREMENTS

In order to fulfil the requirements of sustainable development, a project should try and optimise the financial, technical, social and environmental components, i.e. to ensure that the project can proceed at the lowest cost financially, socially and environmentally. This is sometimes difficult to estimate, measure and achieve and compromises have to be made. However, it is important to set goals from the outset and then strive to achieve them within the cost and technical constraints of the project.

The social and environmental objectives for the project are set out below:

- The site for the weir should be chosen on the basis that the area of inundation will have the minimum impact on: rare island habitats, riverine vegetation, important faunal breeding areas, Red Data Book species, archaeological and cultural sites e.g. graves, dwellings, institutions, businesses, infrastructure, agriculture, rural livelihoods and tourism activities.
- The natural flow in the river should be interrupted as little as possible, because the seasonal cycles in the hydrograph trigger an unknown number of complex ecological processes downstream (see the PEA Report). This is especially important given that the Okavango Delta is a Ramsar site i.e. an area internationally recognised in terms

of the Ramsar Convention as being important for waterfowl. The rich biodiversity of the Delta is also the basis for the lucrative tourism business in Botswana, which is currently the fastest growing economic sector in the country (SAIEA, 2003). The actual minimum flow requirement is not yet known, but it should not be a single flow volume, constant throughout the year, but rather if there are to be any flow disruptions, then the minimum flow should be expressed as a percentage of the hydrograph.

- The movement of sediment should not be interrupted at all because of the predicted impacts on the geomorphology and ecology of the Okavango River and Delta. This means that a method needs to be found to ensure that there is a constant flow of sediment through or round the impoundment.

The main environmental objective is to minimise the negative impacts of the proposed development and to maximise the benefits to ensure the long-term sustainability of the scheme.

E6.3 WEIR SITES

There were several conditions that had to be satisfied before a possible weir site could be selected for further evaluation. These were:

- It must not be constructed on the lip of the Popa Falls;
- It must not be visible to tourists visiting the Falls;
- It must not affect flow over the Falls;
- It must minimise the area of inundation of sensitive habitats, land uses and cultural heritage sites;
- It must minimise the amount of social and economic disruption;
- It must not inundate Angolan Territory over and above the maximum flood level that would occur without a weir in place; and
- It must not inundate the Andara Mission and the Frans Dimbare Youth Centre.

Five sites were identified that satisfied these criteria, and an initial technical, financial, social and environmental evaluation was undertaken. As a result, two sites, Sites 1 and 3, were eliminated during this first screening phase, and the following three sites were analysed in detail:

Site2. This site is located approximately 2 km upstream of the Popa Falls. This site was selected on account of the wide river section thus permitting cofferdams to be built in the river to protect the concrete works during construction.

Site 4. This site is located approximately 4 km upstream of the Divundu bridge and 8.3 km upstream of the Popa Falls, in an area where the river has a gradient of the order of ten times steeper than at Site 2, thus providing the opportunity of a greater head for power generation.

Site 5. This site, which was identified as the study progressed, is located 7.3 km upstream of the Popa Falls and 1 km downstream of Site, 4 and is located at the foot of some rapids. This site offers the opportunity to increase the weir height by 0,75 m for the same Full Supply Level (FSL) as at Site 4.

The locations of these sites selected for detailed analysis are shown on **Figure E6-1.**



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Table E6-1 : Advantages and Disadvantages of Selected Weir Sites

Sites	Advantages	Disadvantages
Site 2	<ul style="list-style-type: none"> • Wide river channel which allows the construction of cofferdams around the concrete works, • Has a short left flank and relatively short right flank, • Would inundate less island habitat than sites 4 and 5, • The utilisation of the additional head of the Falls could improve power generation benefits. 	<ul style="list-style-type: none"> • Too close to the Falls, • Would be visible to tourists approaching the Popa Falls from upstream of the falls, • Would inundate large tracts of land, • Weir height is limited to 7,5 m, • Major relocation of households and businesses etc. required.

