



OKACOM

The Permanent Okavango River Basin Water Commission

Technical Report on Hydro-electric Power Development in the Namibian section of the Okavango River Basin

Colin Christian & Associates CC

February 2009

*Environmental protection and sustainable management
of the Okavango River Basin*

EPSMO

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Okavango River Basin: Trans-boundary Diagnostic Analysis Project

Technical Report on Hydro-electric Power Development in the Namibian section of the Okavango River Basin



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ABBREVIATIONS

FAO	Food and Agriculture Organisation
NNF	Namibia Nature Foundation
CCA	Colin Christian & Associates cc, Environmental Consultant, Windhoek, Namibia
ORB	Okavango River Basin
WTC	Water Transfer Consultants, Engineering Consultants, Windhoek, Namibia
MW	Mega Watts
kV	Kilo Volts
kWh	Kilo Watt Hours
EMCON	EMCON Consulting Group, Windhoek, Namibia
WCD	World Commission on Dams
IUCN	International Union for the Conservation of Nature
TDA	Transboundary Diagnostic Assessment (for the Okavango River and Delta)
TOR	Terms of Reference
DRC	Democratic Republic of Congo

APPENDICES

Appendix A: Popa Falls Hydro Power Preliminary EIA: Key Team Members

1. INTRODUCTION

1.1 *The Hydro Power Component in the TDA*

This report forms part of the Okavango River Basin Transboundary Diagnostic Analysis Project. The overall project is funded by the Food & Agriculture Organisation (FAO). Teams of specialists are involved in each of the three basin states, Angola, Namibia and Botswana. The Namibia Nature Foundation (NNF) has the role of co-ordinating the specialist studies in Namibia.

Colin Christian & Associates cc (CCA) was contracted by NNF to write the report on Hydro Power Development in the Namibian section of the Okavango River Basin (ORB). Colin Christian was approached by NNF because he led the team that undertook the Preliminary Environmental Impact Assessment for the Popa Falls Hydro Power Project (Eco.plan 2003). This EIA was part of a Pre-Feasibility Study compiled for NamPower by Water Transfer Consultants (2003). Colin Christian had also undertaken a development plan for conservation and development of the Rundu Floodplain within the Rundu Townlands (Eco.plan 2002/3) and an EIA for the Kavango Biofuel Project (CCA 2007) proposed for most of the Namibian section of the River. These studies provide background information on the study areas.

The tasks required under the hydro power component of the TDA were: -

1. *“Reassess the status of the Popa Falls HEP proposed development;*
2. *“Estimate the overall benefit and disaggregated benefits;*
3. *“Estimate changes in the river flow regime;*
4. *“Evaluate sustainability and recommend alternatives if appropriate”.*

This study component is a desk top study only based on available information from the EIA and Feasibility Study mentioned above. An interview was also held with a representative of NamPower to help ascertain the current status of the Popa Falls HEP Project.

1.2 *The Popa Falls Hydro Power Proposal*

NamPower commissioned a Pre-Feasibility Study which was completed by Water Transfer Consultants (WTC 2003). The Preliminary EIA was completed by Eco.plan (2003). A list of key team members is provided in **Appendix A**.

The project proposal is summarized as follows: -

- A gated weir would be constructed near Divundu to provide the pressure head needed to generate power. For the preferred option this would be 9.75m in height. Note that the power that can be generated is a function of the volume of water times the distance that it falls. There are no natural drops on the Okavango River in Namibia that are high enough to generate significant power without constructing a high weir.
- There is only one section in Namibia where there is enough fall on the river to make it feasible – this is within the section between Andara and Popa Falls. The

falls themselves were ruled out as being part of a tourist attraction and affecting at least three tourist establishments.

- Three potential sites were identified, but the preferred site (Site 5) was 3,3km upstream from the Divundu Bridge. A weir 9.75m high would create an impoundment 10km long – reaching to just below Andara Mission Hospital.
- The project would be designed as a “run-of-the-river” scheme so that no water was diverted out of the river channel. Instead, hydromatrix turbines would be placed in the weir itself, alternating with sluice gates. Bulb turbines could also be used – placed in the weir.
- The weir would be operated at “full supply level” most of the time with water flowing 300mm over the top of the weir and the rest passing through the turbines and sluice gates. “Tops gates” would be used to keep the level constant at the full supply level. However, during part of the low flow season, the level would drop below the full supply level because the river discharge would not be sufficient to maintain this level.
- At an early stage the need to ensure the uninterrupted passage of sediment through the weir was identified as an environmental pre-requisite. Two options were considered to achieve this. The first option was sluicing. This involved opening all sluice gates for 4 to 6 weeks each year during the peak flow season – thus increasing flow velocities and aiming to remobilize sediment that had settled in the impoundment. No power could be generated during sluicing. The second option was to capture the sediment as it entered the head of the impoundment and pump it via a 10km pipeline to be released below the weir. This aims to ensure uninterrupted flow of sediment and avoid the “down time” for power generation.
- The sluicing option would result in a volume of the order of 20 million m³ of water being released over a few days as the weir empties, then the same volume would be held back again to refill the weir 4 to 6 weeks later. This would obviously have a major impact on the hydrograph. A year’s accumulation of sediment would also be discharged below the weir over 4 to 6 weeks. The implications for the redistribution of that sediment downstream need to be better understood.
- The sediment pumping option is far less disruptive of the natural flow of water and sediment and is therefore preferred for environmental reasons. The feasibility of achieving this has not yet been confirmed.
- The project would be able to generate approximately 20MW of power.

2. CURRENT STATUS OF THE POPA FALLS HYDRO POWER PROJECT PROPOSAL

An interview was held with Mr John Langford, a senior Engineer with NamPower, in December 2008 to ascertain the current status of the Popa Falls Hydro Power project. The following information was obtained: -

The project has been shelved at this stage. The reasons given by NamPower were: -

- The power output was very small – only 20MW. Namibia's demand in 2008 for the winter peak was approximately 538MW. Thus Popa Falls would have contributed only 3.7% of current peak demand.
- The costs of environmental management of the project would be very high.
- The hydromatrix turbines were found to be not ideal for the purpose for which they were proposed. Bulb turbines could be used as an alternative.

NamPower's representative said that the Popa Falls Hydro project could be revisited at some future date (Langford, pers comm).

Namibia's power demand is projected at a "natural" growth of approximately 4.5% but the demand from new sources such as uranium mining could result in a 50% step up in demand. The increased demand is expected to come mainly from the mining sector (ironically, mostly uranium mining), desalination of seawater, industry and domestic demand.

At present approximately half of Namibia's electricity is supplied from Ruacana Hydro Power project on the Kunene River, while most of the balance is imported from South Africa. Due to the growth in internal demand in South Africa the surplus, which they have for years distributed to neighbouring states, is likely to be reduced – based on that country's current generation capacity. Thus Namibia is looking to increase their own generation capacity.

During the preliminary EIA for the Popa Falls Hydro Power proposal, an extensive public participation programme was carried out in Namibia and Botswana. The overall public view was that the project was far too small to be of value, while the environmental impacts and environmental risks were far too high to justify the project. Opposition to the project was particularly strong in Botswana, where the economic benefits of ecotourism for that country are very high. In Namibia the affected local communities were less vocal because they were told by the local chief, at the public meeting, to support the project. More focussed public participation would be needed at grass roots level if the project proposal was to be revisited. The more knowledgeable public and scientists in Namibia and Botswana were generally opposed to the project.

A factor that will influence the viability of the project is plans for extensive irrigation schemes in Namibia and Angola. Eco.plan (2003) found that plans for irrigation in Namibia alone would require 134 million m³ / year. This amounts to 1.3% of the mean annual runoff at Mukwe of approximately 9,585 million m³ / year. This percentage becomes far more significant when the seasonality of flow and abstraction for irrigation are taken into account. The flow of the Okavango River is lowest for the three months of September through November (WTC, 2003). This is also the hottest time of the year with the highest evaporation (Mendelsohn & el

Obeid, 2004). It is also the time of year when most of the irrigation is needed for crop production.

Therefore one needs to consider the rate of abstraction for irrigation compared to the flow during this low-flow season. Eco.plan (2003) obtained the planned abstraction rates for irrigation from the Directorate of Agriculture, namely 15.45m³/s. At a time when the discharge of the river is typically as low as 120 – 150 m³/s, this abstraction amounts to 10 – 13% of the river flow. This will result in a significant reduction in power generation at the very time of year when the power plant is already running below its optimum generation capacity.

The above analysis considers irrigation only in Namibia. Figures for irrigation schemes in Angola were not available, but are expected to be much higher than Namibia's! Therefore it appears that hydro power production on the Okavango River in Namibia is incompatible with large irrigation projects for at least three months of the year.

Future water abstraction for towns and domestic use in Angola and Namibia is unknown, but Namibia may require some 20 million m³/year for Windhoek and Central Areas alone within the next two decades. Evaporation loss from the impoundment was estimated at a further 6 million m³/year. A comprehensive account of the projected water demands in Angola and Namibia would be necessary before reassessing the feasibility of the Popa Falls Hydro Power project.

Climate change is another “wild card” that may reduce the runoff of the Okavango River. A modelling study by scientists at Oxford University predicted a warming and drying trend over the region that includes the catchment of the Okavango River (BBC News / Science-Nature / African Sands ‘set for upheaval’, 30 June 2005). The study predicted that such warming and drying would lead to mobilisation of the Kalahari dunes (currently vegetated) in Angola by 2070.

2.1 Synopsis

The Popa Falls Hydro Power proposal has currently been shelved, but NamPower has not ruled out the possibility of this proposal being revisited at some future date.

Any future feasibility and environmental assessment would need to thoroughly consider at least the following: -

- Impacts of all water abstraction in Angola and Namibia on power production, particularly in the low-flow season.
- A thorough understanding of the Environmental Flow Requirements of the aquatic environment and aquatic biology would be a pre-requisite for any EIA on a dam/weir and hydro power operation.
- How would future abstraction in Angola and Namibia be “capped” so that the viability of the hydro power project was not further eroded in future years?
- The impacts of climate change on hydro power production into the future. A hydro power project is a very long term project.
- Public and scientific resistance to any dams / weirs on the Okavango River is expected to be considerable.
- A detailed cost-benefit analysis, which includes the environmental and social costs and benefits in Namibia and Botswana, would be essential to a full EIA.

- The problem of ensuring an uninterrupted flow of sediment (mainly fine sand) through the impoundment will have to be solved as a pre-requisite for the implementation of any hydro power project, dam or weir on the Okavango River. Sluicing requires a major perturbation of the natural hydrograph and sediment flows, and is very unlikely to be environmentally acceptable. In the author's opinion, supported by that of McCarthy (pers comm) and Ellery (pers comm), sluicing is unlikely to be effective.
- The distribution of costs and benefits will also need to be considered. The project will benefit only or mainly Namibia, while the environmental costs may be experienced in Namibia and Botswana. These environmental costs may translate into economic costs in both countries for certain groups of people. The loss to future generations will include important habitat in Namibia and possible ecological impacts in Botswana. A reduction in biodiversity in the impoundment area will be unavoidable – including species of fish, terrestrial plants, birds, and possibly certain mammals.

In summary, there are many obstacles to the Popa Falls hydro project. In the final analysis the very small benefits will have to be weighed up against the environmental and economic costs, and the international distribution of those benefits and costs.

3. ALTERNATIVES TO THE POPA FALLS HYDRO POWER PROJECT

3.1 *Power Generation Alternatives*

Over the past seven years or more, NamPower has investigated several alternatives for power generation.

Baynes Hydro Power Project is currently the subject of a Feasibility Study and EIA. This project is a joint venture that would supply both Namibia and Angola. It is a much bigger project than Popa Falls, and it may have much lower environmental impacts and risks because it discharges to the sea and not to an inland delta.

Walvis Bay Coal Fired Power Station is also under consideration. It has the disadvantage of being based on non-renewable resources and carbon issues. Its location at Walvis Bay may also be contentious in terms of air pollution.

Power from Slops: Thermal electric power can be generated from oil waste that is discharged from ships. They are not allowed to discharge at sea, therefore this fuel can be bought in Walvis Bay Harbour and burned to generate power.

Kudu Gas, is an option based on natural gas in the sea bed offshore from Oranjemund. It has a production potential of some 800MW for 22 years. However the gas would be expensive and the project is not considered to be able to provide electricity at competitive prices at this stage.

Orange River Hydro Power schemes: Several small hydro power projects (e.g. 100MW each) are being considered on the lower Orange River. These would be operated by independent power producers. These could be developed in the next 3 to 4 years. The lower Orange River is already highly disturbed by major dams, irrigation projects etc. in the catchment. However the Orange River mouth is a proclaimed Ramsar site.

Wind Power: Lüderitz: In the past NamPower has also investigated a wind power generation, which was found to be uneconomical – the capital costs would not be recovered during the life of the turbines. Furthermore, although Lüderitz is the windiest place in Namibia, there are periods of calms for days at a time when no power can be generated. There is no way to store large amounts of electrical energy to bridge these calm periods. Lüderitz is completely calm for 8% of the time Mendelsohn *et al* (2002). For Walvis Bay this figure is 16%.

Solar Power: Solar electricity has begun to make a significant contribution to electricity generation in other countries, such as Kenya. In the USA consumers who have solar panels installed can feed any surplus power into the national grid (e.g. while they are at work during the daytime). These contributions are credited against their consumption – a fact that helps considerably to offset the cost of solar cells.

Nuclear power generation has not been seriously considered in Namibia. Although Namibia is a major producer of uranium, it would need to be enriched overseas before being re-imported as fuel. There is a lack of local expertise in the fields of uranium enrichment or nuclear power generation.

3.2 Power Import Alternatives

Namibia has a number of new options for importing power in the near or distant future.

Livingstone / Caprivi Link: A 220kV powerline is currently under construction to link Namibia to Zambia at Livingstone. This project will take advantage of hydro power from the Zambezi River. It will provide up to 200MW to Namibia.

South Africa: Imports from South Africa via existing infrastructure are likely to continue, though not necessarily at the same rates once existing contracts have been fulfilled. If there are any major new generation plants established in South Africa, this scenario could change.

DRC / Congo River: A long term possibility exists for hydro power generation on the Congo River in the Democratic Republic of Congo. That river has vast hydro power potential and could export all over Africa. However, establishing the supply infrastructure and the political instability in that country are two significant obstacles to be overcome before that potential can be realized. If Namibia does eventually import power from DRC it will probably be as part of a bigger regional supply scheme to southern Africa.

3.3 Demand Side Management, including Solar Water Heating

Demand side management (simply using less electricity) is an issue that has not yet been taken seriously enough in Namibia. Although NamPower did implement the distribution of free power-saving light bulbs, there is still much that can be done to reduce the demand.

One of the most promising and cleanest sources of energy, is solar energy for direct water heating (without electricity). Namibia is an extremely sunny country. Average values for solar radiation over the country as a whole range from 5.4 to 6.4 kWh/m²/day. Namibia receives an annual average of 8 to 11 hours of sunshine per day (Mendelsohn *et al*, 2002).

In 2003 the author calculated the potential contribution that could be made by solar water heating. Namibia's power demand was then approximately 350MW. Approximately 50% of the country's electricity demand was from domestic homes. In an average home electric geysers account for about 40% of consumption. A simple calculation shows that 20% of Namibia's power demand could therefore have been saved if electric geysers were replaced by solar water heaters. At that time this potential saving amounted to 70MW. This is 3,5 times greater than the maximum output of the Popa Falls Hydro Power project!

If industries, schools etc also used solar heating for primary water heating, then further savings could be achieved.

In the author's opinion, if some of the money that may have been spent on developing the Popa Falls Hydro Project was instead spent on promoting and financing solar water heating, then the need for that project could probably be eliminated.

Solar water heating has some major advantages over other “alternative” energy sources: -

- It is the cleanest source of energy on the planet and the technology to capture it is also relatively clean,
- Unlike other clean sources like wind power, energy can be stored in hot water in well insulated cylinders,
- A low level of technology is required. This technology is already tried and proven.

Objections to solar water heating by the average home owner have historically been related to the cost of commercial installation (N\$12,000 – 15,000). This means that it takes several years for the savings on electricity to cover the initial outlay. This scenario is already changing as electricity prices rise in response to the supply-demand situation becoming less favourable. The luxury of cheap electricity in southern Africa is becoming a thing of the past. A number of strategies are needed to fulfil the potential of solar water heating. A few are suggested below.