	<ul style="list-style-type: none"> Storage capacity is less than 2% of the MAR. 	
Site 4	<ul style="list-style-type: none"> Too close to the Falls, Would be visible to tourists approaching the Popa Falls from upstream of the falls, Would inundate large tracts of land, Weir height is limited to 7,5 m, Major relocation of households and businesses etc. required. 	<ul style="list-style-type: none"> Weir height is limited to a FSL of 1010.0 m.a.m.s.l. Higher weirs would inundate the Frans Dimbare Youth Centre, 29% of the total area of islands as determined for January 2003, will be submerged at FSL conditions, Sections of District Road D3402, the 33kV powerline, and telephone line will need to be relocated to higher ground, Construction costs would be high due to additional embankment/wall in the secondary channel.
Site 5	<ul style="list-style-type: none"> Weir height can be increased to 9,75 m to a FSL of 1010.0 m.a.m.s.l. as the river bed is approximately 0.75 m lower than at Site 4, Less relocation of households etc. required, Good founding conditions expected in a rocky river channel, Length of basin at FSL less than for Sites 1, 2 and 3, River channel is wide enough to construct the concrete section within cofferdams leaving sufficient river width to accommodate low frequency floods, Storage capacity is less than 2% of the MAR. 	<ul style="list-style-type: none"> Weir height is limited to a FSL of 1010.0 m.a.m.s.l. Higher weirs would inundate the Frans Dimbare Youth Centre, 30% of the total area of islands as determined for January 2003, will be submerged at FSL conditions, Sections of District Road D3402, the 33kV powerline, and telephone line will need to be relocated to higher ground, Storage capacity only slightly greater than for Site 4 but is still far less than the maximum figure 2% of the MAR at which point sluicing would not be effective.

Site 2 is good from a technical, financial and environmental point of view, but is restricted to a lower weir height, and has greater social impacts. Site 4 is less attractive than sites 2 and 5 from some technical and financial aspects, but is better than site 2 from the social aspect. Site 5 is best in terms of technical and social criteria, and fair from a financial and environmental viewpoint.

E7. HYDRO POWER UNITS

E7.1 ALTERNATIVE COMBINATIONS OF TURBINES CONSIDERED

Four different types of hydro power units and combinations were considered for the evaluation of power generation at the selected sites. These were:

- Hydromatrix turbines;
- Bulb turbines;

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

A Hydromatrix module consists of a base frame containing three turbine generator sets. To achieve the required energy production, the plant needs to consist of nine modules, or twenty seven turbines. The particular advantage of the Hydromatrix concept is the possibility of being able to lower the complete Hydromatrix Module into the weir with the aid of guides similar to those used for stoplogs. The hydraulic design is based on bulb turbine technology. The generator is a standard motor which can be operated as a synchronous machine. The modular concept of the Hydromatrix turbines permits them to be placed across the weir interspersed with spillway gates thus minimising the restriction to flow during floods.

By contrast, the Bulb unit is a horizontal axial turbine with a direct coupling to the generator. The generator is usually bolted to the stay column embedded in concrete. However, the powerhouse would be constructed as a block type structure on either the left or right bank of the river causing asymmetric deposits of sediment in the river.

E7.2 DESIGN DISCHARGE

The flow duration curve derived in the hydrological analysis (**Section E3, Figure E3-1**) was used to calculate the discharge available for power generation. The reservoir capacity, the configuration and number of turbines incorporated, and the weir gate and spillway design are all also important components for maximising the energy output of the alternative schemes being considered.

In addition, it is important to minimise disruption to sediment transport. The mechanics of sediment removal is addressed in the **Section E8**. In order to preserve the natural characteristics of the river as best as possible at the weir site, and to allow the river to flow as naturally as possible during flood flows, all the designs considered include the facility to provide as many openings as possible in the weir across the river section during floods by incorporating a combination of gates and turbines. The Hydromatrix turbines are more appropriate for these conditions.