- Much could be achieved by legislation. For example, it could be a requirement that new houses be fitted with solar water heaters at the time of construction. It is understood that this is already a requirement in Botswana.
- Electricity tariffs could play a role. In Windhoek, a three tier tariff is charged for water to domestic homes. The first few units per month are charged at a very low rate so that everybody can afford water for basic needs. The second and third tiers involve higher and higher rates per unit. People therefore become very careful about their water consumption. The same approach could be taken with electricity. If the thresholds were set cleverly, people with electric geysers would find it economical to convert to solar water heating.
- The Ministry of Mines and Energy initiated a cheap loans scheme for solar water heaters, but it has not enjoyed a high profile. This initiative could be further developed and more aggressively promoted.
- Any initiatives that generate an increased demand for solar water heaters are likely to generate their own momentum. Greater sales volumes and more suppliers would most likely lead to reduced prices. Job creation should provide good distribution of benefits.
- Cheaper designs could be made and manufactured locally. Even black HDPE pipes make good solar water heaters! A number of farmers in Namibia have installed their own home-made systems. Roberts and Bethune (pers comm) report that they installed their own home made system at a cost of N\$3,000 – N\$5,000. This system requires only a low level of technical expertise.

The website of the Namibian Ministry of Mines & Energy has a number of research papers on solar water heating: <http://www.mme.gov.na/energy/renewable.htm>

A report was also prepared by EMCON Consulting Group for the Electricity Control Board entitled “Demand Side Management Study for Namibia” (EMCON, November 2006). This report considers six demand side management options. These are: -

- “Launching a consumer education and awareness campaign,
- Introducing time of use electricity tariffs,
- Disseminating compact fluorescent lights,
- Replacing electric water heaters with solar water heaters,
- Expanding ripple control systems, and

- Conducting energy audits in the commercial and industrial sector.”

EMCON's report provides the findings of the investigation, detailing the cost, benefit and implementation requirements for each of the above options.

Tariff structures could also be used to encourage consumers to use electricity during non-peak demand periods. For example a cheaper rate between midnight and 05:00am could encourage some appliances to be operated during that period. For example, dishwashers and clothes washing machines can be put onto timer switches so that they operate during that off-peak period.

Energy saving architecture is another avenue that has not yet been taken seriously in Namibia. Offices and factories use a lot of electricity for heating and cooling interiors in this climate of temperature extremes. Improved building design can contribute significantly to reducing electricity consumption. This should become a requirement in terms of building regulations.

3.4 Synopsis

- There are a number of power generation alternatives, including a large hydro power prospect on the Kunene River at Baynes – which is currently the subject of an EIA, and smaller potential hydro power projects on the Orange River. Other options are also available, albeit at a higher unit cost for electricity.
- Imports of hydro power from the Zambezi via the new Caprivi powerline will make a significant contribution to Namibia.
- Demand side management has a substantial contribution to make in partially offsetting the growth in demand. Namibia has given some attention to demand side management, but has not considered all the options in this regard, and implementation is still in its infancy.
- Green architecture and improved building regulations has a major role to play in demand side management. This area has received no serious attention by the Government of Namibia to date.
- One of the strategies that offers the greatest promise in terms of demand side management is solar water heating. This alone could save Namibia an estimated 70MW at current consumption rates for water heating. Solar water heating is arguably one of the cleanest sources of energy on Earth.

4. ESTIMATED BENEFITS OF THE POPA FALLS HYDRO POWER PROJECT

The idea of a hydro power plant near Popa Falls was first considered in a report by DWA (August 1969). At that stage it was motivated primarily to support the power demand to pump water for irrigation projects along the Kavango River in Namibia. This demand was estimated then at 15MW, possibly increasing ultimately to 35MW. Secondary motivations were demand from pumping water for domestic and industrial use.

In 2003 NamPower motivated for the Popa Falls Hydro Power project to provide the following benefits: -

- To feed an additional 20MW into the Namibian supply grid, especially for use in the Kavango Region,
- To facilitate development in the Kavango Region,
- To stabilize the Namibian grid, which has long transmission lines,
- Although not stated as a motivation for the project, the power could also be used for the proposed irrigation schemes along the Okavango River in Namibia.

WTC (2003) found that the option that was the most financially and economically viable (Site 5). This would generate up to 23MW of power.

The project cost for the most viable option was estimated by WTC (2003) in the order of US\$ 45 million.

No updates have been done by NamPower on the costs of the development because they decided it was not viable compared to the alternative of constructing a transmission line to bring power from Livingstone – an option that will supply far more power to Namibia than the mere 20MW that Popa Falls could generate. The transmission line from Livingstone is currently under construction.

The financial benefits of the project consist of the revenues derived from the sale of electricity, and the avoided transmission costs for alternatives to get power to the north-east of Namibia. It was found that the project was financially viable, and would still remain financially viable under the following scenarios: -

- if the capital costs rose by up to 10%, or
- if the electricity price in the region drops to 90% of the 2003 price, or
- if power generation decreased by 10%.

The benefits of the project were compared with other supply options and were found to be comparable with the Kudu Gas option, and slightly cheaper than imports from South Africa or Zambia. This applied after taking into account factors relating to the costs of transmission from those three sources.

The project would provide very little direct employment after the construction stage. Some skilled labour would be required to operate the plant but very little local labour would be employed in the long term.

To the extent that the project stimulated the local economy in north-west Kavango and western Caprivi, some benefits would reach the local people. However, the EIA (Eco.plan 2003) found that the area lacks some important ingredients for development – apart from power. It is too far from markets, and soils are very poor for agricultural use. Limited potential for exploitation of timber from natural forests exists. The implication was that provision of power to north west Kavango would not be enough, on its own, to stimulate economic growth in the area. Probably the greatest development potential lies in the tourist sector, but this does not depend on being supplied with electricity from the national grid.

Overall the benefits of the Popa Falls Hydro Power project to Namibia are small, and the benefits to the local people are insignificant. As far as the benefits to the local people are concerned, the same benefits can be realized by importing power from Livingstone.

The environmental costs of the Popa Falls Hydro Power Project may very well outweigh the very modest benefits of the project. Therefore, a comprehensive cost-benefit analysis that includes all environmental costs (especially environmental costs to local people and people in Botswana) would be essential if this project is to be revisited. This would need to consider not only the overall costs and benefits, but also the distribution of costs and benefits with respect to present and future generations.

5. WORLD COMMISSION ON LARGE DAMS

World Commission on Dams (WCD) deserves an introduction here because it is highly relevant to the Popa Falls Hydro Power project, or indeed any other dam, weir or impoundment that may be proposed in future on the Okavango River.

For a few decades in the mid 1900's there was a great deal of enthusiasm around the world for large dams to be constructed. It was believed that dams were a key to releasing a lot of development potential, through irrigation, hydro power, water supply for industry etc. Then, following a number of serious environmental consequences and many dams falling short of their promised benefits, a more sober picture began to emerge which suggested that the benefits of large dams were overrated, and the negative consequences were often far greater than was predicted in the planning stages.

The World Commission on Dams (WCD) was established in 1997 with support from the World Bank and the International Union for the Conservation of Nature (IUCN). The Commission was chaired by Dr Kader Asmal, then Minister of Water Affairs in South Africa. Its objective was to review the development effectiveness of large dams around the world. It considered alternatives for water resources and energy development, and sought to develop internationally acceptable criteria and guidelines for the planning, design, appraisal, construction, operation, monitoring and decommissioning of dams. The WCD produced a set of research reports based on case studies from many different dams around the world.

Based on their case studies, the WCD defined "Large Dams" as follows: -

- Having a height of 15m or more from the foundation, or
- A height of 5-15m **and** a reservoir volume of more than 3 million m³.

The proposed weir near Popa Falls is within the latter category – having a wall height of 9m and a capacity of 16 – 24 million m³.

Many of the findings of the WCD are relevant to Popa Falls Hydro Power proposal (Eco.plan 2003). For example, the impacts included: -

- Loss of forest habitat that was unique on the Okavango River in Namibia,
- Loss of wildlife, birds, and plant species associated with those threatened habitats,
- Loss of aquatic biodiversity in the impoundment area as a result of the change in habitat from shallow, fast flowing water with rapids and pools, to deep calmer water with altered water quality,
- Potential loss of aquatic diversity in downstream floodplains, wetlands, and river channels.
- The materials and services provided to people by downstream floodplains and wetlands may also be threatened.
- Impacts on water quality, water flow, perturbation of the hydrograph, species composition, and migration of fish.
- Loss of some of the most fertile agricultural soils, in the impoundment area, which are used for subsistence production of mahangu.

The WCD found that ecological impacts were usually more negative than positive, and have led, in many cases, to significant and irreversible losses of species and whole ecosystems.

It was also found that mitigation of many of the negative impacts could not be mitigated, or mitigation measures that were implemented enjoyed little success. For example: -

- There is no mitigation possible for loss of habitats, such as riverine forests, rocky rapids and shallow pools.
- Fish bypasses to facilitate migration have had little success, thus affecting breeding success.

The WCD also found many adverse social impacts, including: -

- People living downstream have lost key resources such as fish, which they depend on for good nutrition.
- Adverse health impacts were common, e.g. bilharzia, river blindness¹ and malaria.
- Compensation to displaced people was often inadequate as people were deprived of lifestyle occupations such as fishing, farming, crafts based on reeds etc. No effective social programmes were developed to replace these lifestyle occupations.
- The poor, disadvantaged groups, and future generations often bear a disproportionate share of the social and environmental costs of large dams without gaining a commensurate share of the benefits.
- The social and environmental costs of large dams were often not weighed up against the benefits. This gave a false impression of the net benefits of the projects.

In summary, the WCD found that: -

- The benefits of large dams were frequently overestimated at the planning stage,
- The environmental impacts of dams were usually underestimated and many of the impacts were not anticipated, and
- Measures to mitigate adverse environmental and social impacts were seldom adequate.

The reports of the Commission are extremely valuable in the context of the Okavango River because: -

- They are based on case studies of actual dams around the world over many decades,
- They identify the frequent failure of dams to meet their promised economic objectives,
- They highlight common environmental and social problems arising from dams, which often outweigh the benefits, and

¹ *River Blindness has not yet become a problem in Namibia but it has been elsewhere in Africa.*

- They expose the inequities associated in the distribution of costs and benefits – whereby those who are already marginalized in society are often the losers.

Therefore, the lessons provided by this valuable research project need to be carefully considered in relation to any and all proposals to construct weirs or dams on the Okavango River.

6. ENVIRONMENTAL IMPACTS RELATED TO CHANGES IN THE FLOW REGIME

The Preliminary Environmental Assessment for the Popa Falls Hydro Power Project (Eco.plan, 2003) researched a number of aspects and issues that are included in the TOR for the TDA. A list of key team members is provided in Appendix A. This Chapter 6 deals with issues relating to river flow and sediment flow, both of which have consequences for ecological sustainability. More general environmental impacts are dealt with in Chapter 7, below.

6.1 *Changes in River Flow*

Although the proposed project was a “run-of-the-river” scheme, meaning that no water would be diverted from the river, it would nevertheless have impacts on the hydrograph as explained in this section.

Evaporation

Evaporation at 1,200mm/year would result in a loss of an estimated 6 million m³/year due to the increased surface area of water in the impoundment that is exposed to the air. This amounts to 0.06% of the mean annual runoff.

Filling of the weir

The impoundment created by a 9.75m weir would have a volume of approximately 24,4 million m³. This volume represents approximately 0.25% of the mean annual discharge of the river at Mukwe (9,585 million m³/year)

Allowing for the water already in the channel at the start of filling, it is assumed that something of the order of 20 million m³ would accumulate during filling. Eco.plan (2003) calculated the filling time for various scenarios. If the weir was filled during the high flow season and only 10% of the flow was held back with the rest passing through the sluice gates, then it would take less than 15 days to fill the impoundment. This initial perturbation of the hydrograph could most likely be managed such that it is within the natural variability of the river flow.

Normal operation

Once filled, the weir would be operated at full supply level (with a flow of 300mm over the spillway) for most of the year. As the low flow season approaches (Transitional Season 2) the sluices would be closed one by one to maintain the full supply level. This will result in a slight lag in the hydrograph if the inflow to the impoundment is compared with the outflow through the weir.

NamPower did not propose to use the hydro power plant for peaking power. Therefore the two “high tides” a day that are typical downstream of a hydro power station, such as Ruacana, would not occur. The ecological implications will be explained in Chapter 7, below.

Sluicing of sediment

One of the methods proposed to get sediment (fine sand) through the weir is an annual sluicing process. This requires that all the gates be fully opened for 4 to 6 weeks a year during the flood season. Thus the impoundment is emptied and flow velocities through the impoundment are maximized. To maximise sediment removal this must be done during the peak flow period each year, but that is impossible to predict.

Sluicing takes 4 – 6 weeks. Because no power can be generated during that period, NamPower would want to minimize the “down time”. If it is assumed that the weir is emptied in 7 days, then the water level behind a 9m weir has to be dropped to a natural level of 3m in seven days. A drop of 6m in 7 days is about 85cm/day, which is of the order of 10 times faster than the normal fluctuation of the level beneath the Divundu Bridge. The natural rate of fluctuation there is less than 7cm/day, and normally only 1 or 2cm / day.

The rapid draw-down of water level would increase the erosion of sandy banks and sand islands, because water that had infiltrated the banks and sand islands would flow out of that material more rapidly than can ever occur under natural flow conditions.

Refilling the impoundment would involve a similar rate of change in reverse, which may coincide with Transition Season 2 – the falling hydrograph.

There should be considerable concern over the ecological implications of such enormous perturbations in the hydrograph.

Furthermore, the effectiveness of sluicing is doubted by experts in sediment processes in the Okavango Delta and River. McCarthy (pers comm) and Ellery (pers comm) have argued strongly that sluicing would not be effective in getting the sediment through the weir. Based on experience in the Delta, it is argued that sediment, which is mostly fine sand, would be deposited at the head of the impoundment, i.e. 10km upstream of the weir. Because this sand moves as bedload and not in suspension, it would not be possible to mobilize this sand through the 10km length of the impoundment by sluicing.

The next question is, if the sand was successfully removed by sluicing, how would it then be distributed downstream?

Sluicing would also mobilize clay and organic particles (such as leaf litter and algae) that had settled and accumulated for 10½ to 11 months in the impoundment. This would certainly have significant implications for water quality during sluicing.

For all the above reasons, sluicing is a doubtful option. Not only is its effectiveness questionable, but its impacts would be severe because sluicing cannot be carried out within the natural variation of river flow!

Pumping of sediment

The only solution to the problem of sediment transport that may prove environmentally acceptable would be pumping. This would require the capture of approximately 70,000 m³/year (116,000 tons) as it enters the impoundment and pumping it through 10km of pipeline at low gradient to be discharged below the weir. Such an operation would need to be based on tried and proven technology.

6.2 Sediment Transport

The load of the Okavango River is almost entirely fine quartzitic sand. This is because almost the entire catchment is covered in Kalahari sand – aeolian deposits from a much drier paleo-climate (McCarthy and Ellery, 1998). This sand is gradually eroded by water in the catchment of the River. Because it was originally sorted by wind, the particle size is in a very narrow band of 0.25 – 0.4mm. This sand moves as bedload, not in suspension. Concentrations of silt and clay sized particles, which would move in suspension are at such low concentrations that they are extremely difficult to measure. These facts, combined with very low nutrient status, explain why the water is very clear in the River, even in the height of the flood season.

A large body of research has been carried out at WITS University since 1986 (Okavango Research Group, 1986 – 1998). McCarthy *et al* (1992) and McCarthy *et al* (1997) provide useful explanations of the importance of sediment transport for the Okavango Delta, and the mechanisms of sediment transport. McCarthy (July 2003) compiled an updated report for the Popa Falls EIA by Eco.plan (2003).

McCarthy *et al* (1991) and McCarthy *et al* (1992) established a relationship between flow velocity and bedload discharge for various sites in the Okavango Delta and for a range of flow velocities from 0.27 to 0.74 m/s. The later of those two papers defines this relationship by the equation: -

$$Q = 0.154 U^{3.4}$$

where Q is bedload transport in kg/m/s and U is average flow velocity in m/s.

McCarthy (June 2003) lead a team that measured sediment transport near Divundu for the Popa Falls EIA. This study confirmed that the above relationship held true for the Divundu site, where flow velocities were found to be in the same range.