One means considered for the removal of sediment is sluicing, a method that is widely used on other reservoirs in Southern Africa. One basic requirement is that the capacity of the reservoir has to be less than 2% of the Mean Annual Runoff. The sediment is sluiced through open gates during peak floods, meaning that the river level would fall and that power generation would not be possible during sluicing.

If sluicing were to be adopted, then it was assumed that one month would need to be allowed for this activity reducing the annual operating time of the power plant to 8,000 hours per year. This operating period was assumed in the energy calculations.

E7.3 EVALUATION OF THE SELECTED OPTIONS

Site 2 is close enough to the Falls for the option of incorporating the additional head at the Falls in a scheme layout in order to increase power generation during high flood periods. This option would need to ensure that a minimum flow was maintained over the Falls to satisfy environmental requirements. It would also require a canal to divert the flow through the turbines and allow discharge sufficiently downstream of the Falls to avoid any visual impact.

Three different alternative layouts were analysed, but were all ruled out on financial grounds due to the high costs for the additional civil works required.

Therefore the alternatives that were analysed in more detail were the arrangements for either Hydromatrix turbines only, or Bulb turbines only incorporated into weirs of different heights at each of the three Sites, 2, 4 and 5. The results of the analyses are set out in **Table E7-1** below.

Table E7.1 Power and Energy Production at the Selected Sites

Location	FSL (m.a.m.s.l.)	Bulb Turbines		Hydromatrix turbines	
		Power (MW)	Energy (GWh)	Power (MW)	Energy (GWh)
Site 2	1007.5	15.6	88.7	16.0	83.4
Site 4	1007.5	13.2	67.4	12.6	61.8
	1010.0	19.4	105.3	20.5	102.2
	1012.5	25.5	143.3	27.4	144.1
Site 5	1007.5	16.1	82.6	15.3	77.3
	1010.0	22.2	120.5	23.2	118.2
	1011.0	24.7	135.7	26.9	133.8

Table E7-2 : Summary of Investment Costs per Installed Kilowatt for the Project Alternatives

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 at Site 2	MB1	1007.5	2333		
	MB2	1007.5	2343		
	MB3	1007.5	2463		

The apparent anomaly of increasing investment costs per installed megawatt, when comparing these for Sites 4 and 5 in **Table E7-2**, 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 E7.3** 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.

Table E7-3 : 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		

The above tables identify options with investment costs less than US\$2,200/kW and with costs for annual energy production lower than US\$0.40/kWa. As a result, detailed cost estimates were prepared for the following alternatives:

Table E7-4 : 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	110.0
	Hydromatrix	1011.0

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.

E8. SEDIMENT REMOVAL

The following two methods of sediment removal have been identified to be considered:

- Sluicing of sediments;
- Bypass pumping.

E8.1 SLUICING

The principle of sluicing is that for eleven months of the year, the weir would be operated at the FSL. Then, during the high flow period, assumed to be for one month each year, the gates would be opened fully in order to draw down the level in the basin to the natural water level, almost as if the weir was not there. With the drop in the water level, the velocities will increase sufficiently to remove the sediments that have accumulated within a few hundred metres of the weir. Experience on dams in South Africa has shown that as the velocities increase further upstream due to the rapid drawdown, bedload sediments will also be mobilised and transported through the weir and continue until the flow through the weir has reached its natural flow condition. Sluicing is efficient in high floods and where the reservoir capacity is less than 2% of the MAR, as in this case.

In order to optimise sediment transport by sluicing, it is necessary to sluice during the peak flow each year. However, the timing of the peak discharge in the river varies from year to year, and therefore it is impossible to predict when the peak will occur.