Based on 30-year records of monthly flow velocities for Divundu from Water Affairs, Namibia, it was possible to calculate the average monthly and annual bedload discharge. McCarthy found this to be approximately 117,000 tonnes or 70,000 m³/year.

This was less than, but comparable with the results of studies in the Delta which calculated a discharge of sand entering the Delta of 170,000 tonnes or 100,000 m³/year (McCarthy and Ellery, 1998). In that study, the calculations were based on the wetter years of the 1970's whereas McCarthy (June 2003) used 30 year records which included a number of dry periods.

There is no perfect method for measuring bedload transport, but the Helly-Smith bedload sampler is one method that produces repeatable results. However, questions have been raised about the calibration of this method (Yuqian, 1989). Therefore an independent method was sought to verify McCarthy's results.

A team from the Marine GeoScience Unit of the Council for Geoscience undertook an independent survey at the same time and site as McCarthy using Side-scan Sonar and Bathymetry in April 2003 (Coles, May 2003). This method used high resolution bathymetry and highly accurate differential GPS techniques, which were able to measure the depth of the river bed to an accuracy of 2cm over a representative section of the river channel. The selected section of the river channel was scanned 3 times over a 28 hour period. Sophisticated computer techniques were then applied to measure the advancement of the dunes on the river bed during that period. The results were lower than those of McCarthy but in the same order of magnitude (McCarthy 197m³/day versus Coles 113m³/day).

The bathymetry technique was found to have some drawbacks because it can only be applied to that section of the channel where there are clear dune forms. This is normally in the thalweg, where the fastest flow velocities are found. Where the bed is flat, this method will not measure movement, even though movement is known to occur.

Failure to ensure the ongoing transport of the sediment through the weir impoundment would have the following implications (Eco.plan, 2003): -

- Potential erosion of the riverbed downstream for 10½ to 11 months of the year, including likely removal of the sand banks where African Skimmers nest downstream from Popa Falls.
- Scouring / deepening of the channel bed would reduce the overflow into the floodplains because the channels would become more efficient at transporting water. This would have further ecological impacts.
- If no intervention was applied, sediment would start to accumulate from the head of the impoundment, 10km upstream from the weir. Because flow velocities would be very low in the impoundment (due to its wide cross-sectional area) bedload transport would be very limited. For more than 200 years, sediment transport through the weir would be arrested. Ultimately as the impoundment filled with sand and the sand began to approach the weir, an equilibrium would be reached in which the sand would begin to pass through the weir at roughly the same rate as it entered the impoundment. The impact downstream would be to prevent channel failure for at least 200 years. Studies of sedimentation in the Delta have led to the understanding that it is periodic failure of large distributary channels in the Delta, which keep the Delta in a state of constant change and system renewal. This prevents salinisation of the swamps, and maintains a high diversity of ecosystems and species in the Delta. The rationale for these conclusions is further explained in the next chapter.

7. OTHER ENVIRONMENTAL IMPACTS & SUSTAINABILITY ISSUES IN THE IMPOUNDMENT AREA & DOWNSTREAM

This Chapter summarises the findings of the Preliminary EIA for the Popa Falls Hydro Power Project by Eco.plan (2003) which was written by the author of this report. The summary below cannot adequately reflect the complexities of the subject, and the reader is therefore referred to the original EIA for further detail.

That report assessed each potential impact in terms of the following criteria: -

- The nature of the impact,
- The geographical extent of the impact,
- The duration – short, medium, long term or permanent,
- The intensity (or magnitude) of the impact – where possible at the pre-feasibility stage,
- The probability of the impact actually occurring,
- The level of confidence in the assessment (an indication of where further research was required if the impact could be significant), and
- The significance of the impact for a decision about the environmental acceptability of the project.

For convenience the impacts are divided into bio-physical and socio-economic impacts, but in fact these two are inseparable. For example, any adverse impact on fish would result in nutritional deprivation for many people who rely on fish as an important source of protein in the local subsistence economy.

7.1 *Bio-physical Impacts*

- The impoundment would **inundate** some 4,0 to 5,3 km² of land that was previously dry land. This includes some 1,36 km² or 30% of the **islands** (by area) between the weir and the Angolan border. Much of this land is covered by **riverine woodland**, which would be destroyed. The Tree Atlas of Namibia lists the “Popa Falls / Andara area” as one of the four highest diversity areas for trees in the country (Curtis & Mannheimer, 2005).
- **Rocky rapids, pools and riffles** with fast flowing, well oxygenated water would be replaced by deep, still water. This will result in the loss of certain specialised species of fish. Rocky habitats are scarce on the Namibian section of the Okavango River.
- **Shallow water habitats** for certain species of fish, amphibians and mammals would be lost within the impoundment area.
- **Breeding sites** for Rock pratincoles on rocky rapids would be lost within the impoundment area. Rare and specialised birds such as Pels fishing owl and Western banded snake eagle are likely to be displaced from the impoundment area due to the loss of forest habitat adjacent to water.

- **Water quality** in the impoundment would be affected in a number of ways – increased temperature, and changes in water chemistry as organic sediments accumulate and decompose in the deeper water with lower oxygen content.
- A small reduction in the discharge would occur due to increased **evaporation** and **seepage**. The increase in evaporative loss alone was estimated at 0.50% to 0.66% of the mean annual runoff. The mean annual runoff at Mukwe is 9,585 million m³/year (WTC, 2003). Seepage into the surrounding Kalahari sand would also increase under pressure from the impounded water, but this has not been estimated.
- The risk of **alien aquatic weed infestation** may increase.
- In the absence of effective intervention, **sediment** would accumulate in the impoundment. If systems to move sediment through the impoundment proved to be ineffective, the consequence would be **accumulation of fine sand** (mainly) and some of the fine clays and organic material in the impoundment. It could take 150 to 200 years to fill the impoundment with sediment. This is not a problem for power production as the weir is not required for storage – only to provide sufficient head.
- However, until the impoundment was full of sand, the river and delta would be deprived of this sediment. The result downstream would be **scouring of the river bed and sandy banks**. The extent of the impact would need to be modelled, but it is expected that scouring of the river bed would extend well into the Delta.
- The secondary impacts of deeper and (hydraulically) more efficient channels are expected to include: -
 - **Less overbank flooding** in the Mahango area of Namibia, reduced area of inundation on the floodplains, with severe implications for fish breeding, mammals, birds, and amphibians. Many species of birds occur on these wetlands, several of which are Red Data Species, including Slaty egret, Saddle billed stork, African marsh harrier, Wattled crane (critically endangered and globally threatened), Red winged pratincole, Coppery tailed coucal, Greater swamp warbler.
 - **Sandbanks** in Namibia, which are used by breeding African skimmers, would not be formed,
 - Within the Panhandle of the Delta, **sediment deprivation could prevent channel switching for hundreds of years**. The implications for the Delta will be explained in Chapter 8. In short they include issues such as salinisation of areas, prevention of ecosystem renewal, and prevention of the recycling of the limited nutrients in the Delta ecosystems.
- **Fish migrations** would be disrupted by a 9m high weir. Fish ladders are proposed, but these have not always proved to be effective (WCD, 2000).

Two options to move sediment through the impoundment were explained in Section 6.1 above. These were sluicing or sediment pumping.

Sluicing would have a number of disadvantages

- Because the fine sand is transported as bedload and not in suspension, it would be deposited at the inflow to the impoundment. It is very doubtful that it can be removed by sluicing (Eco.plan, 2003 & McCarthy, pers comm).
- A major perturbation of the **hydrograph** every year if the **sluicing** option is practised (refer to Chapter 6 above).
- Emptying of the impoundment annually would result in rapid **change in water level** - of the order of 10 times greater than the natural change. The result would be erosion of the banks and sandy islands in the impoundment, and most likely further loss of riverine woodland.
- De Moor *et al* (2000) studied the **macroinvertebrates** on the Cunene River between Ruacana and the river mouth. They found that the impacts of the Ruacana hydro power plant on invertebrates were severe because the power station results in two “high tides” a day going downstream as the plant responds to two peaks a day in the power demand curve. Popa Falls would **not** be operated for peaking power so this daily impact on macroinvertebrates would not arise. However, if sluicing was practised a similar effect would be experienced every year during emptying and refilling the impoundment – which **would affect levels much faster than anything that happens in the natural hydrograph**.
- Sediment that had accumulated for 10½ to 11 months of the year would be released in 4 – 6 weeks. This would result in: -
 - major disturbance to **benthic organisms** that are important in the food chain,
 - **Loss of sandbanks** for breeding African skimmers during the low flow season,
 - **Scouring of the channels downstream**, with less overbank flooding during the start of the flood season (transition 1 stage).
- During sluicing, most of the years’ supply of **sediment (fine sand) would be dumped** just below the weir. How this sediment would be redistributed requires to be modelled.
- The clay particles and organic matter that had been accumulated for 10½ to 11 months, would be released during 4 – 6 weeks. Although small in total volume, the concentration would be greatly increased. This would impact significantly on **water quality** during sluicing.
- All the above-mentioned impacts of sluicing may have significant impacts on **biological processes**, such as fish breeding. It may not be possible to predict all these impacts.

The alternative to sluicing would be ongoing pumping of sediment through the impoundment

- This would have no impact on the hydrograph, and most of the negative impacts of sluicing would be avoided.
- However, the **effectiveness** of sediment capture and pumping has not yet been established.

7.2 *Socio-economic Impacts*

The people living along the river in Namibia and the Panhandle in Botswana depend on the river in many ways. There live subsistence lifestyles making use of the relatively more fertile soils close to the river, wood, fish, reeds and medicinal plants. Their lifestyle and resources will be threatened to some extent by the impoundment.

- Compensation is proposed, but **compensation is seldom adequate** for loss of lifestyle occupations (WCD, 2000).
- **Diseases** such as bilharzias and malaria are likely to increase because of disrupted ecosystems, and slow moving water.
- The area may lose some of its appeal for **tourism**. The project would impact strongly on the **sense of place** as a natural environment with people living traditional lifestyles, relatively in harmony with that environment.
- A number of **tourist establishments** in the area may be thus adversely affected – lodges, a Namibia Wild Life Resort and a community campsite.
- Impacts on **fishing** may well extend downstream.

A comprehensive socio-economic assessment is needed in Namibia and Botswana in order to weigh up the costs to local communities against the modest benefits of the project to Namibia.

7.3 *Cumulative & Synergistic Impacts*

The Popa Falls Hydro Power Project must be viewed also in relation to other impacts on the river. A number of cumulative and synergistic impacts will arise from: -

- **Water abstraction** in Angola and Namibia for irrigation (mainly), domestic and industrial use, and
- **Increased nutrient loading** from agriculture, and urban development upstream.

The impacts of these activities are likely to aggravate the impacts of the hydro power project.

8. ECOLOGICAL IMPORTANCE OF SEDIMENT ACCUMULATION IN THE DELTA

8.1 Introduction

Chapter 8 was almost relegated to an appendix for the following reason. It deals with aspects in Botswana, which geographically lies beyond the author's Terms of Reference. It therefore, reluctantly, encroaches on the domain of the TDA team in Botswana. The decision to leave this chapter in this report was taken because it is so integral to an understanding of the impacts of the Popa Falls Hydro Power Project in particular, and any other possible impoundments on the River, in relation to sedimentation processes.

This chapter is a summary of a report by McCarthy (July 2003), prepared for the Popa Falls Hydro Power EIA. It briefly explains the role of sediment in the ecological functioning of the Delta as a background to understanding the impacts of sediment impoundment upstream near Divundu.

The Okavango discharges into an inland delta in Botswana. Only about 2% of the inflow plus rain flows out as surface water via the Boteti River at Maun. The other 98% evaporates – the annual evaporation being about 4 times the annual rainfall. There is no known outflow of groundwater beneath the Delta.

Virtually the entire region, both catchment and delta, is underlain by Kalahari sand. The implications of this very unusual situation are: -

- Okavango River water carries very low concentrations of nutrients because it originates in quartzitic sand,
- The sediment load is comprised almost entirely of fine sand of aeolian origin, which has been reworked by water. There very little silt, mud or clay,
- The concentration of dissolved load is extremely low,
- The Delta wetland has developed around these unusual conditions. Despite being a closed system with high evaporation losses, saline water is rare in the Delta. The Delta exhibits immense habitat and biological diversity. Sediment transport plays a key role in maintaining this diversity and reducing the impact of high evaporation loss.

8.2 Nature of the Sediment

There are three categories of sediment transport in the Delta.

Fine sand

The fine sand that comprises most of the load moves as bedload transport. The grain size is typically 0.25 – 0.4mm with an average of 0.35mm. This sand moves along the bed of the river as ripples and dunes. The volumes of transport were estimated at 170,000 tonnes or 100,000 m³/year (McCarthy and Ellery, 1998). This was later revised, based on longer term flow data records, to 116,000 tonnes or 70,000 m³/year (McCarthy, 2003).

Suspended load

The suspended load consists of fine silt, clay and organic material, which is fine enough to be held in suspension at the typical flow velocities encountered in the river channel. The concentration of this material is only about 8 mg/litre. The total amount of suspended material carried into Botswana each year is estimated at 39,000 tonnes (McCarthy and Ellery 1998). A little of this does settle along the river margins and floodplains in situations where the flow velocities drop to very low levels. (Much of it can be expected to settle in any impoundment such as that created by a weir near Divundu.)

Solutes

The concentration of dissolved solids in Okavango River water is very low, about 40 mg/litre. It has been estimated that about 380,000 tonnes of solutes reach the Delta every year (McCarthy and Ellery, 1998). Of this about 24,000 tonnes leaves the Delta as surface flow and the remainder accumulates in the Delta. This is made up of silica, calcium carbonate, magnesium carbonate, sodium bicarbonate, and potassium bicarbonate.

8.3 Nature of the Okavango Delta

The Okavango Delta lies in a shallow depression formed by rifting. Here sediment deposition has formed an alluvial fan covering some 40,000 km², of which the wetlands occupy a very much smaller area. The alluvial fan is remarkably flat, with relief seldom exceeding 2 metres (Gumbrecht *et al.*, 2001).

After entering Botswana at Mohembo, the River meanders down the “panhandle” and then divides into a number of channels which distribute the water across the alluvial fan. Channel banks are generally made of aquatic plants such as papyrus, growing on a substrate of peat, and not earth. Therefore the channels leak water continually into the surrounding wetlands. This leakage sustains the permanent wetlands in the panhandle and upper fan.

The annual flood typically peaks at Mohembo in April. As the flood rises, more water leaks and the wetlands extend up to 12,000 km². The Delta is so flat that the flood only peaks at Maun in July or August, 250km downstream. Average water depth in the permanent wetlands is about 1,5m, while in the seasonal wetlands it averages only about 30cm. On the floodplains of the fan about 80 to 90% of the water infiltrates the ground, temporarily, and replenishes a near-surface aquifer (Dincer *et al.*, 1976 and Ramberg *et al.*, 2003). The low topographic relief and shallow depth of water results in many islands, particularly in the seasonal wetlands. Then the flood starts to recede once again as surface water evaporates.

8.4 Sediment Dispersal and Deposition, and its Importance in Ecosystem Functioning

Since there is little outflow from the Delta, all of the particulate sediment and most of the solute load is deposited in the Delta.

Solute load

The solute load accumulates in the permanent and especially the seasonal wetlands. After thousands of years of accumulation of salts due to high evaporation and negligible outflow, one would expect to find many saline pans. However, these are rare in the Delta.

The seasonal flood raises the groundwater table beneath the floodplains and islands. The bulk of the seasonal flood is stored temporarily in this way. In the months that follow, this water is lost by evaporation and transpiration by plants in the wetlands and islands, but the dissolved ions remain and their concentration in groundwater steadily increases. At the same time, the water table falls. Trees on the islands are powerful “transpirative pumps” and they lower the water table beneath islands compared to that beneath the surrounding flood plains – so that there is a net flow of groundwater towards the islands.

As the salinity of groundwater rises saturation of dissolved substances is reached. First silica and then calcite are precipitated in the soil. This precipitation causes expansion of the soil and hence island growth. As the salinity rises to toxic levels, plants die. The island interiors are therefore frequently devoid of vegetation. Numerical modeling indicates that the groundwater beneath the interior of an island would become salinised in about 100 to 200 years.