Because of this uncertainty, it is clear that additional investigations into the mode of sediment transport need to be undertaken during the next stage of the project. These will need to include sediment sampling as described in section E5 above, together with mathematical and physical model testing to evaluate the effectiveness of sluicing, and the effect of sluicing downstream of the weir. In addition, the testing will need to consider other environmental issues as follows:

- Determination of where the sluiced sediment would be deposited downstream of the weir;
- What the effect will be on the invertebrates and bacteria etc that inhabit the natural river bed and may be smothered by the release of sediment from the impoundment;
- What effects will occur downstream of the weir during the rest of the year when clear sediment-free water flows over the weir and erosion can be expected to occur as the river regains dynamic equilibrium regarding sediment load;
- Whether there will be any water quality effects by releasing large quantities of organic particles that may have built up in the impoundment;

- To determine how quickly the level will fluctuate during sluicing, and what effect this rate of level change will have on species that may be disturbed by this, and whether erosion will be caused;

Sluicing will have to be continued after decommissioning of the power plant unless the weir were to be removed.

E8.2 BY-PASS PUMPING

A sediment by-pass system was considered as an alternative to sluicing. This has been successfully used in Japan and elsewhere. The system would operate as follows:

- A sediment trap is constructed at a point close to the head of the basin at a point where the velocities have reduced sufficiently to allow sediments to be caught in the trap;
- The sediment trap would discharge its load into a pump sump, and be pumped into a pipeline;
- The pipeline would be approximately 250 mm in diameter and about 10 kms long and discharge at a point immediately downstream of the weir;
- The gradient would have to be designed to ensure that a minimum flow velocity of about 1 m/s is maintained to prevent settlement in the pipeline.

The immediate advantages of incorporating this by-pass pumping alternative is that energy production can be maintained throughout the year as there is no need to open the gates to sluice. The associated negative environmental issues with sluicing would also be eliminated, and sand would be pumped on a continuous basis. There are, however, additional operational aspects associated with this alternative.

It would still be important to model test this option in order to verify the design and size of the sediment trap and pump sump to ensure that the trap functions effectively and to optimise the capacity of the pump and size of the pipeline.

E9. WEIR GATES

The purpose of the spillway gates is to:

- maintain as high an operating water head as possible to maximize power generation,
- open under flood conditions to discharge flood waters,

- to provide sufficient waterway under the gates when open to prevent upstream flooding, and
- to fully open under peak flood conditions to rapidly draw down the water level and increase scouring velocities, to sluice/flush out the sediments that have accumulated in the basin.

Various types of spillway gates were considered, including electrically driven radial gates, automatic scour gates, TOPS gates and no gates. The TOPS gates are preferred as they will open automatically to pass floods when the depth of overtopping exceeds 300 mm, and will close automatically as the flood recedes. All gates will be set to operate simultaneously so that there is an equal opening below the gates to assist with an even scouring effect across the waterway.

When the discharge valve is closed, the ballast tank will fill through the inlets to cause the gate to close to maintain the full supply level. During sluicing operations (Sediment sluicing option) the spillway gates will be lifted clear of the water surface under the gates to maximise outflow velocities.

The gates will be constructed in concrete and require very little maintenance. Manual intervention is required only when it is necessary to lift the gates above the water surface during sluicing operations using hydraulic rams. In the case of the sediment bypass option, manual operation or intervention is not required.

E10. POWER TRANSMISSION ELEMENTS

The power transmission system will consist of a 200 km long 132 kV line to Rundu with a 132 kV line feeder bay in the Rundu supply substation and a switchyard at the hydro power site

The Namibia Transmission Grid is supplied from two main sources. One being the ESKOM grid via the inter-connector from the south, and the other being the Ruacana Hydropower Scheme grid coming from the north west of Namibia. To supply power to the north and eastern regions, long transmission lines are required which result in high electrical transmission losses. The Popa Falls Hydro Power Scheme is ideally placed to reduce transmission losses. This is, however, dependent on the ratio of supply between ESKOM and Ruacana.