The groundwater that is increasing in salinity becomes denser and moves downwards, by density-driven flow, to reach deep saline groundwater which underlies the fresh, near surface groundwater. Despite this trend, the barren interiors of islands have been observed to expand over time. Eventually the island becomes completely salinized and all the trees die. However, this situation is rare – a fact that requires further explanation. The key to that situation lies with the deposition of the bulk of the River’s load, the fine sand. But first, a brief account of the suspended load.

Suspended load

Silt, clay and organic material are a very minor component of the total sediment load. Suspended sediment is transported mainly into the permanent wetlands, where it accumulates along with organic material. Ultimately it forms a component of the peat that underlies the aquatic vegetation. The ecological importance of this material will become apparent later, below.

Bedload

The fine sand is transported along the bed of channels in the Delta. Because the banks are confined by vegetation and not earth, they leak continually and become narrower downstream. Their ability to transport sediment therefore declines and bedload accumulates on the channel beds, causing shallowing of the channels.

Meantime, vegetation growth is normally limited by the low nutrient status of the water in the swamps, especially in the back-swamps. Vegetation lining the channels, however has an advantage as it strips nutrients from the inflowing water. Thus the accumulation of sand on the channel beds is accompanied by upward growth of the flanking vegetation, so that channel depth remains unchanged. Eventually, the entire channel and its flanking vegetation is elevated above the adjacent back-swamps. Down-stream channel gradient declines as channels aggrade, and plants begin to encroach the channel. This culminates in runaway aggradation and the channel fails. Water diverts elsewhere to form new channels, usually along hippo trails.

When a major channel fails, it can result in radical shift in the distribution of water in the Delta. Such a change occurred in the late 1800's when the Thaoge distributary caused a shift in water distribution from the western to the eastern side of the Delta.

When a former wetland is deprived of water, a new sequence of changes begins. Wetlands dry out, the peat catches fire (e.g. due to lightning strikes) and slowly burns down. As the peat burns it releases accumulated nutrients, silt and clays – all of which are in short supply in the Delta, but are essential for terrestrial plants. The soils resulting from the burning of peat are therefore very fertile, producing nutritious grasslands. Areas where peat has recently burned attract large numbers of game. Over time, the nutrients are gradually dissipated, the clays become mixed into the sandy substrate, and the nutritional quality of the grasslands declines.

Channel aggradation and failure is an extremely important process in ecosystem functioning within the Delta, because it results in constant change in water distribution. The vegetation communities are constantly being disturbed, and thus can never achieve climax status. It is this constant change which is responsible for the immense biological diversity of the Okavango Delta.

Channel failure also has another important consequence for toxic salt accumulations in islands. The life of a major distributary channel is about 100 – 150 years, of the same order as the time required to salinize islands. When a major channel fails, the islands that are deprived of water undergo renewal. The water table in the vicinity drops. Rain flushes sodium bicarbonate from the soils to deeper levels, and the toxicity is removed. The precipitated silica and calcite remain however, so the islands retain their form. Through this process, channel failure leads to the renewal of areas affected by toxic salt accumulation.

In the Panhandle region of the Delta, bedload sedimentation also plays an important role. Here the predominant sedimentation process involves sand rather than dissolved salts. The channels here are constantly meandering across the width of the panhandle. Here channel switching is probably very rapid, which may account for the fact that salt accumulation does not occur on the islands in the Panhandle.

Overall, the Delta is a highly complex and well co-ordinated system. Feedback mechanisms act to minimize the potential negative impacts of the high water deficit and to maximize the utilization of limited nutrients that are available. In all of this, bedload transport of sediment plays a pivotal role.

Therefore any impoundment that traps significant volumes of sediment will have significant negative impacts for the Okavango Delta.

9. CONCLUSION

The Popa Falls Hydro Power project has been shelved by its proponent, NamPower at the present time.

Despite the pressing need for power generation in Namibia, there are far more promising options for power generation in the country, including hydro power from the Kunene and Orange Rivers. The import of power from Livingstone via the new powerline through the Caprivi will make a significant contribution to Namibia's power needs. That project is already under construction and will make available ten times more power than the Popa Falls project.

Furthermore, demand side management has the potential to save many times more electricity than Popa Falls project could generate. Implementation of proposed initiatives needs to be speeded up (especially solar water heating) and more initiatives are also needed (e.g. green architecture / environmental building design regulations).

The demand for water abstraction from the Okavango River in Angola and Namibia is growing rapidly – especially for irrigation, but also for domestic and urban use. These demands will erode the future viability of any hydro power project on this river in Namibia.

The project would result in significant adverse ecological impacts in the impoundment area as a result of habitat destruction. This includes loss of diverse riverine woodlands, loss of rocky rapids that support specialist fish species, and local loss of specialised bird species. These impacts cannot be mitigated. The affected habitats are also very scarce in Namibia.

The impacts downstream need to be better understood but could be significant, both in relation to sediment and aquatic ecology.

For all the above reasons, a hydro power plant on the Okavango River in Namibia is a poor option.

Moreover, the costs and benefits, and the distribution of costs and benefits, need to be carefully weighed up – including the environmental and social costs in Namibia and Botswana.

The ecological issues relating to sediment transport are probably as important as any changes in the hydrological regime of the River. Therefore, further modelling of sediment issues is needed – based on an understanding of the fact that almost the entire load of the river is transported as bedload (not in suspension).

Any future proposals for dams or weirs on the Okavango River need to be approached with great circumspection.

Report by: -

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Appendix A:

Popa Falls Hydro Power Preliminary EIA:

Key Team Members

Person	Designation & Company	Role on the EIA Team
Mr Colin Christian	Senior Environmental Scientist and Manager Eco.Plan, Windhoek.	Project Leader, Senior Environmental Scientist, EIA Report Writer
Ms Bryony Walmsley	Managing Director, Eco.plan, Johannesburg	Projector Director, Internal Reviewer
Mr David Parry	Director, Ecosurv, Gaborone	Public Participation in Botswana
Dr John Kinahan	Director, Quaternary Research Services, Windhoek	Specialist Archaeologist
Mr Chris Hines	Consulting Botanist and Ecologist, Windhoek	Specialist Botanist and Ornithologist
Mr Mike Griffin	Zoologist, Ministry of Environment & Tourism, Windhoek	Specialist Zoologist
Ms Shirley Bethune	Consulting Limnologist	Specialist Limnologist
Prof. Terence McCarthy	Professor Geology, WITS University	Specialist Sedimentologist on study of sediment transport
Mr Sven Coles	Head of Marine GeoScience Unit, Council for Geoscience, Stellenbosch.	Specialist in high resolution bathymetry and side-scan sonar study of sediment transport

External Reviewers

Dr Peter Tarr Windhoek	Southern African Institute fro Environmental Assessment,
Dr Peter Ashton	CSIR, Pretoria

The Okavango River Basin Transboundary Diagnostic Analysis Technical Reports

In 1994, the three riparian countries of the Okavango River Basin – Angola, Botswana and Namibia – agreed to plan for collaborative management of the natural resources of the Okavango, forming the Permanent Okavango River Basin Water Commission (OKACOM). In 2003, with funding from the Global Environment Facility, OKACOM launched the Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO) Project to coordinate development and to anticipate and address threats to the river and the associated communities and environment. Implemented by the United Nations Development Program and executed by the United Nations Food and Agriculture Organization, the project produced the Transboundary

Diagnostic Analysis to establish a base of available scientific evidence to guide future decision making. The study, created from inputs from multi-disciplinary teams in each country, with specialists in hydrology, hydraulics, channel form, water quality, vegetation, aquatic invertebrates, fish, birds, river-dependent terrestrial wildlife, resource economics and socio-cultural issues, was coordinated and managed by a group of specialists from the southern African region in 2008 and 2009.

The following specialist technical reports were produced as part of this process and form substantive background content for the Okavango River Basin Trans-boundary Diagnostic Analysis

Final Study Reports	Reports integrating findings from all country and background reports, and covering the entire basin.		
		Aylward, B.	<i>Economic Valuation of Basin Resources: Final Report to EPSMO Project of the UN Food & Agriculture Organization as an Input to the Okavango River Basin Transboundary Diagnostic Analysis</i>
		Barnes, J. et al.	<i>Okavango River Basin Transboundary Diagnostic Analysis: Socio-Economic Assessment Final Report</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Project Initiation Report (Report No: 01/2009)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment EFA Process Report (Report No: 02/2009)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Guidelines for Data Collection, Analysis and Scenario Creation (Report No: 03/2009)</i>
		Bethune, S. Mazvimavi, D. and Quintino, M.	<i>Okavango River Basin Environmental Flow Assessment Delineation Report (Report No: 04/2009)</i>
		Beuster, H.	<i>Okavango River Basin Environmental Flow Assessment Hydrology Report: Data And Models(Report No: 05/2009)</i>
		Beuster, H.	<i>Okavango River Basin Environmental Flow Assessment Scenario Report : Hydrology (Report No: 06/2009)</i>
		Jones, M.J.	<i>The Groundwater Hydrology of The Okavango Basin (FAO Internal Report, April 2010)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 1 of 4)(Report No. 07/2009)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions (Volume 2 of 4: Indicator results) (Report No. 07/2009)</i>
		King, J.M. and Brown, C.A.	<i>Okavango River Basin Environmental Flow Assessment Scenario Report: Ecological and Social Predictions: Climate Change Scenarios (Volume 3 of 4) (Report No. 07/2009)</i>
		King, J., Brown, C.A., Joubert, A.R. and Barnes, J.	<i>Okavango River Basin Environmental Flow Assessment Scenario Report: Biophysical Predictions (Volume 4 of 4: Climate Change Indicator Results) (Report No: 07/2009)</i>
		King, J., Brown, C.A. and Barnes, J.	<i>Okavango River Basin Environmental Flow Assessment Project Final Report (Report No: 08/2009)</i>
		Malzbender, D.	<i>Environmental Protection And Sustainable Management Of The Okavango River Basin (EPSMO): Governance Review</i>
		Vanderpost, C. and Dhlwayo, M.	<i>Database and GIS design for an expanded Okavango Basin Information System (OBIS)</i>
		Veríssimo, Luis	<i>GIS Database for the Environment Protection and Sustainable Management of the Okavango River Basin Project</i>
		Wolski, P.	<i>Assessment of hydrological effects of climate change in the Okavango Basin</i>
Country Reports Biophysical Series	Angola	Andrade e Sousa, Helder André de	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Sedimentologia &</i>

EFA Namibia Hydro-electric Power.

			<i>Geomorfologia</i>
		<i>Gomes, Amândio</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Vegetação</i>
		<i>Gomes, Amândio</i>	<i>Análise Técnica, Biofísica e Socio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final: Vegetação da Parte Angolana da Bacia Hidrográfica Do Rio Cubango</i>
		<i>Livramento, Filomena</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Macroinvertebrados</i>
		<i>Miguel, Gabriel Luís</i>	<i>Análise Técnica, Biofísica E Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Subsídio Para o Conhecimento Hidrogeológico Relatório de Hidrogeologia</i>
		<i>Morais, Miguel</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Análise Rio Cubango (Okavango): Módulo da Avaliação do Caudal Ambiental: Relatório do Especialista País: Angola Disciplina: Ictiofauna</i>
		<i>Morais, Miguel</i>	<i>Análise Técnica, Biofísica e Sócio-Económica do Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final: Peixes e Pesca Fluvial da Bacia do Okavango em Angola</i>
		<i>Pereira, Maria João</i>	<i>Qualidade da Água, no Lado Angolano da Bacia Hidrográfica do Rio Cubango</i>
		<i>Santos, Carmen Ivelize Van-Dúnem S. N.</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório de Especialidade: Angola: Vida Selvagem</i>
		<i>Santos, Carmen Ivelize Van-Dúnem S.N.</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo Avaliação do Caudal Ambiental: Relatório de Especialidade: Angola: Aves</i>
	Botswana	<i>Bonyongo, M.C.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Wildlife</i>
		<i>Hancock, P.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report: Country: Botswana: Discipline: Birds</i>
		<i>Mosepele, K.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Fish</i>
		<i>Mosepele, B. and Dallas, Helen</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Botswana: Discipline: Aquatic Macro Invertebrates</i>
	Namibia	<i>Collin Christian & Associates CC</i>	<i>Okavango River Basin: Transboundary Diagnostic Analysis Project: Environmental Flow Assessment Module: Geomorphology</i>
		<i>Curtis, B.A.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report Country: Namibia Discipline: Vegetation</i>
		<i>Bethune, S.</i>	<i>Environmental Protection and Sustainable Management of the Okavango River Basin (EPSMO): Transboundary Diagnostic Analysis: Basin Ecosystems Report</i>
		<i>Nakanwe, S.N.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Aquatic Macro Invertebrates</i>
		<i>Paxton, M.</i>	<i>Okavango River Basin Transboundary Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Birds (Avifauna)</i>
		<i>Roberts, K.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Wildlife</i>
		<i>Waal, B.V.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Fish Life</i>
Country Reports Socioeconomic Series	Angola	<i>Gomes, Joaquim Duarte</i>	<i>Análise Técnica dos Aspectos Relacionados com o Potencial de Irrigação no Lado Angolano da Bacia Hidrográfica do Rio Cubango: Relatório Final</i>
		<i>Mendelsohn, .J.</i>	<i>Land use in Kavango: Past, Present and Future</i>
		<i>Pereira, Maria João</i>	<i>Análise Diagnóstica Transfronteiriça da Bacia do Rio Okavango: Módulo do Caudal Ambiental: Relatório do Especialista: País: Angola: Disciplina: Qualidade da Água</i>
		<i>Saraiva, Rute et al.</i>	<i>Diagnóstico Transfronteiriço Bacia do Okavango: Análise Socioeconómica Angola</i>

EFA Namibia Hydro-electric Power.

	Botswana	<i>Chimbari, M. and Magole, Lapologang</i>	<i>Okavango River Basin Trans-Boundary Diagnostic Assessment (TDA): Botswana Component: Partial Report: Key Public Health Issues in the Okavango Basin, Botswana</i>
		<i>Magole, Lapologang</i>	<i>Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Land Use Planning</i>
		<i>Magole, Lapologang</i>	<i>Transboundary Diagnostic Analysis (TDA) of the Botswana p Portion of the Okavango River Basin: Stakeholder Involvement in the ODMP and its Relevance to the TDA Process</i>
		<i>Masamba, W.R.</i>	<i>Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Output 4: Water Supply and Sanitation</i>
		<i>Masamba, W.R.</i>	<i>Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin: Irrigation Development</i>
		<i>Mbaiwa, J.E.</i>	<i>Transboundary Diagnostic Analysis of the Okavango River Basin: the Status of Tourism Development in the Okavango Delta: Botswana</i>
		<i>Mbaiwa, J.E. & Mmopelwa, G.</i>	<i>Assessing the Impact of Climate Change on Tourism Activities and their Economic Benefits in the Okavango Delta</i>
		<i>Mmopelwa, G.</i>	<i>Okavango River Basin Trans-boundary Diagnostic Assessment: Botswana Component: Output 5: Socio-Economic Profile</i>
		<i>Ngwenya, B.N.</i>	<i>Final Report: A Socio-Economic Profile of River Resources and HIV and AIDS in the Okavango Basin: Botswana</i>
		<i>Vanderpost, C.</i>	<i>Assessment of Existing Social Services and Projected Growth in the Context of the Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin</i>
	Namibia	<i>Barnes, J and Wamunyima, D</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module: Specialist Report: Country: Namibia: Discipline: Socio-economics</i>
		<i>Collin Christian & Associates CC</i>	<i>Technical Report on Hydro-electric Power Development in the Namibian Section of the Okavango River Basin</i>
		<i>Liebenberg, J.P.</i>	<i>Technical Report on Irrigation Development in the Namibia Section of the Okavango River Basin</i>
		<i>Ortmann, Cynthia L.</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Environmental Flow Module : Specialist Report Country: Namibia: discipline: Water Quality</i>
		<i>Nashipili, Ndinomwaameni</i>	<i>Okavango River Basin Technical Diagnostic Analysis: Specialist Report: Country: Namibia: Discipline: Water Supply and Sanitation</i>
		<i>Paxton, C.</i>	<i>Transboundary Diagnostic Analysis: Specialist Report: Discipline: Water Quality Requirements For Human Health in the Okavango River Basin: Country: Namibia</i>

*Environmental protection and sustainable management
of the Okavango River Basin*

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