The 200 km long, 132 kV powerline to Rundu requires approximately 10 Mvar capacitive power, and the consumers at Rundu approximately 10 MW at a power factor of 0,9, requiring about 4 Mvar inductive power.

During island operation of the power plant with the network of Rundu, the capacitive/inductive load compensation will be handled by the on load tap changers of the Popa Falls step up transformers. During further design stages the need for further compensation equipment at Popa Falls, will have to be assessed.

E11. MITIGATION OF ENVIRONMENTAL IMPACTS.

During the study, several environmental issues and impacts were identified, and preliminary environmental reports were prepared by individual experts on specific aspects.

There are, however, several impacts that cannot be fully quantified until further investigation is undertaken. Hence, the mitigation measures and costs of mitigation can only be estimated on what is known at this stage, and these will need to be re-evaluated during the next feasibility stage.

A summary of the impacts and the preliminary assessment of their significance as known at this stage has been prepared and is contained in **Table E11-1** below.

Table E11-1 : Summary of Impacts and Potential Mitigation Measures and/or further Work

Potential Impact	Preliminary Assessment of Significance*	Potential Mitigation Options and/or Further Studies
Inundation of islands and riverine forest	High	Select Site 2 to minimise impact Detailed ecological studies in EIA
Inundation of rocky habitats	High	Select Site 2 to minimise impact Detailed ecological studies in EIA
Loss of biodiversity, especially Red Data Book species	High	Further ecological studies during EIA
Inundation of huts, businesses	Medium	Select Sites 4 or 5 to minimise impact Reduce weir height at Site 2 Conduct detailed socio-economic assessment
Inundation of infrastructure	Medium	Re-route road Reduce weir height at Site 2 Select Sites 4 or 5 Conduct detailed socio-economic assessment
Inundation of institutions	Medium	Select Site 2 Construct a flood retaining wall at Frans Dimbare centre Reduce weir height at Sites 4 and 5
Inundation of graves and burial sites	High	Avoid cultural and religious sites Relocate graves in consultation with local community
Inundation of archaeological sites	Medium	Detailed archaeological assessment if required
Visual impact of weir on tourist facilities	Low	Select Sites 4 or 5
Reduction in flow of water during construction	Low	Fill basin during flood peak Construct bypass channel
Reduction in flow in river	High	Install TOPS gates to ensure continual flow
Reduction in natural variability in flow	High	Set strict operational guidelines to ensure that flow over the weir reflects the natural hydrograph

		Determine minimum flow requirements for different seasons/flow conditions
Inundation of land during Probable Maximum Floods	Medium	Minimise weir height
Interruption in the free flow of sediment downstream	Potential fatal flaw	Annual sluicing Bypass pumping Modelling
Scour of riverbed downstream of weir and erosion of important habitat	High	Bypass pumping of sediment
Impacts of sediment interruption and sluicing on downstream ecology and geomorphology	High	Bypass pumping
Potential Impact	Preliminary Assessment of Significance*	Potential Mitigation Options and/or Further Studies
Impacts of bypass pumping on downstream ecology and geomorphology	Medium	Distribute sediment release across width of river Pumping must be continuous
Interruption in fish movement	Medium	Fish ladder Fish bypass channel
Impact of noise during construction	Medium	Develop detailed Construction Environmental Management Plan (CEMP) and monitor
Impact of construction on vegetation at weir site	High	Develop detailed Construction Environmental Management Plan (CEMP) and monitor
Impact of construction of substation on vegetation	Low - Medium	Select site to minimise impact on flora and fauna Conduct detailed surveys during EIA
Impact of developing quarries and borrow pits during construction	Low – Medium	Conduct detailed surveys during EIA
Impacts of pollution from oils, diesel, paint, concrete, sediment etc during construction	Medium	Develop detailed Construction Environmental Management Plan (CEMP), monitor and enforce
Impact of eutrophication during and after filling	Medium	Clear all vegetation in the basin prior to filling Make cleared timber available to local community Use local labour to clear vegetation
Impact of erosion during construction	Low	Develop detailed Construction Environmental Management Plan (CEMP) and monitor
Impact of work force on social stability	Low	Employ construction labour locally Develop a community liaison and consultation plan
Impact of work force on STDs in local population	Medium	Employ construction labour locally Develop a community liaison and consultation plan Education and awareness training
Impact of introduced alien plants and animals	Medium	Develop detailed Construction Environmental Management Plan (CEMP), monitor and enforce
Impact of erosion in weir basin during hydro power operations	High	Manage draw down within natural limits of variability Implement bypass pumping instead of sluicing Monitoring
Impact of water pollution during operation	Low	Adhere to EMP or EMS Bypass pumping Monitoring

Impact of noise during operation	Low	Adhere to EMP or EMS
Potential for seismic activity	Low	Conduct seismic risk assessment in Feasibility Study
Potential Impact	Preliminary Assessment of Significance*	Potential Mitigation Options and/or Further Studies
Impact on sustainable livelihoods	Medium	Calculate compensation costs on loss of livelihood as well as on loss of property and land Develop a Resettlement Plan to World Bank standards Include resettlement areas in EIA Use weir impoundment to promote sustainable artisanal fisheries in the area
Potential increase in disease e.g. malaria, bilharzia	Medium	Education and awareness training Spraying programmes Vegetation management within the impoundment Surveillance
Impacts on socio-economic structure of Botswana, especially the tourist industry	Low – High	Detailed socio-economic survey including a cost-benefit analysis Physical modelling of sediment impacts
Impacts on tourism in the project area	Medium	Allow use of impoundment for boating Erect bird and animal viewing hides Make power available locally
Maximise local economic benefits during construction	High	Use local labour during construction Source goods and services locally as far as possible
Maximise local economic benefits during operations	Medium	Make power available locally for small businesses Capacity building programmes
Visual impact of the substation	Low	Careful positioning Use existing trees as a screen or plant indigenous vegetation
Denudation of land following construction	Low	Develop a rehabilitation programme using indigenous species
Impact of power lines on birds	Medium	Careful route alignment planning during EIA
The impact of cumulative effects	Not determined	Incorporate a cumulative effects study in the EIA
Impact of land mines in zone of inundation	High	Clear all land mines prior to land clearance
Impact of climate change on long-term viability of the project	Not determined	Use latest climate and runoff models to predict climate change and viability of project
Impact of catchment land use changes on water flow, quality and sediment production	Not determined	Model land use change for a variety of scenarios under changing climatic conditions
Evaporation and seepage	Low	Minimise water surface area
Impact on future conservation initiatives	High	MET to proclaim additional conservation areas along the Okavango River

E12. FINANCIAL AND ECONOMIC EVALUATION

Section E 7 summarised those alternative schemes that should be subject to more detailed cost evaluation. This was done, and the resulting capital costs of these schemes are shown in Table E.12.1.

Table E12-1 : Summary of Capital Cost Estimates

Option no	Alternative	Total Cost – MUS\$
1	Site 2 : Hydromatrix Units – FSL 1007.50 m.a.m.s.l. – Mass Gravity Abutment	43.532
2	Site 4 : Hydromatrix Units – FSL 1007.50 m.a.m.s.l. – Mass Gravity Abutment	42.917
3	Site 4 : Hydromatrix Units – FSL 1010.00 m.a.m.s.l. – Mass Gravity Abutment	46.082
4	Site 4 : Hydromatrix Units – FSL 1012.50 m.a.m.s.l. – Mass Gravity Abutment	52.262
5	Site 5 : Hydromatrix Units – FSL 1007.50 m.a.m.s.l. – Mass Gravity Abutment	41.130
6	Site 5 : Hydromatrix Units – FSL 1010.00 m.a.m.s.l. – Mass Gravity Abutment	44.379
7	Site 5 : Hydromatrix Units – FSL 1010.00 m.a.m.s.l. – Earth Embankment	44.965
8	Site 5 : Hydromatrix Units – FSL 1010.00 m.a.m.s.l. – Sediment Bypass	41.658
9	Site 5 : Hydromatrix Units – FSL 1011.00 m.a.m.s.l. – Mass Gravity Abutment	45.833

A financial analysis was carried out for the project with the aim of identifying the least cost option. A total of nine alternative options were assessed. For each option, the costs of the project, including capital costs, Operation and Maintenance (**O&M**) costs and transmission costs, were projected assuming a four year implementation period from 1st January 2004 until commercial operation commences followed by 30 years of operation. These costs were set in relation to the energy provided by the project to the load centres of Rundu and Otjikoto, taking into account the transmission losses. Costs as well as energies were discounted to their present values to calculate the levelised unit costs. For the calculation of other financial performance indicators, project costs were compared to project benefits which consist of revenues (based on price projection of the South African Power Pool (**SAPP**)) and avoided transmission costs arising from the deferred upgrade of the Otjikoto-Rundu transmission line.

The ranking of the hydro power plant options according to the financial levelised unit cost shows that Option 8 (construction of a 9.75 m high weir at Site 5 to an elevation of 1010.0 m.a.m.s.l. and a sandtrap at the head of the weir basin) is the least cost option. The option has levelised unit costs of 31.51 US\$/MWh (at a discount rate of 7.5%), an internal rate of return of 10.18 %, a net present value of 13,091 TUS\$, and a benefit/cost ratio of 1.38. A sensitivity analysis confirmed the robustness of the results. The ranking does not change and Option 8 is still financially viable when tested against a 10% increase in capital costs, a 10% reduction in SAPP prices and a 10% decrease in energy output.

Option 8, the preferred hydro power plant option, was then subjected to a cash flow analysis in order to assess the financial performance of the project. Under the assumption of an equity/debt ratio of 50:50, an interest rate of 7% and a loan term of 12 years, Option 8 has a return on equity of 13.27% and a payback period of 8 years. The project thus is financially viable. However, during the early years of operation, the debt service coverage ratio is below

the rate normally required by financing institutions. Therefore several measures are discussed which could mitigate the effects of the low cash flow in the early years.

Finally, an economic analysis was carried out in order to assess the viability of the preferred option from the viewpoint of the entire Namibian economy. For this purpose, the preferred hydropower option was compared with other options for the supply of power to the Rundu and Otjikoto load centres: a 400-800 MW CCGT plant based on Kudu Gas, imports via the SAPP from South Africa, and imports via the SAPP from Zambia. The economic costs of all the alternative options not only include capital costs and O&M costs, but also environmental costs, which in the case of the Kudu Gas plant include the impact of greenhouse gas emissions.

The economic test reveals that Popa Falls is the least cost option for the supply of power to the north-eastern regions of Namibia, followed by Kudu CCGT plant which ranks second. The hydropower project generates power at a level of 30.89 US\$/MWh (at a discount rate of 10%). For the transfer to the load centres, transmission costs of 4.14 US\$/MWh are incurred, leading to total economic levelised unit costs of 35.04 US\$/MWh.

The economic benefits of the Popa Falls Hydro Power Project equal the avoided cost of the best alternative supply option, i.e. the cost of power supply by the Kudu CCGT plant.

E13. IMPLEMENTATION SCHEDULE

The implementation schedule comprises the following phases. Provisional time periods have been allocated to each phase; however, these may need to be revised when the Terms of Reference have been drawn up for the detailed feasibility study component:

- Phase 1 covers the balance of the pre-feasibility study stage which includes the submission of the final report to OKAKOM for comment, the decision making process by NamPower, and the preparation of the Terms of Reference for the detailed feasibility study: 1.5 months;
- Phase 2 comprises the detailed feasibility study which has two components, namely the technical and the environmental studies: 22.5 months;
- Phase 3 comprises the detailed design phase: 8 months; and
- Phase 4 comprises the tender and construction phase: 30 months.

E14. CONCLUSIONS AND RECOMMENDATIONS

E14.1 TECHNICAL ASPECTS

The study has shown that there are three potential sites at which a hydro power plant could be constructed. All sites have advantages as well as disadvantages but Site 5 has proved to be

the site with the most potential in respect of power generation. Several key issues have been identified in the Preliminary Environmental Assessment report, the most important of which relate to the movement of sediment in the Okavango River which must not be disrupted, and the fear that excessive inundation of islands in the weir basin will destroy unique and rare fauna and flora.

Model tests need to be undertaken to establish the most efficient, and acceptable, method to overcome the need to maintain sediment transport. In respect of the island issue, further detailed investigations need to be undertaken by the environmental team during the detailed feasibility study phase, before the consequences of island inundation can be further discussed. Lower dam heights should also be looked at to ascertain the relative economic and environmental sensitivities to different levels.

The proposal that a relatively new concept of turbines, namely the Hydromatrix turbine, be used for the Popa Falls Hydro Power Project has resulted in the project becoming more viable than would otherwise have been the case. The utilisation of the Hydromatrix turbine Modules in combination with the automatic TOPS spillway gates, makes the proposed hydro power project unique and provides a technically sound and cost effective solution.

E14.2 FINANCIAL ASPECTS

The result of the financial analysis clearly shows that a hydro power plant constructed at Site 5 with the sediment bypass system installed, is financially and economically the most viable of all alternatives investigated. The financial performance indicators for the preferred option are as follows:

FIRR	10.18%
FNPV	13.091 TUS\$
Benefit Cost Ratio	1.38
LUC	31.51 US\$/MWh

The economic indicators for the same site are:

EIRR	11.92%
ENPV	3,829 TUS\$
Economic Benefit/Cost Ration	1.14

E14.3 RECOMMENDATIONS

The major objective of the study was to investigate the viability of constructing a hydro power plant in the Divundu area, which is located some 2,5 km upstream of the Popa Falls. The objective has been met with the proposal that a 9,75 m high weir be constructed at Site 5 to an elevation of 1010.0 m.a.m.s.l. which would incorporate 27 Hydromatrix turbines and 6 TOPS spillway gates. This proposal provides for pumping incoming sediments from the head of the weir basin to downstream of the weir, thereby eliminating one of the most crucial issues identified by the Environmental Consultants.

It is therefore recommended that the proposal to construct a hydro power plant at Site 5 near Divundu in the Kavango Region be further investigated in a fully detailed feasibility study, and that the following investigations be carried out during the detailed feasibility study:

- Carry out further detailed analyses of the Hydromatrix Turbine option to establish whether these turbines are able to operate in an island mode configuration. In the event that it is found that this is not possible or remains doubtful, then the bulb turbine option should be further pursued.
- Model testing of the sediment bypass proposal and, if necessary, the alternative of the sediment sluicing proposal,
- A sediment sampling/survey programme be initiated at the start of the detailed feasibility study, the duration of which should not be less than 12 months with a total of 6 sampling trips at three-month intervals,
- Detailed geotechnical investigations, including rotary core drilling, excavation of deep test pits, laboratory tests on cores, electromagnetic surveys to determine the position of structural features, and field investigations to find suitable sources of construction materials, be carried out. Exploratory work should initially be limited to Site 5 but some additional core drilling should also be carried out at Site 4 to establish if founding conditions are similar to those found at Site 5.

In addition to a fully detailed technical feasibility study, a detailed environmental impact assessment would need to be carried out so that the impacts identified in the PEA can be better quantified to enable the technical team to incorporate appropriate cost effective ways of mitigating these impacts.